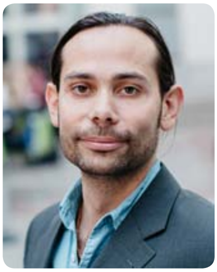
Empirical Essays on Strategic Behavior in the Electricity and Water Sectors

Erik Lundin



Erik Lundin
holds a Master of Economics from Stockholm University. His main research field is applied microeconomics, especially industrial organization and the economics of electricity markets.

ISBN 978-91-7258-995-7

Doctoral Dissertation
in Economics
Stockholm School of Economics
Sweden, 2016

Empirical Essays on Strategic Behavior in the Electricity and Water Sectors

Erik Lundin

Akademisk avhandling

som för avläggande av ekonomie doktorsexamen
vid Handelshögskolan i Stockholm
framläggs för offentlig granskning
fredagen den 10 juni 2016, kl 10.15,
i sal 520, Handelshögskolan, Sveavägen 65, Stockholm

Empirical Essays on Strategic Behavior in the Electricity and Water Sectors

Empirical Essays on Strategic Behavior in the Electricity and Water Sectors

Erik Lundin

STOCKHOLM SCHOOL OF ECONOMICS

Dissertation for the Degree of Doctor of Philosophy, Ph.D.,
in Economics
Stockholm School of Economics, 2016

Empirical Essays on Strategic Behavior in the Electricity and Water Sectors

ISBN 978-91-7258-995-7 (printed)
ISBN 978-91-7258-996-4 (pdf)

Front cover photo:
ⓒ The Malbork Castle Museum, 2016

Back cover photo:
Juliana Wiklund, 2016

Printed by:
Ineko, Göteborg, 2016

Keywords:
Joint ownership, electricity restructuring, electricity distribution, electricity auctions, nuclear, maintenance, collusion, yardstick competition, spatial econometrics, public utilities, water provision, labor efficiency, privatization

Till
Mina föräldrar, mina mor- och farföräldrar, min bror, och Soffia

Foreword

This volume is the result of a research project carried out at the Department of Economics at the Stockholm School of Economics (SSE).

This volume is submitted as a doctor's thesis at SSE. In keeping with the policies of SSE, the author has been entirely free to conduct and present his research in the manner of his choosing as an expression of his own ideas.

SSE is grateful for the financial support provided by the Jan Wallander and Tom Hedelius Foundation which has made it possible to fulfill the project.

Göran Lindqvist
Director of Research
Stockholm School of Economics

Richard Friberg
Professor and Head of the
Department of Economics
Stockholm School of Economics

Preface

The figurine on the cover of this book portrays the Greek god Hermes, the god of commerce and transition. It is crafted from amber collected on the beaches of the Baltic Sea. Because of its shiny brandy color, in Greek folklore amber was believed to be the distillation of sunlight. The ancient Greek word for amber is electron (ἤλεκτρον), meaning "shining sun". Around 600 BC, the Greek philosopher Thales discovered that amber attracts lightweight objects, like feathers, if it is rubbed with a piece of fur. Thales had discovered the principle of static electricity. Thus, when we refer to something as being electric, we say that it is amber-like.

Washed up in abundance on the beaches of the Samland in the south-eastern Baltic Sea, amber became a sought-after trade commodity, and the amber road stretched all the way down to Africa. For example, the breast ornament of the Egyptian pharaoh Tutankhamen (ca. 1341-1323 BC) contains large Baltic amber beads (Reeves, 1990). In 1642, the Prussian government enforced a state monopoly on amber collection and trade (Ley, 1951). However, it was hard to implement an efficient management of the system, partly because it was expensive to maintain the protection of the monopoly. In 1811 the monopoly was abandoned, and for a fee citizens were allowed to engage in the collection and marketing of amber. Spurred by the possibilities of economic success, private actors developed new technologies for collecting the precious pieces. Instead of just looking for amber on the beaches they learned to "fish" amber by casting nets into the surf, and to stir up the sediment in shallows and then drag the nets through the water (amber is only slightly more dense than the brackish water of the Baltic Sea). Even more amber was to be found buried deep under ground, and in 1870 the Prussian government granted the private firm Stantien

& Becker the exclusive amber mining rights in the region. The business was highly successful, and for a period the firm ran both a hospital, a health insurance company, a pension fund, and a school. Seeing the extraordinary success of Stantien & Becker's operations, the Prussian government once again took control of the amber business.

If this book arouses your interest in electricity markets, you will find that there are many paths on which the economic histories of amber and electricity meet. And maybe that trip has just begun. In 2018, the operation of the first solar electricity export project between the Sahara desert and Europe will be launched. The plant is powered by sunlight that is concentrated and pointed onto a central tower using heliostat mirrors. Through an inventive procedure involving molten salt, water is heated and transferred to a steam turbine generator (Nurenergie, 2016). If everything goes according to plan, the TuNur power plant will have a yearly output of 9.5 TWh, exceeding that of Sweden's largest nuclear reactor. Via a landing port in Italy, a submarine transmission line will transport power to the European grid and provide two million homes with electricity. Maybe Tutankhamen, being the son of sun god Ra, has decided that time has come to pardon his looters and let the distilled sunlight flow back to its source.

* * *

Many people have helped making this thesis come to life. I've been fortunate to spend my graduate studies in four different institutions: Stockholm School of Economics (SSE), Research Institute of Industrial Economics (IFN), Stockholm University, and Stanford University. In each place I've been endowed with wonderful colleagues.

First and foremost, I am indebted to my advisors Richard Friberg (SSE), Thomas Tangerås (IFN), and Pär Holmberg (IFN). Richard has put a great effort in sharing his paper writing skills with me. The speed at which he has read each of my drafts and yet provided immensely constructive critique each time is truly outstanding. He has also encouraged me to present my work at conferences and seminars, which I am very grateful for. With Thomas, I have discussed all possible and impossible aspects of electricity markets, and the constant flow of inventive research ideas flowing through his mind is a true inspiration. He was also keen on introducing me to the world's leading electricity researchers already at an early stage of my studies, which has been a tremendous benefit. Pär Holmberg has always taken time to read my drafts and to discuss various aspects of my work with great patience. Every single time I knocked on his door he managed to give the impression that nothing could be more interesting than to discuss some more or less trivial aspect of the electricity market that momentarily caught my attention. Most importantly, all my advisors' great sense of humor and positive attitudes have kept my academic spirit going each day (well, almost each day) at work.

Commencing my graduate studies at Stockholm University, I was fortunate to have my fellow student Anders Österling by my side from day one. His joyful personality kept us going through the first tentative period. The support from our classmates and students in the years above us, especially Miri Stryjan, will always be remembered. Organizing the European Network for Training in Economic Research (ENTER) together with professor Sten Nyberg was also a great experience.

In parallel with my studies at Stockholm University I joined the "Economics of Electricity Markets" research program at IFN, where I also worked as a research assistant prior to joining the graduate program. The importance of the constant support from IFN throughout the years cannot be overstated. Talentedly directed by Magnus Henrekson, IFN has provided me with all the freedom of creativity and time that a graduate student could ask for. The warm atmosphere among the researchers at IFN has made me value every moment in their presence. I would especially like to thank Sven-Olof Fridolfsson, Per Skedinger, and my fellow IFN office mates Aron Berg, Louise Johanneson, and Ewa Lazarczyk Carlson for their great company.

During my fourth year I transferred from Stockholm University to Stockholm

School of Economics. One thing that I valued highly at SSE was the senior researchers' genuine engagement in the student lunch seminars, especially Jörgen Weibull, Tore Ellingsen, and Erik Lindqvist. Among the students, there will always be a special place in my heart for Eleonora Freddi, Paul Elger, Adam Altmejd, Siri Isakson, and Elin Molin. I would also like to thank Isak Kupersmidt and Gustav Karreskog for being excellent office mates during my last year of studies.

Through a generous invitation from professor Frank Wolak I was fortunate to spend one year at the Program on Energy and Sustainable Development (PESD) at Stanford University. I will especially remember the companionship and engaging discussions with Gordon Leslie, the sailing races with Mark Thurber, the kindness of Kathy Lung, and the creative mind and great sense of humor of Frank Wolak. I would also like to thank Mar Reguant for always serving as a role model for every young energy economist. In the midst of her tenure track at the Stanford GSB she made the effort to read my job market paper and provide useful suggestions for improvements on all possible aspects: structure, writing, modeling, and solution technique. I also want to give a special thanks to Eva Meyersson Milgrom and Paul Milgrom for introducing me to the social life at Stanford by inviting me to various adventurous activities, such as hiking in the mountains and sailing on the San Francisco Bay.

Last, but not least, I would like to thank my parents, grandparents, brother, and Soffia for their constant support - Thank you for being there for me!

* * *

Beginning from the third year of my graduate studies, I was employed at the Research Institute of Industrial Economics and associated with its "Economics of Electricity Markets" research program. I am grateful to the Swedish Competition Authority, the Swedish Energy Research Centre (Energiforsk), E.ON, Fortum, Vattenfall, SCA, Svenska Kraftnät, the Swedish Energy Agency, and the Jan Wallander and Tom Hedelius Foundation for financing this thesis. My visit to Stanford University was enabled by the Tom Hedelius Foundation Travel Grant.

Stockholm, April 21, 2016

Erik Lundin

References

Ley, Willy, *Dragons in Amber: Further Adventures of a Romantic Naturalist*, Viking Press, New York, 1951.

Nurenergie, "TuNur heliostat power plant webpage," `http://www.nurenergie.com/tunur/` (accessed April 21, 2016), 2016.

Reeves, C.N., *The Complete Tutankhamun: the king, the tomb, the Royal Treasure*, Thames & Hudson, London, 1990.

Contents

Introduction

This thesis consists of three chapters, examining strategic behavior in the electricity and water sectors in Sweden. Traditionally, production and distribution in both sectors have been operated by vertically integrated, publicly owned utilities. The electricity sector was deregulated in 1996, creating a competitive wholesale market for electricity while keeping distribution as regulated local monopolies. The water sector has not undergone the same development, and the municipalities are still legally responsible for water provision within their geographical boundaries. Strategic aspects of the price formation process in each of these three markets are devoted a separate chapter in this thesis: the wholesale market for electricity (chapter I), electricity distribution (chapter II), and water provision (chapter III).

All three markets are characterized by imperfect competition and almost completely inelastic demand. Because of the inelastic demand, short run deadweight losses due to excessive pricing are negligible. In the long run demand is likely to be more elastic, especially in the electricity market. Electricity intense industries may relocate or shut down if the price increases, and consumers using electricity for heating may switch to alternative heating sources. Strategic behavior may also lead to lead to welfare effects in terms of productive efficiency. In the wholesale market for electricity, I show that the exercise of market power distorts the production mix, so that plants with a high marginal cost are run more often than they would have under perfect competition. On the market for electricity distribution, I examine the impact of private acquisitions of distribution networks on productive efficiency. On the market for water provision, I argue that strategic behavior could increase productive efficiency due to a self-imposed informal yardstick competition among the utilities. The remainder of this introduction summarizes the main results in each chapter.

Chapter I: Market Power and Joint Ownership: Evidence from Nuclear Plants in Sweden

There are three nuclear plants in Sweden. All are jointly owned by three large firms, although each plant has a majority owner with legal operational responsibility. The Swedish firm Vattenfall is the majority owner in the two largest plants. The German firm E.ON is the majority owner in the smallest plant, and is a minority owner in all other plants. The Finnish firm Fortum is a minority owner in two of the plants. Competition authorities have encouraged the owners to voluntarily break the joint ownership without success (Swedish Competition Authority, 2009). Since maintenance is the main conduit explaining the variation in output, I formulate a model of intertemporal choice in which firms choose how to allocate a given amount of output within each year. Using data on production and bidding curves on the day-ahead market, I test the model against data given three behavioral assumptions: unilateral profit maximization, joint profit maximization, and a social planner. I find that the model of joint profit maximization best matches data, indicating that joint ownership has facilitated coordination of maintenance decisions. Terminating the joint ownership and modeling for unilateral profit maximization would lead to a 5 percent reduction in prices. As other thermal plants in the system now run more evenly, in this scenario total system production costs are reduced by 6 percent.

The study makes several contributions: a) It is the first empirical study that distinguishes between the unilateral and collusive outcomes in a setting with joint ownership of specific production plants, b) It is the first study to model plant maintenance as an intertemporal choice in a strategic setting, and c) The methodology is different from previous studies of joint ownership, as I do not rely on the estimation of a "conduct parameter" to identify firm conduct, which is discussed further below.

The use of maintenance to disguise the exercise of market power has previously been discussed in the context of e.g. the British and Californian wholesale markets (Wolak and Patrick, 2001; Borenstein et al., 2002). A better understanding of the strategic aspects of maintenance scheduling is therefore of general interest. As the marginal cost of nuclear is very low, it is usually more efficient to exercise market power by withholding units higher up in the merit order. However, the present study makes the point that the marginal cost does not matter if a certain amount of maintenance *has to* be performed at some point in time. It is then the *intertemporal* variation in marginal revenues that determines if market power is exercised, rather than the static relationship between marginal revenue and marginal cost.

The standard way to determine the competitiveness of oligopolistic markets is to set up a structural model that can be estimated using data on prices, quantities, and exogenous determinants of demand. The researcher does not need access to data on marginal costs. In a typical setup, the goal is to estimate a conduct parameter between zero and one, where zero corresponds to perfect competition, $^1/_n$ corresponds to a symmetric n-firm Cournot equilibrium, and one corresponds to joint profit maximization. The identifying econometric assumptions of such a test in a "text-book" market are outlined by Bresnahan (1982), and has served as the basis for numerous studies. However, the conduct parameter approach has also been criticized to be a poor predictor of market power. An example is given by Kim and Knittel (2006). Using detailed engineering data on marginal costs from the restructured Californian electricity market, they start by computing actual price-cost margins. They find that the estimated price-cost margins implied by the conduct parameter approach usually do not reflect actual price-cost margins, since the estimated margins are highly dependent on assumptions about the functional form of the residual demand function facing strategic firms.

Except for the sensitivity to functional form assumptions, there are also other reasons why conduct parameters are likely to be inadequate measures of market power. The theoretical underpinning when estimating conduct parameters is usually the folk theorem, stating that any quantity between Cournot and joint profit maximization is compatible with some Nash equilibrium in an infinitely repeated game. However, we can usually not be certain that the mechanism behind the folk theorem is the reason why real firms often appear to lie somewhere "in between" Cournot and joint profit maximization. One alternative explanation is given by Steen and Sørgard (1999), who notes that firms may be able to coordinate perfectly on some choice variable(s) but not on others, a behavior that can be characterized as *semicollusion*. In the presence of semicollusion, the researcher may then estimate a conduct parameter above $^1/_n$ but below one when using aggregate data, when it would be more useful to know the choice variable(s) where firms have achieved perfect coordination. In this study, I argue that the operation of nuclear plants ought to be such a variable. Therefore, instead of a conduct parameter, I explicitly test wether the model of joint profit maximization *alone* can predict the variation in the data, using a non-nested hypothesis testing procedure proposed by Davidson and MacKinnon (1981). Similar non-nested hypothesis testing of collusive behavior have been used elsewhere, e.g., by Bresnahan (1987); Gasmi et al. (1992), although it is much less common than estimating conduct parameters.

The study also builds on the more specific literature on strategic behavior in electricity markets. Wholesale electricity markets are run as auctions, where producers and consumers submit supply and demand functions to a power exchange that clears the market where aggregate supply meets aggregate demand. The residual demand function facing each plant can then be computed, rather than estimated. This procedure does not require the researcher to make parametric assumptions about the functional form of demand, or to rely on the strict exogeneity of demand shifters. Hence, there are good opportunities to estimate more precise structural models than in most other markets. A recent study is Reguant (2014), examining the dynamic implications of startup costs when estimating market power in wholesale markets. The present study contributes to the recent structural econometrics literature of strategic behavior in electricity markets, while also adding to the more general literature about the implications of joint ownership for firm behavior.

Chapter II: Effects of Privatization on Price and Labor Efficiency: The Swedish Electricity Distribution Sector

In this paper I examine the effects of privatization, in the form of acquisitions, in the Swedish electricity distribution sector. As the majority of the distribution networks remained publicly owned, I use a synthetic control method to identify the effects on price and labor efficiency. For each acquired network, I create a synthetic control network from a weighted average of the networks that remained publicly owned. The synthetic control network is constructed to have the same technical characteristics and pre-acquisition trend of the outcome variable as the acquired network. In comparison to their synthetic counterparts, I find that networks acquired by private firms increased labor efficiency by on average 18 percent (corresponding to 34 EUR per residential customer and year), while no effect is found on price. Thus, the evidence suggests substantial efficiency gains but that these are not fed through to consumer prices.

To the best of my knowledge, this is the first study to use a synthetic control method to evaluate firm performance in the electricity distribution sector. The method is particularly well suited to estimate the effect of an intervention when the number of potential control units are large, and should therefore be useful also when estimating the effects of network specific interventions in electricity distribution sectors in other countries. Further, results are invariant to the choice of cost function, since the observed cost determinants of an acquired network are identical to those of its synthetic analogue.

Since each acquisition involved several bordering networks that were separately operated by each municipality prior to the acquisitions, I examine to what extent the efficiency gains are likely to be driven by increased economies of scale. Results suggest that the entire effect can be explained by increased economies of scale, questioning the *causal* effect of privatization per se.

Chapter III: Price Mimicking under Cost-of-Service Regulation: The Swedish Water Sector

Ever since Tiebout (1956) pointed out that citizens evaluate the policies of their local governments in relation to the policies of other jurisdictions, the interdependence in policy decisions among local governments has been a major interest in public economics. This paper extends the existing literature by finding evidence of price mimicking among regulated utilities. Since publicly owned water utilities in Sweden are governed by a cost-of-service regulation, prices in neighboring municipalities should not affect the own price other than through spatially correlated cost factors. In contrast, spatial dependence is pronounced. This behavior can be explained in terms of an informal yardstick competition. When consumers use neighboring utilities' prices as benchmarks for costs or as behaviorally based reference prices, utilities will face the risk of consumer complaints and successive regulatory reviews if deviating too much from neighbors' prices. Using a fixed effects spatial Durbin model with data from Swedish municipalities during 2002-2012, I estimate the elasticity of the own relative to neighbors' average price to be 0.14. The interpretation is that if my neighbors raise their prices by on average 10 percent, the own price will increase by 1.4 percent. Thus, the effect is relatively modest but still economically significant. The study also adds to the regulatory literature by noting that an informal yardstick competition may arise also in regulated industries that are not subject to a formal yardstick regulation of the type described by Shleifer (1985).

While allocative efficiency should be more or less unaffected by yardstick competition due to a highly inelastic demand, there is presumably a positive effect on productive efficiency. One of the main rationales behind yardstick regulation is to incentivize firms to reduce costs, since the prices that firms receive are independent of their own costs. A conjecture is then that informal yardstick competition induces a similar mechanism, since firms that are able to cut costs more than their neighbors will incur a profit. However, an important feature of formal yardstick regulation is that firms have identical cost structures, or that the regulator is able to distinguish differences in cost structures across regions. In the present setting, benchmarks are instead rather arbitrary. The higher cost a municipality has relative to its neighbors, the more managers will be incentivized to reduce costs. In sum, even though informal yardstick regulation is a less precise mechanism than formal yardstick regulation, economic reasoning suggests that the presence of informal yardstick competition is positive for productive efficiency.

References

Borenstein, Severin, James B. Bushnell, and Frank A. Wolak, "Measuring Market Inefficiencies in California's Restructured Wholesale Electricity Market," *American Economic Review*, December 2002, *92* (5), 1376–1405.

Bresnahan, Timothy F., "The oligopoly solution concept is identified," *Economics Letters*, 1982, *10* (1-2), 87–92.

Bresnahan, Timothy F, "Competition and Collusion in the American Automobile Industry: The 1955 Price War," *Journal of Industrial Economics*, June 1987, *35* (4), 457–82.

Davidson, Russell and James G MacKinnon, "Several Tests for Model Specification in the Presence of Alternative Hypotheses," *Econometrica*, May 1981, *49* (3), 781–93.

Gasmi, F., J.J. Laffont, and Q. Vuong, "Econometric Analysis of Collusive Behavior in a Soft-Drink Market," *Journal of Economics & Management Strategy*, 1992, *1* (2), 277–311.

Kim, Dae-Wook and Christopher R. Knittel, "Biases in Static Oligopoly Models? Evidence from the California Electricity Market," *Journal of Industrial Economics*, December 2006, *54* (4), 451–470.

Reguant, Mar, "Complementary Bidding Mechanisms and Startup Costs in Electricity Markets," *Review of Economic Studies*, 2014, *81* (4), 1708–1742.

Shleifer, Andrei, "A Theory of Yardstick Competition," *RAND Journal of Economics*, Autumn 1985, *16* (3), 319–327.

Steen, Frode and Lars Sørgard, "Semicollusion in the Norwegian cement market," *European Economic Review*, October 1999, *43* (9), 1775–1796.

Swedish Competition Authority, "Terminate the joint ownership of nuclear plants," `http://www.konkurrensverket.se/globalassets/aktuellt/nyheter/2008pm---bryt-upp-samagandet-inom-karnkraften-dnr-5002008-49646kb.pdf` (accessed April 21, 2016), 2009.

Tiebout, Charles M., "A Pure Theory of Local Expenditures," *Journal of Political Economy*, 1956, *64*, 416.

Wolak, Frank A. and Robert H. Patrick, "The Impact of Market Rules and Market Structure on the Price Determination Process in the England and Wales Electricity Market," Working Paper 8248, National Bureau of Economic Research April 2001.

Chapter 1

Market Power and Joint Ownership: Evidence from Nuclear Plants in Sweden[*]

Abstract

This paper presents an empirical test of the anticompetitive effects of joint ownership, by examining the operation of three nuclear plants in Sweden. Since maintenance is the main conduit explaining the variation in output, I formulate a model of intertemporal choice in which firms choose how to allocate a given amount of output within each year. Using data on production and bidding curves on the day-ahead market, I test the model against data given three behavioral assumptions: unilateral profit maximization, joint profit maximization, and a social planner. Modeling for joint profit maximization best

---

[*] I would like to thank Mar Reguant, Thomas Tangerås, Pär Holmberg, Richard Friberg, Matti Liski, Frank Wolak, Chloé Le Coq, Gordon Leslie, Gustav Karreskog, Anders Österling, Erik Lindqvist, Robert Porter, Birger Fält, seminar participants at the Toulouse School of Economics, Stockholm School of Economics, the Program on Energy and Sustainable Development at Stanford University, participants at the conferences "The Performance of Electricity Markets", "The 7th Swedish Workshop on Competition Research", and "MaCCI Annual Conference 2016" for valuable comments.

matches data, indicating that joint ownership has facilitated coordination of maintenance decisions. Terminating the joint ownership and modeling for unilateral profit maximization would lead to a 5 percent reduction in the price and a 6 percent reduction in system production costs. I identify positive supply shocks in the form of inflow to the hydro power reservoirs as important determinants of the incentives to exercise market power. Therefore, the mechanisms discussed in this paper should be of relevance also in other electricity markets where the share of intermittent production is increasing. As a motivation for the structural exercise, I use a difference-in-differences estimator to identify a shift in the allocation of maintenance towards the winter season, when demand and prices are peaking, at the time of the introduction of the joint ownership. This result is in line with the results from the structural model, as the ability to influence the price is also higher during the winter season.

1 Introduction

Joint ownerships are common in many markets. They may take many forms, such as joint ventures, partial mergers and acquisitions, or joint ownership of production plants. Markets in which joint ownerships have been studied include the automobile sectors in the U.S. and Japan (Alley, 1997), the U.S. airline industry (Azar et al., 2015), the U.S. cellphone industry (Parker and Röller, 1997), U.S. offshore oil tracts (Kenneth Hendricks, 1992), and the Dutch banking sector (Dietzenbacher et al., 2000). In electricity markets, joint ownership arrangements are also frequent. For example, 40 percent of all U.S. power plants are jointly owned, including nuclear plants (U.S. Energy Information Administration, 2014).

A number of potential efficiencies may motivate such links, such as technological complementarities, risk sharing, or cooperation on R&D. However, there are at least two channels by which joint ownership has anticompetitive effects. One is through promoting collusion, in that joint ownership facilitates information- and profit sharing. See Green (1980) for an analysis of how information exchange can induce collusion, and Malueg (1992) for an analysis of how the interconnection of profits induced by joint ownership may facilitate collusion. The other is through a reduction of the unilateral incentives to act competitively (Reynolds and Snapp, 1986). The reason is purely mechanical, in the sense that the linking of profits reduces each firm's incentive to compete. In their setting, firms own shares in each others' production plants, with one owner being the designated "controller" who decides the level of output.

Although the theoretical literature is rich in describing the various channels by which joint ownership affects competition, empirical evidence is sparse. A likely reason is that disentangling the collusive and unilateral outcomes in a setting with joint ownership is challenging, and often requires the researcher to make strong parametric assumptions. I overcome these challenges by studying the data rich environment of the Nordic electricity market where data on supply and demand functions and production is readily available. The data enables me to compute the residual demand functions facing each plant and let firms choose a best-response given that residual demand function. Similar approaches have previously been used to measure market power in electricity markets, see e.g., Borenstein et al. (2002); Wolfram (1999). By contrast, as documented below, previous studies on joint ownership have relied on a more parameterized framework following the work of Bresnahan (1982). In a typical setup, the goal is to estimate a "conduct parameter" between zero and one, where zero corresponds to perfect competition, $^1/_n$ corresponds to a symmetric n-firm Cournot equilibrium, and one corresponds to joint profit maximization. This approach has been criticized to be a poor predictor of market power, especially in dynamic settings (Corts, 1999). An empirical example is given by Kim and Knittel (2006). Using detailed engineering data on marginal costs from the restructured Californian electricity market, they start by computing actual price-cost margins. They find that the price-cost margins implied by the conduct parameter approach usually do not reflect actual price-cost margins, since the estimated margins are highly dependent on assumptions about the functional form of the residual demand function facing strategic firms.

The present study makes several contributions: a) It is the first empirical study that distinguishes between the unilateral and collusive outcomes in a setting with joint ownership of specific production plants, b) It is the first study to model plant maintenance as an intertemporal choice in a strategic setting, and c) The methodology is different from previous studies on joint ownership, as I do not rely on the estimation of a conduct parameter to identify firm conduct.

Specifically, I consider the operation of three Swedish nuclear plants. All are jointly owned by three large firms, although each plant has a majority owner with legal operational responsibility. The firms sell all their physical electricity on the Nordic day-ahead market. It is about half the size of the *Pennsylvania-New Jersey-Maryland* day-ahead market, which is the largest electricity market in the world[1]. Using publicly available information about nuclear outages I identify maintenance as the primary reason for the reductions in nuclear output. I then formulate a model of intertemporal choice in which firms decide

---

[1] If considering the whole EU as a common electricity market, that market is larger than the *Pennsylvania-New Jersey-Maryland* market. However, due to limited transmission capacity between the Nordic region and the rest of Europe, this is not a relevant comparison.

how to allocate output within each year, assuming that yearly output of each plant cannot exceed its observed output. The use of maintenance to disguise the exercise of market power has previously been discussed in the context of the British and Californian electricity markets (Wolak and Patrick, 2001; Borenstein et al., 2002). A deeper understanding of the strategic aspect of maintenance scheduling is therefore of general interest.

Using a unique data set on hourly production and bidding data from the Nordic day-ahead market during 2011-2013, I simulate plant output given three behavioral assumptions: unilateral profit maximization (in which output is determined by the majority shareholder of each plant), joint profit maximization, and a social planner. I find that the model of joint profit maximization matches data best. Terminating the joint ownership and modeling for unilateral profit maximization would lead to a 5 percent reduction in prices. As other thermal plants in the system are also run more evenly, in this scenario total system production costs are reduced by 6 percent. While these figures may appear rather small, one must keep in mind that the effects refer to the whole day-ahead market, out of which the nuclear plants only account for about 20 percent of output. As the optimality condition of a competitive firm states that output should be allocated to equalize prices across periods, I also find that more competitive behavior is associated with less price volatility.

Noting that Swedish capacity factors were below 80 percent throughout the sample period, compared to around 90 percent for other European and U.S. plants of comparable vintages, I also estimate a model where I allow each plant to operate at a capacity factor of up to 90 percent[2]. Under the model of joint profit maximization, I find that firms only expand aggregate output slightly above observed levels, i.e., the output constraint does not bind. Conversely, it is binding under the more competitive models. Hence, the effects on price and production costs of introducing more competitive behavior are now greater (at 11 and 18 percent respectively) due to the expansion of output.

Sweden deregulated its electricity market in 1996, forming the world's first

---

[2] The capacity factor is the ratio of the electrical energy produced by a generating unit for a period of time, divided by the electrical energy that could have been produced at continuous full power operation during the same period.

multinational wholesale market for electricity together with Finland, Norway and Denmark. A series of mergers and acquisitions (M&As) around the turn of the century resulted in a concentration of the ownership structure, and the nuclear plants became jointly owned by three large firms. In 2001 nuclear output started to shift away from the winter season. In the Nordic region, electricity demand and prices are peaking during the winter due to the demand for heating, thus creating incentives for competitive firms to allocate as much output as possible to the winter. At the same time, the ability to influence the price is also higher during the winter, since the system is often capacity constrained and it is more likely that firms are pivotal. Figure 1 depicts the share of yearly output allocated to the winter season (November-March) during 1975-2014. By comparison, the corresponding graph for Finnish nuclear plants, that did not experience a change in the ownership structure, shows that the allocation of Finnish output has remained more stable (Finnish data are only available from 1990). The first vertical line in the figure is at the time of Swedish deregulation (1996), and the second line is at the time of the introduction of the new ownership structure (2001). The figure has been constructed using monthly data on country level nuclear output, and the raw data are depicted in Figure A1 and A2. Even though Sweden and Finland sometimes face different prices due to transmission constraints, the price correlation is above 0.8. Hence, economic incentives how to allocate output are in practice identical for competitive firms operating within the region. To illustrate the change in allocation of Swedish nuclear output, I estimate the difference-in-differences model:

$$q_{ct}^{winter} = \gamma_c + \lambda_t + \delta D_{ct} + \varepsilon_{ct} \tag{1}$$

Where q_{ct}^{winter} is the percentage of output allocated to the winter season, γ_c is a country fixed effect, and λ_t is a dummy variable indicating the time of treatment. The treatment effect is captured by δ, i.e., D_{ct} is an indicator variable taking the value one for all Swedish observations after 2001[3]. Results are sum-

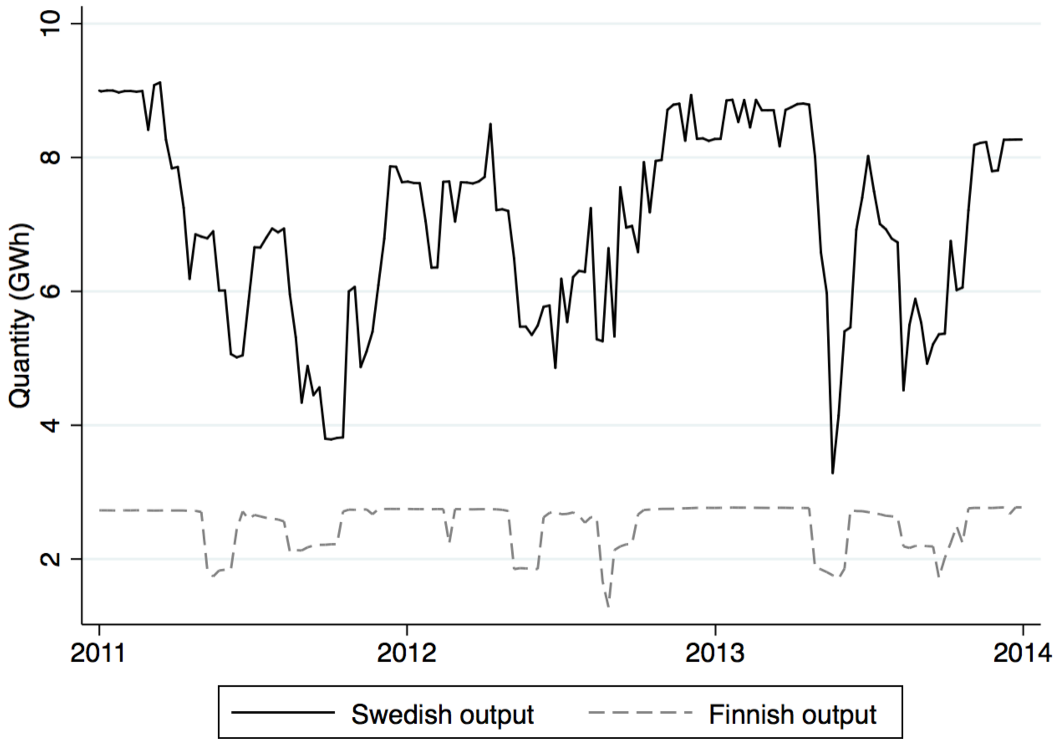
---

[3] It is important to note that the capacity factors of Swedish nuclear plants did not increase during the sample period. If that would have been the case, a reduction in the share of output allocated to the winter season could have been achieved by increasing output during the summer season, in which case the interpretation of δ

Figure 1: Share of yearly nuclear output allocated to the winter season

Note: This figure depicts the share of output allocated to the winter season (November-March) during 1975-2014, using 1990 as a reference year. Finnish data are only available from 1990. Finnish capacity factors increased somewhat during the sample period, while Swedish capacity factors remained roughly constant. Vertical lines are at the time of Swedish deregulation (1996) and at the introduction of the joint ownership (2001).

Figure 2: Swedish and Finnish nuclear output 2011-2013



Note: This figure depicts aggregate weekly nuclear output in Sweden and Finland 2011-2013.

Table 1: Dependent variable: Share of output allocated to the winter season.

Coefficient	(1)
Treatment effect ($\hat{\delta}$)	-3.8***
	(0.62)
Number of observations	50

$*p < 0.10, **p < 0.05, ***p < 0.01$
Note: Difference-in-differences estimate comparing the share of nuclear output allocated to the winter season (November-March) in Sweden and Finland. The unit of measurement is percentage. Standard errors in parentheses.

marized in Table 1, showing that the proportion of output allocated to the winter season decreased by 3.8 percentage points at the time of introduction of the current ownership structure.

A closer look at the weekly output profiles during the years in which detailed data are available (2011-2013) also reveals that within-year output is more volatile in Sweden than Finland. This is illustrated in Figure 2, from which it is evident that Finnish output is concentrated to the winter season, while the Swedish plants experience several "dips" in output during each year. This motivates a further examination if output decisions have been determined by strategic incentives, and if so, to what extent the current ownership structure may have helped to shape these incentives.

The rest of this paper is structured as follows. In Section two, I review the related literature. In section three, I discuss the institutional background and data. In section four, I perform a non-structural econometric test of market power by regressing nuclear output on the ability to influence the wholesale price using an instrumental variables (IV) estimator. I also discuss the rela-

---

would be different. Another event taking place just before the change in the ownership structure, in 1999, was that a small reactor accounting for about 6 percent of Swedish nuclear capacity was permanently shut down (Barsebäck 1). To account for the fact that the shutdown may have affected the results, I re-estimated the model by assuming that Barsebäck 1 produced most of its output during the winter season, with no qualitative change in the results.

tionship between inflow to the hydro power reservoirs and the ability to exercise market power. I present the structural model in section five. Section six presents the results and discusses welfare effects. Section seven concludes.

2 Related literature

Following Reynolds and Snapp (1986), Farrell and Shapiro (1990) analyze a similar setting of joint ownership, but where the marginal cost is a decreasing function of each firm's capital stock. The welfare implications then become less obvious. For example, if a firm with a small capital stock increases its holdings of a rival in which it previously had no financial interest, welfare may rise. As the smaller firm restricts output, the larger firms in the industry will expand output. Since larger firms have lower costs, price will decrease and welfare will increase. Malueg (1992) contrasts with the two previous studies by exploring an infinitely repeated game, revealing that tacit collusion may actually be harder to sustain under joint ownership. The reason is that even if joint ownership reduces the gain from cheating, it also softens the punishment that would follow cheating. The first effect makes collusion more likely, the second effect makes collusion less likely. The net result is ambiguous and depends on the shape of the demand function.

Although the theoretical literature has been successful in describing the competitive effects of joint ownership, empirical evidence is sparse and the few existing studies rely on rather parameterized frameworks. Parker and Röller (1997) study the U.S. cell phone industry, concluding that joint ownership of operating licenses has contributed to market outcomes that often lie closer to a collusive than a non-collusive equilibrium. In 22 percent of all U.S. markets, the equilibrium is found to equal the monopoly price. Alley (1997) studies joint ownership in the Japanese and the U.S. automobile industries. He develops a conjectural variations approach to estimate a conduct parameter reflecting the level of collusion. Although he finds signs of collusion, similar parameter results are found also without taking joint ownership into account, indicating that the unilateral incentives to reduce output due to joint ownership may have been limited. Dietzenbacher et al. (2000) examine the Dutch banking sector, where they allow for indirect shareholdings, i.e., if firm A owns shares in firm B and firm B owns shares in firm C, firm A holds an indirect share in firm C. Using shareholding data and accounting numbers of output values and profits (which allows for calculation of price-cost margins), they fit a structural model and find that the observed price-cost margins are at least 8 percent higher than they would have been without joint ownership. Azar et al. (2015) find a a positive effect on prices of increased joint ownership in the U.S. airline industry, but do not fit a structural model to their data.

Except for joint ownership, the present study also relates to the concept of *semicollusion*, introduced by Steen and Sørgard (1999). They note that firms may sometimes be able to coordinate perfectly on some choice variable(s) but not on others. There are good reasons to believe that nuclear output is such a variable in the present setting. One reason is that joint ownership enhances possibilities to share information and profits. A second reason is that owners can always claim that the timing of a maintenance outage has been necessary for safety reason, which is hard for the regulator to question. A third reason is that very little coordination is needed, since a single maintenance outage in a nuclear reactor may have a large effect on the price. Therefore, I explicitly test whether a model of joint profit maximization *alone* can predict the variation in the data, using a non-nested hypothesis testing procedure proposed by Davidson and MacKinnon (1981). Similar non-nested hypothesis testing of collusive behavior have been used elsewhere, e.g., by Bresnahan (1987); Gasmi et al. (1992), although it is much less common than estimating conduct parameters.

Another related strand of literature studies the use of market power in the Nordic electricity market. Hjalmarsson (2000) estimates a dynamic extension of the Bresnahan-Lau model using data from 1996-1999, concluding that the hypothesis of perfect competition cannot be rejected. Amundsen and Bergman (2000) examine how an increased wave of mergers and partial acquisitions may affect the unilateral incentives to behave competitively, concluding that even small increases in the ownership of competing firms could have anticompetitive effects. Kauppi and Liski (2008) construct a simulation model of hydro production in the Nordic market during 2000-2005, showing that a model where one strategic producer controls 30 percent of the hydro capacity fits data better than a model where hydro producers behave competitively. Damsgaard (2007) presents another simulation model that is tested on data from 2002-2006, without finding any conclusive evidence of market power other than within very limited time periods. Fogelberg and Lazarczyk (2014) study the use of capacity withholding through "voluntary" production failures to exert market power in the Nordic market during 2011-2012. They find indications of strategic withholding of fossil plants, but not nuclear or hydro. However, their analysis relies on a different set of identifying assumptions than the analysis in this study, as they do not make use of bidding or production data.

Studies of unilateral market power in other electricity markets are frequent. Some well-known examples from the British market are Green and Newbery (1992), Wolfram (1999) and Wolak and Patrick (2001), all finding evidence of market power as a contributing factor to market outcomes. Borenstein et al. (2002) and Wolak (2003) study the Californian market during 1998-2000, finding market power to be an important factor in explaining the high wholesale prices during the Californian electricity crisis in 2000. McRae and Wolak (2014) study the New Zealand electricity market and find that all of the four largest firms exercise market power on a systematic basis. Empirical studies of collusion in electricity markets are less frequent. Puller (2007) examines the Californian electricity market, finding that the five large firms were able to raise prices slightly above the unilateral market-power levels in 2000, but fell short of colluding on the joint monopoly price. Sweeting (2007) finds that the behavior of the two largest firms in the England and Wales wholesale electricity market was consistent with tacit collusion during 1996-2000. Fabra and Toro (2005) study the Spanish electricity market during 1998, finding indications of periods with both collusion and price wars.

To the best of my knowledge, no previous study explicitly suggests that nuclear plants have been used to exercise market power, but there are some studies about the relationship between economic incentives and nuclear plant performance. The relationship between operating efficiency and deregulation is studied by Davis and Wolfram (2012). Using a U.S. data set covering 1970-2009, they use a difference-in-differences estimator to find that deregulation and consolidation of ownership are associated with a 10 percent increase in nuclear operating efficiency. However, their study is concerned with the level rather than the intertemporal allocation of output. Using a cross-sectional data set from mainly UK and U.S. plants in 1989, Pollitt (1996) finds some evidence suggesting that regulated, privately owned nuclear plants are more efficient than publicly owned plants. In terms of long run market power, Fridolfsson and Tangerås (2015) argue that incumbent producers' incentives to expand in nuclear capacity could be weak. Increasing nuclear output would reduce the profitability of installed capacity due to the reduction in prices, and could therefore lead to nuclear underinvestment.

3 Institutional background and data

3.1 The Nordic electricity market

The Nordic electricity markets were deregulated during the 1990s, creating a common market for Norway, Denmark, Sweden and Finland. It now includes also Estonia, Latvia and Lithuania. The main trading platform for physical energy is the day-ahead market, in which more than 80 percent of all electricity produced in the region is sold. It has the format of a uniform price auction, and each day at noon market participants submit their bids to the auctioneer for delivery the next day. There is a separate auction each hour. Each participant submits supply or demand functions of up to 62 price steps, with a price ceiling of 2,000 EUR/MWh. The auctioneer then sums the bids to arrive at the *system* supply and demand functions, and clears the market where the system supply function meets the system demand function using linear interpolation[4]. This

---

[4] A unique feature of the Nordic day-ahead market is that bidders commit to bids that are convex combinations of their own submitted price-quantity pairs, which enables market clearing by linear interpolation. In addition to regular bids, participants also have the possibility to submit so-called block bids. A block bid can be distinguished from a regular bid by two characteristics. First, block bids refers to more than one hour, and second, a bid is either accepted or not accepted as a whole. On average, 5 percent and 1 percent respectively of the accepted sell- and buy volumes in the data comes from block bids. At present, I only have data on the volume of accepted

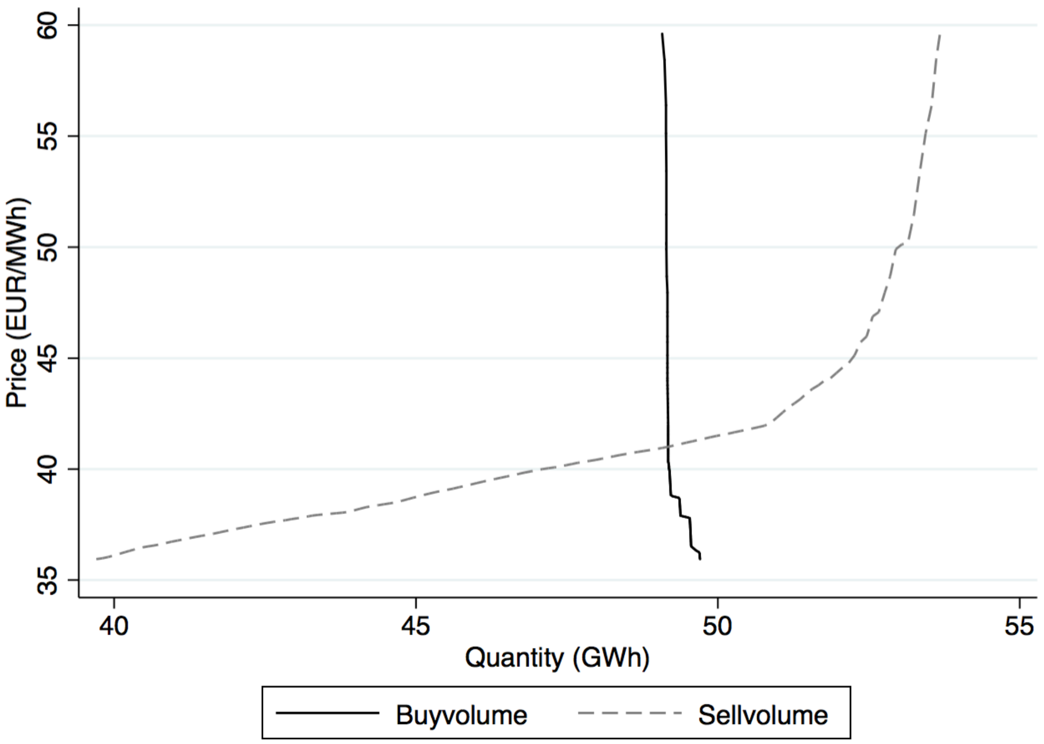
price is called the system price. Figure 3 shows an example of the system supply and demand curves. In absence of transmission constraints, all participants face the system price. If there are bottlenecks in transmission, the market may be divided into 15 different price zones depending on where the bottlenecks occur. The geographical borders of the price zones are illustrated in Figure A3. All Swedish nuclear plants are located within the same price zone (SE3) which follows the system price very closely (the correlation between the system price and the price in SE3 is 0.96). Therefore I use the system price as a proxy for the price received by the nuclear plants. Still, the presence of transmission constraints should increase incentives to exert market power.

The nuclear producers sell all their output on the day-ahead market, and any obligations to deliver electricity through forward contracts are settled financially. The system price is the reference price for the main financial products. Thus, if a producer has sold a forward contract of 1 MWh for a price of 10 EUR and the day-ahead price is realized at 9 EUR/MWh, the producer will receive 1 EUR in cash from the buyer of the contract. It is beyond the scope of this paper to consider the optimal behavior of the firms given their financial positions. However, it is worth to note that the presence of forward obligations should have a positive effect on the unilateral incentives to behave competitively in the day-ahead market, since increasing the day-ahead price will only increase the compensation for electricity that is not already forward contracted. Vertical integration, i.e., when a firm is active in both the wholesale and retail markets, will have a similar effect since retail obligations are usually very similar to forward contracts. See Wolak (2007) for an empirical examination of the competitive effects of forward contracting in the Australian electricity market, and Bushnell et al. (2008) for the competitive effects of vertical integration in three electricity markets in the U.S. The impact of forward contracting on the possibility to sustain collusion is less clear, and has not been studied em-

---

block bids, and not at which price they were bid into the market. For simplicity I therefore assume that block bids are inelastic, i.e., that they enter the market at zero cost. Correspondingly, I only have information about the volume of net exports and not at which price they were bid in. On average, 6 percent of the traded volume comes from net exports. Analogously, I also let net exports enter the auction as inelastic bids. During 2015 the price ceiling for both block- and regular bids was raised to 3,000 EUR/MWh.

Figure 3: System supply and demand



Note: This figure depicts the system supply and demand functions on the Nordic day-ahead market during 2-3 pm, January 19, 2013.

Table 2: Ownership shares by plant and firm

Power plant	Total capacity (GW)	Number of reactors	Vattenfall	E.ON	Fortum
Ringhals	3.7	4	**70**	30	0
Forsmark	3.1	3	**66**	10	22
Oskarshamn	2.3	3	0	**55**	45
		Counterfactual			
Ringhals	3.7	4	**100**	0	0
Forsmark	3.1	3	0	0	**100**
Oskarshamn	2.3	3	0	**100**	0

Note: Ownership structure of Swedish nuclear plants 2002-present. Majority ownership shares in **bold**. The ownership structure in the counterfactual scenario is presented in the bottom three rows.

Table 3: Production mix in the Nordic region

Production type	Percentage of production
Hydro	49
Thermal (non-nuclear)	19
Swedish nuclear	20
Finnish nuclear	7
Wind	5

Note: This table depicts market shares by fuel type for the Nordic market during 2011-2013.

pirically. Theoretical contributions include Liski and Montero (2006), finding that a firm which defects from a collusive agreement will not be able to capture the demand already covered by contract sales, thus increasing the possibility to sustain collusion. Using a similar setup, but where contracts may be of different lengths, Green and Coq (2010) find that the possibility to sustain collusion is decreasing in contract length. The latter result could be of relevance in the present context, since the liquidity in the Nordic forward market is in the quarterly and yearly contracts.

The market is fairly concentrated, and yearly market shares do not display much variation during the sample period. Including nuclear production, the firm with the largest share of total production was the Swedish state-owned firm Vattenfall (19 percent), followed by the Norwegian state-owned Statkraft

(14 percent). The third largest producer was Fortum (12 percent) in which the Finnish state is the majority owner, followed by the German private energy consortium E.ON (7 percent). There are five nuclear plants. Three are located in Sweden and two in Finland. Vattenfall, Fortum and E.ON jointly own the Swedish plants according to the ownership structure depicted in Table 2. The bottom three rows depict the ownership structure in the counterfactual scenario in which the joint ownership is terminated. The nuclear plants are organized as limited liability companies, and the majority owner in each plant also has the operational responsibility for that plant (Energy Markets Inspectorate, 2010). E.ON is the only firm that owns shares in all three plants. E.ON is also the majority owner in Oskarshamn, and Vattenfall is the majority owner in Ringhals and Forsmark. Fortum owns shares in both Oskarshamn and Ringhals.[5] The current ownership structure of the plants was formed around the turn of the century. In 1999, the reactor Barsebäck 1 (with a capacity of 0.6 GW) was permanently shut down as the first step to phase out the Swedish reactors. Since Barsebäck was fully owned by the Swedish firm Sydkraft, Sydkraft acquired shares in Ringhals from Vattenfall as a compensation for the shut down, in an agreement between Sydkraft, Vattenfall and the government. In 2005, the remaining reactor Barsebäck 2 (also with a capacity of 0.6 GW) was shut down. In 2001, Sydkraft acquired shares in Forsmark from Vattenfall in exchange for shares in the German energy firm HEW. Shortly afterwards, E.ON became the majority shareholder in Sydkraft. In 2000 Fortum acquired the Swedish firm Stora Kraft, thereby gaining ownership in both Forsmark and Oskarshamn. For further details about these M&As, see Energy Markets Inspectorate (2006). Nuclear production constitutes about half of the production portfolio of the owners, and hydropower constitutes the major share of the remaining production. Each firm also owns a number of wind farms, and a number of combined heat- and power plants. They are primarily used for dis-

---

[5] Oskarshamn has three reactors, all of which are boiling water reactors. The reactors began operation in 1972, 1974 and 1985. Ringhals has four reactors. The first reactor began operation in 1975, and is a pressurized water reactor. The second reactor began operation in 1976, and is a boiling water reactor. The other reactors began operation 1981 and 1983 and are both pressurized water reactors. Forsmark is the newest plant, and has three boiling water reactors that began operation in 1980, 1981 and 1985 respectively. For further information about the technical characteristics of the plants, see Swedish Radiation Safety Authority (2014).

trict heating, and generate electricity as a by-product. Vattenfall and Fortum also own one conventional peak load thermal plant each. For a complete list of the owners' generation plants, see Vattenfall (2015); E.ON (2015); Fortum (2015). The production mix for the whole market is depicted in Table 3.

A unique feature of the Nordic market is that information about maintenance and failures that involves outages above 100 MW have to be reported in the form of so-called "Urgent Market Messages" that are sent to an online database. Figure A4 shows an example of such a message. The intention of the database is to prevent participants to arbitrage on inside information, and to facilitate production planning. A similar information system is currently being implemented in all European electricity markets through a cooperation among the European energy regulators (ACER, 2015). The database is accessible to all market participants without delay. A message should preferably be posted simultaneously with but no later than 60 minutes after the decision time for a scheduled maintenance, or at the start-time for a failure. The message has to include the estimated start- and stop time of the outage, size of the outage, fuel type, as well as an identification of the plant including the owner. Information contained in a message may be updated by sending so-called follow-up messages. For example, a firm may not be able to provide accurate information about the length of a failure at the time it occurs, or may reschedule previously announced maintenance. In total there are 467 unique events concerning the nuclear plants reported during the sample period, with an average of 4.5 messages per event. 90 percent of the outages (measured in GWh) are due to maintenance. Excluding follow-ups and failures, half of the events had been reported to the database prior to two weeks before the beginning of the outage. Since Swedish nuclear plants are constructed to operate at full available capacity, in theory it should be possible to replicate the output of each reactor just by using information from the Urgent Market Messages. Factually, it happens that output does not correspond exactly with the information provided in the messages. Some messages only contain approximations of the length of an outage. Other messages contain information about coastdowns (i.e. when a reactor gradually decreases production until the fuel in the core is depleted), and these messages do not contain information about output at each specific point in time. However, at least on a weekly basis the information contained in the messages can be used to replicate output very well, with an average absolute deviation from observed output of less than 5 percent. See Figure A5 and A6 for a graphical illustration of how well aggregate nuclear output can be predicted using only the Urgent Market Messages. Although I do not make use of the Urgent Market Messages explicitly in the simulations, I may conjecture that other market participants have good information about nuclear output at the time of bidding in the day-ahead market, and that the majority of all capacity reductions are not due to exogenous events (such as unforeseen production failures), but can be attributed to planned maintenance.

Nordic nuclear producers are not unfamiliar with the exercise of market power. After an extended period of low wholesale prices around the year 2000 due to a large amount of inflow into the hydro reservoirs, nuclear production suddenly dropped unexpectedly in several of the plants. Attention was brought to Vattenfall, who later claimed that: “Sometimes we reduced [nuclear] production when prices were above the variable cost...with the result that prices increased somewhat...but we never did it in agreement with the other co-owners”[6]. In 2006 the Swedish Competition Authority investigated suspicions of coordinated reductions of nuclear production in the Swedish plants in order to raise prices. The authorities found that up until 2002, all production decisions were planned at meetings among the owners in a way that was illegal. However, that practice had been voluntarily interrupted by the time of the investigation and the authorities decided not to investigate the matter further. Since 2002 each owner has the right to a share of the available capacity in each plant (i.e. net of maintenance and other outages), proportional to its ownership share. Each owner then independently requests to the plant operation manager how much of that capacity it would like to use for production (Nordic Competition Authorities, 2007). During 2011-2013, all owners choose to use all capacity available, i.e., maintenance was the way owners controlled the level of output. Nevertheless, the Swedish government has continued to express concerns that nuclear producers are exercising market power, and in 2010 the owners were obliged to adopt a “Code of Conduct” (Energy Markets Inspectorate, 2010) that

---

[6] The quote is a transcript (freely translated from Swedish) from a radio interview with the head of production at Vattenfall. For the whole interview, see Radio Sweden (2006).

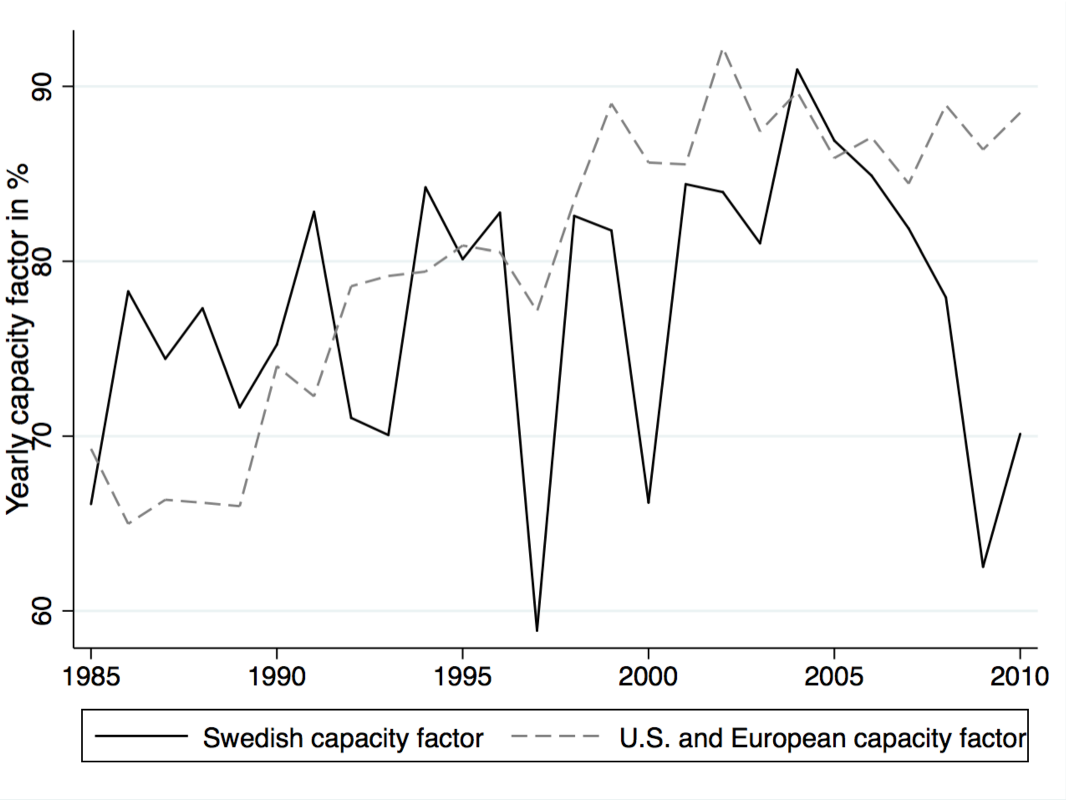
explicitly limits the type of information that may be shared among the owners. However, information that may still be shared is “All information that is relevant in order for the activity at the plant to be operated in a way that is: a) secure, b) rational, and c) efficient”. Therefore, to the extent that maintenance decisions are relevant with regard to either of the points above they may be discussed freely among the owners in a way that does not by default infringe on antitrust legislation. In 2012, the owners signed a regulatory agreement stating that scheduled maintenance should be avoided during the winter period (November-March). However, similar to the formulation in the Code of Conduct, the agreement states that maintenance may still be performed during the winter season if the owners determine that it is necessary due to safety reasons.

3.2 Data

The sample period for the main analysis is 2011-2013. Plant specific hourly nuclear output has been compiled specifically for this study by the Swedish transmission system operator (*Svenska Kraftnät*). System supply and demand curves, data on inflow to the hydro reservoirs, realized prices and quantities, Urgent Market Messages, and the consumption prognosis have been downloaded from the Nordpool FTP-server and is subject to a subscription fee (Nordpool, 2015). Most Nordpool data is also available free-of-charge for manual downloads at the Nordpool downloads center (www.nordpoolspot.com/download-center/). Yearly market shares of the firms’ non-nuclear output have been collected from the market reports of the Nordic Energy Regulators (Nordreg, 2011, 2012, 2013). The monthly production data used in the difference-in-differences exercise in the introduction that spans between 1975-2014 is available for download at Statistics Sweden and Statistics Finland respectively (Statistics Sweden, 2015; Statistics Finland, 2015). When comparing historical capacity factors of Swedish and foreign nuclear reactors, I use data from the IAEA Power Reactor Information System (IAEA, 2015).

Table 1 summarizes the main observed variables. The mean system clearing price is 39 EUR/MWh. The hourly system supply and demand curves contain

Figure 4: International trends in nuclear capacity factors



Note: This figure depicts historical capacity factors of Swedish vs. U.S. and other European nuclear reactors that are currently in operation. Only foreign reactors built before 1974 are included in the sample. Reactors that have been permanently shutdown are excluded. There are 41 foreign and 8 Swedish reactors included in total.

Table 4: Summary statistics of data used in the main analysis

Variable	Mean	St.dev	Min	Max
Observed system clearing price	38.78	14.28	1.38	224.97
Observed system clearing quantity	35.94	7.27	19.89	58.16
Consumption prognosis	43.77	8.92	25.81	68.99
Reservoir inflow	23.99	17.93	2.48	98.54
Production in Oskarshamn	1.52	0.56	0.00	2.36
Production in Ringhals	2.67	0.94	0.00	3.76
Production in Forsmark	2.79	0.55	0.97	3.30
Market share on day-ahead market (excluding nuclear)				
Vattenfall	13	3	11	17
E.ON	3	1	2	4
Fortum	10	0	9	10

Note: Clearing quantity, consumption prognosis, reservoir inflow and plant production are expressed in GWh. Prices are expressed in EUR/MWh. Market shares on the day-ahead market are expressed as percentages. The consumption prognosis is larger than the clearing quantity since some of the electricity consumed is not traded on the day-ahead market.

around 600 price-quantity pairs each (firm specific bid data is not available at present). As depicted in Figure 3, the entire demand function is usually highly inelastic except at very low prices. The supply elasticity varies more. Nuclear- and hydro provide base load production, and are usually supplied at low prices. As demand increases, more thermal production is dispatched and the supply curve becomes steeper. As a result, in peak load hours the supply elasticity is generally lower than in low peak hours. The average price during a peak hour (8 am-8 pm) is 30 percent higher than the average price during a low peak hour, which is comparable to the difference in prices during the winter- and summer periods. The consumption prognosis is determined at 11 am the day before delivery and is about 20 percent higher than the cleared day-ahead quantity, since all electricity consumed is not traded at the day-ahead market but through bilateral contracts. Reservoir inflow, measured in GWh of potential electricity production, is about half of the consumption prognosis, consistent with the fact that hydro production represents about half of the production in the market.

Of all Swedish nuclear plants, Oskarshamn had the lowest capacity factor during the sample period (64 percent), followed by Ringhals (71 percent) and Forsmark (85 percent). Figure 4 compares the trend in capacity factors of Swedish nuclear reactors with reactors in the U.S. and the rest of Europe (excluding the former Soviet Union). Since older reactors tend to have lower capacity factors than newer ones, only foreign reactors constructed before 1975 are included in the sample. All but two of the of the Swedish reactors were constructed after 1974, and those two reactors have been excluded from the sample. Also, all plants that have been permanently shut down are excluded. In other words, all Swedish reactors in the sample are of the same age or younger than the foreign ones, and the mean construction year of a Swedish reactor in the sample is 1979, compared to 1972 for the foreign reactors. It is clear that the positive trend in capacity factors among foreign reactors has not taken place in Sweden. Comparing the years before and after Swedish deregulation, the mean capacity factor of foreign plants increased from 73 percent to 87 percent, while the mean Swedish capacity factor is around 77 percent during both periods. One reason for the relatively low capacity factors may be due to the decision in 1980 (by a referendum) to gradually phase out the nuclear plants, although the only plant that has in fact been shut down is Barsebäck. The decision may have lead owners to refrain from large-scale investments that would mitigate the need for frequent maintenance disruptions.

4 A non-structural econometric test of market power

In this section, I use a non-structural econometric framework to examine if nuclear output responds to the ability to exercise market power. As a measure of the ability to exercise market power I use the (absolute) slope of the inverse system residual demand function evaluated at the market clearing point. I define the system residual demand function as:

$$D_{res}^{system}(p) = D^{system}(p) - S^{system}(p)$$

where $D^{system}(p)$ is the system demand function and $S^{system}(p)$ is the system supply function. The slope is then given by:

$$|\frac{\partial p(D_{res}^{system})}{\partial D_{res}^{system}}|$$

It is a measure of the price increase (in EUR/MWh) that would be the result of a one GWh increase in inelastic supply by any firm in the market. Similar measures of the ability to influence the wholesale price have been used in previous work, see e.g., Reguant (2014) and McRae and Wolak (2014). However, they observe firm specific bids directly. Then, it is possible to compute the residual demand function of firm i according to:

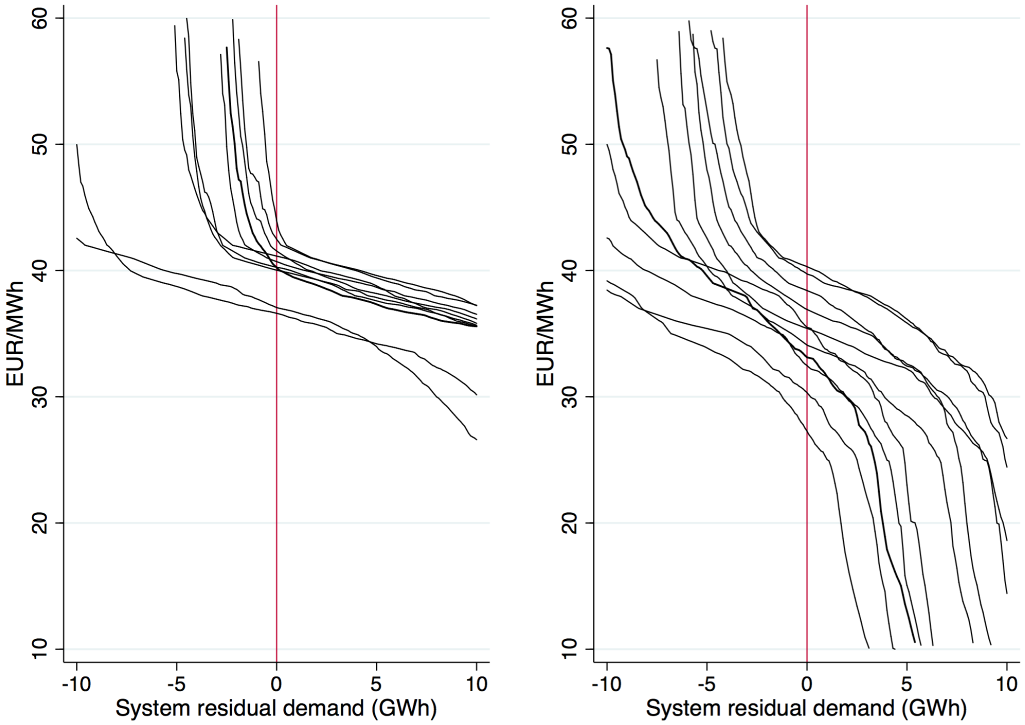
$$D_{res}^{i}(p) = D^{system}(p) - \sum_{j \neq i} S^{j}(p)$$

Where $\sum\limits_{j \neq i} S^{j}(p)$ are the supply bids from all other firms. Although I approximate firm specific bids in the structural section below, for the moment I stick to a measure of market power that is identical across firms, as it imposes a minimal set of assumptions on individual firm bidding. Figure 5 depicts a sample of the system inverse residual demand functions during a month with high demand (February) as well as low demand (June) 2013, at 5 pm.

I compute the slope by taking a quantity window of 0.5 GWh on each side of the market clearing point and interpolate prices at these points. The interpolation procedure is identical to the clearing algorithm used by the auctioneer (apart from the treatment of blockbids). As a robustness test I also compute the slope by instead using a quantity window of 0.25 and 1 GWh respectively. The correlations between all slope measures are above 0.8, confirming that the size of the window is of less importance for how the slope is computed. The median value of the slope is 1, meaning that a 1 GWh reduction in supply would increase the price by 1 EUR/MWh. If instead expressing the slope as an elasticity, i.e.,

$$|\frac{\partial p(D_{res}^{system})}{\partial D_{res}^{system}}| \times \frac{q}{p}$$

Figure 5: System residual demand functions in February and June



Note: This figure depicts random system residual demand functions (i.e. system demand minus system supply) in February (left diagram) and June (right diagram) 2013 at 5 pm.

Where q and p are market clearing quantity and price, the median value is still one, i.e., one percent increase in supply will on average reduce the price by one percent.

Hydropower constitutes around half of the production in the Nordic region, and positive supply shocks in the form of inflow to the hydro reservoirs are important determinants of the ability to exert market power. This relationship is illustrated in Figure 6, displaying a positive correlation between the median slope and the amount of reservoir inflow[7]. Inflow is an exogenous pro-

---

[7] Figure 6 depicts the monthly median slope and inflow. By contrast, Figure A7 depicts the same relationship but instead displaying the mean slope. The relationship is then reversed, with the highest slopes occurring during the winter season. In other words, although occasions of high demand will lead to extremely high slopes during short periods in the winter, reservoir inflow is a better determinant of the possibility to exercise market power when the system is not capacity constrained.

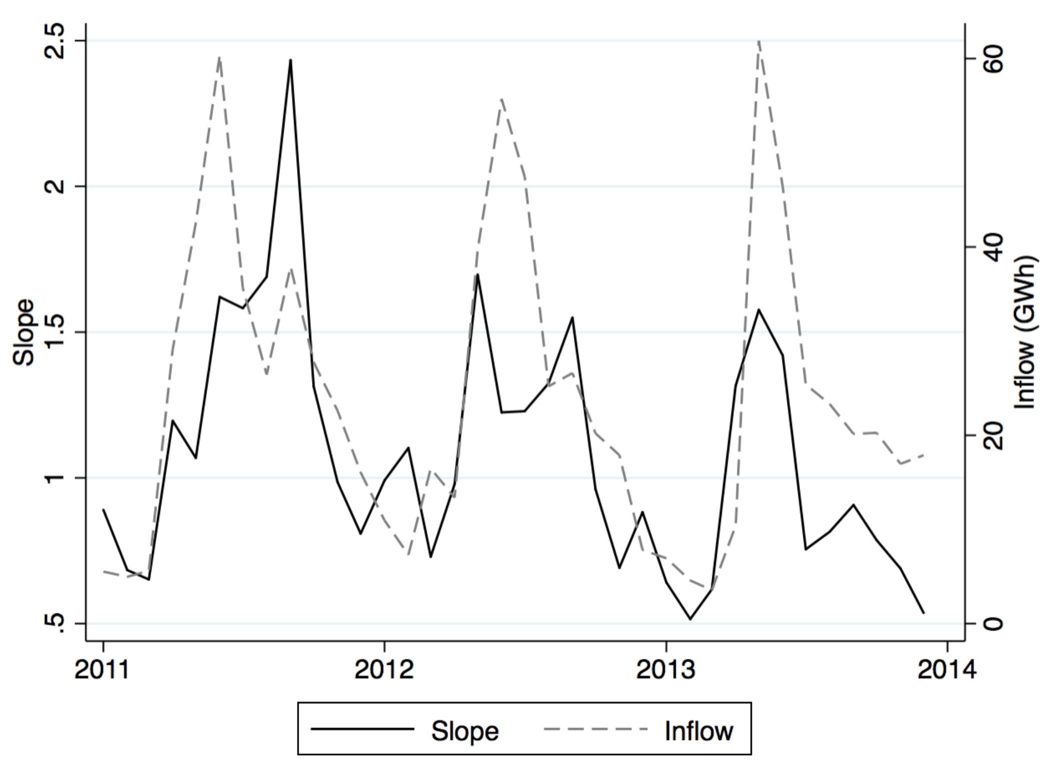
cess where precipitation and melted snow flow into the reservoirs. It follows yearly cycles, and peak inflow is in April-June. During times of high inflow, hydro producers with limited storage possibilities are forced to produce to reduce the risk of overflowing. Førsund (2005) notes that in Norway, where 60 percent of the Nordic hydro production is located, reservoir capacity is concentrated to a small number of firms. Small hydropower firms tend to have less reservoir capacity, and 30 percent of Norwegian hydro production comes from run-of-the-river plants that do not have any storage possibilities at all. This opens up for dominant firms to exercise market power during periods when production constraints are binding. Since periods of high inflow occur during periods when consumption is relatively low, it is notable that the median residual demand function is steep during these periods. If nuclear or other base load generation do not counteract the positive supply shock due to increased reservoir inflow, prices may become very low. Looking at Figure 5 we also see that the slope becomes very steep at low prices in June (right diagram). Conversely, in February (left diagram) the slope is only steep at high prices. Since nuclear producers have very limited access to other thermal base load generation than nuclear, allocating maintenance to exert market power during periods of high inflow is a natural strategy. Figure 7 depicts the relationship between nuclear output and reservoir inflow. The variables display a clear negative correlation (with a correlation coefficient of -0.7). Conversely, the price, which should be the best determinant of output in a competitive market, display a less pronounced covariation with nuclear output (with a correlation coefficient of 0.31).

As a non-structural test of the determinants of nuclear output I estimate:

$$q_t^{nuc} = \alpha + \Theta slope_t + \beta price_t + \rho inflow_w + \mathbf{T}\gamma + \varepsilon_t \tag{2}$$

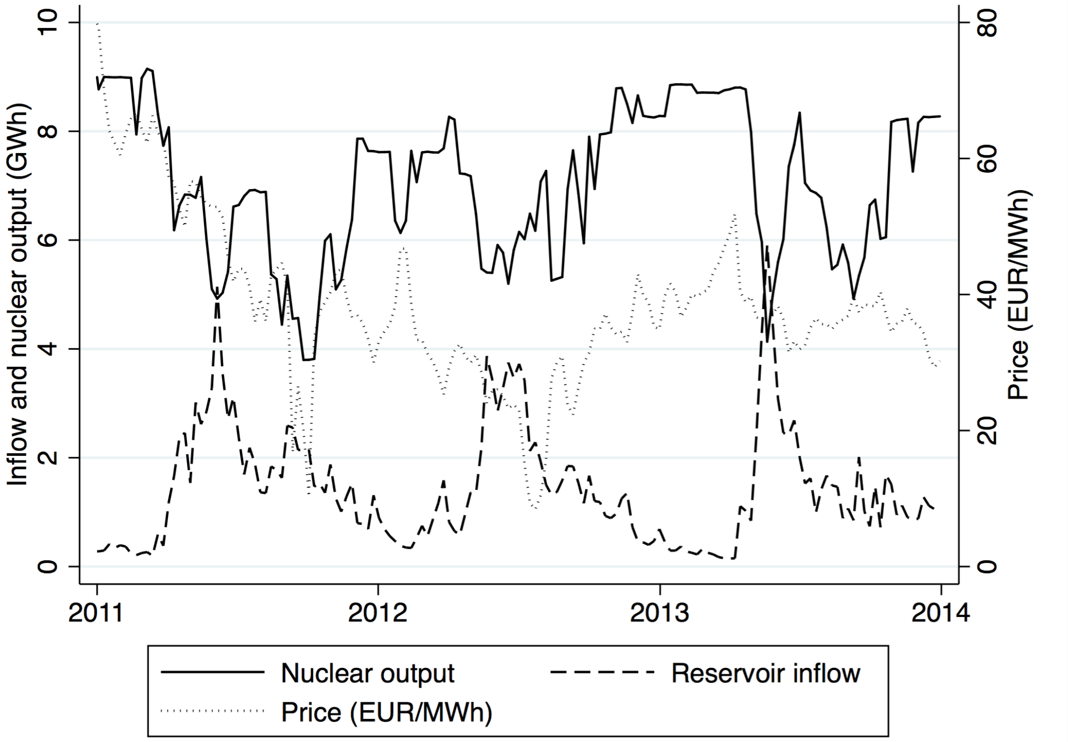
Where q_t^{nuc} is nuclear output in hour t, $slope_t$ is the slope of the inverse system residual demand function, $price_t$ is the day-ahead price, $inflow_w$ is reservoir inflow, and $\mathbf{T}$ is a vector of time fixed effects. Inflow is measured as the total amount of water (in GWh) flowing into the hydro reservoirs in Sweden and Norway. All variables are hourly, except for inflow that is only available on a

Figure 6: Reservoir inflow and slope of residual demand



Note: This figure depicts the median monthly reservoir inflow in Sweden and Norway, as well as the median slope of the system residual demand function.

Figure 7: Nuclear output and reservoir inflow



Note: This figure depicts weekly Swedish nuclear production, reservoir inflow in Sweden and Norway, and day-ahead price. The inflow variable has been scaled by a factor of 0.06.

weekly basis. The expected sign of the coefficient for the slope (Θ) is negative if firms exercise market power. When the slope is steep, restricting output has a large positive effect on the price. The expected sign of the coefficient for the price (β) is positive, as firms should be willing to supply more electricity when the price is high. The expected sign of the coefficient for amount of inflow (ρ) is negative: When there is a lot of inflow, hydro plants are forced to produce, and the only way to push up the price is to reduce nuclear output. Both the price and the slope suffer from endogeneity. Price is endogenous since increased output drives down the price. The slope is endogenous since increased output will usually move the equilibrium to a less steep part of the residual demand function. Therefore I instrument the price and the slope using forecasted consumption the day before delivery and its square. The consumption forecast does not take price into account, and is thus exogenous with respect to the error term. Using forecasted consumption to instrument for price is common practice in the electricity literature, see e.g., Kim and Knittel (2006). The consumption forecast is a strong predictor of both the slope and the price. A potential violation of the exogeneity assumption could arise if production plans are known *ex-ante*, and consumers adjust their consumption plans accordingly. However, the consumption forecast is based on meteorological factors such as forecasted temperature and precipitation, and some macroeconomic variables of economic activity. Therefore, fine-tuned adjustments of consumption plans due to information about nuclear outages are not captured by the consumption forecast. Further, as depicted in Figure 3, demand is often almost perfectly inelastic around the market clearing point, emphasizing the exogeneity of demand with respect to price.

4.1 Results

Looking at Table 5, the slope coefficient $\hat{\Theta}$ is negative in all specifications, which is consistent with the hypothesis that firms exert market power. Without controlling for reservoir inflow, in column (1) we see that a one standard deviation increase in the slope will lead to a reduction in output by 0.38 standard deviations (or approximately 8 percent of mean nuclear output). After controlling for reservoir inflow in (2) the slope coefficient drops by half, confirming that reservoir inflow is a good determinant of the ability to exercise market power. Controlling for seasonal fixed effects (winter, spring, summer and fall) in (3) only changes the coefficient slightly. The OLS estimate of $\hat{\Theta}$ is similar to the corresponding IV estimate in (3). The price coefficient $\hat{\beta}$ is positive in all specifications. Without controlling for reservoir inflow, a one standard deviation increase in the price is associated with a 1.18 standard deviation increase in output. Similar to the slope variable, the price coefficient drops by half when controlling for inflow. However, contrary to the slope variable the price variable again drops by almost half when also including seasonal fixed effects. The OLS estimate of $\hat{\beta}$ is about $^2/_3$ of the IV estimate, indicating that the OLS estimate is biased downwards due to reverse causality.

Table 5: Determinants of nuclear output.

	(1)	(2)	(3)	(OLS)
Slope ($\hat{\Theta}$)	-0.38***	-0.17***	-0.20***	-0.17***
	(0.0026)	(0.0021)	(0.0019)	(0.00070)
Price ($\hat{\beta}$)	1.18***	0.55***	0.35***	0.21***
	(0.0014)	(0.0014)	(0.0014)	(0.00058)
Reservoir inflow ($\hat{\rho}$)		-0.47***	-0.46***	-0.50***
		(0.00050)	(0.00048)	(0.00041)
Year FE	Yes	Yes	Yes	Yes
Seasonal FE	No	No	Yes	Yes
Observations	26304	26304	26304	26304

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$

Note: The dependent variable is hourly nuclear output.Year fixed effects are included in all regressions. Price and slope have been instrumented with forecasted consumption and its square. Cragg-Donald Wald F-statistic is above 100 in all regressions. Standard errors in parentheses. Coefficients are standardized.

The magnitude of the inflow coefficient $\hat{\rho}$ is similar in all specifications, indicating that a standard deviation increase in reservoir inflow is associated with around 0.5 standard deviations reduction in output. However, we should not interpret $\hat{\rho}$ as a purely causal effect. Inflow constitutes a positive supply shock that will drive down the price, so also a competitive producer should react to inflow by restricting output. Even though price is included in the regression, it is instrumented with variation in forecasted consumption only.

5 A structural model of nuclear output

Objective function

In this section, I formulate a theoretical model to simulate optimal nuclear output given three behavioral assumptions: unilateral profit maximization, joint profit maximization, and a social planner. I start by formulating the model of unilateral profit maximization, which serves a a natural starting point as it is the only model that explicitly takes into account the ownership shares in each nuclear plant. Under unilateral profit maximization, the majority owner chooses a level of output that maximizes the sum of its own profit from nuclear- and other (non-nuclear) production. This means that Vattenfall takes the output decisions in Ringhals and Forsmark, while E.ON takes the output decisions in Oskarshamn. Fortum will remain a passive owner in all plants. In the simulation for Vattenfall, Ringhals and Forsmark are aggregated to resemble one large plant, as I assume that the marginal cost of nuclear is constant.

It is a model of best-response, i.e., nuclear output is determined as a best-response given the other bids in the market. Thus, increasing nuclear output will substitute away other production approximately proportionally, due to the almost inelastic demand. The majority owner takes into account both other firms' passive ownership in the plant it controls, as well as its own passive ownership in plants where it is only a minority owner. The more passive ownership the firm has in other plants, the stronger are the incentives to exert market power in its own plant.

I denote the profit of majority owner i by π^i, and the output in the nuclear plant owned by firm i in hour t by q_t^i. The inverse residual demand function facing firm i's nuclear plant during hour t is $p_t(q_t^i)$, firm i's supply function net of nuclear output is $S_t^i(p_t(q_t^i))$, the constant marginal cost of nuclear is f, and the total cost of other production is $C_t^i(p_t(q_t^i))$. Further, the ownership share in firm i's own plant is denoted by η_i^i, and i's passive ownership shares in the plants controlled by firm $j \neq i$ are η_j^i.

The objective function of firm i is:

$$\max_{q_t^i} \quad \pi^i = \sum_{t=1}^{T} \Big\{ \underbrace{p_t(q_t^i)[\eta_i^i q_t^i + \sum_{j \neq i} \eta_i^j q_t^j + S_t^i(p_t(q_t^i))]}_{\text{Total revenue}} - \underbrace{f[\eta_i^i q_t^i + \sum_{j \neq i} \eta_i^j q_t^j] - C_t^i(p_t(q_t^i))}_{\text{Total cost}} \Big\} \tag{3}$$

Since there is a new auction each hour, the profit is expressed as the sum of profits over all hours in the sample period, i.e., $T \approx 26,000$. Letting π^{joint} be the joint profit of the firms, and q^{nuc} be aggregated nuclear output, the objective function under joint profit maximization becomes:

$$\max_{q_t^{nuc}} \quad \pi^{joint} = \sum_{t=1}^{T} \Big\{ \underbrace{p_t(q_t^{nuc})[q_t^{nuc} + S_t^{joint}(q_t^{nuc})]}_{\text{Total revenue}} - \underbrace{f q_t^{nuc} - C_t^{joint}(q_t^{nuc})}_{\text{Total cost}} \Big\} \tag{4}$$

And the corresponding objective function for the social planner is:

$$\max_{q_t^{nuc}} \quad \pi^{planner} = \sum_{t=1}^{T} \Big\{ \underbrace{\int_0^{q_t^{nuc}} p_t(x_t) dx_t}_{\text{Revenue and cons. surplus}} - \underbrace{f q_t^{nuc}}_{\text{Total cost}} \Big\} \tag{5}$$

Differentiating (3) with respect to q_t^i, denoting partial derivatives with subscripts, omitting time subscripts and rearranging yields:

$$p = \frac{\overbrace{\eta_i^i f + C_{q^i}^i}^{\text{Marginal cost}} \overbrace{- p_{q^i}[\eta_i^i q^i + \sum_{j \neq i} \eta_i^j q^j + S_{q^i}^i]}^{\text{Markup}}}{\eta_i^i + S_{q^i}^i} \tag{6}$$

Which gives the optimal bid-price as a function of marginal costs and the price sensitivity of the inverse residual demand function in each individual hour, also taking into account the profit on non-nuclear output. The corresponding equation for the social planner yields the familiar expression $p = f$, i.e., price equals marginal cost.

Constraints

The constraints depend on the technical characteristics of the plants, and do not change depending on the behavioral assumptions of the firms. I denote the maximum hourly output given the installed capacity of firm i's plant by $\overline{q_t^i}$ (which is constant for all t). Denoting the set of all hours belonging to the same week by $\mathbf{w}$, and the set of all hours belonging to the same year by $\mathbf{y}$, the constraints can be expressed as:

$$\begin{aligned} & q_t^i \leq \overline{q_t^i} \\ & q_k^i = q_m^i \text{ if } k, m \in \mathbf{w} \\ & p_t(q_t^i) \leq p_t^{obs} \times x \\ & \sum_{t \in \mathbf{y}} q_t^i \leq \sum_{t \in \mathbf{y}} q_t^{i(obs)} \end{aligned} \tag{7}$$

Where the first constraint in (7) is the capacity constraint of the plant owned by firm i.

The second constraint states that output has to be the same within each week-of-sample. This constraint reflects the fact that it is not possible to shut down a reactor during shorter periods than about a week. The assumption is in line with data. For each plant, the mean hourly (absolute) deviation from the mean weekly output is only 0.5 percent. As a robustness test I also estimated the model setting the constraint to 2, 3, and 4 weeks respectively, with no qualitative differences in the results.

The third constraint states that there is a limit to how much the firm can push up the price by restricting output. Specifically, the constraint introduces a horizontal segment on the inverse residual demand function facing i's plant, for prices above $p_t^{obs} \times x$. There are two reasons for introducing this constraint.

The first is due to regulatory threat. As discussed in section 3, nuclear owners are obliged not to perform maintenance during the winter season unless it can be motivated for safety reasons. For example, removing all output in the nuclear plants controlled by Vattenfall from the system supply function would more than double the price during 30 percent of all hours during the winter season. Since Vattenfall also enjoys a large market share on other output, such a strategy will sometimes be beneficial. However, if that strategy is executed despite the regulatory obligation to refrain from doing so, the probability of the introduction of a severely stricter regulatory framework would increase. Empirical evidence that firms refrain from pushing up prices during periods of intensified regulatory oversight has also been documented in the context of the British electricity market (Wolfram, 1999; Wolak and Patrick, 2001). For a more general description of the trade-off between a monopolist's short term profits and the possibility of future regulation, see Glazer and McMillan (1992). The second reason has to do with the behavior of competing firms. Even though it is likely that an unexpected drop in nuclear output could initially have a very large price effect, the effect would soon be mitigated as other firms adapt their production planning to the new conditions, and start expanding output. In a hydro dominated market, an important aspect of this adaptation is the ability to shift output towards periods with high prices by storing water in the reservoirs. However, there is no natural prior how to determine the value of x. In the baseline estimation, I set x to 1.3, implying that prices above approximately one standard deviation of the observed day-ahead price are not feasible. Qualitatively, results are robust to varying x between 1 and 1.5.

The fourth constraint is the maintenance constraint. It states that simulated yearly output must not exceed observed yearly output. Alternatively, this constraint could have been more precisely stated using data on total reported maintenance in the Urgent Market Messages database. However, as shown in the results section, there are indications that outages reported as failures are not exogenous, but are also determined by strategic considerations. Also, as failures only account for about 10 percent of all output reductions, removing these events from the model only has a minor impact on the problem setup. To see how the introduction of the maintenance constraint affects the allocation of output, I simplify the objective function and express weekly profits as a function of weekly output directly.

Omitting the capacity constraint, the general optimization problem for year y becomes:

$$\max_{q_w} \quad \pi_y = \sum_{w \in \mathbf{y}} \pi_w(q_w)$$

$$s.t.$$

$$\sum_{w \in \mathbf{y}} q_w \leq \sum_{w \in \mathbf{y}} q_w^{(obs)}$$

The Lagrangian is then:

$$L_y = \sum_{w \in \mathbf{y}} \pi_w(q_w) - \lambda(\sum_{w \in \mathbf{y}} q_w - \sum_{w \in \mathbf{y}} q_w^{(obs)})$$

Given that optimal output is positive in each period, the first order conditions can be expressed as:

$$\frac{\partial \pi_k(q_k)}{\partial q_k} = \frac{\partial \pi_l(q_l)}{\partial q_l} \; \forall k, l \in \mathbf{y}$$

Given that $\lambda > 0$, i.e., that the value of increasing total yearly output is positive, marginal revenues will be equalized across all weeks in the sample and equal to λ. Naturally, if the marginal revenue would be higher in week k than in week l, it would be optimal to allocate more output to week k and thereby increase total profits[8]. For the social planner, the marginal value of increased production is the price, meaning that the social planner will seek to equalize prices across periods. For a description of the solution technique used to solve the full optimization problem, see Appendix B.

---

[8] The optimization problem is very similar to the optimization problem faced by a hydro producer, who has to decide how much water to release through the turbine each period. See Førsund (2006) for a further description.

Fitting data to the model

Although some of the model components are observed, I need to make some further assumptions about the bidding behavior of the firms in order to estimate the full model. First, I assume that all nuclear output is bid into the market as inelastic bids, i.e., at zero price. This is a reasonable assumption, as nuclear plants cannot run the risk of not getting dispatched. It is also in line with the shape of the observed system supply function, where around half of all accepted bids enter the supply function inelastically. Thus, I can construct the residual demand function of a nuclear plant in two steps. First I compute the market supply function of other (non-nuclear) output, $S_t(p_t)$, by subtracting the observed aggregate nuclear output from the system supply function. I get $S_t(p_t) = S_t^{system}(p_t) - q_t^{nuclear}$. The residual demand function facing the nuclear plant of firm i is then $q_t^i(p_t) = D_t^{system}(p_t) - S_t(p_t) - \sum\limits_{j \neq i} q_t^j$.

Since I do not have firm-specific bids, but firm-specific market shares, I assume that firm i's bid from other production is a scaled version of $S_t(p_t)$. Let θ^i be the observed market share of firm i net of of nuclear output. Then, the supply function of firm i net of nuclear output is $S_t^i(p_t) = \theta^i S_t(p_t)$. In the baseline model I assume that all non-nuclear output is bid into the market at marginal cost. Thus, firm i's cost function of non-nuclear output is $C_t^i(p_t) = \theta^i \int_{p_t^{min}}^{p_t} S_t(x)dx$. The assumption of competitive bidding of non-nuclear output is certainly a simplification, and will bias the incentives to exert market power downwards. If other production is bid in with a margin, firms will have less incentives to increase nuclear output as it could substitute away other, relatively cheap production. Therefore I also conducted robustness test by varying the markup on other production up to 15 percent, with no qualitative changes in the results.

I approximate the marginal cost of nuclear f by the mean accounting fuel cost for all plants during the sample period, which is EUR 5/MWh, or equivalently 13 percent of the mean day-ahead price. I compiled the accounted cost of fuel from the annual reports of each firm. Due to the small variation in fuel costs across firms and years, results do not change by allowing for the cost to vary. The fuel cost depends both on the direct cost of fuel, which was on average EUR 3.5/MWh, and a mandatory depository fee based on the amount of electricity produced, which was on average EUR 1.5/MWh. The nuclear producers also pay a nuclear tax based on the installed capacity of each reactor. However, a reactor is only exempted from the tax if it remains inactive for more than 90 days. Therefore I do not consider the nuclear tax as a variable cost. I also conducted robustness tests by varying the marginal cost by 3 EUR/MWh in both directions, which only affected results marginally. For further information, see OKG AB (2013, 2014); Forsmark (2013, 2014); Ringhals (2013, 2014).

6 Results

6.1 Model selection

Figure 8, 9, and 10 depict simulated output profiles of all plants given joint profit maximization, unilateral best-response, and a social planner. To simplify the exposition, henceforth I will refer to joint profit maximization simply as collusion. More competitive behavior is associated with more output allocated to the winter season, which is most clearly seen in Figure 10. During each winter, there are periods when the social planner operates the plants at, or close to, the capacity constraint. Conversely, in the other models there is variation in output during the whole year, and in the collusive model the plants are only operating at the capacity constraint during the first months of the sample period. Compared to the collusive model, the social planner would prefer to allocate 5 percent more of yearly output to the winter season, which is comparable to the difference-in-differences estimate in the introductory section.

To examine how well the simulated output profiles match data, I regress observed output on the simulated output under each model, according to:

$$q_w^{obs} = \alpha + \beta_{sim} q_w^{sim} + \mathbf{M}\gamma + \varepsilon_w$$

Where q_w^{obs} is the observed aggregate weekly output of all plants, q_w^{sim} is the simulated output under each model with its associated coefficient β_{sim}, and M is a vector of month-of-sample fixed effects. A perfect fit implies that $\hat{\beta}_{sim} = 1$ and $R^2 = 1$. Results are depicted in Table 6, where each column presents the result from a separate regression.

Table 6: Dependent variable is observed weekly nuclear output.

	Coll.	Uni.	Plan.	Coll.	Uni.	Plan.
Simulated output ($\hat{\beta}_{sim}$)	0.24***	0.19***	0.11***	0.10***	0.086***	0.022
	(0.028)	(0.028)	(0.021)	(0.022)	(0.021)	(0.015)
Month-of-sample FE	No	No	No	Yes	Yes	Yes
Observations	158	158	158	158	158	158
Adjusted R^2	0.31	0.22	0.14	0.83	0.82	0.80

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$

Note: Regressions of observed output on simulated output given different behavioral assumptions. Each column is a separate regression. Standard errors in parentheses.

In the first three columns, no time fixed effects are included. Using adjusted R^2 as goodness of fit measure, we see that the collusive model fits data best with an adjusted R^2 of 0.31. The unilateral model performs somewhat worse with an R^2 of 0.22, and the social planner model has the least explanatory power with an R^2 of 0.14. All models yield positive and highly significant estimates of $\hat{\beta}_{sim}$. When including month-of-sample fixed effects in the following three columns, absolute differences in adjusted R^2 becomes smaller, although the ordering in terms of R^2 remains intact. Also, the coefficient on the planner's output profile becomes insignificant, suggesting that within-month variations in output are mainly driven by strategic considerations. A relevant question is then whether the collusive model *alone* can explain the variation in output, or if firms display behavior that could partly be explained by the other models. There are several reason why firms may not achieve perfect coordination. In the literature, the most discussed one is due to the folk theorem, stating that any quantity between unilateral profit maximization and joint profit maximization is compatible with some Nash equilibrium in an infinitely repeated game. Another reason may be due to periodic deviations from a collusive agreement. Forward contracting and vertical integration may also invoke a behavior that is more

Table 7: J-test of non-nested hypotheses

Alternative model	Month-of-sample FE	$H_0 : \lambda^{alt} = 0$	$H_0 : \lambda^{coll} = 0$
Unilateral	No	0.34	0.00
Planner	No	0.87	0.00
Unilateral	Yes	0.76	0.02
Planner	Yes	0.34	0.00

Note: The table displays p-values for the null hypothesis in relevant J-tests of non-nested hypotheses.

competitive than the collusive one. Also, since Vattenfall is fully owned by the Swedish government, social welfare may be partly included in its objective function, although Vattenfall is instructed by the government to maximize its profit.

To test whether the collusive model alone is the best predictor of firm behavior, following Davidson and MacKinnon (1981) I perform a J-test of non-nested hypotheses by considering the comprehensive model:

$$q_w^{obs} = (1 - \lambda^{alt})\beta_0 q_w^{coll} + \lambda^{alt}\beta_1 q_w^{alt} + \mathbf{M}\gamma + \varepsilon_w$$

Where q_w^{alt} is the simulated output profile of the alternative hypothesis, i.e., unilateral profit maximization or a social planner, and the mixing parameter λ^{alt} determines the relative weight on the alternative model for predicting firm conduct. When no *a priori* information is available, the mixing parameter is not identifiable in the comprehensive model. The J-test works around this by replacing $\beta_1 q_w^{alt}$ with the fitted values from a regression of q_w^{obs} on q_w^{alt} and $\mathbf{M}\gamma$, and then testing the mixing parameter for statistical significance, i.e., $H_0 : \lambda^{alt} = 0$. If the null hypothesis is not rejected, it is also necessary to "reverse" the model and test $H_0 : \lambda^{coll} = 0$ to confirm that this new null hypothesis is indeed rejected (which is not guaranteed). Table 7 displays the p-values for different tests with and without including month-of-sample fixed effects. As seen in Table 7, $H_0 : \lambda^{alt} = 0$ cannot be rejected in any of the four tests. Further, $H_0 : \lambda^{coll} = 0$ is always rejected, consistent with the hypotheses that the collusive model is indeed the true model.

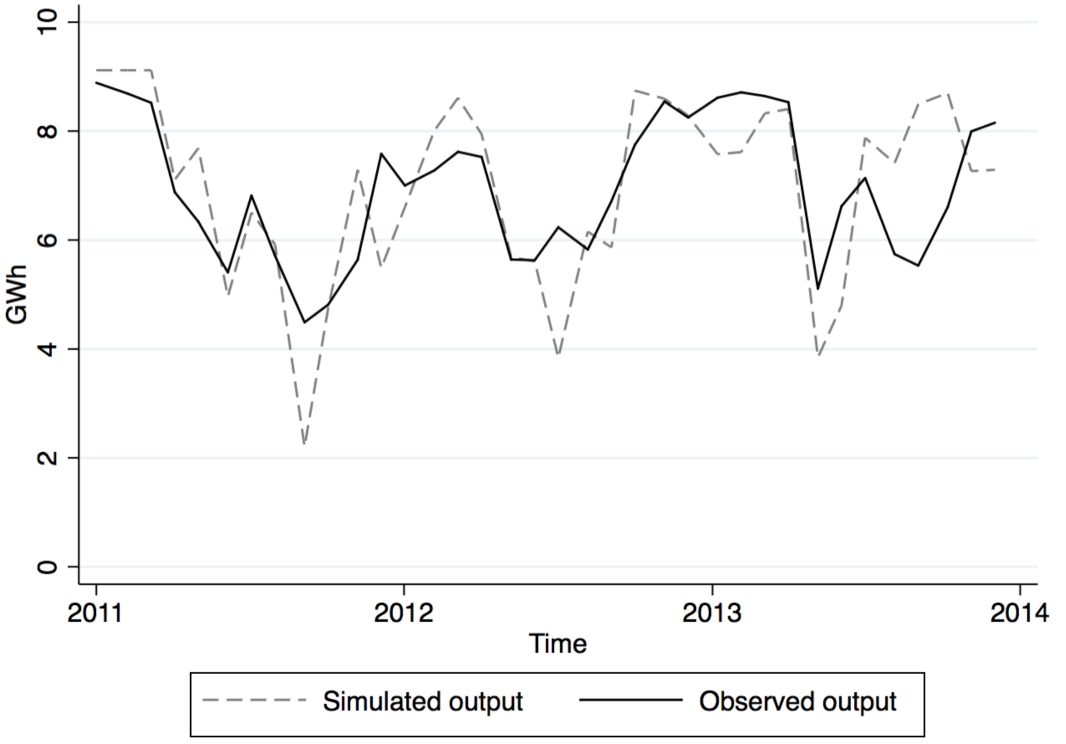
The strategic importance of outages reported as failures

To test whether outages reported as failures are likely to be exogenous events, I begin by cleaning the observed output profile from outages reported as failures. If observed output during a certain hour is 8 GWh, but there was a reported failure of 1 GWh, the new output is 9 GWh. This increases mean output by 10 percent. I then perform a J-test using the simulated collusive output as the dependent variable, and testing whether the new variable is a better determinant of simulated output than observed output. The comprehensive model is now:

$$q_w^{coll} = (1 - \lambda^{obs})\beta_0 q_w^{Net.fail} + \lambda^{obs}\beta_1 q_w^{obs} + \mathbf{M}\gamma + \varepsilon_w$$

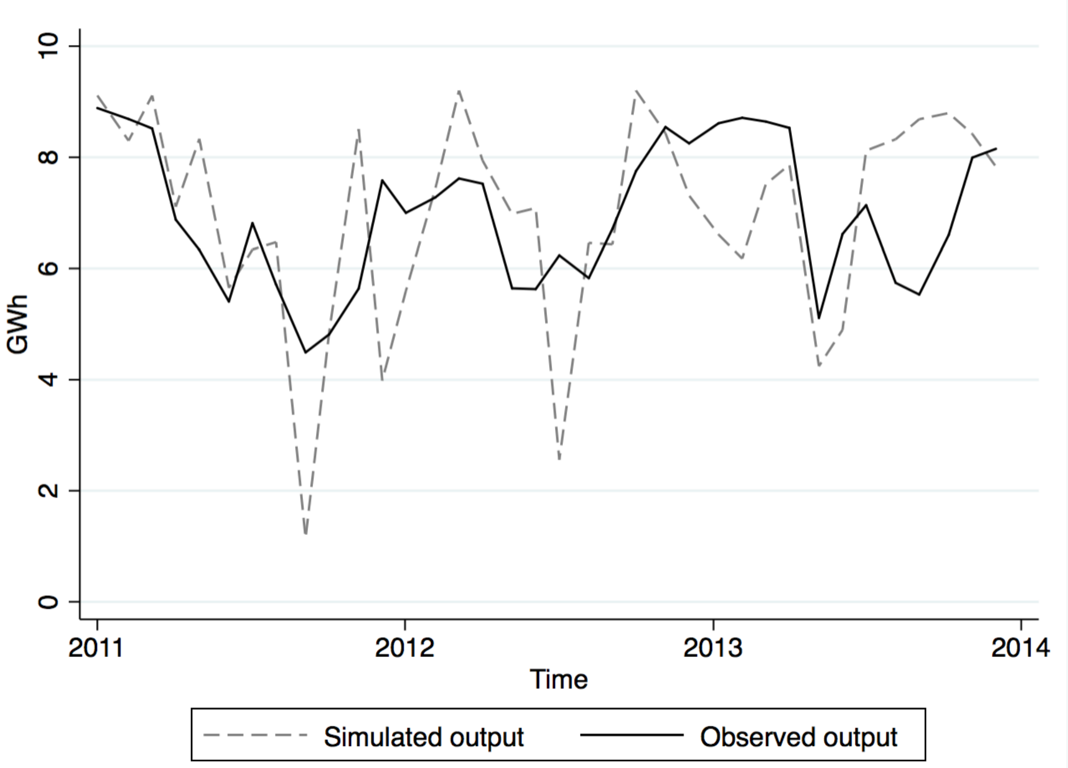
If failures are purely exogenous events, I should not be able to reject $H_0 : \lambda^{\text{obs}} = 0$, as the new variable $q_w^{Net.fail}$ should remove variation from the observed output that is non-strategic. However, the corresponding p-value for this test is 0.04, indicating that $\lambda^{\text{obs}} \neq 0$. When instead testing $H_0 : \lambda^{\text{Net. fail}} = 0$, I find that the p-value is 0.84, confirming that observed output is indeed superior in explaining simulated output. This result gives support to the hypothesis that outages reported as failures are not purely exogenous, but are also driven by strategic considerations.

Figure 8: Allocation of output under collusion



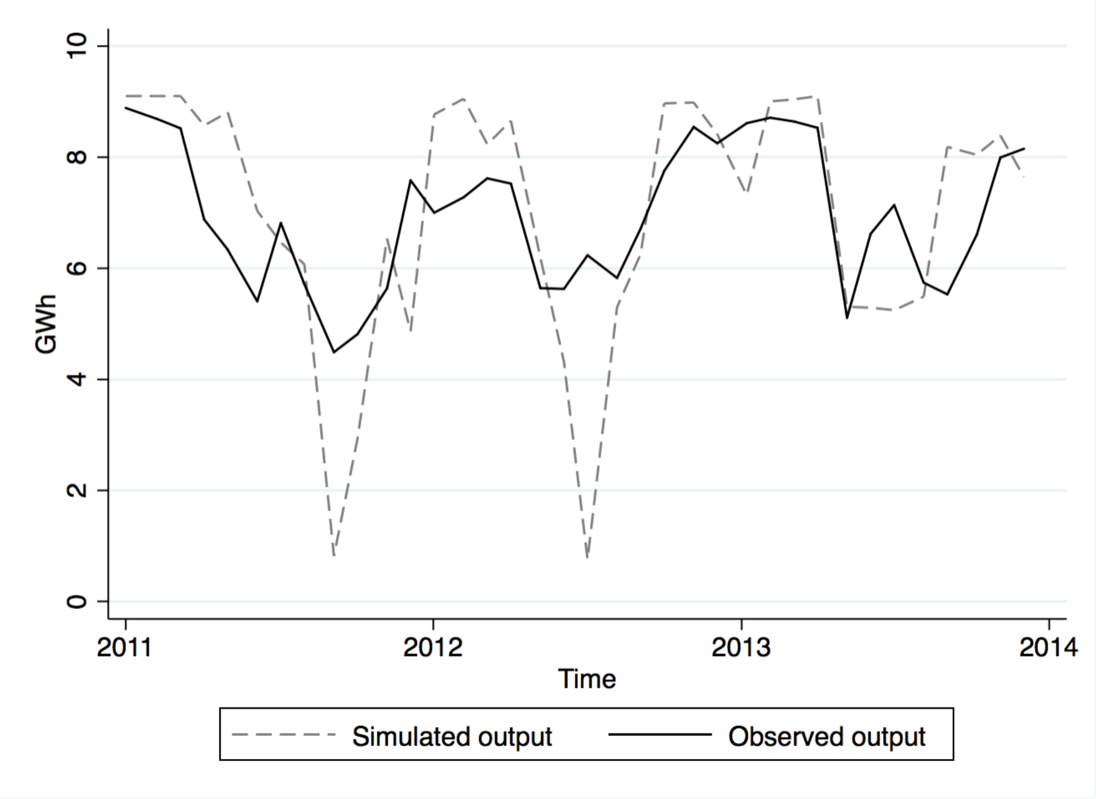
Note: This figure depicts the simulated mean monthly aggregate nuclear output under collusion, as well as observed output.

Figure 9: Allocation of output under unilateral best-response



Note: This figure depicts the simulated mean monthly aggregate nuclear output under unilateral best-response, as well as observed output.

Figure 10: Allocation of output under social planner



Note: This figure depicts the simulated mean monthly aggregate nuclear output under a social planner, as well as observed output.

6.2 Welfare effects of more competitive behavior

In this section I discuss the potential welfare gains of more competitive behavior, using the collusive output profile as a benchmark. In terms of short term deadweight losses, welfare gains are essentially zero due to an almost completely inelastic short term demand. Long term demand is likely to be more elastic due to the sensitivity to production costs by the electricity intensive industry, and the possibility to switch from electric to other sources of heating. However, as it is beyond the scope of this paper to estimate the long term demand elasticity for electricity, I do not provide any estimates of the size of this distortion. The potential short term welfare gains are instead due to lower production costs. As aggregate nuclear output each year is constant, gains in productive efficiencies arise due to a more efficient dispatch of other thermal production. Since more competitive behavior is associated with an equalization of prices across periods, this means that thermal plants are run more evenly, and peaking plants with high marginal costs are switched on less frequently. In combination with a convex system marginal cost function, average system production costs decrease (as a result of Jensen's inequality). Due to the unavailability of engineering cost estimates, I use the inverse system supply function as a proxy for the system marginal cost function[9].

As seen in the first column of Table 8, the unilateral model is associated with 2.4 percent lower production costs. While this figure is rather small, one must keep in mind that the efficiency gain refers to the market as a whole, out of which the nuclear plants only account for about 20 percent. Terminating the joint ownership and letting each firm be the sole owner of one plant each reduces production cost by 6.1 percent compared to the collusive model, given that firms would now play the unilateral game. Under the social planner model, production costs are 7.6 percent lower compared to the collusive model.

---

[9] This approximation rests on the assumption that bids from hydro plants are inelastic. Although hydro production costs are essentially zero, there is an opportunity cost of producing today instead of storing water in the reservoir for future production (the so-called "water-value"). Therefore, some hydro output may be bid in at positive prices. Under the assumption that all water will be used for production at some point in time, shifting hydro output between periods does not alter hydro production costs.

Table 8: Welfare effects of moving from the collusive equilibrium

Model	$-\Delta$ prod.cost	$-\Delta$ price	$-\Delta$ Sd of price
Original maintenance constraint			
Unilateral	2.4	1.2	0.2
Unilateral no joint ownership	6.1	5.1	13.9
Social planner	7.6	6.6	26.3
Allowing for a capacity factor of 90%			
Unilateral	16.7	10.7	2.3
Unilateral no joint ownership	18.1	11.1	4.5
Social planner	20.8	12.3	15.6

Note: This table displays the potential welfare effects of moving to more competitive equilibria. Changes are expressed as percentages.

Another welfare effect of more competitive behavior is the redistribution of surplus from producers to consumers due to a lower mean price level. Unilateral profit maximization is associated with a 1.2 percent reduction in price compared to the collusive model, and terminating the joint ownership would lead to a 5.1 reduction in prices. Under the social planner model, prices are 6.6 percent below the collusive price level. Further, as depicted in column 3, more competitive behavior is also associated with less price volatility. A reduction in price volatility leads to an increase in welfare if consumers and fringe producers are risk-averse, although it is beyond the scope of this paper to quantify how large these gains could be.

Relaxing the maintenance constraint

So far, the analysis has rested on the assumption that the yearly level of output cannot increase, i.e., that all reported outages have in fact been necessary to perform at some point during the year. However, as discussed above, the capacity factors of other European and U.S. plants of comparable or older vintages have remained around 90 percent during the last decade. Therefore, the possibility that firms have exerted market power by performing excessive maintenance should not be overlooked. I test this by relaxing the maintenance constraint and allow for a yearly capacity factor of up to 90 percent. The maintenance constraint associated with equation (7) now becomes:

$$\sum_{t \in \mathbf{y}} q_t^i \leq \sum_{t \in \mathbf{y}} \overline{q_t^i} \times 0.9$$

Results are depicted in the bottom three rows of Table 8. Except for the change in price volatility, all welfare effects are now amplified. The reason is that the new maintenance constraint is not binding in the collusive model. That is, even if firms were equipped with "state-of-the-art" plants that did not need maintenance, firms would still have incentives to withdraw capacity in order to exert market power. The simulated output only increases by around three percent compared to the observed output. Conversely, in both the planner and the unilateral models, the new maintenance constraint is always binding. In effect, both the level and allocation of output is now different in comparison to the collusive model. Now, further production efficiencies arise when expensive thermal fossil-based production is substituted away in favor of nuclear, which causes production costs to drop by 16.7 percent under the unilateral model, and 18.1 percent after terminating the joint ownership. Under the social planner model, production costs drop by as much as 20.8 percent. The reason for the large drop in production costs is that the share of thermal production is relatively small, and a substantial increase in nuclear output is able to substitute away a large fraction of these units. However, the drop in price volatility is relatively small. When all plants are running near full capacity, there is less possibility to shift output between periods to equalize prices.

If neglecting general equilibrium effects in the EU Emissions Trading System, another positive welfare effect of an expansion of nuclear output is that CO_2 emissions are reduced. Since the total output of hydro, wind, and combined heat- and power production depends on exogenous factors, the whole expansion in nuclear production would be compensated by a proportional reduction in fossil based production. Given that nuclear capacity factors increase from 80 to 90 percent, the drop in emissions would amount to an annual reduction of 8 million metric tons of CO_2, which is equivalent to 36 percent of the total Swedish CO_2 emission allowances in 2012[10].

---

[10] According to U.S. Energy Information Administration (2015), 1 kg of CO_2 pro-

7 Conclusion

I study the anticompetitive effects of joint ownership of Swedish nuclear plants, finding that firms exert market power by performing maintenance when the price effect of doing so is large. Although the joint ownership amplifies the majority shareholders' unilateral incentives to exert market power, firm behavior is more consistent with a model of joint profit maximization.

To the best of my knowledge, no previous study has found evidence that firms exercise market power explicitly by withdrawing nuclear capacity. However, as the growth in electricity demand in virtually every developed country is flattening out while the supply of intermittent production in the form of wind and solar is increasing, electricity prices have seen a decline during recent years. Exercising market power by withdrawing nuclear or other base load capacity is then necessary to keep electricity prices up during periods of positive supply shocks in intermittent production. In the Nordic region, intermittent production in the form of hydro power has always constituted a large share of electricity production. The present study finds that variation in intermittent hydro production is an important determinant of the incentives to exercise market power, reinforcing the concern that similar phenomena will arise in other electricity markets in the near future.

From a regulatory perspective it is of special interest that market power is exercised by withdrawing capacity from the market. This means that the regulator cannot effectively monitor firms by estimating the markup on existing bids. Since maintenance schedules are available to other market participants through the Urgent Market Messages database, messages may be used to share information about schemes how to exercise market power. Further research could investigate if strategic incentives shape the way that firms reveal new information to the market, and examine whether the mandatory publication of maintenance schedules has resulted in a more competitive outcome (which is the regulator's intention), or if it has facilitated anticompetitive coordina-

---

duces roughly 1 kWh of electricity. Given an average hourly production expansion of 1 GWh, we get that 8,000 hours × 1 ton = 8 million metric tons annually. Sweden's CO_2 allowance for 2012 was 22.5 million metric tons.

tion. Since the EU is currently implementing regulations to increase the transparency in electricity markets in which maintenance scheduling is an essential ingredient (ACER, 2015), the findings in the present paper are highly relevant from a policy perspective. It is also of interest to note that in e.g. Spain, firms are not completely free to choose the timing of maintenance themselves, but are obliged to reschedule if the transmission system operator finds that too much capacity will be offline at the same time. The findings in the present paper suggests that such an arrangement could lead to a more efficient allocation of maintenance also in the Nordic region.

Another way to promote competition is to oblige firms to divest their nuclear capacity in so-called “virtual power plant auctions”, an arrangement in which the present owner remains the operator of the plant but is obliged to sell its output in an auction separate to the wholesale market (Ausubel and Cramton, 2010). Since their advent in 2001, virtual power plant auctions for various production types, including nuclear, have been used in France, Belgium, Spain, Denmark, Germany, and Portugal.

References

ACER, "Regulation on Wholesale Energy Market Integrity and Transparency," `http://www.acer.europa.eu/remit/About/Regulation/Pages/default.aspx` (accessed April 21, 2016), 2015.

Alley, Wilson A., "Partial Ownership Arrangements and Collusion in the Automobile Industry," *The Journal of Industrial Economics*, 1997, *45* (2), 191–205.

Amundsen, E.S. and L. Bergman, "Will Cross-Ownership Reestablish Market Power in the Nordic Power Market?," Norway; Department of Economics, University of Bergen, Department of Economics, University of Bergen 2000.

Ausubel, Lawrence M. and Peter Cramton, "Virtual power plant auctions," *Utilities Policy*, December 2010, *18* (4), 201–208.

Azar, José, Martin C. Schmalz, and Isabel Tecu, "Anti-Competitive Effects of Common Ownership," Working Paper Series 1235, Ross School of Business 2015.

Borenstein, Severin, James B. Bushnell, and Frank A. Wolak, "Measuring Market Inefficiencies in California's Restructured Wholesale Electricity Market," *American Economic Review*, December 2002, *92* (5), 1376–1405.

Bresnahan, Timothy F., "The oligopoly solution concept is identified," *Economics Letters*, 1982, *10* (1-2), 87–92.

Bresnahan, Timothy F, "Competition and Collusion in the American Automobile Industry: The 1955 Price War," *Journal of Industrial Economics*, June 1987, *35* (4), 457–82.

Bushnell, James B., Erin T. Mansur, and Celeste Saravia, "Vertical Arrangements, Market Structure, and Competition: An Analysis of Restructured US Electricity Markets," *American Economic Review*, March 2008, *98* (1), 237–66.

Corts, Kenneth S., "Conduct parameters and the measurement of market power," *Journal of Econometrics*, 1999, *88* (2), 227 – 250.

Damsgaard, Niklas, "Market Power in the Nordic Power Market," Working Paper Series 2007-003, Econ Pöyry 2007.

Davidson, Russell and James G MacKinnon, "Several Tests for Model Specification in the Presence of Alternative Hypotheses," *Econometrica*, May 1981, *49* (3), 781–93.

Davis, Lucas and Catherine Wolfram, "Deregulation, Consolidation, and Efficiency: Evidence from US Nuclear Power," *American Economic Journal: Applied Economics*, 2012, *4* (4), 194–225.

Dietzenbacher, Erik, Bert Smid, and Bjorn Volkerink, "Horizontal integration in the Dutch financial sector," *International Journal of Industrial Organization*, December 2000, *18* (8), 1223–1242.

Energy Markets Inspectorate, "Ägarstrukturen på elmarknaden," Report EI R2012:21, Energy Market Inspectorate 2006.

_ , "Övervakning och transparens på elmarknaden," Report EI R2010:21, Energy Market Inspectorate 2010.

E.ON, "Production sites in the world," `http://www.eon.com/en/about-us/structure/asset-finder.html` (accessed April 21, 2016), 2015.

Fabra, Natalia and Juan Toro, "Price wars and collusion in the Spanish electricity market," *International Journal of Industrial Organization*, April 2005, *23* (3-4), 155–181.

Farrell, Joseph and Carl Shapiro, "Asset Ownership and Market Structure in Oligopoly," *RAND Journal of Economics*, 1990, *21* (2), 275–292.

Fogelberg, Sara and Ewa Lazarczyk, "Strategic Withholding through Production Failures," Working Paper Series 1015, Research Institute of Industrial Economics March 2014.

Forsmark, Annual report, Forsmark Kraftgrupp AB 2013.

_ , Annual report, Forsmark Kraftgrupp AB 2014.

Førsund, Finn, "The Anatomy of Market Power in Electricity Markets with Hydropower as Dominating Technology," ICER Working Papers, ICER - International Centre for Economic Research 2006.

Førsund, Finn R., "Hydropower Economics," Memorandum 30/2005, Oslo University, Department of Economics November 2005.

Fortum, "Production sites in the world," `http://www.fortum.com/en/investors/marketdata/marketareas/pages/default.aspx` (accessed April 21, 2016), 2015.

Fridolfsson, Sven-Olof and Thomas P. Tangerås, "Nuclear Capacity Auctions," *The Energy Journal*, 2015, *0* (Number 3).

Gasmi, F., J.J. Laffont, and Q. Vuong, "Econometric Analysis of Collusive Behavior in a Soft-Drink Market," *Journal of Economics & Management Strategy*, 1992, *1* (2), 277–311.

Glazer, Amihai and Henry McMillan, "Pricing by the Firm Under Regulatory Threat," *The Quarterly Journal of Economics*, 1992, *107* (3), 1089–1099.

Glover, Fred, Manuel Laguna, and Rafael Martí, "Fundamentals of scatter search and path relinking," *Control and Cybernetics*, 2000, *39*, 653–684.

Green, Edward J, "Noncooperative price taking in large dynamic markets," *Journal of Economic Theory*, 1980, *22* (2), 155 – 182.

Green, Richard and Chloé Le Coq, "The length of contracts and collusion," *International Journal of Industrial Organization*, 2010, *28* (1), 21 – 29.

Green, Richard J and David M Newbery, "Competition in the British Electricity Spot Market," *Journal of Political Economy*, October 1992, *100* (5), 929–53.

Hendricks, Robert H. Porter Kenneth, "Joint Bidding in Federal OCS Auctions," *The American Economic Review*, 1992, *82* (2), 506–511.

Hjalmarsson, Erik, "Nord Pool: A Power Market Without Market Power," Working Papers in Economics 28, University of Gothenburg, Department of Economics 2000.

IAEA, "PRIS database," `https://www.iaea.org/pris/` (accessed April 21, 2016), 2015.

Kauppi, Olli and Matti Liski, "An Empirical Model of Imperfect Dynamic Competition and Application to Hydroelectricity Storage," Working Papers, Massachusetts Institute of Technology, Center for Energy and Environmental Policy Research 2008.

Kim, Dae-Wook and Christopher R. Knittel, "Biases in Static Oligopoly Models? Evidence from the California Electricity Market," *Journal of Industrial Economics*, December 2006, *54* (4), 451–470.

Liski, Matti and Juan-Pablo Montero, "Forward trading and collusion in oligopoly," *Journal of Economic Theory*, November 2006, *131* (1), 212–230.

Malueg, David A., "Collusive behavior and partial ownership of rivals," *International Journal of Industrial Organization*, March 1992, *10* (1), 27–34.

MathWorks, "Description of the fmincon solver," `http://se.mathworks.com/help/optim/ug/fmincon.html` (accessed April 21, 2016), 2015.

McRae, Shaun D. and Frank A. Wolak, "How do firms exercise unilateral market power? Empirical evidence from a bid-based wholesale electricity market," in Eric Brousseau and Jean-Michel Glachant, eds., *The Manufacturing of Markets*, Cambridge University Press, 2014, pp. 390–420. Cambridge Books Online.

Nordic Competition Authorities, "Capacity for Competition: Investing for an Efficient Capacity for Competition: Investing for an Efficient Capacity for Competition: Investing for an Efficient Nordic Electricity Market," Report 1:2007, Nordic Competition Authorities 2007.

Nordpool, “FTP server product details,” `http://www.nordpoolspot.com/services/Power-Data-Services/Product-details/` (accessed April 21, 2016), 2015.

Nordreg, “Nordic Market Report,” Report 3:2011, Nordic Energy Regulators 2011.

_ , “Nordic Market Report,” Report 3:2012, Nordic Energy Regulators 2012.

_ , “Nordic Market Report,” Report 6:2013, Nordic Energy Regulators 2013.

OKG AB, Annual report, OKG AB 2013.

_ , Annual report, OKG AB 2014.

Parker, Philip M. and Lars-Hendrik Röller, “Collusive Conduct in Duopolies: Multimarket Contact and Cross-Ownership in the Mobile Telephone Industry,” *RAND Journal of Economics*, 1997, *28* (2), 304–322.

Pollitt, Michael G, “Ownership and Efficiency in Nuclear Power Production,” *Oxford Economic Papers*, April 1996, *48* (2), 342–60.

Puller, Steven L., “Pricing and Firm Conduct in California’s Deregulated Electricity Market,” *The Review of Economics and Statistics*, February 2007, *89* (1), 75–87.

Radio Sweden, “Interview with production planner at Vattenfall,” `http://sverigesradio.se/sida/artikel.aspx?programid=83&artikel=870163` (accessed April 21, 2016), 2006.

Reguant, Mar, “Complementary Bidding Mechanisms and Startup Costs in Electricity Markets,” *Review of Economic Studies*, 2014, *81* (4), 1708–1742.

Reynolds, Robert J. and Bruce R. Snapp, “The competitive effects of partial equity interests and joint ventures,” *International Journal of Industrial Organization*, 1986, *4* (2), 141–153.

Ringhals, Annual report, Ringhals AB 2013.

_ , Annual report, Ringhals AB 2014.

Statistics Finland, “Monthly nuclear production 1990-2013,” `http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/StatFin__ene__ehk/020_ehk_tau_102_sv.px/?rxid=f214b9f2-a4c7-4231-9e7a-b91c9093d6fb` (accessed April 21, 2016), 2015.

Statistics Sweden, “Monthly nuclear production 1974-2013,” `http://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__EN__EN0108/EltillfM/?rxid=1d169fb6-7387-45b1-bc62-dd4bd58a5d35` (accessed April 21, 2016), 2015.

Steen, Frode and Lars Sørgard, “Semicollusion in the Norwegian cement market,” *European Economic Review*, October 1999, *43* (9), 1775–1796.

Swedish Radiation Safety Authority, “Nuclear power plants in Sweden,” `http://www.stralsakerhetsmyndigheten.se/start/Karnkraft/Anlaggningar-i-Sverige/` (accessed April 21, 2016), 2014.

Sweeting, Andrew, “Market Power In The England And Wales Wholesale Electricity Market 1995-2000,” *Economic Journal*, 04 2007, *117* (520), 654–685.

Ugray, Zsolt, Leon Lasdon, John Plummer, Fred Glover, James Kelly, and Rafael Martí, “Scatter Search and Local NLP Solvers: A Multistart Framework for Global Optimization,” *INFORMS Journal on Computing*, 2007, *19* (3), 328–340.

U.S. Energy Information Administration, “Form EIA-860,” Report, U.S. Energy Information Administration 2014.

_ , “How much carbon dioxide is produced per kilowatthour when generating electricity with fossil fuels?,” `http://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11` (accessed April 21, 2016), 2015.

Vattenfall, “Production sites in the Nordic region,” `http://powerplants.vattenfall.com/#/types=Coal,Biomass,Hydro,Wind,Nuclear/`

`countries=Finland,Denmark,Sweden/view=list/sort=name` (accessed April 21, 2016), 2015.

Wolak, Frank A., "Measuring Unilateral Market Power in Wholesale Electricity Markets: The California Market, 1998–2000," *American Economic Review*, 2003, *93* (2), 425–430.

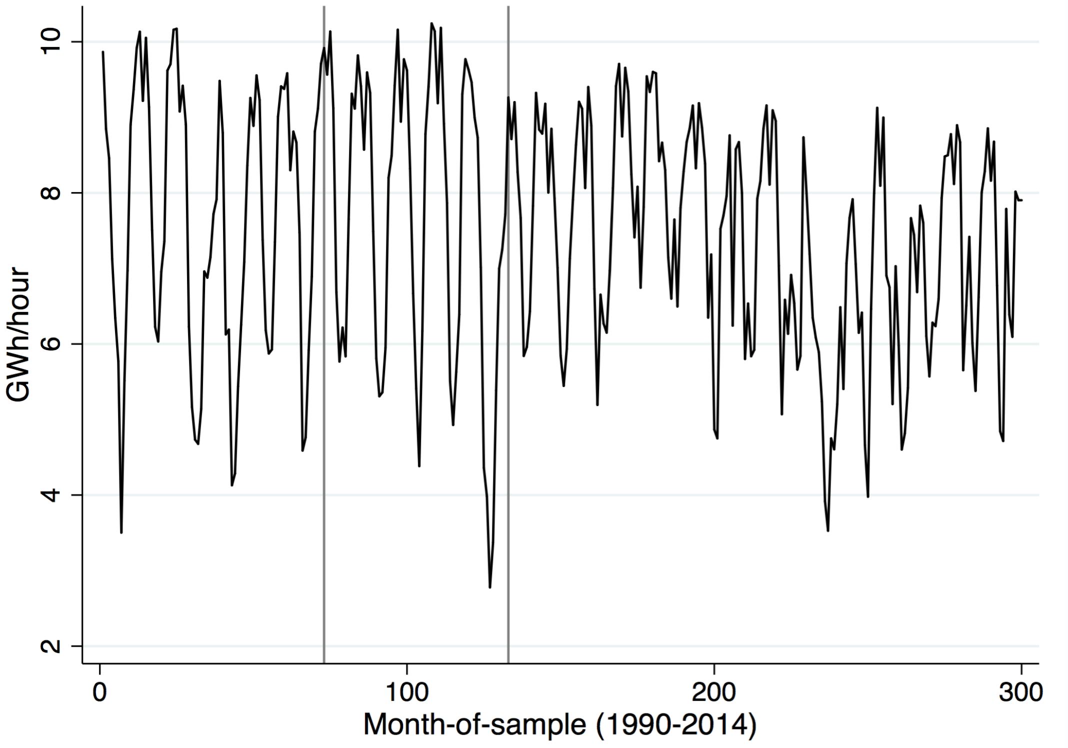
_ , "Quantifying the supply-side benefits from forward contracting in wholesale electricity markets," *Journal of Applied Econometrics*, 2007, *22* (7), 1179–1209.

_ **and Robert H. Patrick**, "The Impact of Market Rules and Market Structure on the Price Determination Process in the England and Wales Electricity Market," Working Paper 8248, National Bureau of Economic Research April 2001.

Wolfram, Catherine D., "Measuring Duopoly Power in the British Electricity Spot Market," *American Economic Review*, 1999, *89* (4), 805–826.

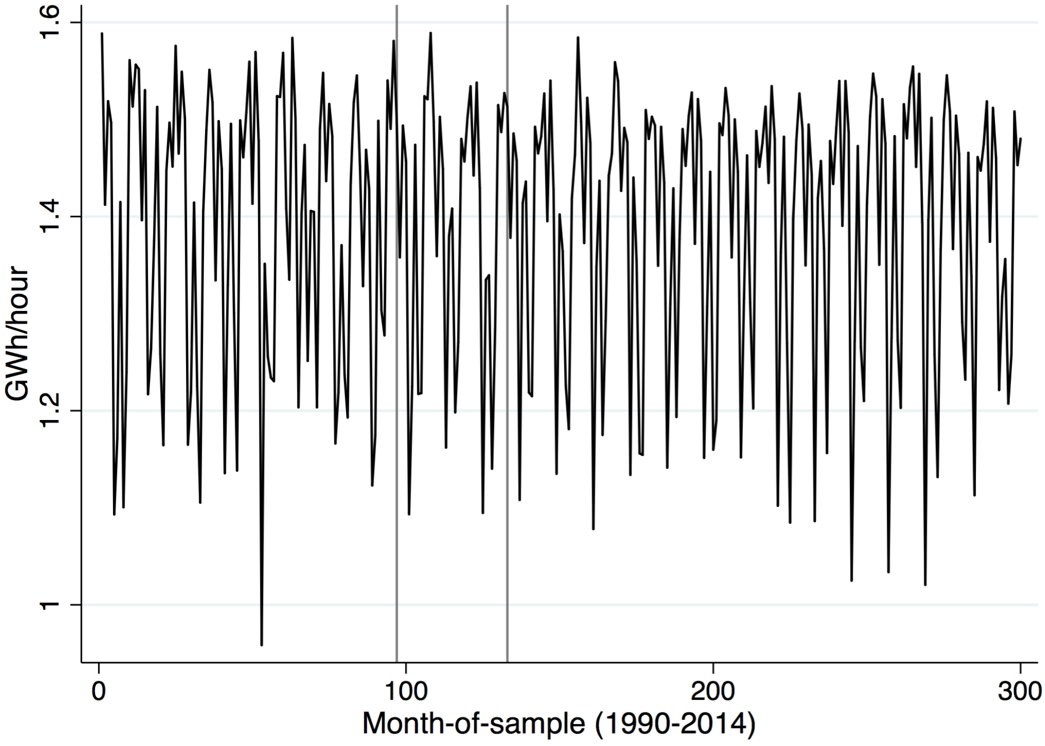
Appendix A

Figure A1: Swedish nuclear output 1990-2014



Note: This figure depicts monthly Swedish nuclear output during 1990-2014. Vertical lines are at the time of Swedish deregulation (1996) and at the time of the introduction of the joint ownership (2001).

Figure A2: Finnish nuclear output 1990-2014

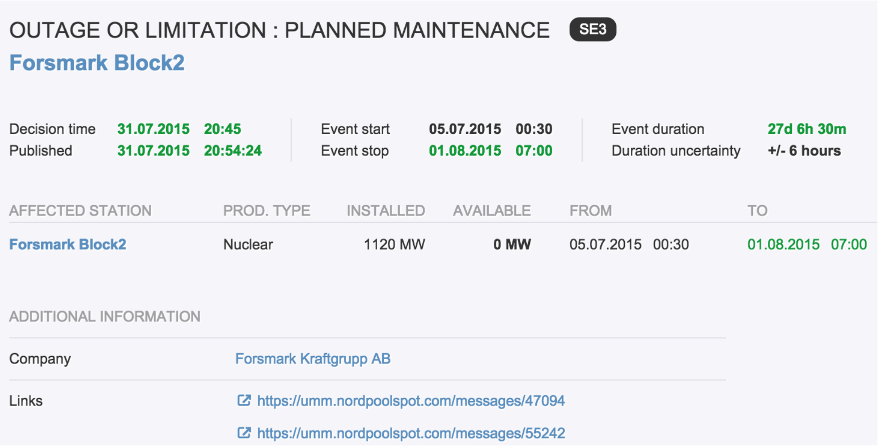


Note: This figure depicts monthly Finnish nuclear output during 1990-2014. Vertical lines are at the time of Finnish deregulation (1998) and at the time of the introduction of the joint ownership (2001).

Figure A3: Price zones in the Nordic electricity market

Note: This figure depicts price zones in the Nordic electricity market. All Swedish nuclear plats are located in zone "SE3".

Figure A4: Example of an Urgent Market Message



OUTAGE OR LIMITATION : PLANNED MAINTENANCE SE3

Forsmark Block2

Decision time **31.07.2015 20:45**
Published **31.07.2015 20:54:24**

Event start **05.07.2015 00:30**
Event stop **01.08.2015 07:00**

Event duration **27d 6h 30m**
Duration uncertainty **+/- 6 hours**

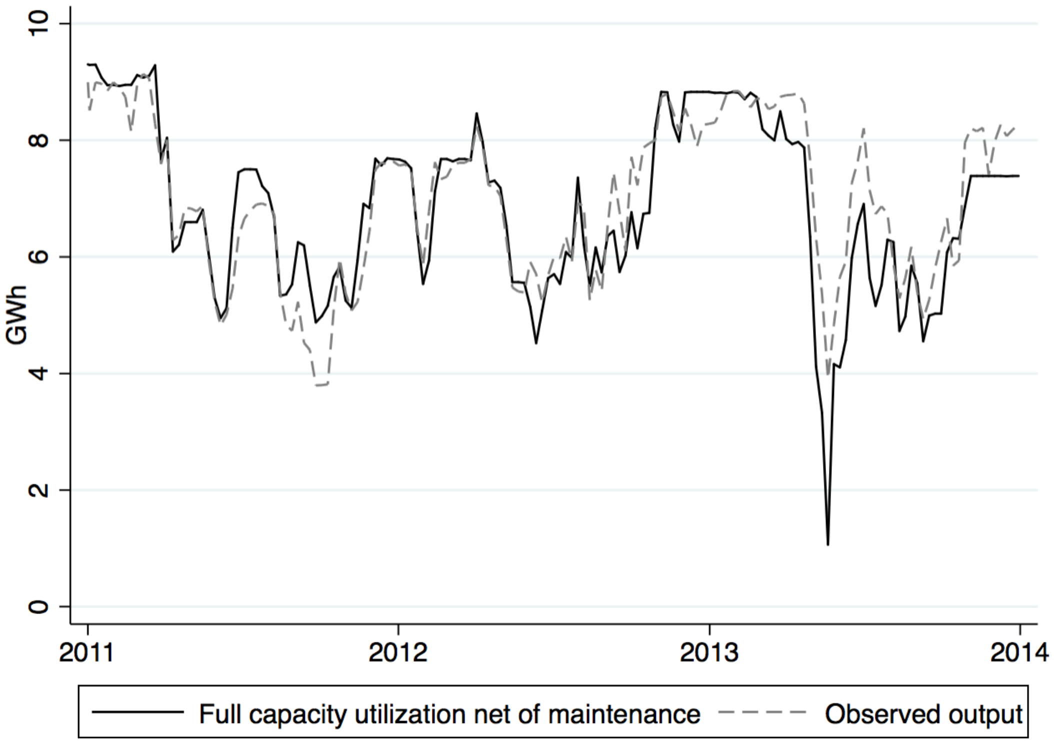
AFFECTED STATION	PROD. TYPE	INSTALLED	AVAILABLE	FROM	TO
Forsmark Block2	Nuclear	1120 MW	**0 MW**	05.07.2015 00:30	01.08.2015 07:00

ADDITIONAL INFORMATION

Company	Forsmark Kraftgrupp AB
Links	https://umm.nordpoolspot.com/messages/47094 https://umm.nordpoolspot.com/messages/55242

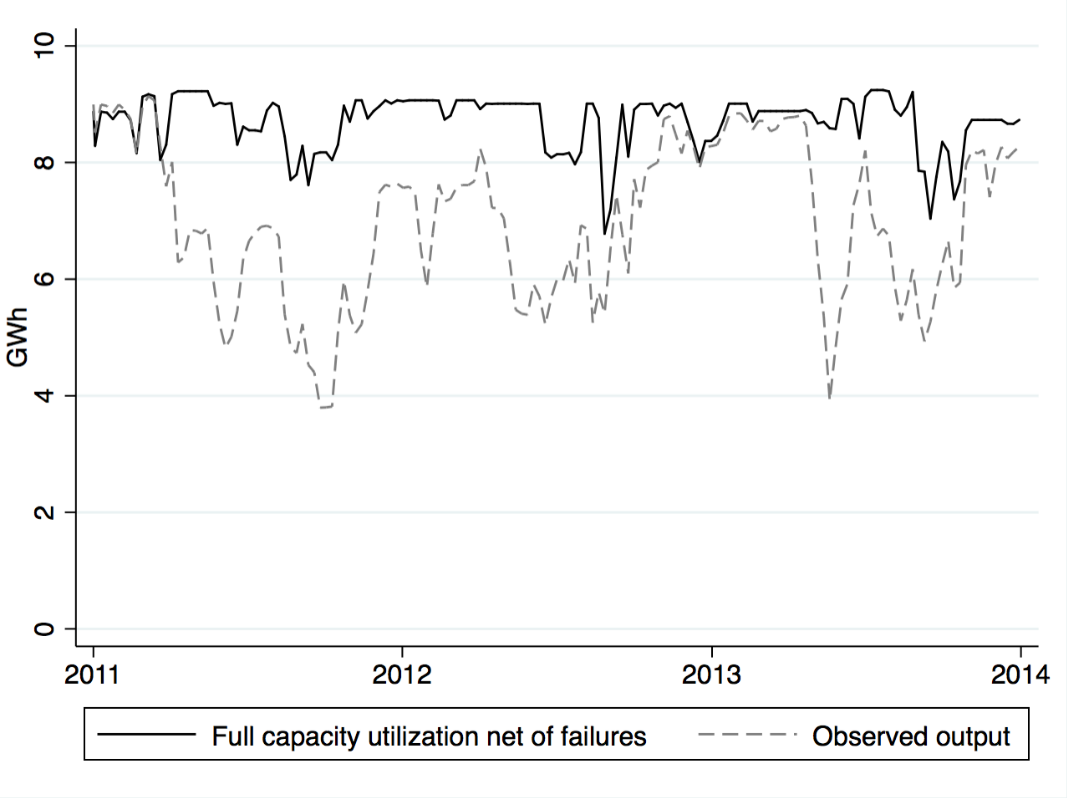
Note: This figure depicts an example of an Urgent Market Message regarding planned maintenance in reactor 2 in Forsmark.

Figure A5: Full capacity utilization net of outages reported as maintenance



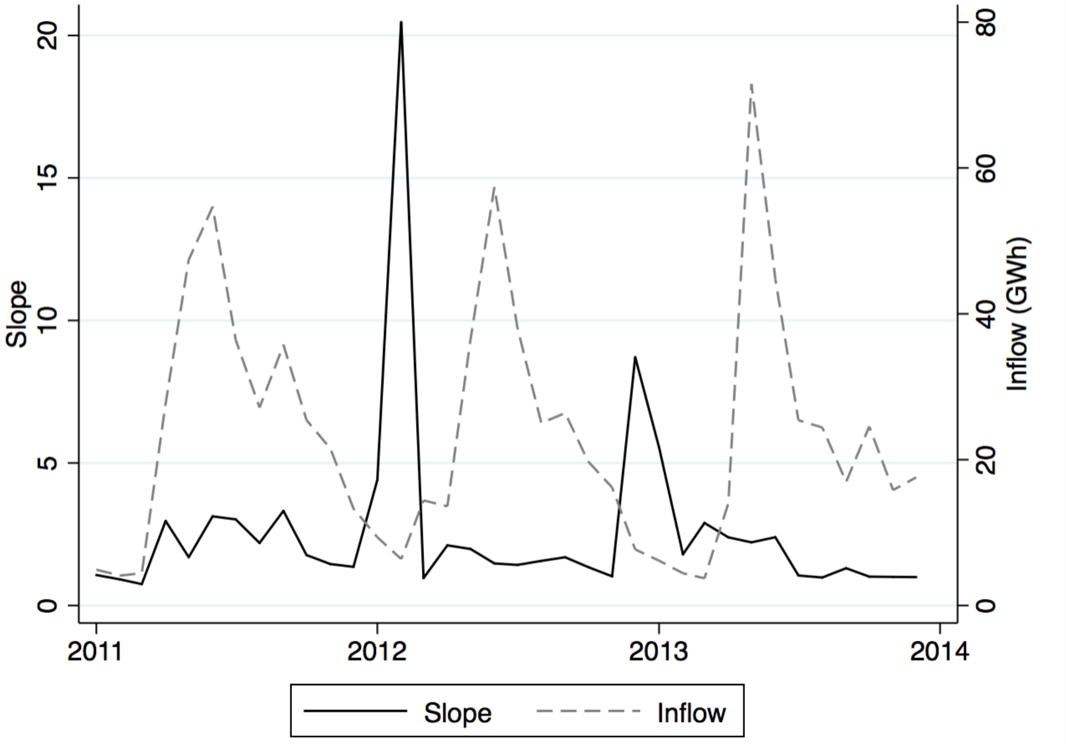
Note: This figure depicts the mean weekly aggregated nuclear output given that all plants would operate at full capacity except during outages reported as maintenance.

Figure A6: Full capacity utilization net of outages reported as failures



Note: This figure depicts the mean weekly aggregated nuclear output given that all plants would operate at full capacity except during outages reported as failures.

Figure A7: Reservoir inflow and mean slope of residual demand



Note: This figure depicts the mean monthly reservoir inflow in Sweden and Norway and the mean slope of the system residual demand function.

Appendix B

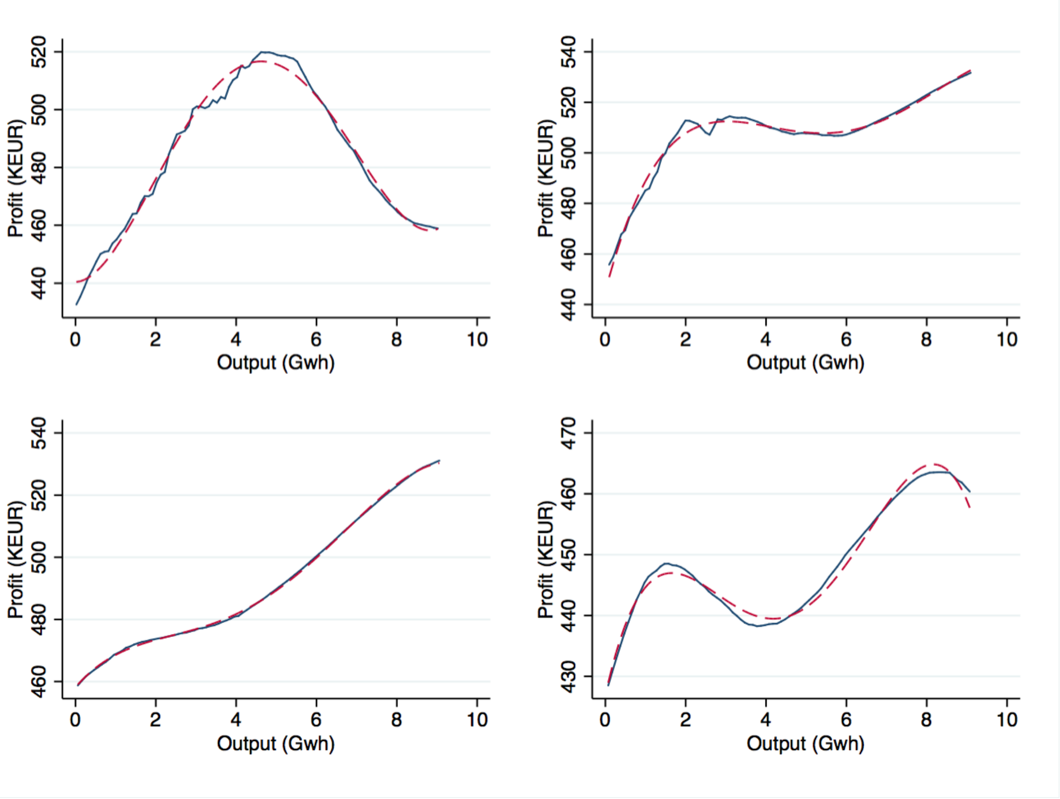
Solution technique

For each maximization problem, I start by discretizing the residual demand function in each hour by fitting it in blocks of 100 MWh. As the smallest plant (Oskarshamn) has a capacity of 2,300 MW, 100 MW is only about 4 percent of its capacity. I then apply the fourth constraint in equation (7), which imposes a horizontal segment on the left part of the inverse residual demand function in each hour of the sample. I then construct weekly profit functions by summing hourly profits over each feasible level of output for each week in the sample. This allows me to express the profit function for week w in terms of weekly output, i.e., $\pi_w^i(q_w^i)$.

In the next step I approximate the weekly profit functions using 4^{th} order polynomials. Alternatively, a more flexible approach could have been used (such as a cubic spline), but this is not necessary. In fact, by visual inspection it rather appears that the fitted values captures the relevant variation in the data while neglecting trivial, irregular variation that is unlikely to influence firm decisions. A sample of the approximations are illustrated in Figure B1, where four different shapes of profit functions are depicted, together with the fitted values (all profit functions are from the collusive model). On the top left diagram, the profit function is concave within the entire feasible output range, with only one local maximum. The top right diagram has a local maximum at around 3 GWh of output, but attains its maximum at the capacity constraint. The bottom left function has a relatively even, positive slope within the whole relevant range. Naturally, this type of profit function gets more frequent the more competitive behavior is assumed. In the social planner framework, all profit functions are concave. Further, in the social planner framework all profit functions are increasing as long as the equilibrium price exceeds the marginal cost of nuclear at the capacity constraint, which is true in 95 percent of all weeks. The bottom right diagram displays a profit function with a local maximum at a very low level of output. However, if expanding output above 4 GWh profits start to increase again, to attain another local maximum at 8 GWh. This stems from the fact that there sometimes are two steep segments on the feasible portion of the residual demand function: One at very high prices, and one at very low prices (this can be seen by looking at the right diagram in Figure 5).

I proceed by solving the problem using Matlab's fmincon solver (MathWorks, 2015). However, the solver can only find a local optimum that satisfies the first order conditions, and is hence no guarantee to find a global optimum since not all profit functions are concave. I therefore combine the fmincon solver with the GlobalSearch algorithm of Matlab's Global Optimization Toolbox. GlobalSearch uses the scatter search algorithm (Glover et al., 2000) to find a large number of potential global solutions, and concludes by choosing the solution with the lowest value of the objective function. Depending on the optimization problem, GlobalSearch found between 40 and 98 local solutions. See Ugray et al. (2007) for a comprehensive description of the GlobalSearch algorithm.

Figure B1: Continuous approximation of weekly profit functions



Note: This figure depicts weekly collusive discretized profit functions for four different sample weeks (solid), as well as the fitted values of 4^{th} order polynomial approximations (dashed).

Chapter 2

Effects of Privatization on Price and Labor Efficiency: The Swedish Electricity Distribution Sector*

Abstract

I examine the effects of privatization, in the form of acquisitions, in the Swedish electricity distribution sector. As the majority of the distribution networks remained publicly owned, I use a synthetic control method to identify the effects on price and labor efficiency. In comparison to their synthetic counterparts, I find that the acquired networks increased labor efficiency by on average 18 percent, while no effect is found on the price. Thus, the evidence suggests substantial efficiency gains but that these are not fed through to consumer prices. Since each acquisition involved several bordering networks that were separately operated by each municipality prior to the acquisitions, I examine to what extent the efficiency gains are likely to be driven by increased economies of scale. Results suggest that the entire effect can be explained by increased economies of scale, questioning the *causal* effect of privatization per se.

---

*I would like to thank Richard Friberg, Thomas Tangerås, and Pär Holmberg for valuable comments. I would like to thank Jonas Lindblom at the Energy Markets Inspectorate for his help in compiling the data.

1 Introduction

When a network industry is privatized, a fundamental controversy lies in the potential increase in productive efficiency due to increased incentives to minimize costs, vs. distortions in allocative efficiency and a subsequent redistribution from consumers to producers due to market power. The electricity distribution sector is particularly well suited for firm performance comparisons since electricity distribution is a homogenous good, and since data on the technical characteristics of the networks as well as accounting data is standardized and reported to a central regulator. At the same time, since the market is regulated, the possibility to extrapolate results to other markets requires care.

In this study, I examine the effects of private acquisitions of publicly owned networks in the Swedish electricity distribution sector. Specifically, I compare the performance of 34 networks that were acquired by private firms around the turn of century, to 105 networks that remained publicly owned. I focus on two outcome variables: price and labor efficiency. I find evidence of an increase in labor efficiency in the acquired networks by on average 18 percent, while no acquisition effect is found on the price. Thus, the evidence suggests substantial efficiency gains but that these are not fed through to consumer prices. All acquisitions examined in the study were conducted by two firms, E.ON and Fortum. The qualitative effects on both outcome variables are similar across firms, although the increase in labor efficiency is both statistically and economically more significant in the networks acquired by Fortum.

To the best of my knowledge, this is the first study to use a synthetic control method to evaluate firm performance in the electricity distribution sector. For each acquired network, I create a synthetic control network from a weighted average of the networks that remained publicly owned. The synthetic control network is constructed to have identical, or close to identical, technical characteristics and pre-acquisition trend of the outcome variable as the acquired network. The effect of the acquisition is then estimated by comparing the factual post-acquisition trend of the outcome variable to that of its synthetic analogue. The method is particularly well suited to estimate the effect of an intervention when the number of potential control firms are large, and should therefore be useful also when estimating the effect of network specific interventions in the electricity distribution sectors in other countries. Also, results are invariant to the choice of cost function, since the observed cost determinants of the acquired network are identical to the cost determinants of its synthetic analogue.

In the synthetic control framework, the counterfactual is that the networks would have continued to be publicly owned by the same organizations as before the acquisitions. However, prior to the acquisitions, the networks were operated separately by the respective municipality in which they were located. Since each of the private firms conducted acquisitions of networks in several bordering municipalities, I also examine if the efficiency gains are likely to be driven by increased economies of scale, since the acquirers could centralize the management of the networks. Using a difference-in-differences (DID) estimator, results suggest that the entire efficiency effect can be explained by increased economies of scale, questioning the *causal* effect of privatization. However, since the private networks became substantially larger than any of the municipality owned networks due to the acquisitions, the identification of this test relies on the possibility to extrapolate outside the data in the municipality owned networks. Therefore, this result should be interpreted with care.

The choice of the electricity distribution sector as a testing ground for studying privatization is not only motivated by the availability of data and the diversity of the ownership structure. Another important factor is the increased skepticism against private ownership in network industries that has developed during the last decade, which can be exemplified by the experiences in Sweden and Germany. Prior to electricity reform, distribution networks in Sweden and Germany were usually owned by the municipalities. In Sweden, the state-owned firm Vattenfall also owned a fair share of the networks, and continues to do so (NordReg, 2011; OECD, 2004). However, the last two decades have seen a transition towards consolidation and privatization of the network ownership structure. In Sweden, the new entrants Fortum and E.ON now have a market share of around 40 percent. Consumer groups claim that the sharp price increases during the last decade are mainly driven by the largest firms (SABO, 2011), and some municipalities have expressed an interest in buying back their networks (Dalarna's newspaper, 2014). Germany has seen a similar development, where the four largest firms acquired shares in numerous local distribution networks during the privatization wave initiated by the municipalities around the turn of the century. However, in contrast to Sweden, there has been a reverse trend in network ownership during recent years. Municipalities, often guided by the will of the local people, have started to repurchase the networks (the so-called *Rekommunalisierung*, or remunicipalization). The two most notable events were the referendums in the two largest German municipalities, Berlin and Hamburg, which in 2013 both voted for the remunicipalization of the electricity, gas, and district heating networks (although the referendum in Berlin failed due to insufficient voter turnout). Similar skepticism towards private ownership of network industries has also been raised elsewhere. For example, the website www.remunicipalisation.org collects data on remunicipalization projects of water provision services throughout the world, recording 235 cases during the last 15 years, impacting 100 million people. The recent years' remunicipalization trend further highlights the importance of examining the effects of privatization in network industries.

Previous studies on the relationship between ownership and efficiency in Swedish electricity distribution are not conclusive. Using stochastic frontier analysis on a panel data set from 2000-2007, Söderberg (2011) finds that private ownership is associated with lower costs than public ownership, although this finding is sensitive to modeling choices. Using data from 1970-1990, Kumbhakar and Hjalmarsson (1998) find that private ownership is on average associated with higher labor efficiency than public ownership. However, they find no conclusive evidence that labor efficiency increased more among the privately owned networks relative to the publicly owned networks. In contrast to the present study, none of the previous studies use ownership changes as the identifying source of variation. International experience also does not provide any clear cut predictions. Borghi et al. (2016) study the interaction effects between quality of government and private ownership in determining the total factor productivity of electricity distribution firms using data from 16 EU countries. When the quality of government is poor, they find that private ownership is associated with higher productivity levels relative to public ownership. However, when the quality of government is high, private ownership is instead associated with lower productivity. In the context of U.S. electricity distribution, Kwoka (2005) finds that public ownership is more efficient, mainly due to a higher quality of service. In a study using data from 14 Latin American countries, Estache and Rossi (2005) find that the relative labor efficiency of private firms depend on the regulatory regime: private firms perform better under price cap regulation, but not under rate-of-return regulation.

2 Institutional background and data

2.1 Regulatory framework

Traditionally, a majority of the Swedish distribution networks have been owned by the municipalities, or by private firms organized as economic associations owned by the electricity consumers in the area where they operated. Some distribution networks were also owned by the state-owned firm Vattenfall, which is also the largest electricity producer in the Nordic region. Before the liberalization of the wholesale market in 1996, a proper incentive regulation for the distribution sector was not considered necessary, although there was a general legal principle stating that publicly owned firms were not allowed to make profits (*självkostnadsprincipen*). The not-for-profit rule did not apply to private firms, that in theory were free to set their own prices. However, under the Electricity Act a consumer could complain about the prices to the National Industrial Board, which involved approximately 25 cases per year (Kumbhakar and Hjalmarsson, 1998). Shortly after the liberalization of the wholesale market, a new regulatory framework was introduced. It was a type of rate-of-return regulation, albeit without being any more precise than that prices should be fair (*skäliga*). Heden (2012) characterizes the evaluation of the tariffs as “pretty ad-hoc”, noting that “There wasn’t any well defined methods for valuation of the distribution firms’ assets, or explicit principles for what would constitute a fair rate-of-return”.

There are several reasons why a traditional rate-of-return regulation may fail to incentivize firms to minimize costs. The most well-known is attributed to Averch and Johnson (1962), showing that firms have incentives to engage in excessive amounts of capital accumulation in order to expand the volume of profits. Laffont and Tirole (1993) discuss how information asymmetries between the regulator and the firm under rate-of-return regulation can lead to several other inefficiencies. Even though the switch from rate-of-return to incentive regulation took place in tandem with the liberalization process in most countries, the insight that also public bureaucrats seek to maximize their own budgets suggests that a proper incentive regulation may increase efficiency also among publicly owned firms (Niskanen, 1968).

One of the ways to get around the misguided incentives provided by traditional regulation is to benchmark firms against each other, in order to achieve a type of artificial yardstick competition (Shleifer, 1985). In the electricity distribution sector, different forms of yardstick regulation have been adopted by countries such as Norway, Australia, and UK. In these models, a best-practice frontier of real firms is identified, against which individual firms can be compared (Jamasb and Pollitt, 2008).

In 2003, Sweden also adopted a proper incentive regulation. However, instead of benchmarking costs against other firms, the allowed revenue was determined to reflect the cost of building and operating a hypothetical network with the same exogenous environmental and demand conditions as the real network. It was called the Network Performance Assessment Model (NPAM). Similar "reference firm" regulations have also been adopted by Chile and Spain (Jamasb and Pollitt, 2008). Sweden formally abandoned the NPAM in 2008 and adopted a revenue cap regulation that has been in place since 2012. During 2009-2011, there was a slight change in the NPAM regulation to facilitate the transition to the new regulation. During these years, the reference cost was computed based on the actual technical characteristics of the physical network, and there was a higher emphasis on price trends, as opposed to the static relationship between costs and price in each separate year (Energy Markets Inspectorate, 2012). The NPAM is described in more detail below.

The Network Performance Assessment Model

The implementation of the NPAM can roughly be summarized by the following steps (the description has largely been adapted from Jamasb and Pollitt, 2008).

1. **Data collection.** Information about the geographical coordinates of customers and their consumption usage are collected, together with the coordinates of the network's connection points to neighboring and overlying regional networks.

2. **Computation of reference network.** The NPAM algorithm constructs a hypothetical reference network, including meters of line per exit point; a density measure to every meter of line; the capacity for every transformer station, and a density measure for every transformer.

3. **Computation of reference network costs.** The investment cost for each network is computed using the standard costs of equipment found in the Swedish Electricity Building Rationalization (EBR) catalogue. The costs of building and operating the network today are derived using cost functions for capital costs, return on capital, operation and maintenance, network administration, and network losses. The costs are also adjusted for quality of service in terms of supply interruptions.

4. **Computation of charge rate and regulatory scrutiny.** The revenue of the actual network is divided by the computed costs of the hypothetical reference network, obtaining the network's "charge rate". The charge rate is computed each year *ex-post*, and the comparison is made only with respect to the previous year's revenue. A charge rate lower than unity indicates that the firm is more efficient than its reference network. If the charge rate is above a certain threshold, the concession holder is subject to a detailed investigation. The trigger charge rate is determined ex-post by the regulator. In 2003 was 1.3, in 2004-2005 it was 1.2, and from 2006 and onwards it was 1.1. If the detailed investigation shows that the charges are justified, the case is closed. Otherwise, the concession holder is imposed to retrospectively lower prices and pay back customers.

Under the NPAM model, *all* firms could in theory be subject to regulatory scrutiny, since the relative performance of the firms should not matter. However, the trigger charge rate is set *ex-post* depending on the choice of the regulator. Thus, it is likely that the trigger charge rate is set such that a "reasonable" share of the firms are exempted from regulatory scrutiny, adding an element of yardstick regulation also to the NPAM model. Further, the use of the EBR catalogue as a determinant of the investment cost of each network adds another element of yardstick regulation to the model, since the costs in the EBR catalogue are determined by actual costs reported by all firms in the industry. It should be noted that the EBR catalogue not only serves as a reference for the cost of physical equipment, but also contains estimates of the number of hours needed to install different types of equipment[1]. Jamasb and Söderberg (2010) examine how network owners have responded to the incentives given by the NPAM regulation, finding that owners respond by inflating (reducing) their costs when they have low (high) charge rates.

Although the long term goal of the NPAM was to make actual revenues contingent entirely on exogenous characteristics that the firms were unable to influence, in this respect the NPAM was not successful. Out of the 16 firms (including Fortum and E.ON) that were imposed to pay back customers after the first round of scrutiny, all of the firms appealed to a higher court. After a lengthy legal process, the firms agreed to pay back parts of their revenues in 2008, amounting to 140 million SEK (Heden, 2012).

2.2 Electricity distribution in Sweden

The Swedish electricity supply chain is physically divided into four vertically separated markets: generation, national transmission, regional transmission, and distribution. A schematic diagram is presented in Figure A1. The wholesale market for electricity is organized on the Nordic power exchange Nord Pool. E.ON and Fortum are important players in all markets except for national transmission, which is completely controlled by the state-owned transmission system operator Svenska Kraftnät. The scope of this paper is limited

---

[1] The risks of coordination on manipulation of costs in the EBR catalogue are impending, and has been noted by the Swedish Competition Authority (2003) and Jamasb and Pollitt (2008).

to the distribution network, which has the lowest voltage and connects end consumers to the system. However, the regional transmission network is subject to the same type of regulation as the distribution network, and is almost exclusively controlled by Vattenfall, E.ON, and Fortum. In a review of the empirical literature, Meyer (2011) documents a range of studies from several countries finding economically significant economies of scope between various stages in the supply chain. Although it is beyond the scope of this paper to quantify its importance in the present setting, one should bear in mind that the regulatory structure does not take economies of scope into consideration, which should provide E.ON and Fortum with a cost advantage compared to municipality owned networks that generally do not engage in generation or regional transmission (although some of the municipality owned firms also own some generation units).

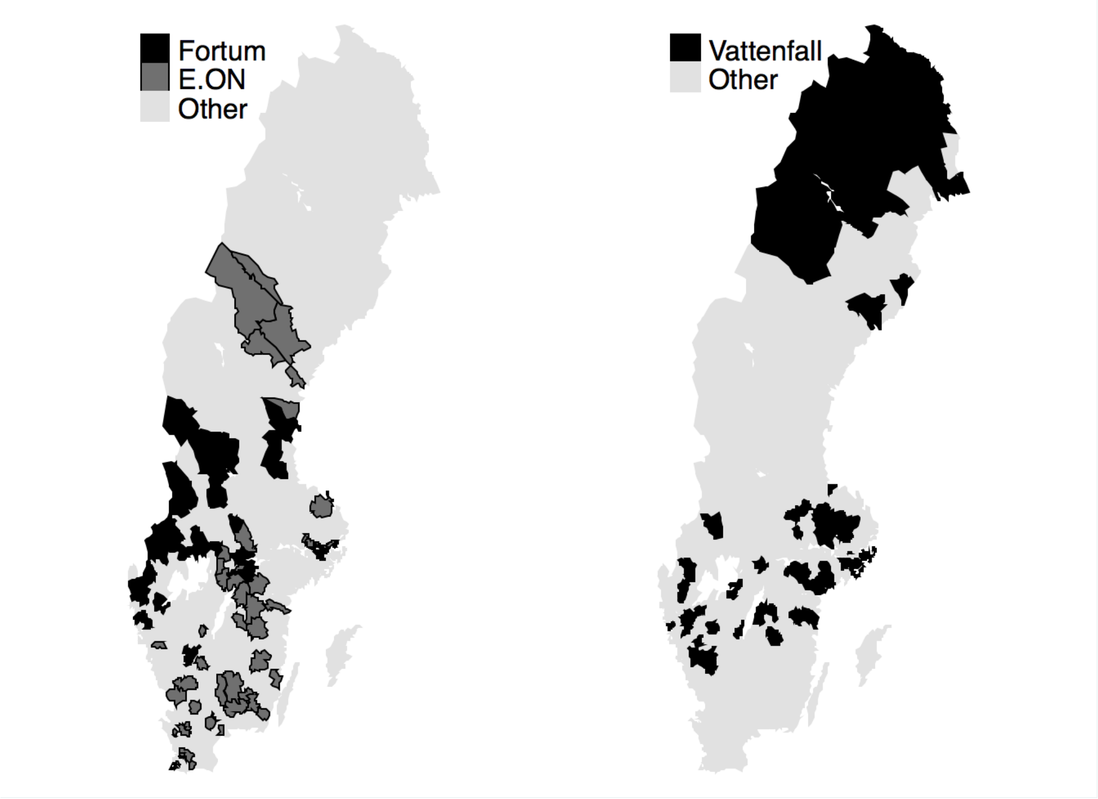
The distribution network is geographically divided into *concession areas*, which legally define each local monopoly by its geographical boundaries. The concession areas are the relevant legal unit when computing the charge rates. Hence, technical and accounting data are available by concession area. Henceforth, I will simply refer to a concession area as a network. Each network can only be operated by one firm, but one firm can be the operator in several networks. If a firm acquires several bordering networks, they are merged into one. Therefore, although 34 publicly owned networks were acquired, complete panel data can only be constructed for five networks (four for Fortum and one for E.ON). Therefore, these networks are much larger than the other networks in the panel data structure, which is discussed further below.

E.ON is a privately owned, publicly traded German energy firm. Fortum is also publicly traded, but the Finnish government owns 51 percent of the shares. However, as there is no reason to believe that the Finnish government would have preferences for Swedish consumer surplus, in the present setting I assume that it behaves as a profit maximizer. E.ON entered the market in 2001, acquiring the majority share in the Swedish firm Sydkraft, which owned both distribution networks and generation. Prior to the acquisition, the combined ownership of the Swedish municipalities Malmö, Oskarshamn, Lund, Landskrona, and Halmstad constituted the greatest voting share in Sydkraft. In

2004 E.ON also acquired the firm Graninge. However, since Graninge was already privately owned, this concession area is excluded from the main specification (including this area does not affect the main results). Fortum was already present in the Swedish market at the beginning of the sample period. However, it was only in 2002 that it became the majority owner in Birka Energy, which it previously co-owned together with Stockholm municipality. During the following two years, E.ON and Fortum also acquired a few more municipality owned networks, but those networks were minor in comparison to the ones owned by Sydkraft and Birka Energy. By the end of the sample period, E.ON had a market share of 20 percent (measured by the number of residential customers), while Fortum and Vattenfall had a market share of 18 percent each. The fourth largest player in the market is the municipality owned Göteborg Energi, with a market share of five percent. Vattenfall did not make any major acquisitions during the sample period. Even though Vattenfall is owned by the Swedish government, Vattenfall may still behave as a profit maximizer as there is no direct link between the local community and Vattenfall. Evidence in line with this view has been found by Muren (2011). In a study of the pricing of Swedish district heating, she finds that large firms like Vattenfall charge relatively higher prices than small firms, even when the large firms are publicly owned. I therefore exclude Vattenfall from the control group, since the control group should ideally only contain firms that are not profit maximizers.

Figure 2 depicts the geographical locations of the networks owned by the three largest firms in 2011. All three firms control parts of the distribution network in Stockholm, which is the capital and the most densely populated area. 30 percent of the remaining networks are operated by private firms. 70 percent of the private firms are economic associations (*ekonomiska föreningar*), owned by the electricity consumers themselves. In total, there are 105 control networks owned by the municipalities. It is not evident that the economic associations are suitable as control groups. On the one hand, they are privately owned and could therefore be considered as profit maximizers. On the other hand, the owners are the local consumers, and they should therefore be fairly free from incentives of overcharging. In the main specification, I therefore remove these firms from the control group. However, including them does not have any major impact on the results.

Figure 2: Network ownership by the three largest firms in 2011



Note: This figure depicts networks owned by Fortum, E.ON, and Vattenfall in 2011. Also networks acquired from private firms are included. To prevent cluttering, the networks owned by Vattenfall are depicted in the right diagram.

2.3 Data

Data has been compiled by the Energy Markets Inspectorate, and is available on a yearly basis during 2000-2011. Some data for later years are available, but not enough to estimate the full model. The data set includes both accounting data and technical characteristics of the networks. Summary statistics of all variables are depicted in Table 1.

I measure output by the number of customers. Alternatively, total electricity consumption could have been used, but data on the number of customers has less missing observations[2]. Since the number of customers is exogenous

---

[2] For a small number of observations, data on the number of customers is missing or

(unless customers relocate due to high electricity distribution prices), demand is inelastic. More than 99 percent of the customers in all networks are low-voltage customers, and the cross-sectional correlation between the number of low- and high voltage customers is above 0.93 for all years in the sample. Therefore, I do not distinguish between the two customer groups, although the cost of serving a high-voltage customer is likely to differ from the cost of serving a low-voltage customer. The control networks are all municipality owned networks that were not acquired by E.ON or Fortum. The acquired networks are all municipality owned networks that were acquired by E.ON or Fortum. Except for the number of customers, the distribution of the variables are relatively similar across groups. A category of data that would be useful to examine, but that is not available for the full sample period is quality of service, which is usually measured by the number and length of outages per customer.

The first outcome variable, price, is defined as revenue per customer and year (the only revenue source is payments from customers). Alternatively, the total price payed by a representative customer could be used, but since the price is a two-part tariff, the average revenue per customer should be more accurate. The average price over the whole sample is 4,300 SEK/customer (10 SEK$\approx$1 EUR). The mean nominal price increase during the sample period is 40 percent (20 percent in real terms). The greatest price increase was in 2010, which was on average 8 percent. The Energy Markets Inspectorate (2011) notes that the sharp increases during the later years in the sample are partly due to costs associated with two great storms in 2005 (*Gudrun*) and 2007 (*Per*). Tougher regulations to prevent outages, and obligations to offer hourly metering of consumption in 2009 are other possible contributing reasons. Further, the local distributors' fees to the national transmission network have increased due to a higher demand on the transmission lines as new wind power plants are incorporated in the system.

The second outcome variable, labor efficiency, is defined as the number of customers per unit of labor. However, to make the outcome variables comparable, instead of labor efficiency I will henceforth refer to its inverse, labor cost,

---

implausible. I then compute the value using linear interpolation between the closest years before and after the missing data point(s).

Table 1: Summary statistics

	Control netw.		Acquired netw.	
	mean	sd	mean	sd
Price (SEK per customer)	4269	1193	4812	928
Staff expenditures (SEK per customer)	801	483	717	428
Other external costs (SEK per customer)	890	699	616	545
Total labor cost (SEK per customer)	1691	787	1333	402
Number of customers (thousands)	22	73	190	167
Density (overhead line meter per customer)	56	46	78	43
Density (ground line meter per customer)	51	25	48	19
Transformer stations per 10000 customers	7	31	6	2
Transformer capacity per customer	281	3799	149	64
Observations	1776		60	

Note: This table depicts summary statistics of the municipality owned control networks that were not acquired (left), and the networks that were acquired by E.ON and Fortum (right).

which is expressed in SEK/customer. Examining the accounting data, the accounted cost for "Staff expenditures" only includes services produced in-house, and not the cost of services that have been outsourced. These services are instead accounted for as "Other external costs", according to the guidelines set by the regulator. Since outsourcing has become increasingly common, these costs should also be taken into account. Therefore, I include "Other external costs" in the labor cost. If the outsourced services instead would have been performed in-house, the wage cost of the service would be separated from the capital cost, such as renting maintenance equipment. A potential source of measurement error is therefore that the labor cost will be overestimated for firms that have a high degree outsourcing. Even in a fixed effects setting, this could lead to biased results as the share of outsourcing can differ between years within the same firm. To illustrate the substitutability between in-house and outsourced services, Figure A2 depicts the inverse trends for these items in the networks acquired by Fortum. The mean labor cost for the whole sample was 1,700 SEK/customer and year, which is about 40 percent of the price. The rest of the costs are mainly capital costs, and costs for electricity to cover

Figure 3: Trends in price and labor cost

Note: The dashed lines depict the mean price and labor cost per customer for municipality owned control networks that were never acquired. The solid lines depict the same variables for networks that were acquired by Fortum or E.ON. The vertical line is in 2003.

transmission losses. The mean accounted operating profit (not reported in the summary statistics) is 601 SEK/customer and year, which is about 14 percent of the price.

Figure 3 depicts the trends in price and labor cost for networks that were acquired, compared to the municipality owned networks that were not acquired. Figure A3 depicts the corresponding trend for networks owned by economic associations. Two years, 2007-2008, stand out as the years with the highest labor costs in the acquired networks. This is partly due to the storm Per that swept through the south of Sweden in 2007 through several of the networks owned by E.ON and Fortum. Except for 2007-2008, the labor costs in the non-acquired networks increased comparatively more than in the acquired networks. Histograms of both outcome variables are depicted in Figure A4.

Among the technical characteristics of the network, the most important cost driver is network density. It is measured by meter of power line per customer. There are two categories of power lines: overhead lines, that are suspended by poles, and lines that are submerged under ground. Overhead lines generally demand more maintenance, and should thus be a more important determinant of labor cost than ground lines (although the initial investment cost is usually higher for underground lines). Other technical characteristics include the number of transformers per customer and the total transformer capacity per customer. The variable measuring economies of scale is the number of customers. Economies of scale arise when the average cost is decreasing in the number of customers served, while network density is kept constant. This variable is almost ten times higher for the acquired networks than for the non-acquired networks, since this figure refers to the number of customers in the merged networks *after* the acquisitions took place. The mean number of customers in the acquired networks during the pre-acquisition period is 21,000 (the median is 16,000), which very similar to the corresponding figure for the non-acquired networks.

How accurate is accounting data?

A disadvantage of relying on accounting data is that firms may have incentives of misreporting, see e.g., Balakrishnan et al. (2012) for evidence on how incentives of financial misreporting are strengthened in markets with imperfect competition. In the present context, firms have incentives of exaggerating their true costs in order to increase their allowed revenue. Even if the NPAM is based on exogenous variables only, there is still a possibility to renegotiate the allowed revenue with the regulator *ex post*. For firms that wish to cross-subsidize divisions that are not subject to regulation, incentives of misreporting may be even stronger, e.g., by letting the administrative staff handle the tasks of the firm's retailing activities, or by letting maintenance staff perform maintenance on equipment owned by the firm's generation division. Even for firms with low charge rates, this may be a beneficial strategy if firms believe that regulation will be tightened if the regulator finds profits to be unreasonably high. As discussed above, Jamasb and Söderberg (2010) find evidence that firms with low charge rates tend to inflate their costs. For Fortum, E.ON and Vattenfall, the possibilities of cross-subsidization should be even greater since these are the only firms that also operate the regional transmission networks. The regional transmission networks are also subject to the NPAM, and these networks are usually located in the same region as the distribution networks. Since the type of costs associated with regional transmission and distribution are similar, it should be relatively easy to transfer costs to the division with the lowest charge rate. A similar argument can be made for firms operating several distribution networks.

Municipalities were not allowed to finance public expenditures through network profits during the sample period, although some of them openly did so without receiving any penalties (SVT, 2015), which could strengthen incentives of misreporting among the municipality owned networks. It could also enhance incentives to inflate costs through overstaffing if the network has a low charge rate and the municipality wishes to increase employment. The prohibition against financing public expenditures through network profits was a remnant from the pre-liberalization “not-for-profit” rule, which was put in place to prevent municipalities from using electricity pricing as an instrument of taxation. In 2015, the Supreme Administrative Court (2015) decided that network profits could be used to finance public expenditures in contradistinction to earlier decisions by the lower court, which should have mitigated incentives for municipalities to transfer costs to the network division of the municipality.

Further, incentives to *understate* costs may arise among owners that are planning to divest their network, as higher profitability should appear more attractive to investors. In the present context, this could be relevant to Fortum that in 2015 divested all its distribution and regional transmission networks to a consortium lead by the Canadian firm Borealis Infrastructure (SvD, 2015). The price tag was approximately 7,000 EUR per residential customer (or 6.6 billion EUR in total). To get a rough idea if the accounted profits appear reasonable in relationship to the price, back-of-the envelope calculations suggest that the highest discount rate that could justify the investment given a perpetuity corresponding to the accounted EBITDA is 2.7 percent[3]. However, the figure appears to be rather low, indicating that accounted costs could be overstated, and possibly that the acquirer was aware of this. By comparison, the benchmark repo interest rate set by the central bank of Sweden averaged at 3.46 percent during the last two decades.

In sum, there are several reasons why accounting data should be interpreted with care, and incentives of misreporting could exist in both directions depending on the individual circumstances of each firm. However, as the revenues of the firms consist exclusively of payments from customers that is relatively easy for the regulator to verify, the accounted revenues are likely to be more accurately reported than the labor costs.

3 Method

3.1 The synthetic control method

The conventional reduced form analysis when assessing the impact of an intervention, such as an acquisition, relies on the DID estimator. However, the DID estimator rests on assumptions that are often not met. First, the DID estimator is biased in the presence of time-varying unobserved confounders. Second, the DID estimator cannot determine which of the non-acquired networks that are most suited as controls, giving all non-acquired networks equal weight in the estimation process. This may not be desirable if some of the non-acquired networks are more similar to the acquired network, and therefore would be more suitable as controls.

The synthetic control method addresses these problems by constructing a synthetic control network from a weighted combination of the non-acquired net-

---

[3] In 2011, Fortum's EBITDA was 190 EUR per residential customer (including the earnings on the regional transmission network). The highest discount factor that can justify the investment given a perpetuity of 190 EUR per year is 2.7 percent ($190/0.027 \approx 7,000$). Figures for later out-of-sample years were only slightly different compared to the figures for 2011.

works, such that the trajectory of the outcome variable and the mean of the control variables in the synthetic network match the acquired network during the pre-acquisition period. Borrowing from the matching literature, the set of all non-acquired networks are usually referred to as the “donor pool”. Since individual weights are restricted to be positive and sum to one, the synthetic control network is constructed without any extrapolation outside the convex hull of the data from the donor pool.

Formally, following the notation in Abadie et al. (2010), suppose that there are $J+1$ networks, and that only the first network is acquired. Since several networks were acquired, one could either construct a representative network, or estimate the acquisition effects separately for each network. As my main results are qualitatively invariant to the choice of method, in the baseline estimation I construct a representative network in order to simplify the exposition, although I also report network specific effects. To construct the representative acquired network, I begin by merging all acquired networks into one large network (containing both E.ON’s and Fortum’s networks). Since the technical characteristics are expressed as fractions of the number of customers, the fact that the size of the merged network is very large does not matter. However, since I also match on the the number of customers, I set the number of customers in the representative network to the median number of customers in the acquired networks prior to the acquisitions, which is around 16,000.

Let Y_{it}^{A} and Y_{it}^{N} be the outcomes that would be observed for network i at time t given an acquisition, and in absence of an acquisition, respectively. Let T_0 be the number of pre-acquisition periods, with $1 \leq T_0 < T$. Let D_{it} be an indicator that takes the value one if network i has been acquired at time t, and zero otherwise. The observed outcome for the acquired network at time t is then $Y_{1t} = Y_{1t}^{N} + \alpha_{1t}D_{1t}$. As the vector of interest is α_{1t}, we need to estimate Y_{1t}^{N} for all periods where we do not have observational data. Suppose that Y_{it}^{N} is given by the factor model

$$Y_{it}^{N} = \delta_t + \boldsymbol{\theta_t}\mathbf{Z_i} + \boldsymbol{\lambda_t}\boldsymbol{\mu_i} + \varepsilon_{it} \tag{1}$$

where δ_t is an unknown common factor with constant factor loadings across networks (cf. a time fixed effects vector in a DID setting), $\mathbf{Z_i}$ is a vector of observed technical characteristics not affected by the intervention, and $\boldsymbol{\theta_t}$ is a vector of unknown parameters. Further, $\boldsymbol{\lambda_t}$ is a vector of unobserved common characteristics, and μ_i is a vector of unknown factor loadings. In a DID setting, the "parallel trends" assumption is the identifying assumption ensuring that time-varying unobserved variables do not bias the results. By contrast, the synthetic control method takes advantage of the fact that there are several networks in the donor pool, and uses a matching algorithm that forces the parallel trends assumption to hold.

Ideally, the variables in $\mathbf{Z_i}$ should be completely exogenous. In the short run, exogeneity seems reasonable. However, in this case it is not possible to determine wether the choice of technical characteristics is compatible with long run cost minimization, but rather if labor use is efficient given the set of technical characteristics. If long run efficiency is of interest, it could be more suitable to instead match only on purely exogenous environmental and demand characteristics (such as the number of customers and size of the concession area). In the framework of the NPAM regulation, this would be equivalent to match on the variables collected in the "data collection" stage. However, an implicit assumption is then that network owners are free to change the physical constituents of the network, and that there is a unique optimal network for a given set of environmental and demand characteristics. These assumptions are questionable, and have been contested by Jamasb and Pollitt (2008). In another study of the Swedish NPAM regulation, Jamasb and Söderberg (2010) find that the reference networks are not adequate representations of the real networks. Taken together, it appears most appropriate to keep the technical characteristics of the network as matching variables, at the expense of not knowing wether the technical characteristics of the networks have been chosen to optimize long term efficiency.

Consider a (J x 1) vector of weights $\mathbf{W} = (w_2,...,w_{J+1})'$ such that $w_j \geq 0$ for $j = 2, ..., J+1$ and $w_2 + \cdots + w_{J+1} = 1$. That is, each particular value of the vector $\mathbf{W}$ represents a potential synthetic control group. The value of the outcome variable for each synthetic control indexed by $\mathbf{W}$ is:

$$\sum_{j=2}^{J+1} w_j Y_{jt}^N = \delta_t + \boldsymbol{\theta_t} \sum_{j=2}^{J+1} w_j \mathbf{Z_j} + \boldsymbol{\lambda_t} \sum_{j=2}^{J+1} w_j \boldsymbol{\mu_i} + \sum_{j=2}^{J+1} w_j \varepsilon_{jt} \tag{2}$$

Suppose that there is a vector of weights $\mathbf{W}^*$ such that

$$\begin{aligned} \sum_{j=2}^{J+1} w_j^* Y_{j1} = Y_{1t} \qquad \forall t \leq T_0 \\ \sum_{j=2}^{J+1} w_j^* \mathbf{Z_j} = \mathbf{Z_1} \end{aligned} \tag{3}$$

i.e., the synthetic control group matches the acquired network both in terms of the pre-treatment trajectory of the outcome variable, and the observed technical characteristics. Then, Abadie et al. (2010) proves that under fairly standard conditions on the unobserved factors:

$$\hat{\alpha}_{1t} = Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt} \tag{4}$$

is an unbiased estimator of α_{1t}, and the mean estimated post-treatment effect is then computed according to $\overline{\alpha}_1 = \frac{1}{T-T_0} \sum\limits_{t>T_0} \hat{\alpha}_{1t}$. In practice, it is often the case that no set of weights exist such that (3) holds exactly. Then, weights are chosen to minimize the mean squared prediction error between the matrix of pre-acquisition characteristics and outcome variable trajectory of the real network, and the corresponding matrix of its synthetic control network.

To determine the precision of $\hat{\alpha}_{1t}$, an inference method akin to the placebo tests used in the conventional DID setting is employed, by iteratively applying the synthetic control method to every network in the donor pool. Then, the mean estimated effect is computed for each placebo run. This iterative procedure provides a distribution of the estimated gaps for the networks that were not acquired. One can then compute the probability that a network chosen at random would produce an estimate at least the size of the estimated effect of the acquired network. In accordance with Abadie et al. (2010), I remove placebo networks with more than twice the mean squared prediction error of the original acquired network, as a large error indicates that the algorithm for finding a proper synthetic analogue did not succeed[4].

In the present setting, a potential caveat is that the number of pre-treatment periods are rather small. To increase the number of pre-treatment periods, I assume that the acquirers could not influence the outcome variables until one year after the acquisitions took place. This is a plausible assumption, as prices are usually revised only once a year, and revisions do not come in effect until at least couple months after the decision. An analogous reasoning can be made in terms of labor costs. A second issue is that E.ON acquired its networks approximately half a year before Fortum (in May 2001 and January 2002 respectively). Therefore, I estimated the model using both 2002 and 2003 as the year of treatment, without any qualitative change in results. In the main specification, I use 2003 as the year of treatment. Naturally, when estimating network specific effects, I instead use 2002 as the year of treatment for the networks acquired by E.ON.

3.2 Accounting for economies of scale when firms acquire bordering networks

An identifying assumption of the synthetic control method is that the acquisition cannot affect the observed predictor variables ($\mathbf{Z}_\mathrm{i}$). While this assumption appears acceptable for most physical characteristics of the network at least in the short run, it is clearly violated if the acquirer is able to enjoy increased economies of scale. For example, the acquirer may be able to use the same administrative staff for several networks, or optimize the use of equipment by transporting it between different regions. Failing to account for such synergies will bias the estimates of the causal efficiency gains of privatization upwards. However, it should be noted that previous studies have found that economies of scale in electricity distribution are limited, and that the main cost driver in electricity distribution is instead economies of density. For ex-

---

[4] I estimate the model using Stata's *synth* package (Abadie et al., 2011).

ample, Hjalmarsson and Veiderpass (1992) study Swedish electricity distribution using cross-sectional data from 1985, finding that economies of scale are considerably less important than economies of density. Further, Salvanes and Tjøtta (1994), also using cross-sectional data, studies Norwegian distribution networks finding economies of scale only for networks with less than 20,000 customers.

Difference-in-differences estimation

Despite its inability to account for *unobserved* time-varying characteristics, an advantage of the DID estimator is that the *observed* control variables are allowed to vary as a response to the acquisitions, enabling the estimation of increased economies of scale when several networks are acquired. The DID estimator is identified by:

$$y_{it} = \alpha + \rho_a + \boldsymbol{\lambda}_t + \delta D_{at} + \mathbf{X}_{it}\gamma + \varepsilon_{it} \tag{5}$$

Where y_{it} is the outcome variable in network i in year t, and α is a constant. The dummy variable ρ_a takes the value one if the network was acquired[5]. $\boldsymbol{\lambda}_t$ is a vector of year fixed effects, and $\mathbf{X}_{it}$ is a matrix of time-varying control variables with its associated coefficient vector γ. $\mathbf{X}_{it}$ contains the same physical characteristics as $\mathbf{Z}_\mathrm{i}$ in equation (1). Due to potential problems with multicollinearity, I add the underground and overground lines to obtain one single variable. The coefficient of interest is δ, capturing the effect of the acquisition dummy variable D_{at}, which takes the value one for all acquired networks in the post-acquisition period, and zero otherwise. Standard errors are clustered by network.

Looking at Figure 2, it is evident that the acquired networks are dispersed. However, for each firm there are also some of the acquired networks that share

---

[5] Alternatively, the model could be estimated using a full set of network fixed effects. However, in that case the coefficient on the number of customers would rely on within-network variation only. Then, scale effects in the control networks cannot be identified, as that would in practice require that unpopulated regions became populated during the sample period.

borders, and I assume that economies of scale can be realized only among the neighboring networks[6]. In terms of accounting units, all bordering networks sharing the same owner have been merged to one unified network at some point during the sample period. On average, there are seven sub-networks within each of the five unified networks. Since panel data can only be constructed for the unified networks, I begin by duplicating each of the unified networks as many times as the original number of sub-networks. Data on the number of customers in the pre-acquisition period is then replaced by the observed number of customers in each of the sub-networks. Suppose that network A (1 customer) and network B (99 customers) are merged into network C (100 customers). In the period following the acquisition, both network A and B will have 100 customers. All other other data entries are kept intact. A complicating factor in estimating the effect using a DID estimator is that each of the smaller networks are given equal weights in the estimation process. In the example above, it is obvious that almost no scale effects can be realized. Therefore, I estimate the model using analytical weights, based on the number of customers in 2000[7]. The model produces coefficients with identical magnitudes as if there would have been one observation for each customer in the whole system, while leaving the sample size and standard errors unchanged. In reality it may take a while before scale effects can be realized, due to labor market regulations, long delivery periods for equipment, etc. Therefore, I perform robustness tests assuming that there is a lag in how quickly scale effects can be realized.

---

[6] A complicating factor is that some of the bordering networks shared the same owner already before the acquisitions. However, in the majority of these cases, a previous acquisition had been made shortly before the network was acquired by E.ON or Fortum. For example, Sydkraft acquired numerous municipality owned networks between 1999-2001, which is the reason why most of these networks remained separate accounting units up until 2003. For a comprehensive review of all major M&As in the Swedish electricity market 1997-2006, see Energy Markets Inspectorate (2006).

[7] I estimated the model using Stata's *aweight* command. Weights have been normalized across groups so that the mean weight of an acquired network equals the mean weight of a non-acquired network.

4 Results

4.1 Results from the synthetic control method

Table 2 shows the pre-acquisition mean of the matched variables in the real acquired network and the synthetic control network respectively. The variables in the real acquired network match the variables in the synthetic networks very well. Importantly, both outcome variables are matched very well, with an absolute difference compared to the real network of less than one percent.

Table 2: Price and labor cost predictor means

	Acquired mean	Synth. (Price) mean	Synth. (Labor) mean
Density (overhead line)	71.43	71.66	71.30
Density (ground line)	43.62	43.87	43.52
Transformer stations	4.27	4.29	4.27
Transformer capacity	9.46	8.87	9.25
Number of customers	16.23	16.15	16.32
Price in 2002	4237.76	.	4242.48
Labor cost in 2002	1197.10	1203.20	.

Note: This table depicts the mean of the predictor variables, including the outcome variables in 2002.

The upper left diagram in Figure 4 compares the trajectory of the price in the acquired network to its synthetic analogue. Both the real and the synthetic network experience an increase in price of around 40 percent throughout the sample period, which is about the same as the industry average. In the first years following the acquisitions, the price in the acquired network is somewhat lower than the synthetic price. This indicates that new owners keep prices low for a number of years after the acquisition, possibly to reduce the risk of being suspected of overcharging, either by the consumers or the regulator. In 2008, the price in the acquired network started to catch up with the synthetic price, and by the end of the sample period the price in the acquired network was 2 percent higher (corresponding to 175 SEK/customer). Thus, the result

Figure 4: Effect of acquisitions on price and labor cost

Note: First row: Trajectory of outcome variables for the real representative acquired network and the corresponding synthetic network in SEK/customer. Second row: Outcome gaps between the real representative network and the corresponding synthetic network, expressed as a percentage of the real observed outcome variable.

gives some support to the views expressed by consumer groups that prices in the acquired networks have increased more than comparable publicly owned networks, given that the period of interest is 2008-2011. However, on average the price in the acquired network is 1.3 percent below the synthetic network during the years following the acquisitions, an effect that is hardly economically significant. The trajectories of the placebo effects in the 73 out of 105 control networks with a mean squared predicted error below the threshold are depicted in Figure A5. The distribution of the placebo estimates also confirm that the effect is not statistically significant, as the estimated effect of -1.3 percent belongs to the 5^{th} decile of the distribution. The trajectories for the full placebo sample are depicted in Figure A6.

One interpretation of the zero effect on the price is that the regulation has been effective, as the acquirers have not been able to push up the price even though it would lead to higher profits. It may also be that the acquirers are afraid that increased prices would lead to more strict regulations in the future.

The upper right diagram in Figure 4 compares the trajectory of the labor cost in the acquired network to its synthetic analogue. In contrast to the price, the trajectories differ substantially, and the average acquisition effect is -18 percent, or correspondingly -360 SEK per customer. The effect is mainly driven by a sharp increase in the labor cost of the synthetic network. The gap is depicted in the bottom right diagram of Figure 4, where it is clear that the effect has increased over time. This is expected, since it should take some time to change the organizational structure of the networks due to labor regulations etc. The trajectory of the placebo effects are depicted in Figure A5. None of the estimates of the 37 networks in the placebo group which had a mean squared prediction error below the threshold are lower than the estimated real effect. Since there are 37 networks in the placebo sample, this means that the chance of randomly estimating an effect as large as the real estimated effect is less than five percent.

Network specific effects

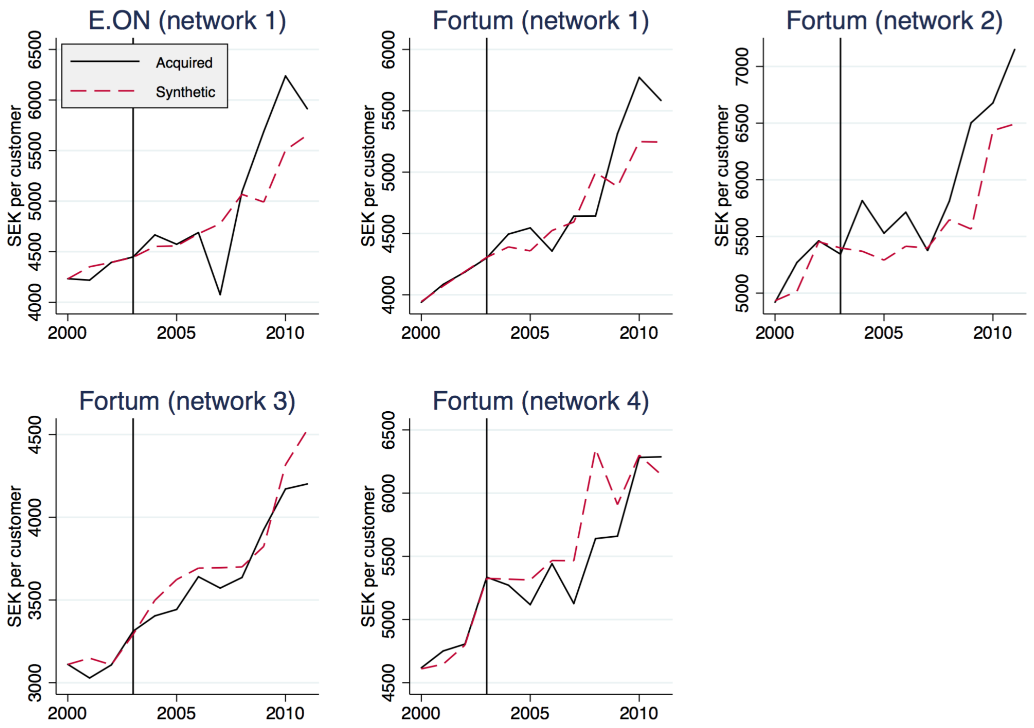
Network specific effects are presented in Table 3, and trajectories of the outcome variables are depicted in Figure 5 and 6. Results are broadly in line with the results using the representative network. The price effect in each of the networks is small, and the average effect is an increase in the price of 1.4 percent. The largest effect of 6.6 percent is found in Fortum's network 2, but in comparison to the placebo estimates the effect is still not significant. The effect on labor cost is negative for all networks, although the networks acquired by Fortum have experienced a comparatively larger reduction in labor costs. In this light, it appears plausible that the storm Per in 2007 did fact inflate the labor costs of E.ON, as the observed labor cost in 2007 is larger than for any other year. The mean effect across all networks at -25 percent is somewhat larger than the estimated effect when only considering one representative network.

Table 3: Network specific effects

	Labor cost mean	Price mean
E.ON (network 1)	-4.9	2.6
Fortum (network 1)	-27.9	0.3
Fortum (network 2)	-34.1	6.6
Fortum (network 3)	-25.4	1.5
Fortum (network 4)	-31.7	-3.8
Mean across networks	-24.8	1.4

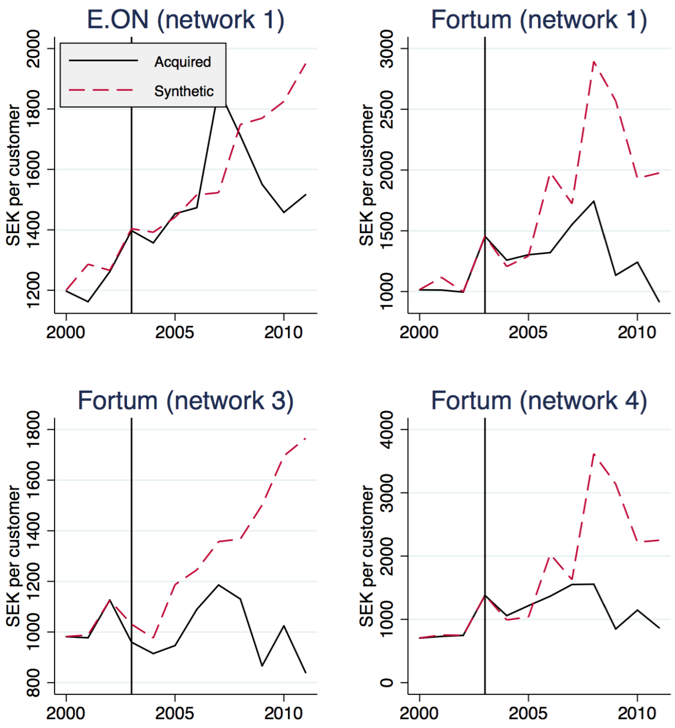
Note: Network specific effects, expressed as percentage gaps compared to the synthetic networks.

Figure 5: Network specific effects on price



Note: Trajectory of the price in the real acquired networks and the corresponding synthetic networks in SEK/customer.

Figure 6: Network specific effects on labor cost



Note: Trajectory of the labor cost in the real acquired networks and the corresponding synthetic networks in SEK/customer.

4.2 Results from the difference-in-differences estimation

The first two columns in Table 4 depicts the results assuming that scale effects could be realized immediately at the time of the acquisitions. The acquisition effect on both price and labor are now *positive*, at 7 and 16 percent respectively, in contrast to the results from the synthetic control method. The new results indicate that the acquirers have not been able to realize the economies of scale that would be theoretically possible. However, there are several caveats associated with this result. First, as discussed above, it is not likely that scale effects can be realized immediately. Therefore, in columns (3) and (4) I do not increase the number of customers in the acquired networks until in 2007, to allow for four years to adapt to the new circumstances. Both effects now drop by half, but are still both statistically and economically significant. Still, since the publicly owned control networks have substantially fewer number of customers than the acquired networks, the results rely on extrapolating the estimated scale effect to networks larger than the control networks, which is another reason why results should be interpreted with care.

Table 4: Difference-in-differences estimates.

	(1) Price	(2) Labor	(3) Price	(4) Labor
Acquisition effect ($\hat{\delta}$)	0.069**	0.16**	0.029*	0.081*
	(0.034)	(0.069)	(0.017)	(0.046)
Customers	-0.037**	-0.088***	-0.031**	-0.092***
	(0.017)	(0.025)	(0.015)	(0.024)
Density	0.17***	0.21***	0.17***	0.20***
	(0.040)	(0.049)	(0.041)	(0.050)
Transformer stations	0.15	0.089	0.15	0.089
	(0.098)	(0.077)	(0.099)	(0.077)
Observations	1632	1632	1632	1632

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$

Note: Dependent variables are price and labor cost per customer.

Standard errors are clustered by network. All variables are logged.

First (last) two columns assume scale effects could be realized in 2003 (2007).

Standard errors in parentheses.

The other coefficients all have the expected signs: In column (2), increasing the number of customers by 1 percent leads to a 0.09 percent decrease in the labor cost. This effect appears relatively low, but is in line with previous studies indicating that scale economies in electricity distribution are in fact modest. As expected, economies of network density is larger, and an increase in the meter of transmission line per customer by 1 percent leads to an increase in the price of 0.17 percent, almost six times as much as the corresponding coefficient on the number of customers. The corresponding scale- and density effects on the price are smaller than the effects on the labor cost, but still statistically significant. For both outcome variables, the effect of increasing the number of transformer stations per customer is positive, as expected, but statistically insignificant.

5 Conclusion

Using a synthetic control method, I examine the effects of privatization in the Swedish electricity distribution sector. Specifically, I examine the effects of private acquisitions of municipality owned distribution networks, that were conducted around the turn of the century. In comparison to their synthetic counterparts, I find that the acquired networks increased labor efficiency by about 18 percent, while no effect is found on the prices. Thus, the evidence suggests substantial efficiency gains but that these are not fed through to consumer prices.

Since each acquisition involved several bordering networks that were separately operated by the municipalities prior to the acquisitions, I examine to what extent the efficiency gains are likely to be driven by increased economies of scale. Results suggest that the entire efficiency gain can be explained by increased economies of scale, questioning the *causal* effect of privatization per se. However, since the final size of the privatized networks are substantially larger than any of the municipality owned networks in the control group, the identification of this test relies on the possibility to extrapolate outside the data in the control group. Therefore, this result should be interpreted with care.

A topic that could be of interest for future studies concerns the endogeneity of the acquisition decisions, i.e., a selection-into-treatment problem. For example, private firms may opt to acquire networks with the largest potentials for efficiency increases. This could be both with respect to the internal management of the network, or that acquirers look for combinations of networks where the potential for synergy effects are considerable. In some respect, one of the virtues of privatization may be the ability to spot such networks, which relates to the more general discussion on how selection problems should be treated in the literature on privatization of network industries in general.

Just as the concept of private ownership deserves a more nuanced review than what is offered by the present study, so does public ownership. Within the context of labor efficiency, it may for example be that publicly owned firms prefer to offer relatively higher wages and other benefits than private firms *ceteris paribus*, in which case it is more appropriate to interpret variations in the labor cost as also reflecting how revenues are distributed between workers and owners.

A shortcoming of the present study is that data on the quality of service (measured by the number and length of outages) has not been able to obtain for the whole sample. As results from previous studies indicate that publicly owned distribution networks achieve a higher quality of service than privately owned networks (see e.g. Kwoka, 2005), this would be a useful outcome variable to examine in future research.

Finally, there may have been other motives for the acquisitions than profiting on distribution per se. Since both Fortum and E.ON control a fair amount of generation facilities in Sweden, they may have incentives to give a disproportionately high priority to the maintenance of distribution lines in connection to their own generation facilities, or in other ways influence the physical constitution of the network to suit their specific needs. They may also use private information about bottlenecks in transmission or power line failures to predict price formation in the wholesale market, creating a strategic advantage compared to other firms. It could therefore be of interest to look into dimensions of market power that considers the strategic aspects of controlling both generation and distribution within the same area, as opposed to examining the behavior in each market separately.

References

Abadie, Alberto, Alexis Diamond, and Jens Hainmueller, "Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California Tobacco Control Program," *Journal of the American Statistical Association*, 2010, *105* (490), 493–505.

_ , _ , and _ , "SYNTH: Stata module to implement Synthetic Control Methods for Comparative Case Studies," Statistical Software Components, Boston College Department of Economics October 2011.

Averch, Harvey and Leland L. Johnson, "Behavior of the Firm Under Regulatory Constraint," *The American Economic Review*, 1962, *52* (5), 1052–1069.

Balakrishnan, Karthik, Daniel A. Cohen, Xavier Giroud, Kose John, Christo Karuna, April Klein, Thomas Lys, and Raj Mashruwala, "Product Market Competition and Financial Accounting Misreporting," Working Paper, 2012.

Borghi, Elisa, Chiara Del Bo, and Massimo Florio, "Institutions and Firms' Productivity: Evidence from Electricity Distribution in the EU," *Oxford Bulletin of Economics and Statistics*, 2016, *78* (2), 170–196.

Dalarna's newspaper, "Municipalities wants to buy back the electricity network," `http://www.dt.se/dalarna/mora/mora-beredd-kopa-tillbaka-salda-elnatet` (accessed April 21, 2016), 2014.

Energy Markets Inspectorate, "Ägarstrukturen på elmarknaden," Report EI R2012:21, Energy Market Inspectorate 2006.

_ , "Utvecklingen av elnätsavgifter 2009-2010," Report PM 2010:03, Energy Market Inspectorate 2011.

_ , "Bedömning av elnätsföretagens nätavgifter nätavgifter 2011," Report Ei R2012:13, Energy Market Inspectorate 2012.

Estache, Antonio and Martín A. Rossi, "Do regulation and ownership drive the efficiency of electricity distribution? Evidence from Latin America," *Economics Letters*, 2005, *86* (2), 253 – 257.

Heden, H, *Energimarkandsinspektionen - en sekellång historia*, Energimarkandsinspektionen, ISBN 978-91-977417-1-2, 2012.

Hjalmarsson, Lennart and Ann Veiderpass, "Efficiency and Ownership in Swedish Electricity Retail Distribution," *The Journal of Productivity Analysis*, 1992, *3*, 7–23.

Jamasb, Tooraj and Magnus Söderberg, "The Effects of Average Norm Model Regulation: The Case of Electricity Distribution in Sweden," *Review of Industrial Organization*, May 2010, *36* (3), 249–269.

_ **and Michael Pollitt**, "Reference models and incentive regulation of electricity distribution networks: An evaluation of Sweden's Network Performance Assessment Model (NPAM)," *Energy Policy*, May 2008, *36* (5), 1788–1801.

Kumbhakar, Subal C. and Lennart Hjalmarsson, "Relative performance of public and private ownership under yardstick competition: electricity retail distribution," *European Economic Review*, January 1998, *42* (1), 97–122.

Kwoka, John E., "The Comparative Advantage of Public Ownership: Evidence from U.S. Electric Utilities," *The Canadian Journal of Economics / Revue canadienne d'Economique*, 2005, *38* (2), 622–640.

Laffont, Jean-Jacques and Jean Tirole, *A Theory of Incentives in Procurement and Regulation*, 1 ed., Vol. 1, The MIT Press, 1993.

Meyer, Roland, "Vertical Economies and the Costs of Separating Electricity Supply: A Review of Theoretical and Empirical Literature," Bremen Energy Working Papers 0006, Bremen Energy Research April 2011.

Muren, Astri, "Exploatering eller reglering av naturliga monopol? Exemplet fjärrvärme," Report 2011:2, Expertgruppen för miljöstudier 2011.

Niskanen, William A., "The Peculiar Economics of Bureaucracy," *The American Economic Review*, 1968, *58* (2), 293–305.

NordReg, "Economic regulation of electricity grids in Nordic countries," Nordic Energy Regulators, report nr.7, 2011 2011.

OECD, "Germany - Regulatory Reform in Electricity, Gas, and Pharmacies," Country Studies 2004.

SABO, "Large price increases in networks owned by E.ON, Fortum and Vattenfall," `http://www.sabo.se/aktuellt/nyheter_s/2011/mar/Sidor/St%C3%B6rst-pris%C3%B6kningar-i-eln%C3%A4t-%C3%A4gda-av-EON-Fortum-och-Vattenfall.aspx` (accessed April 21, 2016), 2011.

Salvanes, Kjell G and Sigve Tjøtta, "Productivity differences in multiple output industries: an empirical application to electricity distribution," *Journal of Productivity Analysis*, 1994, *5* (1), 23–43.

Shleifer, Andrei, "A Theory of Yardstick Competition," *RAND Journal of Economics*, Autumn 1985, *16* (3), 319–327.

Söderberg, M., "The Role of Model Specification in Finding The Influence of Ownership and Regulatory Regime on Utility Cost: The Case of Swedish Electricity Distribution," *Contemporary Economic Policy*, 2011, *29* (2), 178–190.

Supreme Administrative Court, "Case 6667–6669-14," `http://www.hogstaforvaltningsdomstolen.se/Domstolar/regeringsratten/Avg%C3%B6randen/2015/November/6667-6669-14.pdf` (accessed April 21, 2016), 2015.

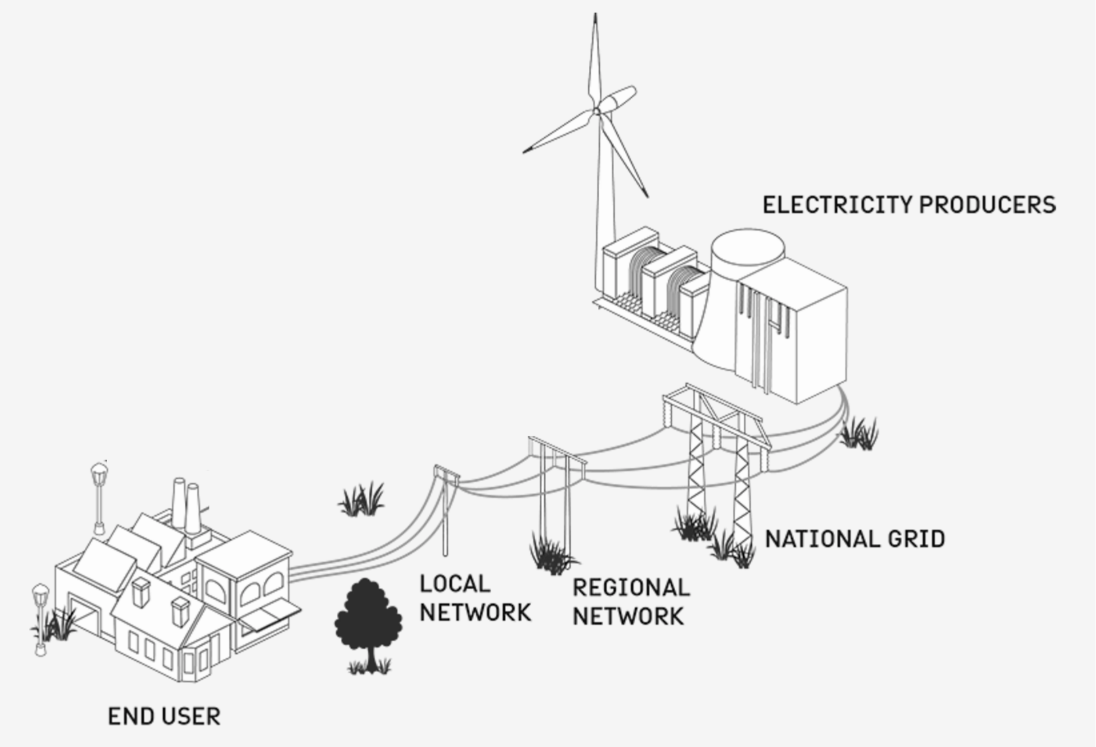
SvD, "Fortum säljer sitt svenska elnät," `http://www.svd.se/fortum-saljer-sitt-svenska-elnat` (accessed April 21, 2016), 2015.

SVT, "Borås Elnät utreds av Högsta förvaltningsdomstolen," `http://www.svt.se/nyheter/lokalt/vast/boras-elnat-utreds-av-hogsta-forvaltningsdomstolen` (accessed April 21, 2016), 2015.

Swedish Competition Authority, "Consultation response to the NPAM framework," `http://www.konkurrensverket.se/Beslut/03-0538.htm` (accessed April 21, 2016), 2003.

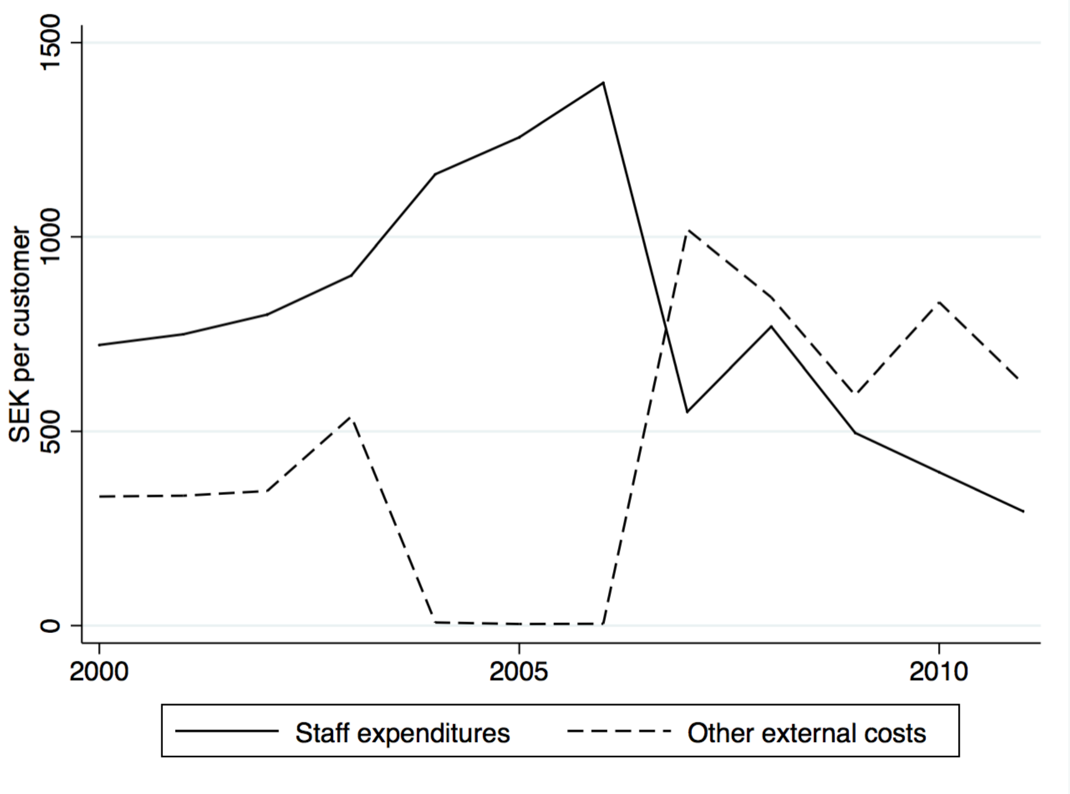
Appendix A

Figure A1: Schematic diagram of the physical supply chain



Note: This figure depicts a schematic diagram of the physical route of electricity. The “local network” is equivalent to the distribution network. Source: Svenska Kraftnät.

Figure A2: Staff expenditures and Other external costs in networks acquired by Fortum

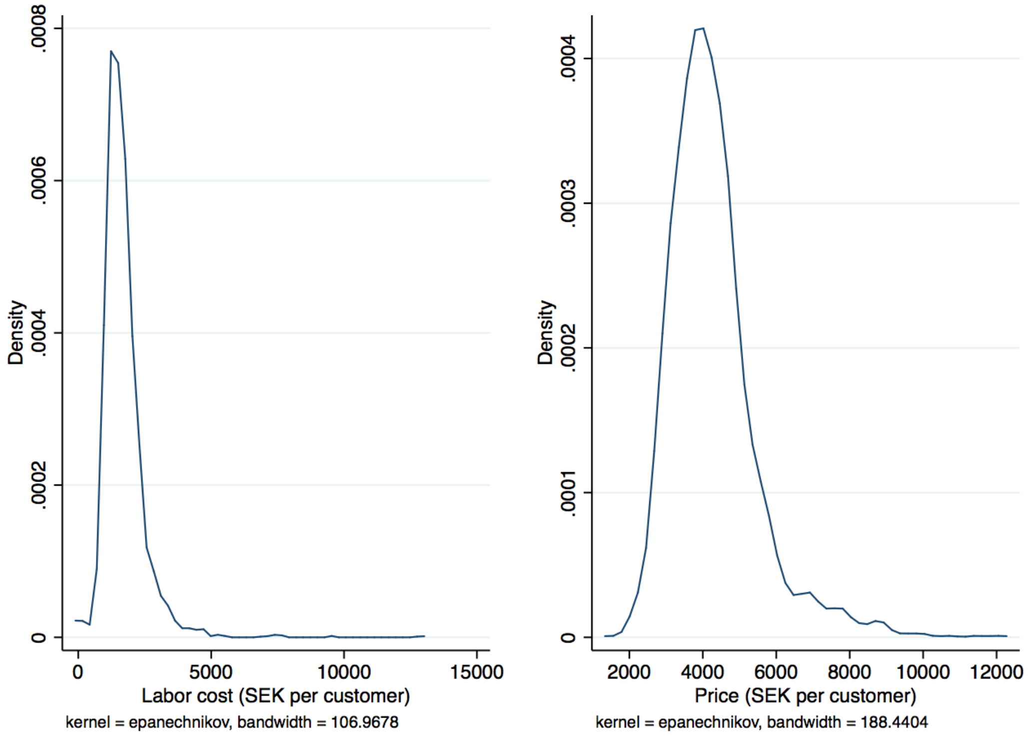


Note: This figure depicts the mean accounted labor cost per customer in the networks acquired by Fortum, disaggregated into Staff expenditures and Other external costs.

Figure A3: Trends in price and labor cost including networks owned by economic associations

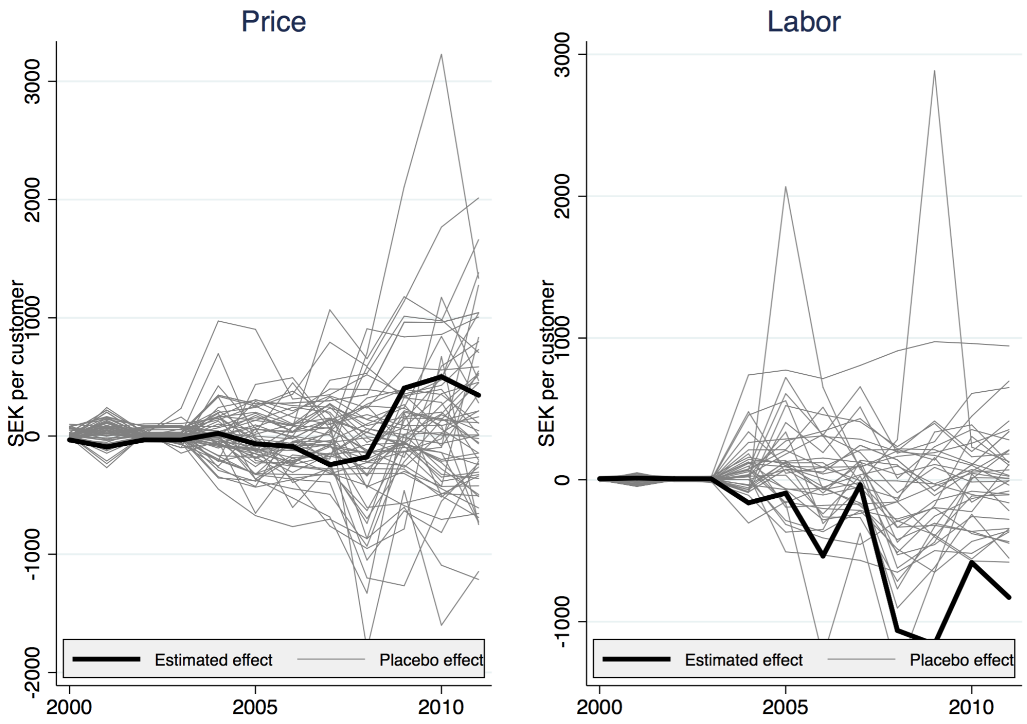
Note: The dashed lines depict the mean price and labor cost per customer for municipality owned networks that were never acquired, including networks owned by economic associations. The solid lines depict the same variables for networks that were acquired by Fortum or E.ON. The vertical line is in 2003.

Figure A4: Density functions of labor cost and price



Note: This figure depicts density functions of the outcome variables during the whole sample period for all networks.

Figure A5: Trajectory of placebo effects



Note: Trajectory of outcome gaps between real and synthetic networks for each network in the sample. Networks with a mean squared prediction error more than twice as large as the acquired network are excluded.

Figure A6: Trajectory of placebo effects (full sample)

Note: Trajectory of outcome gaps between real and synthetic networks for each network in the sample. All potential control networks have been included.

Chapter 3

Price Mimicking under Cost-of-Service Regulation: The Swedish Water Sector[*]

Abstract

This study provides an empirical test of price mimicking among regulated utilities. Since publicly owned water utilities in Sweden are governed by a cost-of-service regulation, prices in neighboring municipalities should not affect the own price other than through spatially correlated cost factors. In contrast, spatial dependence is pronounced. This behavior can be explained in terms of an informal yardstick competition. When consumers use neighboring utilities' prices as benchmarks for costs or as behaviorally based reference prices, utilities will face the risk of consumer complaints and successive regulatory reviews if deviating too much from neighbors' prices. Using a fixed effects spatial Durbin model with data from almost all Swedish municipalities during 2002-2012, I estimate the elasticity of the own relative to neighbors' average price to 0.14.

---

[*] I would like to thank Richard Friberg, Pär Holmberg, and participants at the 2014 ENTER-Jamboree for valuable comments.

1 Introduction

Ever since Tiebout (1956) pointed out that citizens evaluate the policies of their local governments in relation to the policies of other jurisdictions, the interdependence in policy decisions among local governments has been a major interest in public economics. Especially, the focus has been on tax setting and the provision of public services. This paper extends the existing literature by examining strategic interactions in the pricing decisions of regulated utilities. It also adds to the regulatory literature by noting that yardstick competition may also arise in regulated industries that are not subject to a formal yardstick regulation. Specifically, I examine the pricing decisions of Swedish water utilities over 2002-2012. Since publicly owned water utilities in Sweden are governed by a cost-of-service ("c-o-s") regulation, prices in neighboring municipalities should not affect the own price other than through spatially correlated cost factors. In contrast, utilities are found to mimic the prices of their neighbors.

The basic setup in a model of yardstick competition typically involves a regulator and a number of local monopolists with identical cost functions. For a seminal contribution, see Shleifer (1985). The cost function is unknown to the regulator. For any given firm, the price that the firm gets is equal to the average self-reported cost of the other firms. If a firm reduces costs when its twin firms do not, it profits. If it fails to reduce costs when other firms do, it incurs a loss. Thus, firms are incentivized to achieve productive efficiency. But if the citizens of a jurisdiction evaluate the performance of the local policy makers by comparing with the surrounding jurisdictions this can also generate a type of yardstick competition even in absence of a central regulator. A presumption is then that citizens can punish the firm, either by lobbying for lower prices or the replacement of managers, or by voting the local policy maker out of office.

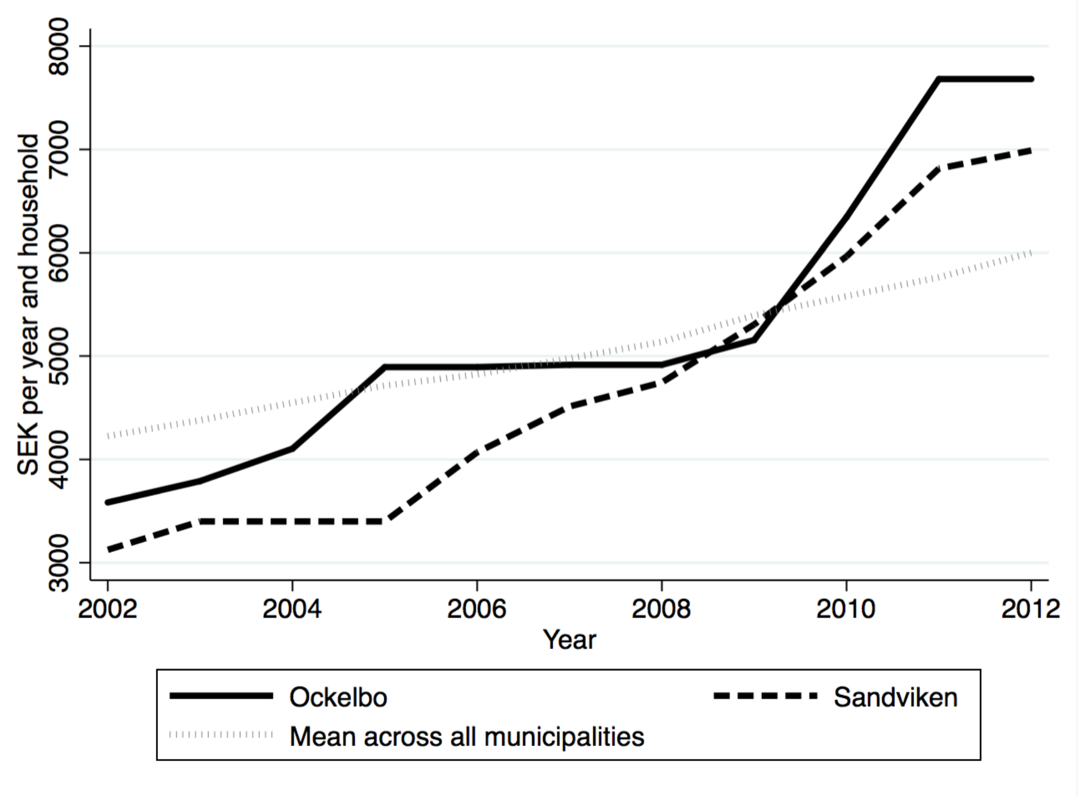
Informal yardstick competition is not unknown in public economics. For instance, Besley and Case (1995) have adapted Schleifer's original model to describe a system with asymmetric information between voters and politicians. The latter are assumed to know more about the cost of providing public services than the former. Consonant with the large literature on multiagent incentive schemes (see e.g. Holmström, 1982) they show that it makes sense for voters to appraise their incumbent's relative performance if neighboring jurisdictions face correlated cost shocks. Since tax rates are a proxy for the price of public production, citizens will evaluate the performance of their local policy makers by comparing their tax rates with those of neighboring jurisdictions. This induces local policy makers to mimic their neighbors' tax policies in order not to look bad in comparison and be voted out of office.

Geys (2006) notes that even in absence of correlated cost shocks, informal yardstick competition may arise if neighbors' tax rates serve as behaviorally based *reference prices* by which the own tax rate is compared, thereby generating the so-called *transaction utility* introduced by Thaler (1985). The most important factor for determining the reference price is fairness, and the transaction utility for buying a certain good is positive if the realized price is less than the reference price. Thus, if citizens believe that it is fair that they pay the same tax as their neighbors, the transaction utility will depend on the difference between their own and their neighbors' taxes.

Is informal yardstick competition also at play in utility markets? Theoretically it should be easier for citizens to compare the performance of individual utilities than the total production of public services. First, utilities produce comparatively homogenous goods, e.g., electricity distribution, water provision, district heating, and telecommunications. By contrast, a bundle of public services, or even a single one, may vary a lot in quality. Therefore, public services are harder to compare both in relation to quality and fairness principles. Further, the tax rate is merely an approximation of the price of public services, while a well-defined price for a utility service serves as a natural benchmark for efficiency. Recently, some studies have found evidence of yardstick competition in the pricing decisions of unregulated utilities, see Klien (2012); Söderberg and Tanaka (2012). However, to the best of my knowledge, this is the first study to observe yardstick competition in a market subject to a c-o-s regulation. Given that utilities comply with the regulatory framework there is no scope for such behavior. On the other hand, if regulatory monitoring is loose citizens may use neighboring utilities' prices as benchmarks for good performance or as reference prices, inducing utilities to mimic the prices of their neighbors.

Arguably, the Swedish water sector provides an excellent testing ground for the existence of informal yardstick competition among regulated utilities. Water services have for a long time been provided by publicly owned utilities, independently organized by each municipality. They are regulated by a loosely monitored c-o-s regulation, and Haraldsson (2013) notes that 45 percent of the municipalities do not even fulfill basic legal accounting requirements. Many of the utilities also belong to publicly owned energy conglomerates, facilitating cross-subsidization between divisions. This should make leeway for a fair degree of arbitrariness in the pricing decisions. As of 2012, price differences were substantial, ranging from 3,000 to 10,000 SEK (1 SEK $\approx$ 0.1 EUR during the sample period) per year for a regular household. Many municipalities have price trends that follow closely the trend of their neighbors, for no apparent reason. As an illustrative example, Figure 7 shows the price trends in two neighboring municipalities, Ockelbo and Sandviken.

Figure 7: Trends in water prices for a typical household



Note: This table depicts time trends in the water price for the two neighboring municipalities Ockelbo and Sandviken, as well as the mean across all 288 municipalities in the sample. The unit of measurement is the total cost (fixed plus variable cost) in SEK for a typical stand-alone house consuming 150 m^3 per year.

In both municipalities, prices have increased by 120 percent during the last decade, compared to the industry average of 42 percent. The price increase in Ockelbo could largely be explained by high investments, which are on average 1,000 SEK per year and resident for the years when data on investments were available, compared to the industry average of 600 SEK per year. By comparison, the neighboring municipality Sandviken invested only 300 SEK per year, which is well below the industry average. Sandviken's water utility is both physically and organizationally isolated from every other water system in the region. Further, Sandviken's water utilities are part of a publicly owned energy conglomerate, which should facilitate cross-subsidization. This raises concerns whether Sandviken raised its price in response to the price increases in Ockelbo, and if so, whether such pricing strategies have been adopted on a systematic basis.

Using a fixed effects spatial Durbin model with data from almost all Swedish municipalities during 2002-2012, I estimate the elasticity of the own relative to neighbors' average price to be 0.14. The interpretation is that if my neighbors raise their prices by on average 10 percent, the own price will increase by 1.4 percent. Thus, the effect is relatively modest but still economically significant. Results from cross-sectional data using even more detailed information about the technical characteristics of the utilities suggest an even higher degree of spatial dependence. However, due to the absence of fixed effects these estimates should be interpreted with care. Further, spatial dependence is not attenuated in municipalities with politically stable electorates, suggesting that managers' decisions rather than political influence is the main driving mechanism behind the result.

The rest of this paper is structured as follows. Section two reviews the related literature and discusses some theoretical predictions, section three describes the institutional framework and the data, section four presents the model, section five presents the results, section six provides a further discussion on the underlying mechanisms and implications for efficiency, and section seven concludes.

2 Related literature

What predictions can be made based on previous literature? The strategic interactions between local governments can be divided into two broad categories: "spillover models" and "resource flow models".[1] In the spillover framework each jurisdiction chooses the level of a decision variable, but the jurisdiction is also affected by decisions elsewhere (without triggering any physical flows of goods, residents or capital across borders). The resource flow model, on the other hand, recognizes that policy makers adjust their policy decisions in order to attract certain residents or capital to the jurisdiction, or to attract cross-

---

[1] For a more thorough review of these models, see Brueckner (2003); Revelli (2005).

border shopping. While it is true that water prices in theory could be an important determinant for the location of water intensive industries, 94 percent of the water used in industrial production is extracted from water sources owned by the firms themselves (Statistics-Sweden, 2013). Regarding migration flows, water prices are likely to affect the choice of living only on the margin. Water prices have a much smaller impact on the regular household's budget than other policies that differ between municipalities, such as local income tax rates. Hence, spillover models are more relevant in the present setting.

Yardstick competition is an example of a model in which spillovers help citizens to judge the performance of their government. The studies most closely related to the present one are Klien (2012) and Söderberg and Tanaka (2012).[2] Klien investigates yardstick competition among Austrian water utilities using a panel data set covering 2000-2009. He finds some evidence of yardstick competition, but since utilities are free to set their own prices, nothing can be said about the utilities' regulatory compliance. Söderberg and Tanaka study price setting in the Swedish unregulated district heating sector using cross-sectional data from 2004. They find that privately owned utilities mimic the prices of their publicly owned neighbors, since the privately owned utilities are threatened by customer complaints that may lead to retaliations from local elected officials (publicly owned utilities are assumed to set prices that maximize social welfare).

A related strand of literature examines yardstick competition in the provision of social services and tax rates. For instance, Solé-Ollé (2003) finds evidence of yardstick competition in tax rates among Spanish municipalities. He also finds a positive relation between tax mimicking and a low electoral margin, suggesting that politicians facing a higher risk of being voted out of office are relatively

---

[2] As discussed in the introduction, these markets are not subject to a c-o-s regulation. Still, it should be noted that in none of these markets utilities are completely free to set their own prices. The Austrian utilities are not allowed to set prices that exceed twice the total cost of production. However, Klien (2012) notes that "…price setting appears very ad-hoc and discretionary…" (p.6) and that "…the Austrian water sector…is characterized by the absence of a regulator…" (p.6) Similarly, the Swedish market for district heating is in theory regulated by a specific district heating law. But this regulation does not cover price setting per se, so the market may be characterized as unregulated, as argued by Konkurrensverket (2013).

more prone to mimic their neighbors. In another study, Revelli (2006) finds evidence of yardstick competition in the social service provision of UK local authorities. Other studies try to instead examine yardstick competition in the productive efficiency of local governments directly. For instance, Revelli and Tovmo (2007) find evidence of yardstick competition in the productive efficiency of Norwegian municipalities. Geys (2006) does the same for Flemish local governments, and uses the ratio of tax revenues to the quantity of locally provided public goods as the decision variable. With respect to the decision variable, the two latter studies lie closest to the present study since water prices are expressed in terms of price over quantity directly.

For fundamental insights in the strategic interactions between the regulator and the firm under asymmetric information, see Laffont and Tirole (1993). For instance, they describe how a c-o-s regulation may lead to overinvestment, lack of incentives to reduce costs and subsequent distorted prices.

3 Institutional background and data

3.1 The Swedish water sector

The Swedish public sector has three layers of government: national, county and municipal. The local units are responsible for the provision of important welfare services. The municipalities supply education, child care, social assistance and care for the elderly, while medical care and public transport are organized at the county level. Municipalities have the constitutional right of self-government. The degree of autonomy refers both to the right to decide on the provision of public services and the right to set income tax rates. The income tax is also the municipalities' main source of income. For a long time, the municipalities have also been responsible for the provision of water- and sewerage services, electricity distribution, and district heating. Due to the privatization wave in the 1990s, the electricity distribution and district heating sectors are now a mix of public and private ownership. Water provision is still the legal responsibility of the municipalities. However, bordering municipalities sometimes operate their water systems jointly, either by outsourcing the operation to the same private firm, or through a common publicly owned utility. These municipalities are likely to exhibit a higher degree of spatially correlated unobserved cost-shocks than other municipalities. However, each municipality still owns the pipes and the treatment plants within its borders, and prices are set individually by each municipality.

The pricing of water provision is regulated by law, stating that "The fees must not exceed what is necessary to cover the costs necessary to organize and operate the water facilities"[3]. The Water and Sewage Act follows the traditional Swedish legal principle stating that publicly owned utilities are not allowed to make profits (*självkostnadsprincipen*). A noteworthy addendum is found in 29 §, in which the legislator distinguishes between connection fees and user fees. The connection fees should be set to cover the costs of connecting a new property to the system, and the user fees should be set to cover the operating costs of the water facilities. The present study will focus on the user fees, although in theory one could instead have chosen to study the connection fees. However, since the user fees are changed more often than the connection fees, user fees are better suited to estimate a fixed effects model. There is no official regulatory supervisor, but the Swedish Water Supply and Sewage Tribunal adjudicate legal disputes relating to water supply and sewerage. Complaints occur on a relatively frequent basis, and there are several cases where residential consumers have initiated complaints that have led to price revisions (SWSST, 2013). In at least one recent case, customers have based their complaint on the difference in price compared to a neighboring region. The Water Supply and Sewage Tribunal found that the price discrimination was illegal, and prices were revised. Specifically, this case was concerned with price discrimination within a municipality. Municipalities are only allowed to price discriminate between geographical regions if it can be justified by differences in the costs of water provision.

---

[3] Excerpt from the Swedish Water and Sewage Act (SCS, 2013), freely translated from Swedish.

3.2 Data

The data set consists of 288 Swedish municipalities during 2002-2012[4]. Some variables are only available for 2004, and only for 243 of the municipalities. Therefore, the fixed effects estimates are also complemented by cross-sectional estimates. Table 1 shows descriptive statistics for each variable, and Figure A2 shows detailed descriptions of the variables including data sources.

Table 1: Descriptive statistics

Variable	Mean	Std. Dev.	Min.	Max.	Obs.
Dependent variable					
Water price	5050	1281	2015	9745	3168
Cost factors					
Single-family houses	6913	6180	517	54840	3168
Apartment buildings	8398	27303	151	405452	3168
Population	31598	62128	2420	880008	3168
Wage	21560	692	20100	24500	243
Purification plants	15	13	0	71	243
Pipeline length	264	243	16	2157	243
Capacity utilization	8	7	0	62	243
Connected residents	30246	67445	1200	850100	243
Investment	12812	37272	-9879	475000	243
Other factors					
Extraordinary income-cost	3168	39130	-1071406	1341354	3168
Government grant	190278	295530	-1199547	3975628	3168
Tax rate	21	1	17	33	3168
Municipality surplus	51897	303241	-3756467	8722432	3168
Leftwing	0.47	0.49	0	1	3168

Note: This table shows descriptive statistics of each variable. For a detailed description of each variable and its source, see Figure A2.

---

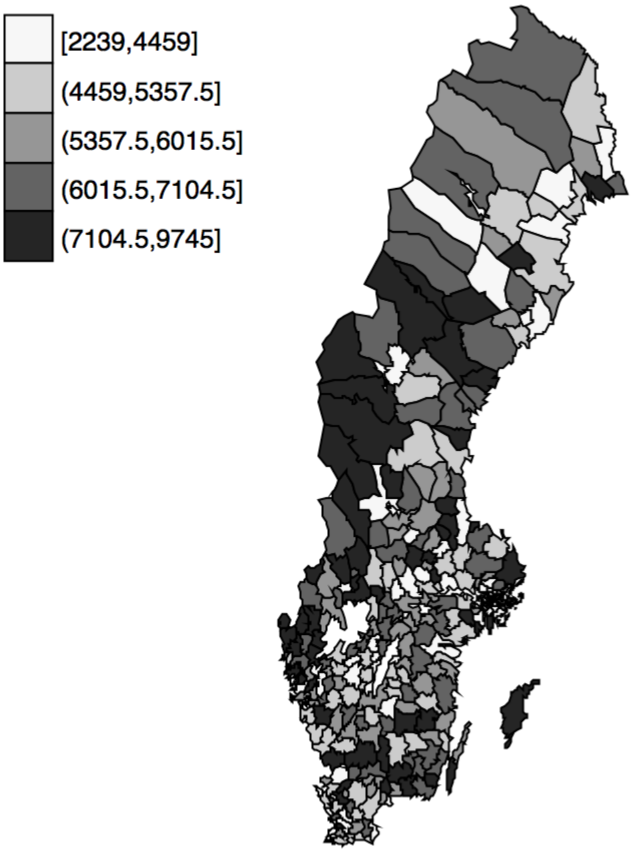
[4] In total there are 290 municipalities. Huddinge municipality has been excluded due to missing data on water prices, and Knivsta municipality has been excluded since it was formed in 2003 (Knivsta was earlier a part of Uppsala municipality).

The main variable of interest is “Water price”which is defined as the total cost for water- and sewerage services paid by a typical single-family house consuming 150 m^3 water each year. The water fee is constructed as a two-part tariff. For a typical household, the fixed part accounts for 43 percent of the total cost of the water service (the standard deviation of this figure is 11 percent). Figure 8 depicts a map illustrating the water price during 2012, and Figure A1 shows a histogram of the dependent variable for the whole sample. Moran’s *I* [5] for the dependent variable is 0.24 (the raw correlation between the own and neighbors’ price is 0.46).

---

[5] Moran’s *I* is a measure of spatial autocorrelation, see Moran (1950) for a technical discussion.

Figure 8: Water price in 2012



Note: This figure depicts the water price in SEK. It is the total cost (fixed plus variable cost) of water in 2012 for a typical stand-alone house consuming 150 m^3 per year. The lowest cost is 2,239 SEK, the highest cost is 9,745 SEK and the median cost is 5,735 SEK. Darker shading represents a higher price.

The independent variables can be divided into two groups. The first group contains cost factors. The included cost factors are the number of single-family houses, number of apartment buildings, population, the average wage for a public servant, the number of purification plants, pipeline length, capacity utilization (expressed as m^3 of delivered water per meter of pipeline), number of residents connected to the water system, and investments. The last six of these variables are only available for the year 2004.

The second group contains variables that in theory should not influence prices if utilities comply with the regulatory framework. These variables could potentially influence the price of water if rents are transferable between the utility and the municipal budget. The first variables consist of accounting data from the municipalities themselves. Extraordinary income (net of extraordinary costs) could prevent politicians from raising prices, so the expected sign is negative. Government grants constitute an extra income for the municipality, so the expected sign is negative. The expected sign for the municipality surplus is negative, since economic problems could be partly compensated for by raising prices. The expected sign for the tax rate is ambiguous since revenues from the utilities could be both complements and substitutes to tax revenues. Last, I have also included a dummy variable indicating the political affiliation of the ruling coalition (taking the value one if the Social Democrats or the Left Party are members of the ruling coalition). The expected sign is ambiguous, but since the estimated coefficient is small and insignificant throughout all specifications I will not comment further on the potential effects of political affiliations.

4 The model

4.1 The fixed effects model

Even though the control variables should reflect the relevant cost factors as well as other potential determinants of the water price, there may be spatially correlated time-varying omitted variables. I estimate two main models to control for such correlation, referred to as the *spatial mixed model* and the *spatial Durbin model*.

Intuitively, the identifying assumption of the Durbin model is that the omitted variables follow the same spatial structure as the included control variables. By exploiting the spatial correlation in the observed variables, the spatial dependence in the water price is identified. *Ceteris paribus*, the estimated spatial dependence in the water price will be high if the spatial correlation in the observed control variables is low. For technical details, see Anselin (1980). The mixed model, on the other hand, makes no precise assumptions about the spatial structure of the omitted variables other than that they are responsible for any linear spatial correlation in the error term. The mixed model nests the spatially autoregressive model ("SAR") and the spatial error model ("SEM"). The SAR is the most "naive" model, since it only assumes spatial dependence in the dependent variable. Conversely, the SEM model only assumes spatial dependence in the error term. LeSage and Pace (2009) show that the mixed model suffers from identification issues if the control variables do not make a material contribution towards explaining the variation in the dependent variable. Therefore, they argue that the Durbin model should be used as a general benchmark. Then, the researcher should test models against each other using nested hypothesis testing. I follow this procedure, and also estimate the SAR and SEM models separately to see how coefficients differ in comparison to their corresponding coefficients in the mixed model.

Formally, the models can be expressed as:

$$p_{it} = \alpha + \mathbf{y}_{\mathrm{t}} + \mathbf{m}_i + \mathbf{X}_{it}\boldsymbol{\beta} + \rho \mathbf{W}_i \boldsymbol{p}_t + u_{it} \qquad (SAR) \tag{1}$$

$$p_{it} = \alpha + \mathbf{y}_{\mathrm{t}} + \mathbf{m}_i + \mathbf{X}_{it}\boldsymbol{\beta} + \lambda \mathbf{W}_i \boldsymbol{\eta}_t + u_{it} \qquad (SEM) \tag{2}$$

$$p_{it} = \alpha + \mathbf{y}_{\mathrm{t}} + \mathbf{m}_i + \mathbf{X}_{it}\boldsymbol{\beta} + \rho \mathbf{W}_i \boldsymbol{p}_t + \lambda \mathbf{W}_i \boldsymbol{\eta}_t + u_{it} \qquad (Mixed) \tag{3}$$

$$p_{it} = \alpha + \mathbf{y}_{\mathrm{t}} + \mathbf{m}_i + \mathbf{X}_{it}\boldsymbol{\beta} + \rho \mathbf{W}_i \boldsymbol{p}_t + \mathbf{W}_i \mathbf{X}_t \gamma + u_{it} \qquad (Durbin) \tag{4}$$

Where p_{it} is the water price in municipality *i* in year *t*, α is a constant, and $\mathbf{y}_t$ and $\mathbf{m}_i$ are year and municipality fixed effects. $\mathbf{X}_{it}$ is a matrix of time-variant control variables with its corresponding coefficient vector $\boldsymbol{\beta}$. The coefficient of interest is ρ, which determines the spatial dependence in the water price. $\mathbf{W}_i$ is a municipality-specific vector of spatial weights, and u_{it} is the i.i.d. error term. The coefficient λ determines the spatial dependence in the error term in the SEM and mixed models. The coefficient vector γ determines the spatial dependence in the control variables. The notation is similar across models, even though the models are somewhat different. This is common practice in spatial econometrics, and the notation follows that of LeSage and Pace (2009).

The entries in the full symmetric spatial weights matrix **W** are:

$$w_{ij} = \begin{cases} \frac{1}{d_{ij}} & \text{If } j \text{ is a neighbor of } i \\ 0 & \text{Otherwise} \end{cases}$$

Where d_{ij} is the normalized distance between municipalities *i* and *j*. Normalization implies that all rows sum to one. This means that even in regions where municipalities' areas are large, the impact of neighbors' prices is assumed to be of the same magnitude as for regions where municipalities' areas are small. Distance is calculated based on the coordinates of the municipal office in each municipality, which is usually located in the most densely populated area. For each municipality, neighbors are defined as the ten nearest municipalities, independent on if they share borders. It is impossible to know exactly where the appropriate cutoff point should be. Therefore, I conduct robustness tests where the number of neighbors in **W** range between five and fifteen.

Since **W** is symmetric, OLS estimates of ρ suffer from a mechanical simultaneity bias (see Azomahou and Lahatte (2000) for a formal proof). Therefore a maximum likelihood approach is used. Technical details of the estimation procedure are provided by LeSage and Pace (2009)[6]. All variables are logged, and standard errors are clustered by municipality.

Some further robustness tests

It should be noted that the Durbin model is no complete fix for omitted variable bias. What about the existence of omitted variables that have a higher de-

---

[6] The models are estimated using Stata's *xsmle* command, which is described by Belotti et al. (2013). Coordinates of the municipal offices have been obtained using Stata's *geocode* command, which is described by Ozimek and Miles (2012).

gree of spatial correlation than the included variables? For example, the availability of water could constitute such a cost shock. In the case of a drought or water contamination in one location, nearby regions are also bound to be affected. Therefore, as a complement to the maximum likelihood models, I also estimate the SAR model using an instrumental-variable approach. I use neighbors' prices during the preceding year as instruments for neighbors' current prices. The exclusion restriction is then that any correlation between the own price and neighbors' past prices must go through neighbors' current prices.

Further, a fair amount of nearby utilities are operated by the same firm, which also should increase the presence of spatially correlated cost shocks. Therefore, I also estimate all models while excluding all municipalities whose water systems are jointly operated. This removes 30 percent of the sample.

To test whether price mimicking is attenuated in politically stable municipalities (as these politicians should be less worried about loosing voter support due to high water prices), I estimate the models while removing municipalities where the ruling coalition has received on average 50±3 percent of the votes in the elections that took place during 2002-2012[7]. This removes 30 percent of the municipalities. The identification strategy is not without hurdles, since coalitions of local governments are often formed after taking election results into account. Unlike in Swedish national politics, it is not uncommon that coalitions are formed across the traditional left-right wing scale, and the average number of parties in the ruling coalition is three.

4.2 The cross-sectional model

For the cross-sectional data to provide valid estimates, it is necessary that the covariates capture all cost factors, including the time-invariant ones. Therefore, these estimates should be regarded only as supplements to the fixed effects

---

[7] In total there were three elections; 2002, 2006 and 2010. All municipalities carry out elections simultaneously. Since there are no term limits, it is not possible to approximate the importance of voter support with the presence of binding term limits.

model. Still, it is of interest to see how much of the variation in prices that can be explained by the extended set of cost factors alone. In these estimates, I only control for cost factors, and remove the additional control variables. This also minimizes risks of over-specification, since the total number of observations in this sample is only 243. The estimation technique is identical to the panel estimates except for the IV-estimate, since time-lagged variables rely on panel data. Instead, I employ the generalized spatial two-stage least squares estimator for cross-sectional models proposed by Kelejian and Prucha (1998). This estimator uses information from all control variables and constructs an instrument matrix from their spatial lags. The exogeneity assumption is that any correlation between neighbors' characteristics and the own price must go through neighbors' price, conditional on the own characteristics[8]. A robustness check is conducted by including only those municipalities that did not engage in any water trading with other municipalities during 2004. This choice is motivated by the fact that these networks should be disconnected from all other water systems, minimizing the risk of cost-spillovers. These municipalities comprise 56 percent of the total sample (138 municipalities). Just as for the data on the extended set of cost factors, data on water trading is at present only available for 2004.

5 Results

5.1 Results from the fixed effects model

Results from the main specification are presented in Table 2.

In all maximum likelihood estimations, $\hat{\rho}$ (the spatial dependence in the water price) is between 0.14-0.17. The interpretation is that if the neighbors of a municipality raise their price by on average 10 percent (weighted by their relative inverse distances), the own price will increase by 1.4-1.7 percent. Thus, the effect is relatively modest but still economically significant. It is statistically

---

[8] The estimator has been implemented using Stata's *spreg* command, which is described in detail by Drukker et al. (2013).

Table 2: Fixed effects estimates

	OLS	SAR	SEM	Mixed	Durbin	SAR(IV)
$\hat{\rho}$ (W × Water price)		0.1745^{***}		0.1569	0.1438^{***}	0.3051^{*}
$\hat{\lambda}$ (W × Error term)			0.1740^{***}	0.0200		
Apartment house	0.0702	0.0596	0.0485	0.0587	-0.0655	0.0495
Single-family house	0.0103	0.0096	0.0090	0.0096	-0.0019	0.0040
Population	-0.3129^{**}	-0.2812^{**}	-0.2963^{**}	-0.2816^{**}	-0.2175	-0.1771
Tax rate	0.3554	0.3658	0.3926	0.3674	0.4302	0.4351
Extra income-cost	0.0033^{***}	0.0028^{***}	0.0023^{***}	0.0028^{***}	0.0032^{***}	-0.0003
Government grant	-0.0075^{***}	-0.0075^{***}	-0.0075^{***}	-0.0075^{***}	-0.0074^{***}	-0.0091^{***}
Municipality surplus	0.0009	0.0007	0.0004	0.0007	0.0007	0.0755
Leftwing	0.0063	0.0058	0.0053	0.0058	0.0045	0.0056
W × Apartment house					0.2892^{***}	
W × Single-family house					0.0377	
W × Population					-0.2210	
W × Tax rate					-0.3771	
W × Extra income-cost					0.018^{**}	
W × Government grant					0.0022	
W × Profit					0.0047	
W × Leftwing					0.0128	
Log lik.		5333	5333	5333	5355	
Observations	3168	3168	3168	3168	3168	2880

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$

Note: Fixed effects estimates using data from 2002-2012. The dependent variable is water price. All variables have been logged. Year- and municipality fixed effects are included in all models. Standard errors are clustered by municipality. In the IV model, the first time-lag of W × Water price is used as an instrument for W × Water price.

significant in all specifications except for the mixed model, which is likely due to the identification issues discussed above.

The SAR model is only relevant in cases where there are no omitted variables, otherwise the Durbin model is more appropriate. Wald tests show that the Durbin model is the preferred choice[9]. Robustness tests using alternative definitions of the weight matrix in the Durbin model by varying the number of neighbors between 5 and 15 are coherent. All estimates of $\hat{\rho}$ are significant on the 5 percent level and the magnitude ranges between 0.12-0.14. Removing all municipalities that engage in some type of joint operation confirms that the effect is statistically significant, although the magnitude is lower ($\hat{\rho} = 0.1$). Results from this estimation are presented in Table A1.

The IV-estimate of $\hat{\rho}$ is 0.31, which is around twice the magnitude compared to the maximum likelihood estimators. As a comparison, the OLS estimate is 0.29 and significant on the 5 percent level (the spatial lag of the water price in the OLS specification in Table 2 has been excluded in order to avoid misspecification). Since the OLS estimate is biased upwards by construction, any estimate above 0.29 should be questioned. Consequently, there are reasons to doubt the exogeneity assumption of the IV-estimator. A plausible explanation is that utilities differ in how quickly they respond to persistent shocks. If my neighbors respond to a common shock before I do, my price today will be more correlated with neighbors' past prices than their prices today. Hence, the exogeneity assumption will be violated. Another plausible reason is that price mimicking is not only simultaneous, but also backward looking. Therefore, the IV-estimate is likely to be biased upwards[10].

---

[9] Since the SAR model is nested within the Durbin model, the procedure is to test the null hypothesis $\hat{\gamma}$=0, i.e., that all coefficients on the spatial lags of the independent variables are zero. This test shows that we cannot reject the presence of omitted variables (the p-value is 0.07, indicating that there is only a trivial probability that the spatial lags of the independent variables are zero). A similar test can be made for the mixed model, since it nests both the SAR and the SEM models. When testing the restriction $\hat{\rho}$=0, the p-value is 0.25, and when testing the restriction $\hat{\lambda}$=0 the p-value is 0.89. This indicates that there is a stronger case for spatial dependence in the water price than in the error term, and therefore the SEM model is rejected.

[10] Theoretically, the latter issue should be attenuated by instead instrumenting using the second time-lag. However, since this actually increases $\hat{\rho}$ (the magnitude is 0.47

The cost factor that has the strongest impact on price is population, with a statistically significant coefficient of -0.3 in four of the six specifications. The interpretation is that a ten percent increase in the population is associated with a three percent decrease in the water price. Given that population is a good proxy for the amount of delivered water, the result indicates that higher capacity utilization is associated with lower costs, as it appears unlikely that pipeline length and the number of water treatment plants have changed proportionally to the change in population during the sample period. The reason why the number of apartment buildings or single family houses have no impact on the price could be due to the connection fee, which in theory should finance the cost of connecting new properties to the network. It could also be due to a relatively small within-municipality variation in these variables during the sample period.

Given that the utilities do not fully comply with the regulatory framework, some of the variables relating to the financial situation of the municipalities have the expected signs. An extra income in the form of a government grant leads to a statistically significant lower price, even if the elasticity is less than one percent. The positive effect of the tax rate (ranging between 0.36-0.44) indicates that increased prices are used as complements to increased taxes, although the effect is not statistically significant. Extraordinary income as well as the municipality surplus appears to have a positive effect on the price (although the effect of the surplus is insignificant), while the expected effect is the opposite if financial distress is remedied through higher prices. Both these coefficients are small, with elasticities below 0.01. However, if utility profits subsidize the general budget, these coefficients will suffer from a positive simultaneity bias. Finally, the political affiliation of the ruling coalition has no economically or statistically significant effect on prices.

Since the variables relating to the financial situation of the municipalities only show modest effects on the price, it is not surprising that basic results are similar when estimating the models when only controlling for cost factors. These

---

and is significant on the 5 percent level), this solution is not adequate. Another option would have been to instrument using neighbors' characteristics. However, this also resulted in higher estimates of $\hat{\rho}$ than the OLS estimate.

results are presented in Table A2. When estimating the Durbin model excluding municipalities in which the incumbent coalition's electoral support is 50 ± 3 percent, $\hat{\rho}$ is 0.15 and significant on the 5 percent level. Thus, it does not appear that a politically stable electorate attenuates price mimicking.

5.2 Results from the cross-sectional model

Results from the main cross-sectional specification are presented in Table 3. Estimates of $\hat{\rho}$ are consistently higher than in the panel estimates, and range between 0.22-0.27 (all estimates are significant on the 10 percent level or lower). A Wald test shows that the SAR model cannot be rejected in favor of the Durbin model[11]. Since several of the cost factors have statistically and economically significant effects on the dependent variable, the mixed model is identified. Examining the mixed model coefficients, we can also conclude that there is only a trivial amount of spatial error correlation ($\hat{\lambda}$ is 0.08 and insignificant). The IV-estimate of $\hat{\rho}$ is only marginally lower than in the mixed model, which is comforting. In contrast to the panel estimates, there are no apparent reasons why the exogeneity assumption should be violated here.

Several of the covariates have a significant impact on the water price. The variable that has the strongest impact is capacity utilization. If capacity utilization increases ten percent, price drops almost two percent. This confirms results from the panel estimates, given that the "population" variable in the panel data is merely a proxy for the amount of delivered water. In this light, it is not surprising that the number of connected residents has a relatively modest effect on the price. The second most important cost factor is pipeline length per connected resident. The negative coefficient indicates returns to density, which has previously been found in studies of other countries (Nauges and Berg, 2008; Mizutani and Urakami, 2001). The number of purification plants has a positive and significant impact on the price, indicating that it is more costly to supply a given amount of water using several plants. However, the effect is comparatively small. Investment cost also has the expected sign. Given that around half of the investments are financed by user fees (and the rest by connection fees), back-of-the-envelope calculations indicate a depreciation time of around 35 years, which seems reasonable. Finally, the mean wage for a civil servant has a positive effect, although the precision is low in most specifications.

Robustness results show that the spatial dependence is not isolated to munic-

---

[11] Testing the null hypothesis that $\hat{\gamma}$=0, the p-value was 0.29, showing that we cannot reject the null hypothesis that the spatial lags of the independent variables are zero.

Table 3: Cross-sectional estimates

	OLS	SAR	SEM	Mixed	Durbin	SAR(IV)
$\hat{\rho}$ (W × Water price)		0.267***		0.2460*	0.234**	0.225*
$\hat{\lambda}$ (W × Error term)			0.291***	0.0799		
Purification plants	0.0351***	0.0280**	0.0388***	0.0298**	0.0335**	0.030**
Pipeline length	-0.1339***	-0.1246***	-0.1084***	-0.1219***	-0.1048***	-0.126***
Capacity utilization	-0.1975***	-0.1859***	-0.1669***	-0.1827***	-0.1718***	-0.187***
Connected residents	-0.0923***	-0.0975***	-0.0999***	-0.0983***	-0.0915***	-0.098***
Investment	0.0142**	0.0134***	0.0118**	0.0132**	0.0126**	0.013**
Single-family houses	0.0325	0.0208	0.0186	0.0204	0.0076	0.024
Wage	0.3107	0.6653**	0.3774	0.6271*	0.5851	0.563
W × Purification plants					-0.0226	
W × Pipeline length					-0.1421	
W × Capacity utilization					-0.1869	
W × Connected residents					0.1554	
W × Investment					0.0108	
W × Single-family houses					0.0138	
W × Wage					-0.3565	
Log lik.		167	165	167	172	
Observations	243	243	243	243	243	243

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$

Note: Cross-sectional estimates using data from 2004. All variables have been logged. The dependent variable is water price. Standard errors in parentheses. In the IV estimate, neighbors' characteristics are used to instrument for W × Water price.

ipalities that have interconnected networks. In fact, estimates were on average even higher in the small sample. Full results from the robustness tests are presented in Table A3. In sum, the cross-sectional estimates indicate an even stronger spatial dependence than the panel estimates. However, since the risk of misspecification is inherently larger when fixed effects are absent these results should be interpreted with care.

6 A further discussion on underlying mechanisms and implications for efficiency

Previous studies on strategic interactions between local governments have assumed that the policy maker is a local politician who maximizes votes rather than profits. However, the majority of decisions related to operation and pricing are presumably handled by managers directly. This notion is supported by the observation that spatial dependence is not attenuated in municipalities with politically stable electorates. If politicians mimic their neighbors' policies in order to gain votes, they should be less inclined to do so in municipalities where small changes in electoral support do not matter for political power. Also, the covariates reflecting the financial situation of the municipalities only have a minor effect on pricing decisions. The view that utilities are largely independent entities is confirmed by Haraldsson (2013) in a recent government report about accounting standards of Swedish water utilities. He argues that "Due to weak external control and a lack of interest from politicians, the quality of financial accounting is largely dependent on the individual [utility] official's knowledge and ambitions" (p.6, freely translated from Swedish). While it is certainly possible to interpret politicians' disinterest as a general aversion towards external auditing, the fact remains that since utilities are not financed by tax revenues, politicians' incentives for keeping track of the utilities' budgets are reduced. Even if managers cannot be voted out of office directly, their jobs will be at stake if it is considered that they run the utility inefficiently, or if consumers believe that utilities abuse their monopoly power. Consumers may exercise their power either by complaining to the local authorities directly, or to the Swedish Water Supply and Sewage Tribunal. Whether consumers are motivated by rational or behavioral reasons, a strategic response from managers is to set prices that conform to the prices of neighboring utilities.

Another topic that has been overlooked so far is implications for efficiency. While allocative efficiency should be more or less unaffected by yardstick competition due to a highly inelastic demand, there is presumably a positive effect on productive efficiency. One of the main rationales behind yardstick regulation is to incentivize firms to reduce costs, since the prices that firms receive are independent of their own costs. A conjecture is then that informal yardstick competition induces a similar mechanism, since the firms that are able to cut costs more than their neighbors will incur profits. However, an important feature of formal yardstick regulation is that firms have identical cost structures, or that the regulator is able to distinguish differences in cost structures across regions. In the present setting, benchmarks are instead rather arbitrary. In sum, even though informal yardstick competition is a less precise mechanism than formal yardstick regulation, economic reasoning suggests that the presence of informal yardstick competition has a positive effect on productive efficiency.

7 Conclusion

This study provides an empirical test of price mimicking in the pricing decisions of regulated utilities. Since publicly owned water utilities in Sweden are governed by a c-o-s regulation, prices in neighboring municipalities should not affect the own price other than through spatially correlated cost factors. In contrast, spatial dependence is pronounced. Using a spatial Durbin model with fixed effects, the elasticity of the own relative to neighbors' average price is estimated to 0.14. Cross-sectional data is examined, using more detailed data on the technical characteristics of the utilities. These estimates point towards an even stronger spatial dependence. However, due to the increased risk of misspecification in the absence of fixed effects, results from the cross-sectional sample should be interpreted with care.

The spatial dependence in prices can be explained in terms of an informal yardstick competition: When consumers use neighboring utilities' prices as benchmarks for costs or as behaviorally based reference prices, utilities will face the risk of consumer complaints if they deviate too much from neighbors' prices. Just as under formal yardstick regulation, there are incentives to reduce costs. If a utility is able to cut costs relative to its neighbors, only a part of the cost reduction needs to be translated into a lower price. Thus, economic reasoning suggests that the presence of informal yardstick competition has a positive effect on productive efficiency.

Further, spatial dependence is not attenuated in municipalities with politically stable electorates. In coherence with this result, prices only appear to be marginally affected by the overall financial situation of the municipality, suggesting that managers' decisions rather than political influence is the main driving mechanism behind price mimicking.

References

Anselin, Luc, "Estimation Methods for Spatial Autoregressive Structures." PhD dissertation, Regional Science Dissertation and Monograph Series nr 8. Ithaca: Cornell University 1980.

Azomahou, Téophile and Agénor Lahatte, "On the Inconsistency of the Ordinary Least Squares Estimator for Spatial Autoregressive Processes," Working Papers of BETA 2000-12 2000.

Belotti, Federico, Gordon Hughes, and Andrea Piano Mortari, "xsmle-A Command to Estimate Spatial Panel Models in Stata," German Stata User Group Meetings 2013 09, Stata Users Group Jul 2013.

Besley, Timothy and Anne Case, "Incumbent Behavior: Vote-Seeking, Tax-Setting, and Yardstick Competition," *American Economic Review*, March 1995, *85* (1), 25–45.

Brueckner, Jan K., "Strategic Interaction Among Governments: An Overview of Empirical Studies," *International Regional Science Review*, April 2003, *26* (2), 175–188.

Drukker, David M., Ingmar Prucha, and Rafal Raciborski, "Maximum likelihood and generalized spatial two-stage least-squares estimators for a spatial-autoregressive model with spatial-autoregressive disturbances," *Stata Journal*, June 2013, *13* (2), 221–241.

Geys, Benny, "Looking across borders: A test of spatial policy interdependence using local government efficiency ratings," *Journal of Urban Economics*, November 2006, *60* (3), 443–462.

Haraldsson, Mattias, *Sarredovisning inom VA-branschen*, Vol. 2013-21, Svenskt Vatten Utveckling, 2013.

Holmström, Bengt, "Moral Hazard in Teams," *Bell Journal of Economics*, Autumn 1982, *13* (2), 324–340.

Kelejian, Harry H and Ingmar R Prucha, "A Generalized Spatial Two-Stage Least Squares Procedure for Estimating a Spatial Autoregressive Model with Autoregressive Disturbances," *The Journal of Real Estate Finance and Economics*, July 1998, *17* (1), 99–121.

Klien, Michael, "Institutional and Political Aspects of Public Infrastructure Provision," Technical Report EPPP DP No. 2012-04, Chaire EPPP, Sorbonne Business School 2012.

Konkurrensverket, Konkurrensverket, Uppdragsforskningsrapport 2013:1, 2013.

Laffont, Jean-Jacques and Jean Tirole, *A Theory of Incentives in Procurement and Regulation*, 1 ed., Vol. 1, The MIT Press, 1993.

LeSage, J.P. and R.K. Pace, *Introduction to Spatial Econometrics* Statistics: a Series of Textbooks and Monographs, C R C Press LLC, 2009.

Mizutani, Fumitoshi and Takuya Urakami, "Identifying network density and scale economies for Japanese water supply organizations," *Papers in Regional Science*, 2001, *80* (2), 211–230.

Moran, P. A. P., "Notes on Continuous Stochastic Phenomena," *Biometrika*, 1950, *37* (1/2), pp. 17–23.

Nauges, Céline and Caroline Berg, "Economies of density, scale and scope in the water supply and sewerage sector: a study of four developing and transition economies," *Journal of Regulatory Economics*, October 2008, *34* (2), 144–163.

Ozimek, Adam and Daniel Miles, "GEOCODE: Stata module to geocode data," Statistical Software Components, Boston College Department of Economics May 2012.

Revelli, Federico, "On Spatial Public Finance Empirics," *International Tax and Public Finance*, August 2005, *12* (4), 475–492.

_ , "Performance rating and yardstick competition in social service provision," *Journal of Public Economics*, February 2006, *90* (3), 459–475.

_ **and Per Tovmo**, “Revealed yardstick competition: Local government efficiency patterns in Norway,” *Journal of Urban Economics*, 2007, *62* (1), 121 – 134.

SCS, *Water and Sewage Act*, Swedish Code of Statutes 2006:412, 2013.

Shleifer, Andrei, “A Theory of Yardstick Competition,” *RAND Journal of Economics*, Autumn 1985, *16* (3), 319–327.

Söderberg, Magnus and Makoto Tanaka, “Spatial price homogeneity as a mechanism to reduce the threat of regulatory intervention in locally monopolistic sectors,” Working Papers hal-00659458, HAL 2012.

Solé-Ollé, Albert, “Electoral accountability and tax mimicking: the effects of electoral margins, coalition government, and ideology,” *European Journal of Political Economy*, November 2003, *19* (4), 685–713.

Statistics-Sweden, *Official records of Swedish statistics*, Statistics Sweden, www.scb.se, 2013.

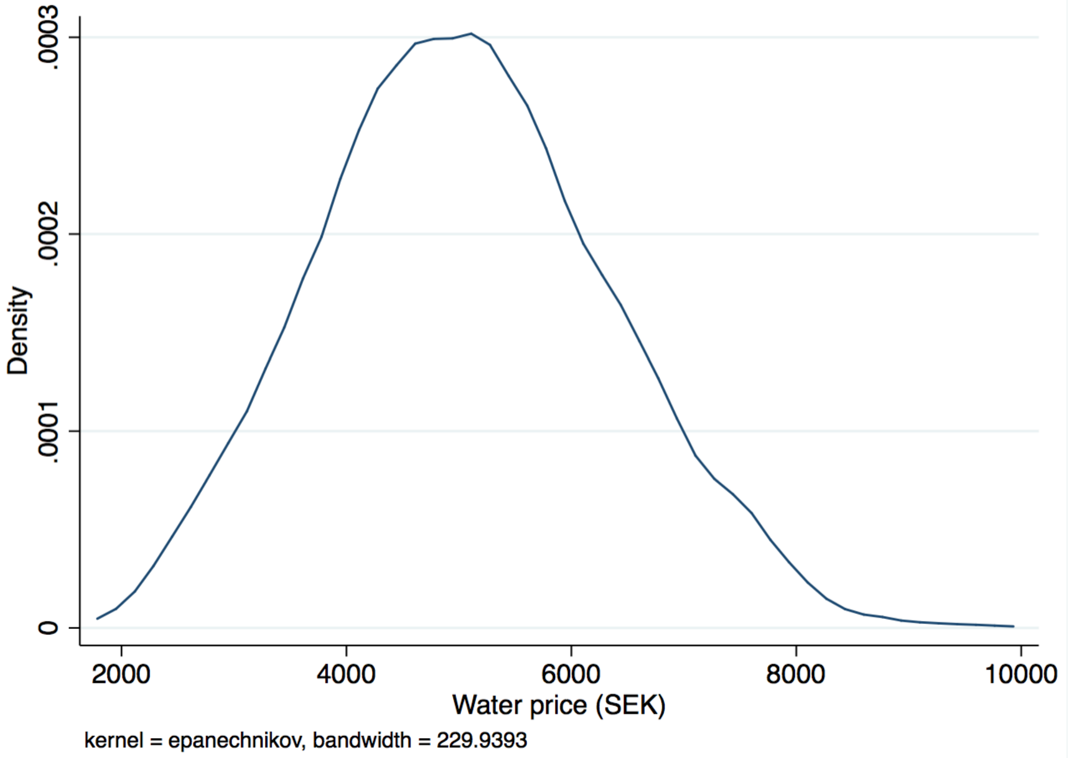
SWSST, “Official legal records,” `http://www.domstol.se/Statens-va-namnd/` (accessed April 21, 2016), 2013.

Thaler, Richard, “Mental Accounting and Consumer Choice,” *Marketing Science*, 1985, *4* (3), pp. 199–214.

Tiebout, Charles M., “A Pure Theory of Local Expenditures,” *Journal of Political Economy*, 1956, *64*, 416.

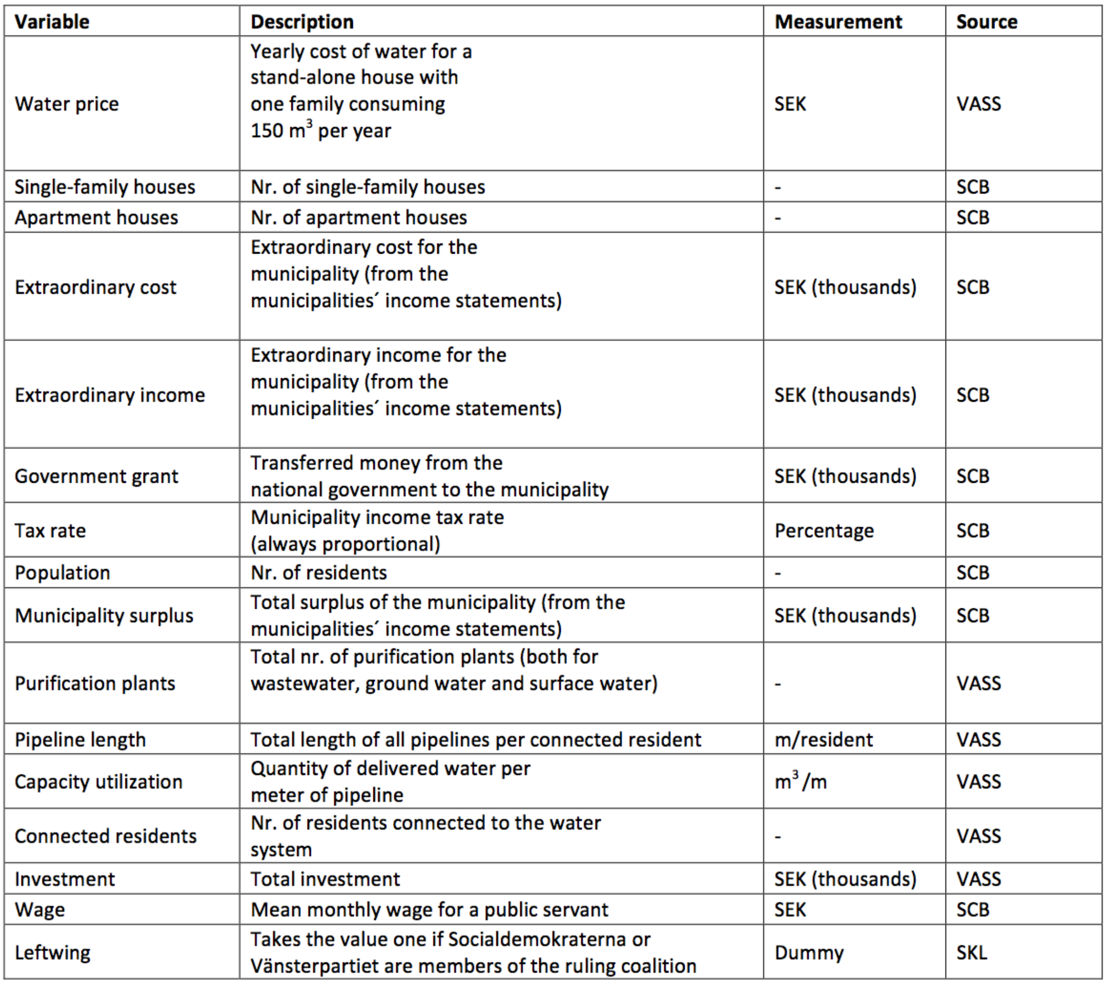
Appendix A

Figure A1: Histogram of the water price



Note: This figure depicts a kernel density plot of the water price for the whole sample, i.e., a total of 3168 observations for 288 municipalities during 2002-2012. The unit of measurement is the total cost (fixed plus variable cost) in SEK for a typical stand-alone house consuming 150 m^3 per year.

Figure A2: Detailed description of the variables



Variable	Description	Measurement	Source
Water price	Yearly cost of water for a stand-alone house with one family consuming 150 m^3 per year	SEK	VASS
Single-family houses	Nr. of single-family houses	-	SCB
Apartment houses	Nr. of apartment houses	-	SCB
Extraordinary cost	Extraordinary cost for the municipality (from the municipalities´ income statements)	SEK (thousands)	SCB
Extraordinary income	Extraordinary income for the municipality (from the municipalities´ income statements)	SEK (thousands)	SCB
Government grant	Transferred money from the national government to the municipality	SEK (thousands)	SCB
Tax rate	Municipality income tax rate (always proportional)	Percentage	SCB
Population	Nr. of residents	-	SCB
Municipality surplus	Total surplus of the municipality (from the municipalities´ income statements)	SEK (thousands)	SCB
Purification plants	Total nr. of purification plants (both for wastewater, ground water and surface water)	-	VASS
Pipeline length	Total length of all pipelines per connected resident	m/resident	VASS
Capacity utilization	Quantity of delivered water per meter of pipeline	m^3/m	VASS
Connected residents	Nr. of residents connected to the water system	-	VASS
Investment	Total investment	SEK (thousands)	VASS
Wage	Mean monthly wage for a public servant	SEK	SCB
Leftwing	Takes the value one if Socialdemokraterna or Vänsterpartiet are members of the ruling coalition	Dummy	SKL

Note: VASS is Vattentjänstbranschens statistisksystem (data has been downloaded from www.vass-statistik.se) SCB is Statistics Sweden (data has been downloaded from www.scb.se). SKL is Sveriges Kommuner och Landsting (data has been downloaded from www.skl.se).

Table A1: Fixed effects estimates, excluding municipalities with joint operation

	OLS	SAR	SEM	Mixed	Durbin	SAR(IV)
$\hat{\rho}$ (W × Water price)		0.1132*		0.0978	0.1014*	0.305*
$\hat{\lambda}$ (W × Error term)			0.1125*	0.0162		
Apartment house	0.0834	0.0768	0.0732	0.0762	-0.0055	0.0657
Single-family house	0.0485	0.0457	0.0457	0.0457	0.0397	0.0371
Population	-0.3652**	-0.3469**	-0.3462**	-0.3468**	-0.2199	-0.2516
Tax rate	0.3965	0.4189	0.4436	0.4211	0.6212*	0.4507
Extra income-cost	0.0298	0.0293	0.0284	0.0294	0.0351	-0.0003
Government grant	0.0420	0.0367	0.0348	0.0366	0.0112	0.0275
Municipality surplus	0.0338	0.0333	0.0341	0.0335	0.0205	0.0755
Leftwing	0.0049	0.0045	0.0043	0.0045	0.0032	0.0011
W × Apartment house					0.1578	
W × Single-family house					0.0281	
W × Population					-0.3029	
W × Tax rate					-0.9633	
W × Extra income-cost					0.1587	
W × Government grant					-0.0972	
W × Profit					0.0047	
W × Leftwing					0.0130	
Log lik.		3970	3969	3970	3977	
Observations	2299	2299	2299	2299	2299	2090

$^{*}\ p < .10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

Note: The dependent variable is water price. All variables have been logged. Year- and municipality fixed effects are included in all models. Standard errors are clustered on the municipality level. In the IV model, the first time-lag of W × Water price is used as an instrument for W × Water price.

Table A2: Fixed effects estimates, including only cost factors as covariates

	OLS	SAR	SEM	Mixed	Durbin	SAR(IV)
$\hat{\rho}$ (W × Water price)		0.1778^{***}		0.1486	0.1593^{***}	0.312^{**}
$\hat{\lambda}$ (W × Error term)			0.1778^{***}	0.0338		
Apartment buildings	0.0866	0.0732	0.0616	0.0709	-0.0135	0.0722
Single-family houses	0.0115	0.0102	0.0090	0.0098	-0.0007	0.0363
Population	-0.3808^{***}	-0.3362^{**}	-0.3533^{**}	-0.3396^{**}	-0.2675^{*}	-0.2364
W × Apartment buildings					0.2630^{**}	
W × Single-family houses					0.0501	
W × Population					-0.2647	
Log lik.		5317.9456	5317.1206	5317.9963	5329.2552	3728.9289
Observations	3168	3168	3168	3168	3168	2880

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$

Note: The dependent variable is water price. All variables have been logged. Year- and municipality fixed effects are included in all models. Standard errors are clustered by municipality. In the IV model, the first time-lag of W × Water price is used as an instrument for W × Water price.

Table A3: Cross-sectional estimates, only including disconnected networks

	OLS	SAR	SEM	Mixed	Durbin	SAR(IV)
$\hat{\rho}$ (W × Water price)		0.3951***		0.2749	0.3866***	0.47***
$\hat{\lambda}$ (W × Error term)			0.4269***	0.1764		
Purification plants	0.0218	0.0199	0.0179	0.0193	0.0184	0.016
Pipeline length	-0.2010***	-0.1652***	-0.1684***	-0.1675***	-0.1766***	-0.159***
Capacity utilization	-0.2109***	-0.1836***	-0.1853***	-0.1860***	-0.1925***	-0.180***
Connected residents	0.0456	0.0527	0.0362	0.0483	0.0512	-0.106***
Investment	0.0142*	0.0127*	0.0114	0.0124*	0.0145*	0.014***
Single-family houses	0.1062*	0.0561	0.0883	0.0661	0.0734	0.051
Wage	0.1172	0.3691	0.4119	0.3796	0.3778	0.350
W × Purification plants					0.0592	
W × Pipeline Length					-0.0482	
W × Capacity utilization					0.0103	
W × Connected residents					0.1009	
W × Investment					0.0055	
W × Single-family houses					-0.1229	
W × Wage					-1.0121	
Sq. Corr.		0.2871	0.2659	0.2843	0.3034	
Var. Ratio		0.2602	0.2091	0.2502	0.2624	
Log lik.	91.6738	98.3900	98.0487	98.4356	99.4846	
Observations	138	138	138	138	138	138

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$

Note: Cross-sectional estimates using data from 2004. All variables have been logged. The dependent variable is water price. Only municipalities that did not buy or sell water during 2004 have been included.