UMEÅ UNIVERSITY

Energy Efficiency, District Heating and Waste Management

Essays on Environmental Economics

Alejandro Egüez

Umeå School of Business, Economics and Statistics (USBE)
Department of Economics
Umeå 2020

Dissertation for PhD
ISBN: 978-91-7855-386-0 (print)
ISBN: 978-91-7855-387-7 (pdf)
ISSN: 0348-1018
Umeå Economic Studies No. 979
Cover illustration: Sandaruwani Dassanayake (Fiverr.com/Sanda5)
Electronic version available at: http://umu.diva-portal.org/
Printed by: Cityprint i Norr AB
Umeå, Sweden 2020

To Gaby and our daughters,

Emilia and Valentina

Abstract

Paper [I] investigates the energy efficiency of multi-dwelling buildings in Sweden to find out whether the ownership type matters. More specifically, we investigate whether rental apartment buildings are less energy efficient than cooperative apartment buildings and whether public ownership has a negative impact on energy efficiency. A conceptual framework is presented to illustrate that such differences could be explained by the split incentives problem and deviations from profit maximizing interests. The empirical analysis is based on a unique dataset that combines data from energy performance certificates with ownership data on residential units. The results indicate that cooperative apartment buildings are significantly more energy efficient than buildings with rental apartments. The results also indicate that publicly owned buildings have somewhat lower energy performance than privately owned ones.

Keywords: energy efficiency, energy performance certificates, multi-dwelling buildings, ownership, principal-agent, public versus private management, split incentives

Paper [II] Incomplete information may be one reason why some households do not invest in energy efficiency even though it would benefit them to do so. Energy performance certificates (EPCs) have been promoted to overcome such information shortages. In this paper, we investigate whether EPCs together with mandatory home energy audits make households more likely to invest in energy efficiency. Our study takes advantage of the mandatory nature of the EPCs to avoid the potential selection bias problem that typically applies to studies using voluntary energy audits as the treatment. Our treatment group consists of single-family houses in Sweden sold from 2008, i.e., when EPCs became legally required in connection with sales of residential buildings, to 2015; while the control group consists of houses sold between 2002 and 2008, i.e., without an EPC. The results show that there is no statistically significant treatment effect for most of the measures that a household can take to improve the energy performance of their house. The significant treatment effect that we do find concerns a few heating system-related measures.

Keywords: energy performance certificates, home energy audits, quasi-natural experimental design, incomplete information, investment decision, energy efficiency gap, policy evaluation

Paper [III] The price of district heating in Sweden is unregulated and differs substantially among different networks. This paper investigates if the price variation can partly be explained by ownership status, i.e., whether the network companies are privately- or municipally-owned. The empirical analysis is based on data on district heating prices, ownership status, and network characteristics for the period 2012-2017. The results show that prices are higher in privately-owned district heating networks than in municipally-owned networks, especially in the fixed component of the price. It is argued that municipal and private companies' divergent objectives may be part of the explanation for these differences. Finally, district heating prices are positively correlated with the market prices for heat pumps, regardless of ownership, which suggests a general price-setting strategy based on the price of substitutes.

Keywords: district heating prices, ownership, public versus private, natural monopoly, two-part tariff

Paper [IV] assesses whether and to what extent income and the stringency and enforcement (S&E) of environmental regulation influence compliance with the EU Waste Hierarchy (EWH), i.e., how EU member states treat waste. The EWH prioritizes waste prevention and re-use over recycling, which is ranked above waste to energy (WtE), while incineration and landfilling are the least preferred options. Biennial panel data for the period 2010–2016 is used to create a compliance index based on the waste treatment alternatives in the EWH. The waste (excluding major mineral waste) of 26 European Union countries is examined. This study is the first of its kind to regress an EWH compliance index on income, the stringency and enforcement of environmental regulation, and other variables that are also expected to affect the relative benefits and costs of waste treatment, such as population density, heating demand, and electricity prices. The shares of landfilling, incineration, WtE, and recycling are also modeled to capture the effect of these variables in the waste treatment mix. The stringency and enforcement of environmental regulation are found to have a positive effect on compliance with the EWH, which has increased over time.

Keywords: EU waste hierarchy, waste treatment ladders, income, policy stringency, policy enforcement.

Acknowledgements

I feel gratitude to many people who made this Ph.D. not only possible but enjoyable. Thanks to Runar Brännlund and Thomas Broberg, who did a fantastic job supervising this thesis. I learned a lot from you during these years and will take forward this knowledge. Thanks for your patience and understanding of my "learning curve." I greatly appreciate it. Thanks to Gauthier Lanot and Lars Persson who, as coordinators of the Ph.D. program in different years, always took great care of my progress.

I am very grateful to my co-authors. Thanks, Andrius Kazukauskas, and thanks again, Thomas Broberg, for being excellent co-authors. I hope that we can continue to collaborate in the future. I want to also express my gratitude to the discussants in the pre-seminars. Your feedback helped me to improve the chapters in this thesis, so thank you, Aemiro Melkamu, Brian Danley, Jesper Stage, Lars Persson, Linda Wårell, and Tommy Lundgren. Besides the pre-seminars, I had the opportunity to present different "work in progress" versions of the articles in this thesis in various settings. Thanks to all the questions and suggestions I received from participants, mainly from Ammarnäs winter conferences and internal seminars at the Department of Economics (previously TEPN workshops). A special thanks to my dear friend Ralf Bilke, who took the time to read and discuss many drafts and provided useful inputs from his experience as a practitioner.

This Ph.D. project is part of Umeå University's Industrial Doctoral School for Research and Innovation (IDS). I want to thank my partner company, Umeå Energi, for all the support provided during these years. Thanks to Jörgen Carlsson, Ulf Kullh, Henrik Bristav, Johan Brändström, Erik Torshage, and André Norberg. The perspectives from your experience in the energy industry and waste management were beneficial for a better understanding of the practical context in which the different articles in this thesis have developed. Thanks to all my colleagues at IDS (Batch 2014), and thanks to Anna Linusson and Benkt Wiklund, at Umeå University, for making the IDS possible. I want to also acknowledge the Green Technology and Environmental Economics Research Platform for Sustainability Assessment at Umeå University. Thanks to the J. C. Kempe Foundation at Umeå University for awarding me travel grants for the spring semesters 2017 and 2018.

While not in Umeå, I spent most of my time in Gothenburg. Thanks Mikael Mangold for letting me be at RI.SE during the autumn of 2018. Thanks also to

Jessica Coria and Elizabeth Földi at the University of Gothenburg's Environmental Economics Unit for arranging a place for me to sit during the autumn 2017 and spring 2018 semesters.

My time in Umeå was spent working in a very positive work environment thanks to the people there. Thanks to all my colleagues at the Departments of Economics at Umeå University and Forest Economics at SLU for all the talks and laughs over the years. My door will be forever open to you all, so do not hesitate to keep in touch.

These years as a Ph.D. student were also years in which I witnessed my daughters' first years. I started this Ph.D. when my oldest daughter was six months, and four years later, my youngest daughter was born. To some extent, parenthood gave me the opportunity to strengthen my friendship with many families (*barnfamiljer*) to whom I am incredibly grateful: the Garcés Lemke, the Krause Vargas, the Mankingos, the Nieves Rodríguez, and the Quintero Soto. Your friendship is a treasure. Thanks for being aware of me and asking more than once during these years the forbidden, yet my favorite question: "How is your Ph.D. going?" Now you know the answer. Thank you for letting me be part of your life, and let's keep enjoying good food, good wine, and good company! *Carpe diem.*

I enjoyed being a Ph.D. student, but I cannot imagine myself being a Ph.D. student 24/7. And that is because of the amazing family and friends in and outside academia that I am privileged to have. Gaby, Emilia, and Valentina, you provide me with balance and motivation in every aspect of my life, not least during my time as a Ph.D. student. To my parents, Martha and Fabián, my brother Pedro, and my family in law: gracias, gracias y mil gracias! Your support in this journey is just another example of your unconditional love.

Alejandro Egüez

October 2020

This thesis consists of an introductory part and four self-contained papers related to energy efficiency, district heating, and waste management:

Paper [I]

Broberg, T. and Egüez, A. (2018) Blame it on the owner – Ownership and energy performance of multi-dwelling buildings. *Energy Economics* 72, 108-119. https://doi.org/10.1016/j.eneco.2018.03.026

(Reprinted with permission)[1]

Paper [II]

Broberg, T., Egüez, A. & Kazukauskas, A. (2019) Effects of energy performance certificates on investment: A quasi-natural experiment approach. *Energy Economics* 84, 104480. https://doi.org/10.1016/j.eneco.2019.104480

(Reprinted with permission)[2]

Paper [III]

Egüez, A. (2020) Ownership and district heating prices: The case of an unregulated natural monopoly. Umeå Economic Studies No. 980

Paper [IV]

Egüez, A. (2020) Compliance with the EU Waste Hierarchy: A matter of stringency, enforcement, and time. Umeå Economic Studies No. 981

[1] Author's reprint in thesis is allowed by Elsevier.
https://www.elsevier.com/about/policies/copyright/permissions
[2] *Id.*

Table of Contents

1. Introduction

One of the biggest challenges in environmental economics is understanding the incentives and choices in society. Economic agents such as households, companies, and states may respond to incentives, and these responses can affect the environment in different ways. Incentive structures can be associated with institutional elements such as ownership, information, and regulation. This thesis examines these elements in the energy efficiency, district heating, and waste management sectors. The papers in this thesis are self-contained and address the following questions:

Paper [I]: What effect do ownership and incentive structures have on the energy performance of multi-dwelling buildings (MDB)?

Paper [II]: What effect do Energy Performance Certificates (EPCs) have on energy efficiency investment decisions?

Paper [III]: What effect does ownership have on the price differential between district heating networks?

Paper [IV]: What effect do income and the stringency and enforcement (S&E) of environmental regulation have on how waste is treated, in particular regarding compliance with the EU Waste Hierarchy (EWH)?

The following subsections provide a general overview of the key aspects of energy efficiency, district heating, and waste management that have motivated the papers in this thesis. Then, section 2 summarizes each paper. Section 3 shows the links between the papers. Section 4 highlights the main conclusions and identifies areas of further research.

1.1. Energy efficiency

Energy efficiency refers to the amount of energy required to obtain a certain energy output or services (Patterson, 1996). From a technical perspective, the ratio between energy input and output can be measured in physical units. From an economic perspective, energy inputs have a price and the use of energy services generates utility. Energy efficiency improvements have multiple benefits; for example, a more efficient use of energy resources may promote energy security and emissions reductions, *cæteris paribus* (IEA, 2015). For these reasons, energy efficiency is one of the top priorities in energy and climate policy agendas

worldwide, not least in Europe. The European Green Deal's overarching aim is to achieve climate neutrality in Europe by 2050. At the national level, Sweden's target for residential and non-residential buildings is a 50 per cent reduction in total energy use per heated unit area by 2050 (relative to 1995).

Despite the multiple benefits of energy efficiency and the cost-effectiveness of its measures, its full potential is yet to be exploited. The difference between the current level of energy efficiency and the level that would be cost-effective is acknowledged in the literature as the energy efficiency gap (Jaffe & Stavins, 1994). Information failures, institutional hindrances, and misaligned incentives are some of the reasons explaining this gap (Broberg & Kazukauskas, 2014; Gillingham & Palmer, 2014).

Papers [I] and [II] in this thesis contribute to a better understanding of the energy efficiency gap in the residential sector. The former is concerned with misaligned incentives and the latter, with information failures. The main contribution of paper [I] is the quantification of the portion of the energy efficiency gap due to the split incentives problem between tenants and owners, and the portion due to managerial differences between ownership types. In the case of information failures, the novelty offered by paper [II] is the design of a quasi-natural experiment that evaluates the effect of an information instrument, in this case Energy Performance Certificates, on energy efficiency investments. Paper [II] takes advantage of the mandatory nature of EPCs, unlike previous studies that mostly use treatment groups comprising voluntary participation in specific information programs.

1.2. District heating

District heating is a system in which water is heated in one or more central facilities and is distributed through a local network of pipes to satisfy a heating demand. District heating has been one of the main players of Sweden's energy transition in the last century. The first district heating system in Sweden started in Stockholm in the 1950s, but its planning started back in the 1920s (Frederiksen & Werner, 2013). Until the 1960s, firewood and fuel oil were the main fuels used for residential heating (Kander, 2002). From the 1960s, district heating, together with direct electric heating, replaced a great extent of individual heating systems based on firewood and fuel oil (Werner, 2017). Heat pumps started to become widespread from the 1990s (Johansson, 2017). Nowadays, district heating and heat pumps are the main heating sources in Swedish residential buildings (Energimyndigheten, 2019).

The distribution networks of district heating can be considered a natural monopoly (Söderholm & Wårell, 2011). The exercise of monopoly power is a common concern in natural monopolies; therefore, prices may be regulated through, for example, price caps. However, one characteristic of the district heating market in Sweden is that prices have been unregulated since 1996. Ownership has also diversified and prices differ between networks. In this setting, it is important to understand the elements affecting district heating prices. Paper [III] in this thesis contributes to understanding these factors, focusing on how ownership of district heating affects its prices. District heating prices have a two-part tariff structure consisting of a fixed and a variable component. Paper [III] makes an original contribution through its analysis of the ownership effect on each price component.

Together with ecological sustainability and security of supply, competitiveness is one of the pillars of Sweden's energy policy (IEA, 2019). In exploring the role of ownership in district heating prices, paper [III] in this thesis also examined the competition of heat pumps with district heating. Heat pumps become more competitive with lower electricity prices and higher efficiency (Li, et al. 2019). For example, in the case of ground source heat pumps, efficiency in terms of the average seasonal coefficient of performance (SCOP) has doubled from 2.2 in the 1970s to 4.5 nowadays, i.e., 1 kWh of electricity delivers 4.5 kWh of heat (Johansson, 2017). Substitution possibilities, at least in the long run, have influenced how district heating prices are set. Paper [III] also analyzes the relationship between district heating prices and the market prices of heat pumps.

1.3. Waste management

Economic growth is generally associated with the extraction of raw materials from natural resources. The production and consumption processes inherent to economic activity generate waste that needs to be treated taking into account societal well-being. This is the foundation of a resource-efficient economy, a necessary condition in the circular economy paradigm.

Waste management systems have evolved under the influence of economic drivers as well as environmental and health concerns. As early as the nineteenth century, dust-yard collection and recycling systems in London appeared in part due to the attractive market value of dust demanded by the brick industry and agriculture. The system collapsed when the price of dust dropped once the brick industry started using alternative input materials, such as sand. Together with sanitation concerns, this price drop led to the establishment of a municipally-organized waste management system in London (Velis et al. 2009).

Waste management systems and technology have evolved dramatically since then, but how countries treat waste is still influenced by economic drivers as well as environmental and health concerns. Countries treat waste based on the relative costs and benefits of waste treatment options. Environmental and health concerns triggered the development of the EU Waste Hierarchy (EWH), which has its origins in Lansink's Ladder, a waste management hierarchy devised in the 1970s (Lansink, 2017). The EWH in the EU Waste Framework Directive establishes the following order of priority: waste prevention and reuse; recycling; recovery, e.g., waste-to-energy (WtE); and disposal, e.g., incineration and landfilling. Countries are free to implement specific policies to promote the EWH. If these policies are in line with the EWH, and assuming they are effective, they will affect the relative costs of each alternative in the ladder.

Paper [IV] in this thesis analyses different country characteristics that may have an effect on how countries treat waste, and therefore, their compliance with the EWH. Previous literature has analyzed the effect of country characteristics, such as income and population density, on landfilling or other waste treatment methods (Ichinose, Yamamoto, & Yoshida, 2011; Karousakis, 2009; Mazzanti, Montini, & Nicolli, 2009a, 2009b; Mazzanti & Zoboli, 2008; Nicolli, Mazzanti, & Iafolla, 2012). Paper [IV] builds a compliance index based on the waste treatment options in the EWH, making an original contribution to the field in this way. This index is regressed on country characteristics that are expected to affect the relative benefits and costs of landfilling, incineration, WtE, and recycling. A better understanding of these elements is due, since a transition towards the upper levels of the EWH is one of the main focus areas of the 2020 European Commission's Circular Economy Action Plan.

2. Summary of the papers

2.1. Paper [I]

Blame it on the owner – Ownership and energy performance of multi-dwelling buildings

As mentioned before in section 1.1, the energy efficiency gap is the difference between the current level of energy efficiency and the level that would be cost-effective (Broberg & Kazukauskas, 2014; Gillingham & Palmer, 2014). Misaligned incentives among stakeholders may partially explain the energy efficiency gap in the residential sector. Paper [I] investigates to what extent different incentive structures—such as split incentives between tenants and landlords, and differences in profit maximization interests between public and private rental companies—affect the energy performance of multi-dwelling buildings (MDB) in Sweden. One of the main contributions of paper [I] is the development of a conceptual framework to illustrate how these incentive structures affect the energy performance of MDB under different types of ownership. Different types of ownership considered include owner-occupied cooperative apartment associations (COAA) and public and private rental MDB. Moreover, paper [I] adds to the literature by enhancing the empirical evidence revealing these differences.

In Sweden, rental costs usually include the tenant's heating bill, which is therefore paid by the landlord. So, while landlords may have incentives to invest in the building's energy efficiency, the tenant may not have incentives to use energy efficiently. In this context, the split incentives mainly concern a problem of energy use. From the landlord's perspective, and especially in the case of profit-maximizing private landlords, cost-based rent setting may discourage energy efficiency investments if they serve to lower the operating costs. In this case, landlords may have to share the return on their investments with the tenants. In paper [I], the differences in energy performance between rental MDB and owner-occupied MDB, i.e., COAA, offer an estimate of the energy efficiency gap due to split incentives concerning energy use and other regulatory aspects such as cost-based rent setting. In addition, the effects of public and private management are quantified by estimating the differences in energy performance between public and private rental MDB.

Results show that COAA buildings have better energy performance than rental apartment buildings, and the difference in energy performance is relatively small

between MDB owned by private and municipal rental companies, after controlling for the buildings' characteristics. Considering the energy performance of COAA as the benchmark, public rental MDB could reduce their energy use, on average, by 6.5–8 kWh per m^2 (4.3–5.2%) and private rental MDB by 5–6.7 kWh per m^2 (3.4–4.8%). However, this potential should be interpreted as conservative, since COAA may also have opportunities to reduce the energy efficiency gap. The difference in energy performance between public and private rental MDB is 1.4–1.5 kWh per m^2.

The policy implications of these results set the basis for future research. From a strict energy perspective, transforming rental MDB to COAA may alleviate some principal-agent-related problems and would perhaps lead to higher energy performance. In COAA, members are the beneficiaries of the actions they take towards more efficient use of energy and making cost-effective energy efficiency investments. However, the energy-related benefits of transforming rental MDB into COAA, or privatizing rental companies, are limited and may conflict with the objectives of municipal ownership (and rent regulation) that form part of broader social policies, e.g., the alleviation of residential segregation. Still, previous research by Mangold et al. (2018) shows that "economically disadvantaged groups are over-represented in buildings with poorer energy performance." The energy efficiency gap only concerns cost-effective energy efficiency improvements, so a priori there is potential to harmonize energy and social objectives, but further research addressing these issues is needed.

As previously mentioned, in Sweden, the heating bill is usually included in a tenant's rent and is thus paid by the landlord. Individual metering and debiting of the tenant's heat, as well as water usage, could provide economic incentives to the tenant for more efficient energy use. However, this would create another split incentive problem because landlords would have fewer incentives to invest in the energy efficiency of the building and its appliances. As an alternative, information-based instruments such as peer comparisons that allude to social norms may have an effect on energy use (Broberg & Kazukauskas, 2014). Since heating is included in the rent, but the electricity bill is not, further research should address spillover effects.

The energy use data and energy-related building characteristics analyzed in paper [I] come from the Energy Performance Certificates (EPCs) registry administered by the National Board of Housing, Building and Planning (Boverket). EPCs are valid for ten years, and future research should be conducted when new EPCs become available, e.g., to evaluate their effectiveness. In this case, changes in the

methodology should be critically assessed when comparing the two waves of EPCs (von Platten et al. 2019).

2.2. Paper [II]

Effects of energy performance certificates on investment: A quasi-natural experiment approach

Incomplete information and bounded rationality may partially explain the energy efficiency gap indicated by the question of why households do not invest in energy efficiency even though it is cost-effective to do so (Broberg & Kazukauskas, 2014; Gillingham & Palmer, 2014). EPCs have been promoted to overcome energy-related information shortages. For single-family houses (SFH) in Sweden, an EPC is required when the property is sold, and it includes recommendations of cost-effective measures to improve the energy performance of the house based on information from an on-site energy audit. Paper [II] investigates whether EPCs make households more likely to invest in energy efficiency.

An experimental research design is required to rule out counterfactual energy efficiency investments that would have taken place anyway in the absence of EPCs (the treatment). EPCs became mandatory in 2008, so they cannot be a randomly-assigned treatment. However, since they are the result of an exogenous policy change, a quasi-natural experimental design is possible (Meyer, 1995). Paper [II] diverges from previous literature by not using voluntary energy audits as the treatment, which may lead to methodological issues concerning potential selection bias (Alberini & Towe, 2015; Considine & Sapci, 2016; Frondel & Vance, 2013; Hirst & Goeltz, 1985; Hirst & Grady, 1982). Paper [II] also adds to the existing literature by analyzing several energy efficiency measures separately.

The data is based on a survey sent out between May and July 2017 to households in Sweden living in detached, semi-detached, and terraced houses built in 2002 or earlier. Households were asked whether their houses had been subject to specific investments in the last ten years, i.e., 2007–2017. The control group in the quasi-experimental design consists of houses without an EPC and which were sold between 2002 and 2008. The treatment group consists of houses sold from 2008, when EPCs became mandatory in order for the house to be sold, to 2015. Treatment effects are estimated using probit regression models, as well as nearest neighbor matching as the estimator of the average treatment effect.

Results show that, overall, EPCs do not have an effect on the household's investment decisions concerning energy efficiency. However, if specific measures

are analyzed, EPCs have a positive effect on investments in water-based heating systems (radiators), new indoor temperature sensors, and new heating systems using district heating or pellets. More specifically, a house with an EPC is 8% more likely to install water-based heating systems and new radiator valves than a house without an EPC. The corresponding figure is 6–8% for new indoor control systems and 8–10% for radiator valves. The perceived benefit of these types of interventions mainly relates to energy efficiency, which may explain the positive treatment effect of EPCs that provides energy-related information to households. Concerning other actions, such as changes of windows, doors, or roofs, energy efficiency may not be the main consideration, and other drivers such as improvements in comfort or esthetics may influence a household's investment decisions.

From a policy perspective, EPCs respond to EU Directives, and countries are responsible for their implementation. The limited effectiveness of EPCs raises concerns about their cost-effectiveness. In the current situation, EPCs are mainly conducted to comply with the requisites to sell a house, and energy efficiency is not necessarily the main driver to having an EPC. Improved communication may increase the perceived utility and effectiveness of EPCs. Paper [II] also revealed that households are not only driven to make energy efficiency improvements for financial reasons. As such, EPCs could emphasize other co-benefits associated with the suggested measures, like positive effects on the environment, or improvements in indoor comfort. Further research should evaluate the effects of these changes.

2.3. Paper [III]

Ownership and district heating prices: The case of an unregulated natural monopoly

District heating networks are local natural monopolies, and, as such, the possibility of exercising market power cannot be ruled out (Söderholm & Wårell, 2011; Wissner, 2014). District heating prices in Sweden are unregulated and differ between networks, which have different ownership types. The ownership of district heating networks has diversified since deregulation measures were introduced in 1996 (Werner, 2017). These price differentials may be justified by local network characteristics that affect the costs of district heating systems. However, if ownership could also explain the differences in prices, these effects need to be estimated. Ownership may affect price setting if the objectives of the companies differ. For example, private companies may prioritize profit maximization, while municipal companies may have broader social objectives,

which allow them to sacrifice profits to achieve such objectives. Paper [III] investigates to what degree ownership can explain the differences in prices among district heating networks.

Furthermore, since district heating prices typically have a two-part tariff structure consisting of a fixed and a variable component, the paper examines whether the price differential corresponds to these components in multi-dwelling buildings and single-family houses. This distinction between the price components, which previous studies have not tested, is useful in investigating whether the objectives of the companies, characterized by their ownership type, explain the price differentials between the Swedish district heating networks. More specifically, in the case of a two-part tariff, a profit-maximizing monopolist may use the fixed component of the price to extract as much as possible of the consumer surplus. Likewise, a cost-based monopolist may use the fixed price component to cover their fixed costs and avoid losses.

District heating is not exempt from the competition of other heating alternatives, at least in the long run, considering switching costs. For example, ground-source heat pumps have become more competitive in recent years because of their increased efficiency (Johansson, 2017). Besides, electricity prices may also affect the relative prices of district heating and heat pumps. Another aspect that characterizes the Swedish district heating market is the Price Dialogue, a self-regulation platform instituted by district heating and real estate companies where these parties meet and discuss future prices. Paper [III] adds to the empirical evidence not only by using updated data compared to previous studies—such as Åberg, Fälting, & Forssell (2016); Andersson & Werner (2003, 2005, 2001); Colnerud Granström (2011); Hansson (2009); Muren (2011)—but also by incorporating in its analysis the costs of heating with heat pumps and participation in the Price Dialogue.

The empirical model used in paper [III] can be described as a reduced form model where the factors affecting the demand and cost functions determine the price of district heating. These factors, together with the companies' managerial objectives, determine the equilibrium price of district heating. Results show that district heating prices in networks owned by private companies are 3% higher than the average price of municipally-owned networks, and that the price differential is concentrated in the fixed component. The fixed component of the district heating price in networks owned by private companies is 17% and 24% higher than the average fixed price component in municipally-owned networks for

MDB and SFH, respectively, which may indicate that private companies generally prioritize profit maximization.

Paper [III] also shows that district heating prices are correlated with the price of heating with heat pumps, confirming that they are substitutes. Concerning the Price Dialogue, results show that district heating prices in MDB are 2.7% higher in networks that are members of the Price Dialogue compared with those that are not. In SFH the difference is 1.3% However, this result should not be interpreted as a causal relationship. The Price Dialogue aims to promote transparency and trust between district heating companies and their customers. Further research should explore whether more transparency and trust could affect the possibilities to set higher prices.

From a policy perspective, the question of price regulation is always valid in natural monopolies where market power may be exercised. However, price regulation is not always justified because regulating prices is not costless. Relative to the average household's disposable income, the differences in prices between ownership types are minimal, and it is very unlikely that consumers will exert pressure in favor of price regulation, at least in the current situation.

2.4. Paper [IV]

Compliance with the EU Waste Hierarchy: A matter of stringency, enforcement, and time

The European Waste Framework Directive establishes that countries should implement waste legislation and policies to apply the EU Waste Hierarchy (EWH). The EWH prescribes an order to prioritize waste treatment options. Waste prevention and re-use are at the top of the hierarchy, followed by material recycling, WtE, and lastly waste disposal methods such as incineration and landfilling. In practice, it is expected that countries treat waste based on the relative costs and benefits of waste treatment options. Characteristics such as income, population density, heating demand, and environmental policies differ between countries and may influence the cost-benefit structure of waste treatment options, and therefore compliance with the EWH. Paper [IV] hypothesizes that the differences in country characteristics explain why they treat waste differently, and therefore also exhibit different levels of compliance with the EWH.

One of the main contributions of paper [IV] is the construction of a waste hierarchy compliance index based on the shares of landfilling, incineration, WtE, recycling, and specific weighting coefficients to reflect different scenarios. This

index is regressed on income, stringency and enforcement of environmental regulation, and other variables such as population density, heating demand, and electricity prices, which are also expected to affect the relative benefits and costs of the waste treatment options in the EWH. The shares of landfilling, incineration, WtE, and recycling are also modeled to capture the effect of the analyzed country-characteristics in the waste treatment mix. The data corresponds to the period 2010–2016, with biennial observations.

Results show that stringency and enforcement of environmental regulation have a positive effect on compliance with the EWH. More specifically, higher stringency and enforcement of environmental regulations are associated with a decrease in the share of landfilling. Concerning income, results show a positive relationship with the share of WtE, which is technologically intensive. However, results also indicate that income has a negative relationship with the share of recycling and a positive relationship with WtE, which indicates that WtE substitutes recycling when income increases. Population density reveals a positive relationship with compliance with the EWH, mainly driven by the fact that waste incineration and recycling are favored over landfilling and WtE when population density increases. Finally, results support a positive relationship between heating demand and the share of WtE.

From a policy perspective, paper [IV] shows that stringency and enforcement of environmental regulations matter. Compliance with the EWH has improved over time, which suggests a positive effect of the Waste Framework Directive from 2008. If social preferences are in line with the objectives of the EWH, society will strive for stringent and enforceable regulations to increase compliance with the EWH. The environmental policy indicator in paper [IV] measures stringency and enforcement in a broader sense. Further research is required to assess the effectiveness of specific waste policies and the conditions for their replicability in countries with heterogeneous characteristics.

3. Links between the articles in this thesis

The articles in this thesis are self-contained. However, there are links between them which are discussed below. Figure 1 synthesizes how the four papers in this thesis relate to each other.

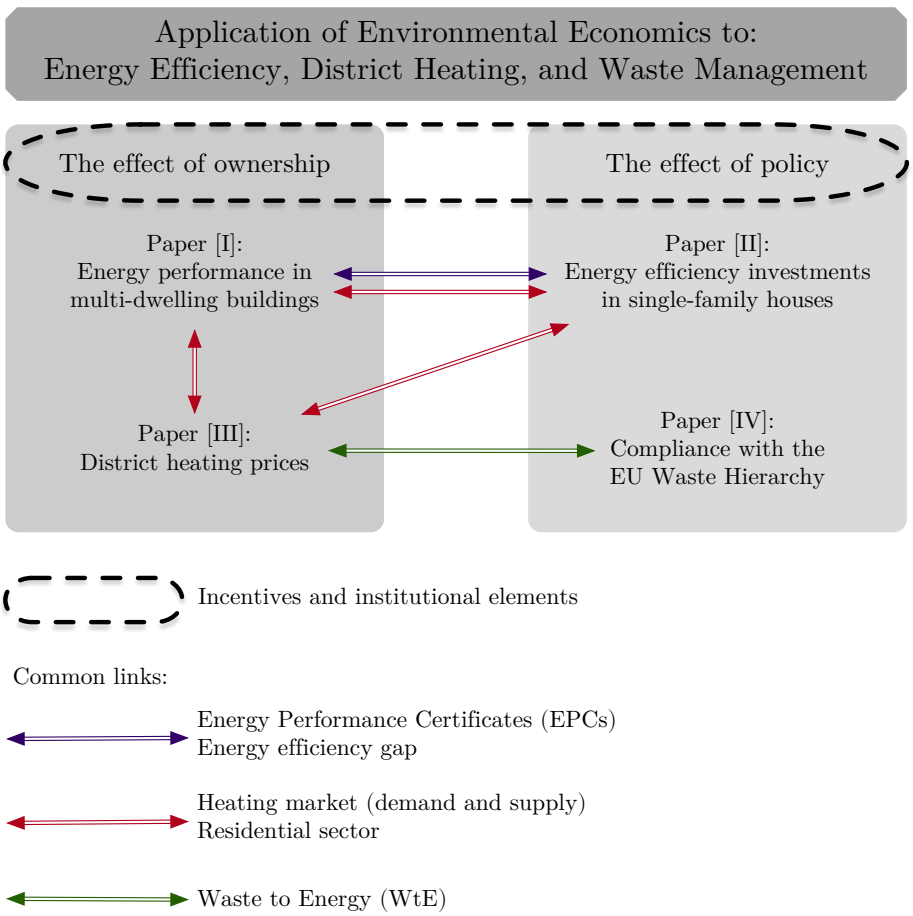

Figure 1: Relationships between the papers in this thesis

3.1. Ownership

Owners may differ in their goals and incentives. Papers [I] and [III] address the effects of ownership in energy performance and district heating prices, respectively. Although covering different contexts, both papers demonstrate that ownership matters.

As mentioned before, paper [I] estimates the effect of ownership on the energy performance of multi-dwelling buildings (MDB). Tenants in rental MDB have different incentives for caring about energy performance compared to owner-occupied MDB: an example of the split incentives problem (Gillingham, Harding, & Rapson, 2012; Krishnamurthy & Kriström, 2015; Levinson & Niemann, 2004; Maruejols & Young, 2011; Murtishaw & Sathaye, 2008). Incentives may also differ between private and municipal landlords within rental MDB. Profitable energy efficiency investments are attractive for private landlords if profit maximization is their main driver. In the case of municipal landlords, profits are not the only objective, and further social or political purposes influence their management and investment decisions (Boardman & Vining, 1989; Dixit, 1997; Kaufman, 1990; Shleifer, 1998).

Paper [III] investigates the effect of ownership on district heating prices. The differing goals of energy companies may partially explain why prices in private district heating networks are higher than municipally-owned networks. Private companies are assumed to maximize their profits and, in a monopoly situation, they set prices accordingly. In the case of municipal companies, profit maximization may not be the ultimate goal, which allows them to sacrifice a certain level of profit to achieve broader social objectives (Åberg, Fälting, & Forssell, 2016; Kaufman, 1990; Nygårds, 2011). As mentioned before, paper [III] analyzes whether ownership can explain differences in district heating prices in MDB and SFH.

3.2. Policies

Environmental externalities and the lack of information are examples of market failures that justify policy interventions (Hepburn, 2010; Sterner & Coria, 2013). Energy performance certificates, addressed in paper [II], are a policy instrument that could be motivated by information failures. EPCs provide energy-related information, in this case, of residential properties. The EWH, addressed in paper [IV], may be motivated by the association of waste with adverse environmental and health effects. The Waste Framework Directive and the EWH are part of the European waste policy. Individual countries are responsible for implementing their own policies to comply with this Directive.

3.3. Additional common links

Besides the institutional elements described previously, the papers herein have further connections. For example, energy efficiency's cost-effective improvement potential, also known as the energy efficiency gap, motivates papers [I] and [II].

However, in paper [I], principal-agent problems are the source of the energy efficiency gap, while information failures motivate paper [II]. Papers [I] and [II] study EPCs in the residential sector. However, their aims and object of study differ. Paper [I] focuses on MDB, while paper [II] explores SFH. Paper [I] uses data from the EPCs and other sources to evaluate the effect of ownership on the energy performance of MDB. Paper [II], instead, studies the effectiveness of the EPCs as a policy tool to promote energy efficiency investments in SFH. Paper [III] covers MDB and SFH, but with the aim of ascertaining the role of ownership on district heating prices.

The heating market links paper [III] with papers [I] and [II]. Paper [III] focuses on district heating prices but also discusses alternative heating forms such as heat pumps. Heating is the main energy use analyzed in papers [I] and [II]. By 2017, the energy consumption of households reached 87 TWh, which accounts for nearly a quarter of the total final energy use (378 TWh). Two-thirds of these 87 TWh were used for heating and hot water in MDB and SFH. MDB mainly used district heating (24 TWh), while SFH used 15.2 TWh of electric heating, 10.4 TWh of biomass, and 5.5 TWh of district heating (Energimyndigheten, 2019).

Finally, WtE is a common link between papers [III] and [IV]. In the EWH addressed in paper [IV], WtE has a higher priority than landfilling and waste incineration without energy recovery, but a lower priority than recycling and waste prevention. By 2018, half of the treated household waste in Sweden was being utilized for energy recovery. Waste is an important fuel for district heating and the co-production of electricity in combined heat and power (CHP) plants. The total energy production from waste is 17.5 TWh, of which 2.2 TWh are used to produce electricity and 15.3 TWh are used for district heating (Swedish Waste Management Association, 2018). The demand for district heating is 50 TWh (Energimyndigheten, 2019).

4. Conclusions and further research

This thesis shows how institutional elements such as ownership, information, and policies may affect the incentives behind the decisions that economic agents take concerning energy efficiency (papers [I] and [II]), prices (paper [III]), and waste management (paper [IV]). The following are the main conclusions of each paper:

Paper [I]

- Ownership and energy performance are linked in a conceptual framework.
- Ownership matters for the energy performance of multi-dwelling buildings.
- Tenant-owned buildings show better energy performance than rental apartment buildings.
- The difference in energy performance between private and municipal rental company buildings is small.

Paper [II]

- We test if the Swedish energy performance certificate scheme affects investments in energy efficiency using a quasi-natural experiment.
- We find no significant overall effect on energy efficiency investments.
- We do find significant treatment effects for a few heating system-related measures.

Paper [III]

- Data confirms that district heating prices are higher in private networks than in municipally-owned networks.
- The price differential mainly concerns the fixed price component.
- The different objectives of municipal and private companies may partially explain these differences.
- District heating prices are correlated with the market prices of heat pumps.

Paper [IV]

- A compliance index is created on the basis of the waste treatment ladders of the EU Waste Hierarchy.
- Higher stringency and enforcement of environmental regulation is related to less landfilling.
- Compliance with the EU Waste Hierarchy has increased over time.

While the papers in this thesis answer particular research questions, new questions for further research also arise.

Paper [I] shows that owner-occupied cooperative apartment associations have better energy performance than rental apartment buildings and that private rental buildings have slightly better energy performance than municipally-owned rental buildings. While paper [I] highlights some of the reasons that may explain these differences, further research is required to assess whether bridging these differences could contribute to broader social objectives, such as alleviating residential segregation. Moreover, further research is necessary to evaluate alternatives, such as information-based instruments that minimize the inefficient use of energy due to the split incentives problem. Also, since in Sweden heating is often included in the rent, but the electricity bill is not, further research could estimate spillover effects.

Energy performance certificates are valid for ten years, which means that the second wave of certificates has already started and will continue in the coming years. The arrival of new data could open possibilities for further research. For example, it would be interesting to use a difference in differences approach to compare the changes in the energy performance of buildings that switched ownership type between these years, with that of buildings that remained under the same ownership. The new wave of EPCs also brings new challenges, especially concerning the comparability of the data in the case that variables and measurement criteria differ between the old and new EPCs.

Paper [II] shows that the effect of EPCs on energy efficiency investments is narrowed to specific types of improvements. Despite the challenges EPCs present concerning cost-effectiveness, it is problematic to abandon EPCs because they correspond to broader EU legislation. Improvement potential exists concerning, for example, the way how the content in EPCs is communicated to users. Further research could evaluate the effectiveness of different communication strategies, for example, using experimental methods.

Paper [III] estimates the effect of ownership on district heating prices. Further research aiming to estimate cost functions and the markup differences between companies could better estimate possible market power exercise. Paper [III] incorporates Price Dialogue membership into the empirical analysis. This incorporation is a first step, but further research is necessary to explore whether more transparency and trust between district heating companies and their customers, which are the Price Dialogue's aims, could affect the possibility of setting higher prices or vice versa. Paper [III] also addressed the competition

district heating faces from heat pumps. Results show a correlation between district heating prices and electricity prices. However, further research from an energy systems perspective is required to evaluate the interaction between these markets, especially concerning the effect of changes in electricity demand on power networks.

Paper [IV] shows that stringency and enforcement of environmental regulations matter for the treatment of waste in compliance with the EWH. However, the environmental policy indicator in paper [IV] measures stringency and enforcement in a broader sense. Further research is required to assess the effectiveness of specific waste policies and their replicability conditions in countries with heterogeneous characteristics.

References

Åberg, M., Fälting, L., & Forssell, A. (2016). Is Swedish district heating operating on an integrated market?–Differences in pricing, price convergence, and marketing strategy between public and private district heating companies. *Energy Policy*. https://doi.org/10.1016/j.enpol.2015.12.030

Alberini, A., & Towe, C. (2015). Information v. energy efficiency incentives: Evidence from residential electricity consumption in Maryland. *Energy Economics*. https://doi.org/10.1016/j.eneco.2015.08.013

Andersson, S., & Werner, S. (2003). *Fjärrvärme i Sverige 2001–En analys av ägande, jämställdhet, priser och lönsamhet i svenska fjärrvärmeföretag med vissa internationella utblickar*.

Andersson, S., & Werner, S. (2005). *Fjärrvärme i Sverige 2003–En analys av råvarukostnader, ägande, jämställdhet, priser och lönsamhet i svenska fjärrvärmeföretag*.

Andersson, S., & Werner, S. E. (2001). *Svensk fjärrvärme: ägare, priser och lönsamhet*. Energy Systems Technology Division, Chalmers University of Technology.

Boardman, A. E., & Vining, A. R. (1989). Ownership and performance in competitive environments: A comparison of the performance of private, mixed, and state-owned enterprises. *The Journal of Law & Economics*. https://doi.org/10.1086/467167

Broberg, T., & Kazukauskas, A. (2014). Inefficiencies in residential use of energy–A critical overview of literature and energy efficiency policies in the EU. *International Review of Environmental and Resource Economics*. https://doi.org/10.1561/101.00000070

Colnerud Granström, S. (2011). *EI R2011:08 Analys av fjärrvärmeföretagens intäkts-och kostnadsutveckling*. Swedish Energy Markets Inspectorate (Energimarknadsinspektionen). Retrieved from https://www.energimarknadsinspektionen.se/Documents/Publikationer/rapporter_och_pm/Rapporter 2011/EI_R2011_08.pdf

Considine, T. J., & Sapci, O. (2016). The effectiveness of home energy audits: A case study of Jackson, Wyoming. *Resource and Energy Economics*. https://doi.org/10.1016/j.reseneeco.2016.02.004

Dixit, A. (1997). Power of incentives in private versus public organizations. *American Economic Review*. https://www.jstor.org/stable/2950949

Energimyndigheten. (2019). Energy in Sweden 2019. Retrieved from https://www.energimyndigheten.se/globalassets/statistik/energilaget/energy-in-sweden-2019.xlsx

Frederiksen, S., & Werner, S. (2013). *District Heating and Cooling*. Lund, Sweden: Studentlitteratur Lund.

Frondel, M., & Vance, C. (2013). Heterogeneity in the effect of home energy audits: Theory and evidence. *Environmental and Resource Economics*. https://doi.org/10.1007/s10640-013-9632-4

Gillingham, K., Harding, M., & Rapson, D. (2012). Split incentives in residential energy consumption. *The Energy Journal*. https://doi.org/10.5547/01956574.33.2.3

Gillingham, K., & Palmer, K. (2014). Bridging the energy efficiency gap: Policy insights from economic theory and empirical evidence. *Review of Environmental Economics and Policy*. https://doi.org/10.1093/reep/ret021

Hansson, J. (2009). The Swedish District Heating Market: Firm Ownership and Variations in Price, Costs of Production and Profitability. Masters Thesis. Uppsala University.

Hepburn, C. (2010). Environmental policy, government, and the market. *Oxford Review of Economic Policy*. https://doi.org/10.1093/oxrep/grq016

Hirst, E., & Goeltz, R. (1985). Estimating energy savings due to conservation programmes. The BPA residential weatherization pilot programme. *Energy Economics*. https://doi.org/10.1016/0140-9883(85)90035-0

Hirst, E., & Grady, S. (1982). Evaluation of a Wisconsin utility home energy audit program. *Journal of Environmental Systems*. https://doi.org/10.2190/J9G1-8QJ2-PR55-1UEK

Ichinose, D., Yamamoto, M., & Yoshida, Y. (2011). Reexamining the waste-income relationship. GRIPS National Graduate Institute for Policy Studies. Discussion Paper, 10.

IEA (2019), *Energy Policies of IEA Countries: Sweden 2019 Review*, IEA, Paris https://www.iea.org/reports/energy-policies-of-iea-countries-sweden-2019-review

IEA (2015), *Capturing the Multiple Benefits of Energy Efficiency*, IEA, Paris https://www.iea.org/reports/capturing-the-multiple-benefits-of-energy-efficiency

Jaffe, A. B., & Stavins, R. N. (1994). The energy-efficiency gap. What does it mean? *Energy Policy*. https://doi.org/10.1016/0301-4215(94)90138-4

Johansson, P. (2017). *A Silent Revolution: The Swedish Transition towards Heat Pumps, 1970–2015*. TRITA IEO–R 2017:10.

Kander, A. (2002). Economic Growth, Energy Consumption and CO2 Emissions in Sweden 1800–2000. PhD Thesis. Lund University.

Karousakis, K. (2009). MSW generation disposal and recycling: Empirical evidence from OECD countries. In M. Mazzanti & A. Montini (Eds.),

Waste and Environmental Policy. London: Routledge. Routledge Explorations in Environmental Economics.

Kaufman, B. E. (1990). A new theory of satisficing. *Journal of Behavioral Economics*. https://doi.org/10.1016/0090-5720(90)90016-Z

Krishnamurthy, C. K. B., & Kriström, B. (2015). How large is the owner-renter divide in energy efficient technology? Evidence from an OECD cross-section. *The Energy Journal*. https://doi.org/10.5547/01956574.36.4.ckri

Lansink, A. (2017) Challenging Changes – Connecting Waste Hierarchy and Circular Economy. The Netherlands: LEA Nijmegen.

Levinson, A., & Niemann, S. (2004). Energy use by apartment tenants when landlords pay for utilities. *Resource and Energy Economics*. https://doi.org/10.1016/S0928-7655(03)00047-2

Li, H., Song, J., Sun, Q., Wallin, F., & Zhang, Q. (2019). A dynamic price model based on levelized cost for district heating. *Energy, Ecology and Environment*. https://doi.org/10.1007/s40974-019-00109-6

Mangold, M., Österbring, M., Overland, C., Johansson, T., & Wallbaum, H. (2018). Building ownership, renovation investments, and energy performance–A study of multi-family dwellings in Gothenburg. *Sustainability*. https://doi.org/10.3390/su10051684

Maruejols, L., & Young, D. (2011). Split incentives and energy efficiency in Canadian multi-family dwellings. *Energy Policy*. https://doi.org/10.1016/j.enpol.2011.03.072

Mazzanti, M., Montini, A., & Nicolli, F. (2009a). The dynamics of landfill diversion: Economic drivers, policy factors and spatial issues: Evidence from Italy using provincial panel data. *Resources, Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2009.06.007

Mazzanti, M., Montini, A., & Nicolli, F. (2009b). Waste Kuznets Curves, regional policies and spatial effects: Evidence on waste generation and landfill diversion from Italy.

Mazzanti, M., & Zoboli, R. (2008). Waste generation, waste disposal and policy effectiveness: Evidence on decoupling from the European Union. *Resources, Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2008.07.003

Meyer, B. D. (1995). Natural and quasi-experiments in economics. *Journal of Business & Economic Statistics*. https://doi.org/10.1080/07350015.1995.10524589

Muren, A. (2011). Exploatering eller reglering av naturliga monopol. Stockholm. Rapport till Expertgruppen För Miljöstudier, 2, 7.

Murtishaw, S., & Sathaye, J. (2008). Quantifying the effect of the principal-agent problem on US residential energy use. ACEEE Summer Study on

Energy Efficiency in Buildings.

Nicolli, F., Mazzanti, M., & Iafolla, V. (2012). Waste dynamics, country heterogeneity and European environmental policy effectiveness. *Journal of Environmental Policy and Planning*. https://doi.org/10.1080/1523908X.2012.719694

Nygårds, P. (2011). *Fjärrvärme i konkurrens* (SOU 2011:44). Stockholm.

Patterson, M. G. (1996). What is energy efficiency?: Concepts, indicators and methodological issues. *Energy Policy*. https://doi.org/10.1016/0301-4215(96)00017-1

Shleifer, A. (1998). State versus private ownership. *Journal of Economic Perspectives*. https://doi.org/10.1257/jep.12.4.133

Söderholm, P., & Wårell, L. (2011). Market opening and third party access in district heating networks. *Energy Policy*. https://doi.org/10.1016/j.enpol.2010.10.048

Sterner, T., & Coria, J. (2013). *Policy Instruments for Environmental and Natural Resource Management, Second Edition*. New York: Routledge. https://doi.org/10.4324/9781315780894

Swedish Waste Management Association. (2018). *Swedish Waste Management 2018*.

Velis, C. A., Wilson, D. C., & Cheeseman, C. R. (2009). 19th century London dust-yards: A case study in closed-loop resource efficiency. *Waste Management*. https://doi.org/10.1016/j.wasman.2008.10.018

Von Platten, J., Holmberg, C., Mangold, M., Johansson, T., & Mjörnell, K. (2019). The renewing of Energy Performance Certificates–Reaching comparability between decade-apart energy records. *Applied Energy*. https://doi.org/10.1016/j.apenergy.2019.113902

Werner, S. (2017). District heating and cooling in Sweden. *Energy*. https://doi.org/10.1016/j.energy.2017.03.052

Wissner, M. (2014). Regulation of district-heating systems. *Utilities Policy*. https://doi.org/10.1016/j.jup.2014.09.001