

Energy Efficiency

in buildings in the Baltic states
and the Nordic countries

XIAOYING LI

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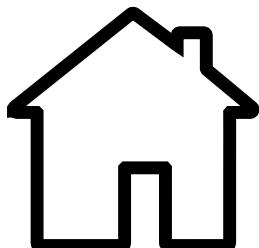
SÖDERTÖRN DOCTORAL DISSERTATIONS



Energy Efficiency

**in buildings in the Baltic states
and the Nordic countries**

XIAOYING LI



Södertörns högskola

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Abstract

Paper [I] estimates the impact of the energy performance requirements in building codes on energy efficiency in Swedish multi-apartment buildings. The results, relying on specific energy use data from energy performance certificates (EPCs), indicate that the implementation of performance-based regulation results in a 13.5% increase in energy efficiency above a general trend of 1.69% per year for buildings with district heating and a 10.1% increase for those with electric heating above a trend of 0.40% per year. The tightened building codes do not show strong effects on further increasing energy efficiency, however. The effect of building codes is modest for buildings with better energy performance, but more substantial for buildings where the actual energy use exceeds the required levels. Furthermore, a structural break analysis indicates a significantly greater increase in efficiency in the period of performance-based regulation than before. In addition to the regulation effects, the results indicate empirical evidence of the energy efficiency gap; the estimated energy use from engineering models is substantially lower than measured energy use for comparable construction.

Paper [II] estimates the effects of retrofit programmes of old Soviet-era multi-apartment buildings in Lithuania on realized dynamic energy savings by analyzing monthly energy bills. The study employs a quasi-experimental state-of-the-art research design to assess the causal effect of retrofits on energy savings. The results suggest that retrofits are associated with a 50% to 59% reduction in average space heating consumption across different post-retrofit periods. Moreover, retrofits also have a short-lived effect on electricity savings of 3% to 3.6%. However, given the average heating prices of the study sample, the cost-benefit calculations indicate that energy savings were not sufficiently large to cover the initial investment costs.

Paper [III] assesses the energy performance gap - the discrepancy between realized energy savings and the predictions made by engineers. The results show that, on average, the predicted savings are fully realized for a retrofit program of multi-apartment buildings in Lithuania. The paper also explores the determinants expected to explain differences in the energy performance gap across the retrofitted buildings. The results suggest that multi-apartment buildings managed by outsourced specialized housing management companies tend to realize higher energy savings after retrofits than buildings managed by communities of apartment owners. Furthermore, compared with retrofitted buildings that achieve the minimum required energy class of C, the performance gap tends to be larger for those buildings that target a higher energy class of A or B.

Paper [IV] explores the marginal effects of energy price inflation on various inflation expectations in Sweden. The time-invariant marginal effects are reasonably small. However, the flexible machine learning method of kernel-based regularized least squares (KRLS) estimations indicate significant time-varying patterns in the marginal effects. The marginal effects are highly volatile during the period of recent high energy price inflation. Nevertheless, the volatility tends to be lower, and the

marginal effects reduce to around 0 at the end of the sampling period. Among all potential economic factors, energy price inflation can systematically explain the variations in marginal effects.

Keywords: energy efficiency, building regulation, multi-apartment buildings, retrofit, energy performance gap, housing management, energy price inflation, inflation expectations

Abstract

Paper [I] uppskattar effekten av krav på energiprestanda i byggnormerna på energieffektiviteten i svenska flerbostadshus. Resultaten, baserade på specifika energianvändningsdata från energiprestandacertifikat (EPCs), tyder på att implementering av prestationsbaserad reglering resulterar i en 13,5% ökning av energieffektiviteten över en generell trend på 1,69% per år för byggnader med fjärrvärme och en 10,1% ökning över en trend på 0,40% för de med elvärme. De skärpta byggreglerna visar dock inte starka effekter på att ytterligare öka energieffektiviteten. Effekten av byggregler är blygsam för byggnader med bättre energiprestanda men mer betydande för byggnader där den faktiska energianvändningen överstiger de erforderliga nivåerna. Vidare indikerar en strukturell brottsanalys betydligt större effektivitetsökning under perioden med prestationsbaserad reglering än tidigare. Utöver regleringseffekterna indikerar resultaten empiriska bevis på energieffektivitetsgapet. Den uppskattade energianvändningen från tekniska modeller är väsentligt lägre än den uppmätta energianvändningen för jämförbart byggande.

Paper [II] uppskattar effekterna av ombyggnadsprogram av gamla sovjettidens flerlägenhetsbyggnader i Litauen på realisera dynamiska energibesparningar genom att analysera månatliga energiräkningar. Studien använder en kvasi-experimentell forskningsdesign för att bedöma orsakseffekten av ombyggnad på energibesparningar. Resultaten tyder på att ombyggnader är förknippade med en minskning på 50 % till 59 % av den genomsnittliga uppvärmningsförbrukningen under olika perioder efter renovering. Dessutom har ombyggnader också en kortlivad effekt på elbesparingen på 3 % till 3,6 %. Givet de genomsnittliga uppvärmningspriserna i undersökningsurvalet tyder dock kostnads-nyttoberäkningarna på att energibesparingarna inte var tillräckligt stora för att täcka de initiala investeringskostnaderna.

Paper [III] bedömer energiprestandagapet – skillnaden mellan realisera och beräknade energibesparningar som gjorts av ingenjörer. Resultaten visar att de förväntade besparingarna i genomsnitt realiseras fullt ut för ett efterrenoveringsprogram av flerbostadshus i Litauen. Uppsatsen utforskar också de bestämningsfaktorer som förväntas förklara skillnader i energiprestandagapet mellan olika renoverade byggnader. Resultaten tyder på att byggnader med flera lägenheter som förvaltas av utlokaliserade specialiserade bostadsförvaltningsbolag tenderar att realisera högre energibesparningar efter renoveringar än byggnader som förvaltas av gemenskaper av lägenhetsägare. Jämfört med renoverade byggnader som uppnår den lägsta erforderliga energiklassen C, tenderar dessutom prestandagapet att vara större för de byggnader som är inriktade på en högre energiklass A eller B.

Artikel [IV] utforskar de marginella effekterna av energiprisinflation på olika inflationsförväntningar i Sverige. De tidsinvarianta marginaleffekterna är rimligt små. Den flexibla maskinellärningsmetoden för kärnbaserade KRLS-uppskattningar indikerar dock signifikanta tidsvarierande mönster i marginaleffekterna. Marginaleffekterna är mycket volatila under den senaste tidens höga energiprisinflation. Ändå tenderar volatiliteten att vara lägre och marginaleffekterna minskar till runt 0 i slutet av

urvalsperioden. Bland alla potentiella ekonomiska faktorer kan energiprisinflationen systematiskt förklara variationerna i marginaleffekterna.

Nyckelord: energieffektivitet, byggreglering, flerbostadshus, renovering, energipriscupangap, bostadsförvaltning, energiprisinflation, inflationsförväntningar

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Introduction

Buildings constitute the category of objects for energy use in the European Union (EU) which accounts for the largest share of energy, about 40% of final energy use—buildings also account for 36% of energy-related greenhouse gas emissions in the EU (EC, 2021a). Improving energy efficiency in buildings is widely viewed as a cost-effective way of achieving climate and energy goals.¹ From a policy perspective, the EU has established the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED) to boost highly energy-efficient building stocks by 2050 (EC, 2021a). Two main regulatory instruments are currently being implemented to promote energy efficiency in buildings in the EU. One is constituted by building regulations limiting energy use in newly constructed buildings, and the other is constituted by renovation programs that have the target of improving energy efficiency for old buildings (EC, 2018). For the energy system, improving energy efficiency would play a crucial role in achieving competitive, secure and sustainable energy in the Baltic Sea region (EC, 2021b).

Energy use in residential buildings is mainly for heating (ODYSSEE, 2021). Among all heating alternatives, district heating is the most popular heating solution in both the Baltic states and the Nordic countries. The majority of heat energy in multi-apartment buildings is provided via the centralized district heating system. With energy sources being similar in countries across the Baltic Sea region, understanding energy efficiency potential in multi-apartment buildings is therefore crucial for achieving the national and regional level climate and energy goals.

Another common condition faced by countries across the Baltic Sea region is that large amounts of residential buildings tend to be old, with most of them having been built before 1990. Facing energy challenges, both the Baltic States and the Nordic countries have similar long-term renovation strategies. Moreover, the Renovation Wave is ongoing across the region, aiming to at least double the annual energy renovation rate in the following ten years (EC, 2020).

Most studies focus on actual energy savings in response to regulation and renovation programs are from Western European countries or the United States (e.g., Levinson, 2016; Fowlie et al., 2018; Coyne and Denny, 2021). Previous studies measuring energy efficiency improvements in countries across the Baltic Sea region are mainly based on bottom-up engineering approaches. This thesis fills a knowledge gap by evaluating the effects of current energy efficiency policies on actual realized

¹ Energy efficiency in buildings refers to using less energy to heat and cool buildings, and to run appliances (Patterson, 1996).

energy savings in the Nordic and Baltic countries. The focus is on multi-apartment buildings in Sweden and Lithuania.

In particular, Paper [I] estimates the effects of building regulations on energy savings for newly constructed multi-apartment buildings in Sweden. Paper [II] evaluates the effects of retrofit programmes on realized dynamic energy savings for old Soviet-era multi-apartment buildings in Lithuania. Furthermore, connecting with Paper [III], Paper [III] measures the energy performance gap—the discrepancy between actual energy savings and engineer-predicted savings for multi-apartment buildings in Lithuania. The gap issue links Paper [III] with Paper [I]. Paper [I] identifies the energy performance gap in another way—the discrepancy between actual energy use and the estimated energy use from engineering models for multi-apartment buildings in Sweden. In Paper [IV], the focus turns from energy efficiency in buildings to inflation issues. Given the recent developments of high inflation and energy prices, the paper explores the relationship between energy price inflation and inflation expectations in Sweden.

Various econometric methods and statistical strategies are employed throughout the empirical papers in this thesis. The data used in Paper [I] is cross-sectional at the building level. A basic Ordinary Least Squares (OLS) estimation is first applied to assess the average regulation effects. Complementary quantile regression and structural break analysis are also employed. Furthermore, the study also applies nearest-neighbour matching estimation to estimate the regulation effects on energy savings and to compare the effects across climate zones. Paper [II] is based on panel data, collected across both houses and time points. The paper employs staggered differences-in-differences estimations, considering the heterogeneous retrofit effects across buildings and the dynamic retrofit effects over time. Specifically, the interaction-weighted estimator proposed by Sun and Abraham (2021), as well as a general matching method for panel data proposed by Imai et al. (2021), are separately employed in the paper. Since the dataset used includes information on predicted energy savings from renovations by engineers, paper [III] further measures the energy performance gap and employs simple OLS regression models to investigate the main determinants of the energy performance gap. The data used in Paper [IV] is different from that used in the previous three papers. Paper [IV] is based on time-series data. An autoregressive distributed lag (ARDL) model is first employed to identify time-invariant relationships. For capturing time-varying dynamics, a flexible machine learning method, kernel-based regularized least squares (KRLS) estimations, is also used in the paper (Ferwerda et al., 2017).

Paper [I]

Impact of building regulations on energy efficiency: Evidence from energy use in Swedish multi-apartment buildings

Building regulations govern the energy efficiency of new buildings. To comply with the energy declarations and achieve the policy goals of reducing the climate impact of buildings, performance-based regulations were introduced in Sweden in 2006. Furthermore, energy requirements for specific energy use have been subsequently tightened to enhance the energy performance of new construction. The new regulations set the maximum permitted limits for energy use, allowing buildings to meet a higher standard than the regulatory requirements.

In this paper, I estimate the impact of the introduced and tightened performance-based building codes on energy efficiency by focusing on multi-apartment buildings constructed between 2000 and 2019 in Sweden. Using measured energy use data from energy performance certificates, I find that there is an estimated time trend toward greater energy efficiency, at a rate of 1.69% per year for buildings with district heating and 0.40% per year for electrically heated buildings. After accounting for the time trend of increasing energy efficiency, the results indicate that the implementation of performance-based regulation results in a 13.5% increase in energy efficiency for buildings with district heating and a 10.1% increase for those with electric heating. However, there is no evidence to suggest that the tightened building codes have strong effects on further increasing energy efficiency.

For recent new buildings under stricter codes, it is observed that approximately 55–65% of the new buildings in the sample have energy use below the regulatory level. The level of compliance with the regulation is generally decreasing over time. Using the quantile regression, I find that the regulatory effects are relatively modest for buildings with better energy performance and more substantial for buildings where the actual energy use exceeds the required standards. Furthermore, results from a complementary structural break analysis indicate that there is a shift toward significantly greater efficiency after the regulation implementation. One potential explanation is that with the adoption of performance-based building codes adoption of energy efficiency measures are accelerated.

In addition to various findings related to the effects of regulation, the study has also identified empirical evidence of the energy efficiency gap. When estimating the effects of stricter building codes with the matching method, I find that the magnitudes of the average actual savings are lower than those of the corresponding required tightened levels, especially for buildings with district heating. In addition, when esti-

mating the energy efficiency gains using data that includes both estimated and measured energy use values, I find the estimated energy use values are largely smaller compared to energy use based on measured values. This observed gap is both economically and statistically significant.

In this study, I also conduct a causal analysis based on nearest-neighbor matching to compare the effects of regulatory effects across different climate zones. The causality is not identified for buildings with district heating, but it is found for electrically heated buildings. From methodological perspective, in comparison to recent empirical studies estimating the average effects of building codes (e.g., Jacobsen and Kotchen, 2013; Levinson, 2016), this study provides more insightful information related to the regulation effects by applying quantile regression and structural break analysis.

Paper [II]

Realized dynamic effect of retrofits on energy consumption in Soviet-era multi-apartment buildings

Soviet-era dwellings were designed and built at a time when energy was abundant and cheap, and 170 million people still live in these mostly non-retrofitted and very energy-inefficient buildings (Meuser and Zadorin, 2015). Old multi-apartment buildings that are almost all connected to district heating systems in post-communist countries in Central and Eastern Europe and the former Soviet Union are notorious for being a symbol of energy waste.

Retrofit programs of old and very energy-inefficient housing stock from the Soviet era are widely believed to be a real win-win opportunity for mitigating climate change and tackling acute energy poverty issues in Eastern European urban neighborhoods. Several studies in post-Soviet countries mainly focus on the effects of tariff reforms on poverty (Krauss, 2016 in Armenia) and household energy use (Alberini et al., 2019 and 2020 in Ukraine; Alberini et al., 2022 in the Republic of Georgia). However, retrofit effects on energy efficiency improvements have never been investigated by using actual building-level energy consumption data.

In this paper, we evaluate the effectiveness of old Soviet-era multi-apartment buildings retrofits (modernization) on realized energy savings in one of the post-Soviet countries, Lithuania. We use a quasi-experimental research design to assess the causal effect of retrofits on energy savings. Due to the concern surrounding the self-selection issue, we first restrict our sample to ever-retrofitted buildings by using later-completed retrofits as the control group. We employ the event-study method and apply the interaction-weighted estimator to categorize renovated buildings into “cohorts” based on retrofit completion date. We also compare energy consumption for space heating and electricity in multi-apartment buildings that are retrofitted and buildings that have never been retrofitted by using propensity score matching method to find never-retrofitted buildings that share similar building characteristics.

Using large-scale building level data from four major cities in Lithuania between 2014 and 2019, we find that retrofitting old buildings decreases energy consumption for space heating by 50% to 59% up to three years after the retrofit. Moreover, the retrofit generates a spillover effect by reducing electricity consumption by 3% to 3.6% in the early years after the retrofit. We also estimate the long-term benefits of retrofits – the money savings due to lower energy consumption in the future – compared with the initial investment costs. The cost-benefit calculation indicates that the overall internal rate of return over a 30-year time horizon is -4%. Although building retrofits

can result in other benefits, such as reducing emissions and improving health, the benefits of energy efficiency investments are significantly less than the costs from the private perspective.

Our study makes methodological contributions by considering the heterogeneous retrofit effects across buildings and the dynamic retrofit effects over time. The case study of Lithuania has implications for housing retrofit policies in other Central and Eastern European and former Soviet countries.

Paper [III]

The energy performance gap and its determinants in Soviet-era multi-apartment buildings

Deep renovation, which significantly reduces energy consumption for heating, is seen as crucial in dealing with energy security and for meeting climate policy targets, especially in post-Soviet countries with notoriously energy-inefficient residential housing stock. The multi-apartment building retrofit program in Lithuania is a government-led initiative aimed at improving the energy efficiency of residential buildings in the country. The goal of the program is to encourage apartment owners to implement energy-efficient measures such as insulation, replacement of windows and doors, and modernization of heating systems. One critical question is whether these retrofits can achieve the energy savings promised by the engineering model.

In this paper, we first measure the energy performance gap—the discrepancy between actual energy savings and engineer-predicted savings for multi-apartment buildings in Lithuania. We observe that the performance gap varies between negative and positive values. On average, the predicted savings from the engineering model are fully realized by the actual savings. As a robustness test to see whether actual savings match predicted savings, we use the same event-study model as in paper [II] to calculate alternative actual savings based on the estimated actual saving rate, taking counterfactuals into consideration. The actual energy savings for space heating estimated based on the event-study approach is only slightly smaller than predicted savings.

In a second step of the analysis, we conduct a simple econometric assessment to investigate the statistical significance of the main determinants of the energy performance gap. Several potential predictors of the energy performance gap, including Energy Efficiency Measures (EEMs), targeted energy class and the type of housing administrator for each multi-apartment building are considered. Our results suggest that multi-apartment buildings managed by outsourced specialized management companies have a smaller performance gap compared to those with owner-elected housing administrators. Retrofits are likely to be more professionally managed by housing companies, who have staff specializing in building management and energy efficiency. Moreover, the targeted energy class after retrofit is a significant determinant in explaining the performance gap. Compared with retrofitted buildings that achieve the minimum required energy class of C, the performance gap is more problematic for those targeting energy class A or B.

The contribution of this paper goes beyond the existing literature by measuring the significance of different factors affecting energy performance gaps for the retro-fitted Soviet-era multi-apartment buildings connected to district heating systems (e.g., Allcott and Greenstone, 2017 in US; Filippidou et al., 2019 in Netherlands; Christensen et al., 2021 in US). This study yields important policy implications for post-communist countries in Central and Eastern Europe and the former Soviet Union with very similar multi-apartment building stocks, ownership structures, space heating systems and cultural and institutional settings.

Paper [IV]

Time-varying nexus of Swedish energy price inflation and inflation expectations

The continuously high energy prices prevailing since the Covid-19 pandemic have raised concerns about rising inflation expectations and persistently high inflation over a number of future years. Inflation expectations represent the beliefs and forecasts regarding future inflation rates, playing a crucial role in private consumption and investment decisions. In the context of a modern monetary policy regime, these expectations are also important for policy decisions, given the time lag between policy actions and their impacts.

An essential question is to what extent have inflation expectations been affected by energy price shocks. Most studies have focused on the US and the Euro areas, often without encompassing the Covid-19 pandemic or periods of high energy and headline inflation (e.g., Coibion and Gorodnichenko, 2015; Hammoudeh and Reboredo, 2018; Caraiani, 2023).

In this paper, we examine the nexus between energy price inflation and various inflation expectations in a small open economy, Sweden. We estimate the marginal effects of energy price inflation on household one-year inflation expectations, professional one-year and five-year inflation forecasts, and market-based five-year, five-year forward inflation expectations. The results from estimating autoregressive distributed lag (ARDL) models suggest that impacts are rather small, especially on long-term expectations. We also employ kernel-based regularized least squares (KRLS) estimations, a flexible machine learning method, to identify the time-varying marginal effects. The results demonstrate highly volatile marginal effects during the recent period of high energy price inflation, irrespective of the type of inflation expectations in question. The diffused marginal effects reflect challenges for managing inflation expectations during periods of extremely high energy inflation. Nevertheless, the volatility tends to be lower, with the marginal responses of both households and professional forecasters reducing to around 0 at the end of the sample periods.

We also investigate the potential factors that can explain the variations in marginal effects. The results indicate that only energy price inflation shows a clear systematic pattern, which plays a crucial role in explaining the time-varying feature of the marginal effects. Furthermore, the finding that marginal effects are not particularly sensitive to changes in the energy price index implies that the pursuit of high energy

prices as part of the energy transition may not necessarily lead to significant alterations in forecasts of future rates of inflation.

We contribute to the literature by providing insights into how energy price inflation has influenced various inflation expectations in a small open economy – particularly during the Covid-19 pandemic and its aftermath, a period characterized by extremely high energy price inflation. Furthermore, the paper makes a methodological contribution by employing a machine learning method, KRLS estimation, to estimate pointwise marginal effects in studying time-varying nexuses of prices and inflation expectations.

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Here the impacts of building codes and retrofit programs on energy efficiency improvements in countries across the Baltic Sea region are evaluated, with a focus on residential buildings in Sweden and Lithuania. This study contributes to the literature by estimating the actual energy savings achieved through these regulatory instruments in multi-apartment buildings connected to district heating systems.

Xiaoying Li is a researcher in department of economics at Södertorn University. This study is her doctoral thesis, written within the research area of Politics, Economy and the Organization of society (PESO) and the Baltic and East European Graduate School (BEEGS).

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