Housing Market Structure and Energy Efficiency Renovation

Eglė Jakučionytė Swapnil Singh*

January 16, 2026

Abstract

Why do residential energy efficiency renovation rates remain low even with generous subsidies? We show that local housing market structure fundamentally shapes renovation incentives. Using administrative data covering all dwelling transactions and renovation projects in Lithuania, we document a puzzle: renovation activity is lowest in thick urban markets despite these markets offering higher net returns. We develop a search-and-matching model where market thickness creates a hold-up problem. The model's predictions align with three empirical patterns: thick markets exhibit smaller percentage price gains from renovation, yet higher net returns due to lower cost-to-price ratios, and lower renovation rates. Counterfactual analysis shows that equalizing renovation incentives across markets would require subsidies in major cities nearly three times higher than in rural areas, revealing substantial efficiency costs of spatially uniform policies.

Keywords. Energy efficiency renovation, residential real estate, regional variation in property values, repeated-sales model, search and matching model

JEL. Q56, R31, R32, R38, D83

*Jakučionytė: Bank of Lithuania and Vilnius University. Address: CEFER, Bank of Lithuania, Totoriu St. 4, LT-01121 Vilnius, Lithuania. Email: ejakucionyte@lb.lt. Singh: Bank of Lithuania and Kaunas University of Technology. Address: CEFER, Bank of Lithuania, Totoriu St. 4, LT-01121 Vilnius, Lithuania. Email: ssingh@lb.lt. The views expressed in the paper are those of the authors, and do not necessarily reflect the view of their institutions.

Governments worldwide have committed substantial resources to improving residential energy efficiency, yet deep renovation rates remain stubbornly low. In the European Union, where buildings account for 40% of energy consumption and 36% of greenhouse gas emissions, annual deep renovation rates hover around 0.2%—far below the levels required to meet climate targets (European Commission, 2020). A large literature attributes this "energy efficiency gap" to market failures on the household side: credit constraints that prevent liquidity-constrained owners from financing upfront costs or information frictions that obscure the returns to investment (Allcott and Greenstone, 2012; Myers, 2019), behavioral biases that lead to excessive discounting of future energy savings (Allcott and Taubinsky, 2015; Gerarden et al., 2017), and coordination failures among co-owners in multi-unit buildings (Gillingham and Palmer, 2014). While these explanations account for important barriers to investment in energy efficiency, they do not fully explain the pronounced spatial variation in renovation activity that arises even under uniform regulatory frameworks, technologies, and subsidy schemes.

This paper argues that a key, and thus far overlooked, determinant of renovation behavior is the structure of the local housing market in which the dwelling will ultimately be traded. Energy efficiency improvements generate long-lived benefits that accrue over the remaining tenure of the current owner and, upon sale, are partially capitalized into the transaction price. The fraction of these benefits that the owner captures depends critically on two features of the local housing market: the probability that the owner separates from the dwelling before the investment fully pays off, and the share of future housing-service improvements reflected in the resale price. Both features vary systematically with market thickness—the volume of transactions relative to the housing stock. We show that this variation can rationalize patterns of renovation activity that are difficult to explain through standard channels, including the counterintuitive finding that renovation rates are *lower* in thick, liquid urban markets than in thin rural ones.

The core mechanism operates as follows. Renovations require immediate, irreversible expenditure but deliver benefits over many years. An owner who expects to move soon may sell before recovering these benefits through reduced energy bills. If, upon resale, the owner could fully capitalize the present value of remaining benefits into the sale price, the timing of separation would be irrelevant for the investment decision. However, in housing markets characterized by search frictions and limited bargaining power, prices are determined not only by the quality of matches, but also by bargaining between matched buyers and sellers. The interaction of high separation probability and limited surplus extraction creates a hold-up problem: owners in thick markets rationally anticipate

that they will move before capturing full benefits and that resale will not compensate them adequately. This suppresses renovation incentives precisely where turnover is the highest.

Our empirical setting is Lithuania, a country that provides an unusually clean laboratory for studying these forces. Lithuania's housing stock is dominated by Soviet-era apartment blocks—standardized concrete structures built between 1960 and 1990 that now suffer from thermal inefficiency. Since 2005, the government has operated one of Europe's most comprehensive renovation programs, offering subsidies that cover project development costs, preferential loan terms, and direct cost-sharing of up to 40% for energy-efficiency investments. Crucially, these subsidies are uniform across the country: a building in Vilnius – the capital of Lithuania and its largest city – faces the same subsidy schedule as one in a small rural municipality. This uniformity allows us to isolate the role of local housing-market conditions from policy heterogeneity. Despite nearly two decades of program operation and generous incentives, fewer than 15% of eligible buildings have been renovated, and renovation activity varies substantially across municipalities despite uniform subsidies.

We assemble a novel dataset combining three administrative sources: the universe of dwelling transactions from Lithuania's Real Property Cadastre (2010–2023), detailed project-level records on all completed renovations from the national program administrator, and building-level characteristics including construction year, size, and energy ratings. This combination offers three identification advantages. First, we observe the complete transaction history for each dwelling over the sample period, enabling a repeated-sales design that eliminates bias from time-invariant unobserved heterogeneity at the dwelling level (Brounen and Kok, 2011; Fuerst and McAllister, 2011; Aydin et al., 2020). Second, we observe actual renovation costs at the building level, allowing us to compute net returns rather than merely gross price premia—a distinction that proves quantitatively crucial. Third, the institutional setting features standardized renovation packages and uniform subsidies, minimizing concerns about selection on unobserved project quality or policy endogeneity.

Our empirical analysis establishes three sets of facts. First, we estimate the effect of renovation on apartment prices using a repeated-sales framework. Comparing the same apartment before and after its building is renovated, and controlling flexibly for time-varying local demand conditions, we find that renovation increases prices by approximately 8% on average. This estimate is robust to alternative specifications, sample restrictions, and controls for neighborhood-specific trends. While positive and statistically significant, this price appreciation is modest relative to renovation costs: after subtracting the owner's share of building-level renovation expenditure (net of subsidies), the average net return is approximately −25%. This finding helps explain low take-up: renovation is not privately profitable

for the average household, despite being socially desirable.

Second, we document regional heterogeneity in both gross and net returns that aligns with housing-market thickness. Lithuania's three largest cities—Vilnius, Kaunas, and Klaipėda—account for over 60% of the country's population and exhibit thick housing markets with high transaction volumes. Paradoxically, these cities display *lower* gross price effects from renovation: the estimated price premium is roughly 3% in large cities versus 11% in smaller municipalities. Yet net returns tell the opposite story: because apartment prices are much higher in large cities while renovation costs are geographically uniform, the cost-to-price ratio is 0.14 in large cities compared to 0.42 elsewhere. This means net returns, while negative everywhere, are substantially *less negative* in thick markets (-18% versus -32%).

Third, we show that renovation activity is higher in precisely those markets where our estimated net returns are most unfavorable. The three largest municipalities, despite their relatively higher net returns, renovate at lower rates than smaller municipalities with worse net returns. This pattern is inconsistent with models in which renovation decisions depend solely on expected profitability. We rule out several alternative explanations: the pattern is not driven by differential access to credit (large cities have deeper financial markets), differences in building characteristics (we control for age, size, and structure type), or selection into the estimation sample (results are robust to alternative sample definitions). What distinguishes large cities is not their cost structure or credit environment but their housing-market dynamics: higher turnover, more transactions, and—we argue—the associated hold-up problem.

To interpret these facts and quantify the mechanism, we develop a search-and-matching model of the housing market that incorporates an endogenous renovation decision. The model builds on the canonical framework of Wheaton (1990) and Krainer (2001), extended to include thick-market effects in the spirit of Ngai and Tenreyro (2014). Households own differentiated dwellings and face stochastic separation shocks that force them to sell and search for new housing. The search is frictional: buyers are randomly matched with sellers and draw idiosyncratic valuations from a distribution whose upper support increases with market thickness, capturing the idea that thicker markets offer better matching opportunities. Prices are determined by Nash bargaining.

Into this environment we introduce a renovation decision. Before learning whether they will separate, owners choose whether to pay a fixed cost to upgrade their dwelling's energy efficiency. Renovation provides additive benefits to housing services—capturing the technology of insulation, window replacement, and heating-system upgrades—that accrue to whoever occupies the dwelling.

The key tension is that renovation costs are borne immediately, but benefits are split between the current owner (who enjoys them until separation) and future owners (who receive them upon purchase). The share captured by the current owner depends on both the probability of staying (which determines direct benefit duration) and the fraction of future benefits capitalized into the sale price (which depends on bargaining power).

The model generates three predictions that we find in the data. First, gross price effects decline with market thickness. Renovation provides a fixed absolute benefit, but this represents a smaller percentage gain in thick markets where baseline prices are elevated by better matching. Second, net price effects increase with market thickness. Although percentage price gains are smaller, renovation costs represent a much smaller fraction of property values in expensive markets, making the cost-adjusted return more favorable. Third, and most importantly, renovation rates decline with market thickness when thickness arises primarily through higher separation rates rather than larger housing stocks. Higher separation probability increases the likelihood of selling before capturing renovation benefits. The combination generates a renovation threshold that increases with market thickness, rationalizing the observed pattern of lower renovation activity in Lithuania's largest cities.

We validate the model through two exercises. First, we calibrate the model using observed housing-market parameters—separation probabilities measured as transaction-to-stock ratios, housing stock sizes, and plausible values for renovation costs and bargaining power—and compute predicted renovation thresholds for each municipality. These thresholds correlate strongly and negatively with observed renovation rates: a one-standard-deviation increase in the predicted threshold is associated with a reduction in renovation activity that exceeds the mean renovation rate. The relationship is robust to controlling for municipality and year fixed effects. Second, we examine the model's comparative statics directly. Consistent with theory, municipalities with higher separation probabilities exhibit lower renovation rates conditional on housing stock size, and this relationship operates through the threshold mechanism the model identifies.

Finally, we conduct a counterfactual policy analysis to quantify the efficiency costs of uniform subsidies. Using the calibrated model, we compute the municipality-specific subsidy rates that would equalize renovation thresholds across municipalities, thereby providing equivalent private incentives regardless of local housing-market conditions. The results are striking: while some rural municipalities would require minimal additional support (less than 5 percentage points above current rates), Lithuania's three largest cities would need subsidy increases of about 15 percentage points to achieve incentive parity. In the most challenging urban submarkets, equalization would require overall sub-

sidy rates approaching 50%. These findings suggest that uniform national policies systematically under-incentivize renovation in thick markets.

Related literature: Our paper relates to and contributes to several strands of literature. First, we advance the search-and-matching literature on housing markets by introducing a durable investment decision — energy-efficiency renovation — into a framework in which market liquidity and turnover risk shape the distribution of surplus between buyers and sellers. Canonical models beginning with Wheaton (1990) and extended by Krainer (2001); Diaz and Jerez (2013) emphasize how search frictions generate dispersion in prices, time-on-market, and inventory dynamics. More recent work highlights thick-market effects: in liquid markets, the availability of multiple trading partners raises match quality and compresses sellers' bargaining power (Ngai and Tenreyro, 2014; Genesove and Han, 2012; Anenberg and Bayer, 2020).

Second, our paper contributes to the empirical literature on the capitalization of energy efficiency in housing markets. A large body of work documents positive price premia for energy-efficient or "green-labeled" dwellings using hedonic or repeat-sales designs (Brounen and Kok, 2011; Fuerst and McAllister, 2011; Kahn and Kok, 2014; Bisello et al., 2020; Fuerst et al., 2016). However, much of this evidence relies on cross-sectional comparisons or certification-based measures of efficiency that may conflate energy performance with unobserved quality. Recent quasi-experimental and repeated-sales approaches, such as Myers (2019) and Aydin et al. (2020), find more modest capitalization effects, consistent with our estimates. Our empirical contribution differs in two important respects. First, we observe realized renovation costs for all projects in a nationwide program, allowing us to quantify net private returns, rather than gross appreciation alone—something largely absent in the existing literature. Second, we document substantial spatial heterogeneity in both gross and net returns despite uniform subsidies, with gross premia smaller yet net losses attenuated in thick urban markets. This pattern does not arise in standard hedonic models but follows naturally from our theoretical emphasis on turnover and surplus division.

Third, our findings connect to the literature on regional heterogeneity in housing returns and the role of market structure in shaping investment incentives. A growing set of papers highlights how local economic conditions, demographic dynamics, and credit markets generate persistent dispersion in housing returns across space (Gyourko et al., 2013; Van Nieuwerburgh and Weill, 2010; Han, 2013; Amaral et al., 2024, 2025). Our results complement this literature by showing that even identical investments—standardized energy-efficiency upgrades—yield markedly different private returns across municipalities due to housing market thickness, rather than preferences or fundamen-

tals. In this sense, our paper bridges urban and environmental economics by identifying a structural mechanism—turnover risk interacting with bargaining—that produces spatially uneven incentives for renovation under nationally uniform policies.

Finally, our paper relates to research on the "energy-efficiency gap," which documents persistently low adoption of seemingly cost-effective energy-saving technologies. Explanations include liquidity constraints, information frictions, behavioral biases, and coordination failures in multi-unit buildings (Allcott and Greenstone, 2012; Gillingham and Palmer, 2014; Gerarden et al., 2017; Allcott and Taubinsky, 2015). In post-socialist housing systems similar to Lithuania's, low financial literacy, weak institutions, and collective action frictions have also been emphasized (Asmare et al., 2023; Kažukauskas and Li, 2024). While these channels matter, they do not fully explain why renovation activity is lowest in the municipalities with the highest prices, deepest credit markets, and greatest construction capacity. Our contribution is to identify a complementary mechanism—market-structure-induced hold-up—through which owners rationally underinvest because they expect to separate before recouping benefits and cannot fully capitalize remaining value in resale. Our policy counterfactuals show this mechanism has first-order implications: uniform subsidies can systematically under-incentivize renovation in thick markets, implying that spatially differentiated subsidies or mechanisms to enhance seller surplus capture may be necessary to achieve renovation targets.

The remainder of the paper proceeds as follows. Section 1 provides institutional background on Lithuania's housing stock and renovation program. Section 2 describes our data and presents summary statistics. Section 3 develops the empirical analysis, documenting price effects, regional heterogeneity, and the relationship between market thickness and renovation activity. Section 4 presents the theoretical model, derives its predictions, validates them against the data, and conducts counterfactual policy analysis. Section 5 concludes.

1. Background

This section establishes the institutional context for our analysis by examining Lithuania's Soviet-era housing legacy and the renovation program designed to address its energy inefficiencies. We first describe the characteristics and geographic distribution of Soviet-built apartment blocks, then detail the structure and performance of Lithuania's renovation program.

1.1 Soviet-era Residential Buildings

Following World War II, Lithuania remained under Soviet occupation. The Soviet Union implemented an industrialization policy that triggered rapid urbanization, with Lithuania's urban population share growing from 30% before the war to 68% by the 1980s (Burneika et al., 2019).

To accommodate this urban influx, Soviet authorities initiated large-scale housing projects consisting of uniform concrete residential buildings. These structures embodied brutalist architecture principles, favored for cost-effectiveness and construction speed (Andrusz, 1985).

This construction legacy persists today. As of 2011, Soviet-era buildings housed 67% of Lithuanian residents (Hess and Tammaru, 2019). These apartment blocks are often centrally located and concentrated in specific neighborhoods. Figure 1 shows that in Lithuania's four largest cities, numerous neighborhoods comprise over 75% Soviet-era housing, with these high-concentration areas typically clustered near city centers.

Now several decades old, many Soviet-era apartment blocks suffer from deteriorating conditions and poor energy efficiency, resulting in high heating costs for residents. As we show below, the average non-renovated apartment block was built in 1976, with the most common energy rating being class F — the second lowest efficiency grade.

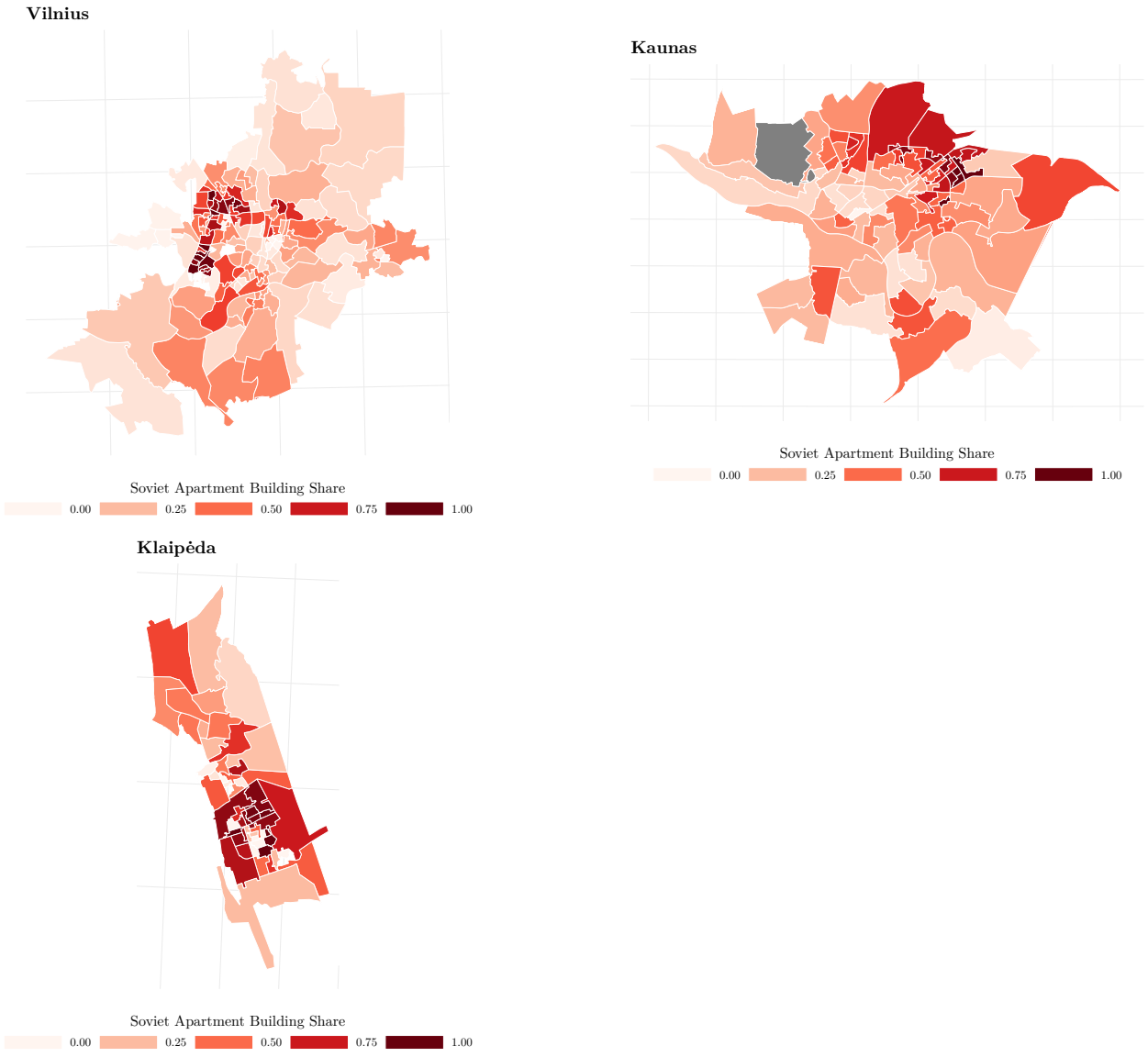
The low energy efficiency and deteriorated condition creates the policy imperative for energy efficiency renovation programs. This we discuss next.

1.2 The Lithuanian Multi-apartment Buildings Renovation Program

To address the energy inefficiency of its aging housing stock, particularly the Soviet-era apartment blocks that dominate urban landscapes, Lithuania initiated a comprehensive renovation program as early as 2005, aiming to enhance both energy efficiency and livability of run-down apartment blocks.

The structure of the renovation program reflects a multifaceted approach to incentivizing renovation. Since 2011 the government provides full subsidies (100%) for creating renovation projects and their administration, as well as for construction maintenance. Since 2009 interest rates on renovation loans are fixed at 3%, with the government covering the difference. The subsidy rate for investments in energy efficiency measures has fluctuated over time, reflecting policy adjustments and changing priorities. In Table 1 we show the subsidy rate over time, also listing main differences in requirements. The full table of these measures is provided in Appendix Table A1. We start Table 1 with year 2009 be-

Figure 1: Share of Soviet-built apartments in the largest cities in Lithuania



Source: Real Property Cadastre and Register.
Notes: Each panel maps the share of Soviet era apartments built in 1960–1990 by neighborhood (electoral district). Darker shading indicates higher shares. Panels show Vilnius, Kaunas, and Klaipėda.

cause previously the subsidy rate was contingent on a different scheme than A–D ratings. After 2009 the subsidy rate for investments enhancing energy efficiency was set at 15%. In 2013 the contingency scheme became more nuanced and more generous: for renovation projects achieving at least 40% of energy savings, the policy introduced additional subsidy rates on top of the 15% rate. The additional rates vary from 15% to 25% depending on the project timeline. The policy became stricter in 2015, when new renovation projects were required to achieve at least class C and 40% energy savings to be entitled to additional subsidies. Finally, in 2018 the rate differentiation collapsed to one requirement

Table 1: Subsidy rate for investments enhancing energy efficiency (shortened)

	2009-12	2013-08	2015-01	2015-07	2018-01	2022-11
at least class B is achieved						30%
additionally 20% for the heating system modernization expenses						Yes
at least class C and 20% of energy savings	15%					
at least class C and 40% of energy savings					30%	
additionally 10% for the heating system modernization expenses					Yes	
at least class D and 20% of energy savings		15%	15%	15%		
additionally at least class D and 40% of energy savings & investment project before Dec 31 2014		15-25%	15-25%	20-25%		
at least class C and 40% of energy savings & investment project after Jan 1 2015			15-20%	15-20%		

Source: Resolutions of the Government of the Republic of Lithuania; summarized by the authors.
Notes: The table summarizes the main subsidy schemes for multi-apartment building renovation (energy efficiency improvements) over time. See Appendix Table A1 for a more detailed report on these subsidy policies. Columns denote the period of applicability, while rows indicate eligibility criteria based on achieved energy class and minimum energy savings. Earlier schemes (2009–2015) focused on achieving at least class C or D with specified savings thresholds, while later reforms (2018–2022) shifted support to projects achieving class B or higher. In certain periods, additional subsidies were available for modernization of heating systems. Reported subsidy rates reflect the maximum state co-financing share of investment in energy efficiency.

– projects have to achieve at least class C and 40% energy savings to receive a 30% subsidy rate. In 2022 the policy became even stricter, requiring to achieve at least class B. The subsidy rate remained set at 30%.

Concerns surrounding the policy: Despite some positive outcomes, the program faces several challenges (Lithuania National Audit Office, 2020). The National Audit Report highlights issues such as low participation rates, with 35% of selected projects not being implemented due to objections from apartment owners. Quality concerns plague the investment planning phase, with 78% of applications requiring adjustment and 29.3% facing rejection. Implementation delays are common, with 31% of projects experiencing setbacks of over 18 months due to discrepancies in investment plans.

The program's effectiveness is further hampered by inefficiencies in project selection, which does not always prioritize the most energy-efficient proposals. A significant funding gap exists, with the demand for funds in 2017–2018 (€519.85 million) almost doubling the amount agreed with

financiers for soft loans. Monitoring and data collection inadequacies also persist, potentially leading to inaccurate assessments of the program's impact and effectiveness.

In response to these challenges, the government has implemented changes. Amendments effective from January 1, 2020, expanded the scope of state support to include modernization of heating substations, water systems, and installation of individual heating meters. However, the lack of robust procedures for evaluating and utilizing monitoring data at the Ministry of Environment hinders continuous improvement of the modernization process.

2. Data and Stylized Facts

2.1 Data

Sources: We combine three administrative datasets to analyze renovation effects on apartment prices. Our primary data sources are: (1) the Real Property Cadastre and Register, providing universe-level information on dwellings and transactions; (2) completed renovation project records from the Environment Projects Management Agency (APVA); and (3) postcode mapping data from Lithuanian Post.

Property and Transaction Data. The Real Property Cadastre provides complete coverage of Lithuania's housing stock as of 2023, including dwelling characteristics (square area, rooms, floor, amenities), construction year, and imputed values from the State Enterprise Centre of Registers (SECR). Transaction records span 2010–2023 with unique dwelling identifiers, sale prices, dates, and transaction types. We focus on standard purchase transactions (98% of all sales) and exclude partial ownership transfers to minimize measurement error, losing approximately 1% of observations.

Renovation Project Data. The APVA dataset contains detailed information on all completed renovations since 2013, including project costs, subsidy amounts, realized energy savings achieved, and realized final energy class ratings. We supplement this with approximately 500 pre-2013 renovations for robustness checks. Projects are matched to properties using building addresses. Since some large apartment blocks contain multiple buildings with separate renovation timelines, we restrict analysis to buildings with single renovation projects or simultaneous multiple projects.

Postcodes. we use the dataset provided by Lithuanian Post to augment address information with 5-digit postcodes. The postcode information allows us to create a measure of neighborhoods; specifically, we

classify addresses into neighborhoods using 2-digit postcodes.

Sample selection: The final sample contains observations for dwellings in residential buildings built over the period 1941–1990 and larger than 200 square meters area. These restrictions narrow down the sample to Soviet era buildings and drops individual houses. To identify the effect of renovation on house prices we will estimate a repeated-sales model. For this end, we will also restrict the final sample even more by limiting it to dwellings that were transacted twice in the sample period.

2.2 Stylized Facts

Summary statistics: Table 2 presents summary statistics for our sample. In the sample of residential buildings constructed between 1946 and 1992 with at least one dwelling transacted between 2010 and 2023, 3,042 buildings underwent renovation (Column 2), representing approximately 4.5% of all buildings in the sample. These renovated buildings comprise 26,137 dwellings (apartments), representing approximately 11.7% of all dwellings in the sample.

The substantial differences in average square area and number of apartments between renovated and non-renovated buildings suggest that the non-renovated sample includes a significant number of individual houses or buildings with one to two apartments. To address this potential bias, we restrict the sample to buildings with a square area greater than 200 square meters. This restriction increases the share of renovated buildings to 3,034 or 14.2% of all buildings.

Comparing columns (3) and (4) reveals that renovated buildings are, on average, older than non-renovated ones. Renovated buildings also tend to be larger, both in terms of average square area and number of apartments. However, both renovated and non-renovated buildings have an average of four floors.

Renovated buildings are more likely to be located in cities (92% vs. 68% for non-renovated), but less likely to be in the top-3 cities (20% vs. 28% for non-renovated). After renovation, the most common energy class is C, compared to F for non-renovated buildings, indicating substantial energy efficiency gains from renovation.

For the final sample of dwellings we impose three additional conditions: 1) they have to be sold twice between 2010 and 2023; 2) their second sale has to be at least one year later than the first sale; 3) dwellings have to be located in buildings that were not renovated or experienced one renovation project only. The first restriction constructs the required sample for a repeated sales model, whereas the second restriction excludes apartment with very frequent sales that might exhibit different pricing

Table 2: Summary statistics

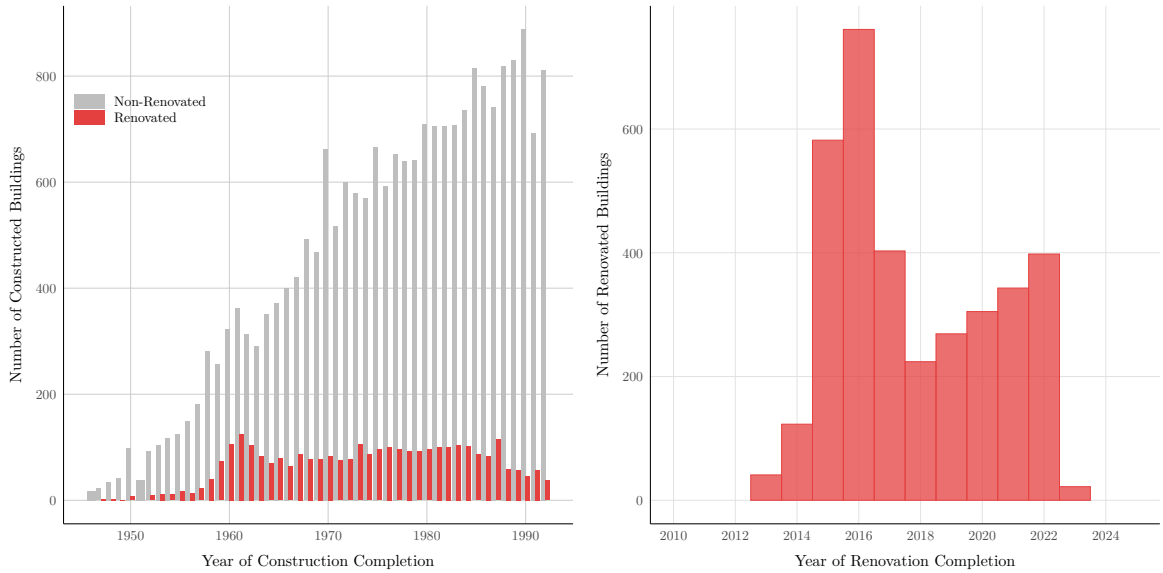
Construction year:	1946–1992							
Square area:	full sample		> 200 m^2					
Number of sales:	≥ 1		≥ 1		2			
Renovation status:	No	Yes	No	Yes	No	Yes		
Renovated between observed sales:							No	Yes
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Number of buildings	64196	3042	21415	3034	9915	1953	757	1196
Number of dwellings	197083	26137	151558	26115	24121	4312	2493	1819
Average construction year	1971	1974	1977	1974	1977	1974	1974	1974
Average building square area	631	2042	1690	2047	2675	2371	2172	2497
Average number of apartments	13	31	28	31	42	37	34	39
Average number of floors	2	4	4	4	5	5	5	5
Mode of energy class as of 2023	F	C	F	C	F	C	C	C
Mode of energy class after renovation		C		C		C	C	C
Share of buildings in cities	0.4	0.92	0.68	0.92	0.83	0.94	0.95	0.94
Share of buildings in top 3 cities	0.12	0.2	0.28	0.2	0.4	0.22	0.21	0.22

Source: Real Property Cadastre and Register, APVA.
*Notes:*The sample is progressively restricted from the full universe of Soviet-era residential buildings (columns (1)–(2)) to buildings larger than 200 m^2 (columns (3)–(4)) to exclude individual houses, and finally to buildings with dwellings sold twice between 2010–2023 (columns (5)–(8)) for the repeated-sales analysis. Renovation status in columns (7)–(8) indicates whether renovation occurred between the two observed sales. Building characteristics are measured as of 2023. Cities refer to urban areas within municipalities, while "top-3 cities" specifically denotes Vilnius, Kaunas, and Klaipėda.

behavior. The third restriction reduces a measurement error from assigning the renovation effect to the wrong apartment if the building was renovated in several phases over several years. Columns (5)–(8) report the statistics for the final sample. The additional restrictions reduce the number of unique buildings to 11,686 and the number of unique renovated buildings to 1,953 (16.5% of the final sample). The number of unique dwellings decreases to 28,433, out of which 4,312 dwellings are located in renovated buildings (15.2% of the final sample of dwellings) as showed in column (6). This restriction alters some previously observed patterns: (1) Renovated buildings remain older on average but become smaller (2,371 square meters compared to 2,675 square meters for non-renovated buildings); (2) renovated buildings now have fewer apartments on average (37 vs. 42 for non-renovated buildings); and (3) the location difference persists but narrows: 94% of renovated buildings are in cities compared to 83% of non-renovated buildings.

The reduced difference in urban location shares may be attributed to the exclusion of less liquid, likely rural properties when restricting the sample to dwellings with two sales. However, the difference

Figure 2: Renovated residential buildings by construction year and renovation year



(a) Distribution by construction year

(b) Distribution by renovation year

Source: Real Property Cadastre and Register, APVA.
Notes: Left panel shows counts of renovated and non-renovated buildings by construction year. Right panel shows counts of renovated buildings by renovation completion year.

in the share of buildings located in the top-3 cities becomes more pronounced: 22% of renovated buildings are in the top-3 cities compared to 40% of non-renovated buildings. This increased disparity in locations suggests that renovation is predominantly concentrated in smaller cities.

Columns (7) and (8) further differentiate renovated buildings based on whether the renovation occurred between the observed sales. This step pins down the number of dwellings (1,819) that experienced the change in the renovation status and thus will be used in the repeated-sales framework as treated units, allowing for a more nuanced analysis of the renovation's impact on property values and characteristics.

The renovation program explicitly targeted blocks of apartments that received building permits before 1993. We observe that buildings constructed between 1950 and 1995, as evidenced by renovation data (Figure 2a), became the main beneficiaries of the program. The grey or red shaded bars show the number of non-renovated or renovated buildings for the specific construction year. The scale of the program has also varied over time, with annual completions ranging from slightly over 200 to 700 buildings (Figure 2b). Between 2012 and 2016, there was an increase in the number of renovated apartment buildings, followed by a decline during 2017 and 2018 and a modest increase afterwards. Taken together, Figure 2 illustrates the issue of the low take-up of the renovation program subsidy: a

large fraction of buildings constructed during the period 1950–1990 remain unrenovated.

The program's regulatory framework stipulates that before 2018, subsidies are contingent on achieving a minimum energy class of D after the renovation. In 2018–2022, however, class C is the required minimum energy class (Table 1). These requirements have resulted in class C being the most common energy class among renovated buildings. Data from the APVA indicates significant energy savings, with renovated buildings averaging close to 62% reduction in energy consumption (Appendix Figure A1a). Interestingly, however, there is a weak relationship between gain in energy efficiency and cost of renovation (Appendix Figure A1b).

Regional variation: Regional disparities in renovation activity are striking. Table 3 documents this variation across Lithuania's municipalities. The three largest cities—Vilnius, Kaunas, and Klaipėda—which together account for more than 60 percent of the country's population and exhibit the thickest housing markets, display notably lower renovation rates than smaller municipalities. Vilnius, the capital and largest market, has renovated only 7.6% of its Soviet-era apartment stock, while Kaunas reaches 10.7% and Klaipėda 16.2%. In contrast, the remaining 51 municipalities collectively achieve a renovation share of 16.2%, matching or exceeding the rates in the major cities. The mean renovation share across the three largest cities is 11.5%, substantially below the national average.

Table 3: Share of renovated Soviet apartment blocks across municipalities

Municipality	Soviet-era buildings	Renovated	Renovation share
Vilnius	3737	283	0.076
Kaunas	3094	330	0.107
Klaipėda	1498	242	0.162
Other regions	16117	2616	0.162
Mean (3 largest cities)			0.115
Std. dev. (all municipalities)			0.151

Source: Real Property Cadastre and Register, APVA.
Notes: This table reports the share of Soviet-era apartment blocks (constructed between 1946 and 1992) with a total building area exceeding 200 square meters that have undergone renovation.

This pattern is paradoxical from a standard investment perspective. Lithuania's largest municipalities possess greater fiscal capacity, deeper credit markets, and better access to construction and renovation services. If renovation decisions were driven primarily by financial constraints or supply-side factors, we would expect *higher* renovation rates in thick urban markets, not lower. Yet the data reveal the opposite. Further, the standard deviation of renovation shares (0.151) approaches the mean

itself, yielding a coefficient of variation above 0.9. This substantial heterogeneity emerges because of a spatially uniform national policy as we show below using a search-and-matching framework with turnover risk and limited surplus extraction.

The rest of the paper intends to explain this stylized fact as it has implications for the design of renovation subsidy policy. We do so by first providing empirical results which inform the modeling choices we make. Then, we develop a theory that captures the observed patterns.

3. Results

Our empirical analysis proceeds in three stages. First, we establish the baseline relationship between renovations and apartment prices using a repeated-sales approach that eliminates unobserved heterogeneity across units. Second, we document substantial regional variation in renovation effects, showing that while gross price gains are lower in Lithuania's largest municipalities, net returns are actually higher due to more favorable cost-price ratios. These empirical findings motivate our theoretical framework in Section 4, where we develop a search-and-matching model to explain how market thickness can generate the observed regional heterogeneity in renovation incentives.

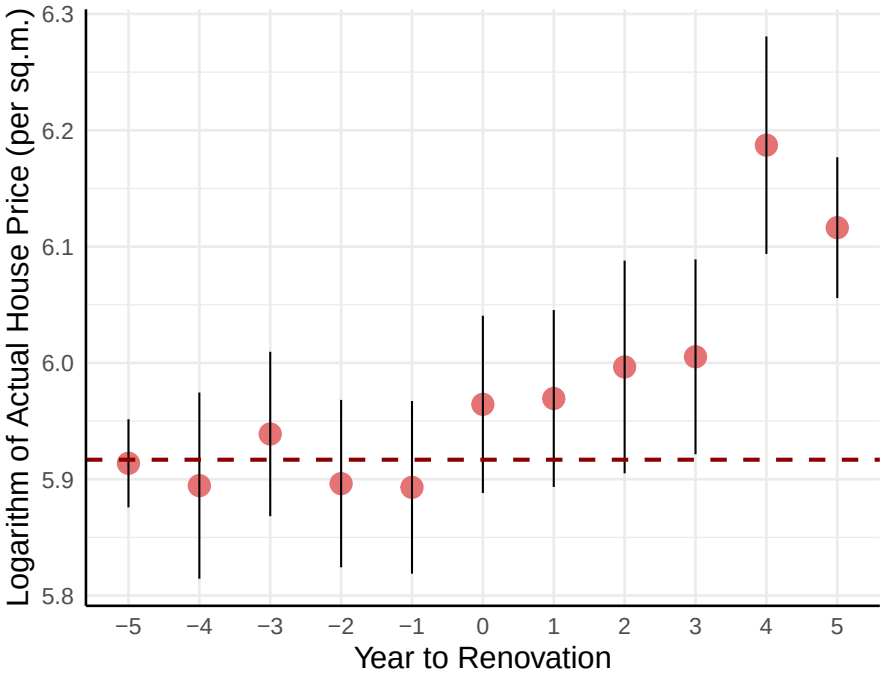
3.1 Non-parametric Evidence

Before turning to formal econometric analysis, we examine the raw relationship between renovations and apartment prices. This non-parametric approach reveals the underlying patterns in our data without imposing modeling assumptions, helping to guide our subsequent empirical strategy.

We construct a "years-since-renovation" variable measuring the time elapsed between renovation completion and each transaction. For apartment i renovated in year t^{ren} and sold in years t^1 and t^2, this variable takes values from $t^1 - t^{\text{ren}}$ to $t^2 - t^{\text{ren}}$. This allows us to track price dynamics around renovation events, though the irregular timing of apartment sales prevents a formal event study approach.

Figure 3 plots average log prices per square meter against years since renovation. The pattern emerges: apartments sold after renovation command higher prices than the pre-renovation average, however, the difference becomes statistically significant for transactions occurring more than three years since renovation. This premium appears to grow over time, reaching its peak for apartments sold four years post-renovation.

Figure 3: Apartment prices before and after renovation



Source: Real Property Cadastre and Register, APVA.
Notes: The figure plots average log prices per square meter against years since renovation, where year 0 denotes the renovation completion year. Transactions occurring more than 5 years before or after renovation are binned at the endpoints. Vertical black lines indicate 95% confidence intervals constructed using bootstrapped standard errors.

This non-parametric evidence suggests a positive association between renovations and apartment prices. However, it does not account for observable apartment characteristics, unobserved heterogeneity, or potential confounding factors. In the following section, we present results from our repeated-sales model, which addresses these limitations by exploiting within-apartment variation and controlling for time-varying neighborhood characteristics.

3.2 Estimation Results

To identify the effect of renovations on apartment prices, we employ a repeated-sales model that compares prices for the same apartment before and after renovation. This approach eliminates bias from unobserved time-invariant apartment characteristics such as location quality, building design, or neighborhood amenities.

We estimate:

$$\Delta p_{ij,t^1,t^2} = \beta_0 + \beta_1 \cdot \text{Renovated}_i + \gamma_{t^1} + \gamma_{t^2} + \delta_{j,t^1} + \delta_{j,t^2} + \epsilon_{ij,t^1,t^2} \tag{3.1}$$

where i indexes apartment, j indexes 2-digit postcode, and t^1 and t^2 are the two points in time when apartment got transacted. The dependent variable $\Delta p_{ij,t^1,t^2} = \log\left(P_{ij,t^2}\right) - \log\left(P_{ij,t^1}\right)$ is the log price change for apartment i between its first (t^1) and second sale (t^2). P_{ij,t^1} and P_{ij,t^2} denote deflated prices per square meter in the first and second transactions, respectively. We deflate using a quarterly housing price index and winsorize at the 1st and 99th percentiles. $\texttt{Renovated}_i$ is our renovation indicator, equal to one if apartment i underwent renovation between its two observed sales. The coefficient β_1 captures the average price effect of renovation.

We include year fixed effects for both sales (γ_{t^1}, γ_{t^2}) to control for aggregate price trends. We also include postcode-by-year interactions δ_{j,t^1}, δ_{j,t^2} where j indexes 2-digit postcodes. These controls absorb time-varying neighborhood demand shifts that could confound our renovation effect.

Our identification strategy relies on the timing of renovations being uncorrelated with unobserved apartment-specific shocks that affect price growth. The postcode-by-year interactions control for local demand trends, while the repeated-sales structure eliminates time-invariant heterogeneity.

3.2.1 Price effect of renovation

Gross price effect: Table 4 presents our primary results across increasingly stringent specifications. Column (3), our preferred specification, includes fixed effects for sale years, postcodes, and their interactions to control for aggregate shocks and localized demand shifts. We find that renovations increase apartment prices by 8.8% on average, depending on the specification, demonstrating clear market recognition of energy efficiency improvements.

Net price effect: The critical question is whether these price gains justify renovation expenditures. Columns (4)–(6) present cost-adjusted estimates where we subtract imputed renovation costs from price changes for renovated units. We allocate building-level renovation costs to individual apartments proportionally by floor area, as renovation costs scale directly with apartment size.

The cost-adjusted results reveal a stark contrast: renovation investments generate negative net returns of approximately 22.3%. This substantial gap between price appreciation and renovation costs suggests that homeowners cannot recover their full investment through higher property values

Table 4: Repeated-sales model results

Dependent Variables:	log price change			log net price change		
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Renovation dummy	0.0809***	0.0900***	0.0875***	-0.2417***	-0.2141***	-0.2229***
	(0.0224)	(0.0164)	(0.0164)	(0.0265)	(0.0237)	(0.0222)
First sale year	Yes	Yes	Yes	Yes	Yes	Yes
Second sale year	Yes	Yes	Yes	Yes	Yes	Yes
Municipality × First sale year		Yes			Yes	
Municipality × Second sale year		Yes			Yes	
Municipality		Yes			Yes	
Postcode × First sale year			Yes			Yes
Postcode × Second sale year			Yes			Yes
Postcode			Yes			Yes
Observations	28,356	28,356	28,356	28,259	28,259	28,259
Renovated apartments	1,819	1,819	1,819	1,722	1,722	1,722
R^2	0.01390	0.14977	0.17261	0.02279	0.15775	0.18067

Source: Real Property Cadastre and Register, APVA.
Notes: The table presents baseline repeated-sales model estimates of renovation effects on apartment prices. The dependent variable in columns (1)-(3) is the log difference in deflated price per square meter between second and first sales. The dependent variable in columns (4)-(6) adjusts for renovation costs by subtracting deflated renovation costs per square meter from the price change for renovated apartments. Renovation costs are imputed at the apartment level by allocating total building renovation costs proportionally based on apartment area. All prices are deflated using a quarterly housing price index and winsorized at the 1st and 99th percentiles. Progressive specifications add municipality-level and postcode-level fixed effects interacted with sale years to control for time-varying local demand conditions. Standard errors are clustered at the 2-digit postcode level.

alone.

3.2.2 Regional Variation in Renovation Effects

While our baseline results reveal that renovation investments generate negative net returns on average, this aggregate finding masks regional heterogeneity. The gap between price gains and renovation costs varies dramatically across Lithuanian municipalities, driven primarily by differences in local housing market conditions rather than renovation costs themselves.

To understand the sources of regional variation in net renovation returns, we decompose the net price effect into its constituent components. For any apartment i in neighborhood j, the net return

can be written as:

$$\log\left(P_{ij,t^2} - c_{ij}\right) - \log\left(P_{ij,t^1}\right) = \log\frac{P_{ij,t^2} - c_{ij}}{P_{ij,t^1}} = \log\left(\frac{P_{ij,t^2}}{P_{ij,t^1}} - \frac{c_{ij}}{P_{ij,t^1}}\right)$$

where the first term in the logarithm represents the gross price effect and the second term is the cost-price ratio. Regional differences in net returns can thus arise from variation in either gross price appreciation or the relative burden of renovation costs.

Table 5: Renovation cost and apartment price variation across regions

	mean cost (€/m²)	mean price (€/m²)	cost-price ratio
	(1)	(2)	(3)
Top-3 cities	106.8	846.2	0.14
Other municipalities	108.6	352.6	0.42

Source: Real Property Cadastre and Register, APVA.
Notes: The table compares mean renovation costs, mean apartment prices, and their ratio between Lithuania's three largest cities (Vilnius, Kaunas, and Klaipėda) and all other municipalities. Costs and prices are measured in euros per square meter and computed using the sample of apartments that got sold twice between 2010 and 2023. The cost-price ratio is calculated as the mean of the renovation cost divided by the apartment price of the first sale in each region.

Table 5 reveals striking differences in this cost-price ratio across regions. While renovation costs per square meter are virtually identical between Lithuania's three largest municipalities (€106.8) and other areas (€108.6), apartment price levels differ dramatically. The three largest municipalities command average prices of €846 per square meter—more than double the €353 average in other municipalities. This price differential translates into vastly different cost-price ratios: renovation costs represent only 14% of apartment values in the largest municipalities compared to 42% elsewhere—a threefold difference.

To formally analyze how these regional differences affect renovation returns, we augment our baseline model by interacting the renovation indicator with location dummies:

$$\Delta p_{ij,t^1,t^2} = \beta_0 + \beta_1 \cdot \text{Renovated}_i + \beta_2 \cdot \text{Renovated}_i \times \text{Top-3}_j + \gamma_{t^1} + \gamma_{t^2} + \delta_{j,t^1} + \delta_{j,t^2} + \epsilon_{ij,t^1,t^2} \quad (3.2)$$

where Top-3_j is an indicator for apartments in the three largest municipalities.

Table 6 presents the results, examining both gross price effects (columns 1–2) and net effects (columns 3–4) across regions. The findings reveal a striking paradox. Column (2) shows that gross

Table 6: Repeated-sales model: heterogeneity by location

Dependent Variables:	log price change		log net price change		cost-price ratio	log cost	price change
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Renovation dummy	0.0875***	0.1102***	-0.2229***	-0.2696***			39.78***
	(0.0164)	(0.0182)	(0.0222)	(0.0277)			(5.543)
Renovation dummy × top-3		-0.0826***		0.1633***			-4.728
		(0.0310)		(0.0358)			(17.47)
top-3					-0.3844***	0.0318	
					(0.0873)	(0.0345)	
Fixed-effects							
first-sale year	Yes	Yes	Yes	Yes			Yes
second-sale year	Yes	Yes	Yes	Yes			Yes
postcode-first-sale year	Yes	Yes	Yes	Yes			Yes
postcode-second-sale year	Yes	Yes	Yes	Yes			Yes
postcode	Yes	Yes	Yes	Yes			Yes
renovation-end year					Yes	Yes	
Observations	28,356	28,356	28,259	28,259	1,819	1,819	28,356
Renovated apartments	1,819	1,819	1,722	1,722	1,819	1,819	1,819
R^2	0.17261	0.17289	0.18067	0.18167	0.07251	0.03497	0.20385

Notes: The table presents baseline repeated-sales model estimates of renovation effects on apartment prices. Indicator variable "top-3" has value one for buildings in the three largest municipalities (Vilnius city, Kaunas city and Klaipeda city) and zero otherwise. Net prices are computed by subtracting the relevant renovation costs for those apartments that got renovated before the sale. Models in columns (8) and (9) are estimated using the sample of only those apartments that got renovated between the two observed sales. The cost-price ratio is computed as the ratio of deflated renovation cost to deflated price of the first sale. The log cost variable (column (6)) is computed as log deflated renovation cost per square meter. All prices are deflated using a quarterly housing price index and winsorized at the 1st and 99th percentiles. The dependent variable in column (7) is computed as a difference in deflated price levels. Standard errors are clustered at the 2-digit postcode level.

price effects are actually *lower* in the three largest municipalities—renovated apartments there experience 8.3 percentage points smaller price gains, resulting in a 2.8% gross effect compared to 11.0% elsewhere. However, column (4) demonstrates that net effects tell the opposite story: the largest municipalities achieve a net return of −10.6% versus −27.0% in other areas—a 16.3 percentage point advantage.

This reversal occurs because cost-price ratios dominate the regional comparison. Column (5) confirms that the cost-price ratio is 38.44 percentage points lower in the largest municipalities, more than offsetting their smaller gross price gains. Column (6) verifies that this difference stems entirely from the price denominator rather than renovation costs—there are no statistically significant differences in log renovation costs across regions.

These patterns suggest that renovation investments face very different economic environments

across Lithuania's housing markets. In smaller municipalities, renovation costs represent a substantial fraction of property values, making cost recovery challenging even with solid price appreciation. In contrast, the largest municipalities offer a more favorable cost-price environment where identical renovation expenditures represent a smaller relative burden, improving net returns despite weaker gross price performance.

Column (7) provides additional insight into this mechanism by examining absolute rather than percentage price changes. The lack of significant regional differences in absolute price gains confirms that renovation produces similar nominal value increases regardless of location. The regional variation in gross percentage effects thus reflects differences in the price base rather than the absolute benefits of renovation.

3.2.3 Robustness checks

We conduct several robustness checks to validate our main findings across multiple dimensions: specification choices, sample composition, and alternative explanations for regional variation.

Specification robustness. Appendix Table A2 shows the estimation results using price growth rates instead of log differences. We find that the gross price effect is 7.9% and the net price effect is -23.4%. Also, the gross price effect is 14.9% lower in the top-3 municipalities, yielding an -2.3% gross effect for this region. The net price effect is 7.9% higher in the top-3 municipalities, however, the estimate of this interaction term is not significant. Thus, the main baseline findings carry through. To ensure our regional findings are not driven by spatial aggregation choices, Appendix Table A3 employs 3-digit rather than 2-digit postcode fixed effects, producing nearly identical results.

We also verify that our regional heterogeneity is not driven by Vilnius alone. Appendix Table A4 excludes Vilnius and finds that Kaunas and Klaipėda still exhibit a 10% lower gross effect but a 12.3% higher net effect compared to other municipalities, with a 35.8 percentage point lower cost-price ratio. In the specification with growth rates in prices rather than log price changes, the gross effect is lower by 17.6% and the regional difference in the net effect is not statistically different.

Sample robustness. First, we address potential bias from disproportionately deteriorated properties by excluding apartments priced 50% or more below their predicted values in Appendix Table A5. This restriction removes potentially distressed sales that might bias our renovation effect estimates upward. Our core results remain qualitatively unchanged: renovations increase prices by 7.8–8.8% but generate negative net returns of 19.3–22.2%.

Second, we verify our results hold under alternative sample restrictions. Appendix Tables A6–A7 present results when we: (i) increase the minimum building size threshold to 300 square meters to exclude individual houses better; and (ii) drop buildings renovated between 2005 and 2012, which we treat as non-renovated in our main analysis due to incomplete data on renovation projects. Across all specifications, we consistently find positive gross price effects of 7.9–8.7% and negative net effects of 22.3–23.3%. The regional variation is consistent too.

Alternative explanation: unpaid renovation loans.. A potential concern is that our regional findings reflect differential loan uptake rather than market thickness effects. If residents in larger municipalities systematically take renovation loans while those elsewhere pay cash, transferred loan obligations could depress prices more in urban areas, explaining lower gross effects there.

To test this alternative explanation, we augment the model in 3.1 by including an estimate of transferred renovation costs – the renovation loan. We impute the value of unpaid renovation loans at the time of each sale based on the parameters of government-subsidized renovation loans, specifically, a fixed 3% interest rate and a 20-year term. We assume that all apartment owners took loans rather than paid upfront.

The estimation results in Table 7 show that the imputed loan does not explain the spatial variation in the gross price effect. In columns (1)–(4) we analyze the effect on the log price change and in columns (5)–(8) we present the results for the price growth rate. In column (2) the renovation effect on log price change is still 8 percentage points lower in top-3 municipalities, similarly as without accounting for imputed renovation loans, but the interaction variable of the renovation dummy and renovation costs (the value of imputed renovation loan) is statistically insignificant. Only including renovation costs as a ratio to the first-sale price makes makes this factor play a role in determining the price gain from renovation. It seems that it is the first-sale price that drives the effect rather than the costs variable. In column (4) we observe that including the log of the first-sale price absorbs the spatial variation of the renovation effect as the interaction effect of the renovation dummy and top-3 municipalities dummy becomes insignificant. The results with the price growth rate are qualitatively similar.

Summary and implications. Our empirical analysis reveals three key patterns that challenge conventional wisdom about energy efficiency investments. First, while renovations generate positive price appreciation in the neighborhood of 8-9%, these gains fall substantially short of renovation costs, creating negative net returns of approximately 19-23%. Second, this shortfall varies across regions:

although gross price effects are paradoxically lower in Lithuania's largest municipalities, net returns are significantly higher due to more favorable cost-price ratios. Third, these regional differences cannot be explained by differential loan uptake patterns, pointing to fundamental differences in how housing markets capitalize efficiency investments.

4. A Theory of Market Thickness and Renovation Incentives

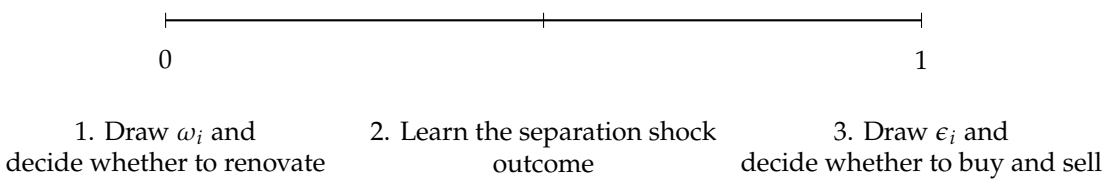
To explain the empirical patterns documented above, we develop a search-and-matching model of the housing market where market thickness – the volume of transactions – affects both the returns to renovation and homeowners' incentives to invest in energy efficiency.

The key insight is that market thickness creates a trade-off for homeowners considering renovation. In thick markets, homeowners face higher separation probabilities and more liquid resale markets, but limited bargaining power means they cannot capture the full value of their investments. This mechanism can simultaneously explain why gross price effects are lower in large cities (higher baseline prices make percentage gains lower) while net price effects are more favorable (lower cost-price ratios), and why renovation activity remains subdued in the most liquid markets.

4.1 Model Environment

We model a one-period economy with $\overline{\nu}$ identical households, each initially owning one house. The timing unfolds in three stages as shown in Figure 4:

Figure 4: Timing of household decisions



Stage 1: Renovation Decision. Each household i privately observes its idiosyncratic renovation benefit ω_i, capturing household-specific factors such as preferences for energy efficiency, varying baseline conditions, or heterogeneous renovation needs. Households then decide whether to renovate, paying fixed cost $c > 0$ to obtain additional housing services $b > 0$. Crucially, we assume renovation

benefits are *additive* – a renovated house provides housing services $h + b$ regardless of baseline quality h. This reflects the nature of energy efficiency improvements (insulation, windows, heating systems) that provide similar absolute benefits across different properties.

Stage 2: Separation Shock. After renovation costs are sunk, nature determines which households must relocate. With probability $(1 - \phi)$, a household receives an exogenous separation shock – representing job relocation, family changes, or other life events – forcing it to sell and search for new housing. This creates a pool of $v = (1 - \phi)\overline{v}$ houses for sale, where market thickness depends on both the separation rate $(1 - \phi)$ and housing stock $\overline{v}$.

Stage 3: Search and Matching. Separated households enter the market simultaneously as buyers and sellers. Each buyer is randomly matched with one seller and draws a match-specific housing service flow $\epsilon_i \sim F(\epsilon, v)$ determining their valuation of the matched house. We assume $F(\epsilon, v)$ exhibits first-order stochastic dominance in v: thicker markets (higher v) generate stochastically higher match quality, reflecting greater choice and selection opportunities in liquid markets.

If total surplus from trade is positive, the transaction occurs at a Nash bargaining price with seller bargaining power $\theta \in (0, 1)$. Otherwise, the buyer receives zero utility and the seller retains the house, earning outside option r (interpretable as rental income).

4.2 Decision Problems and Equilibrium

4.2.1 The Renovation Decision

Each household chooses whether to renovate by comparing expected payoffs under uncertainty about future separation, creating a fundamental tension between immediate costs and uncertain future benefits.

Payoff Without Renovation. If household i does not renovate, it receives expected utility:

$$V_i^{NR} = \phi h + (1 - \phi)[B + O^{NR}]$$

where h is the housing service flow from an unrenovated house, B is the expected buyer value (identical across households), and O^{NR} is the expected seller value for an unrenovated house. With probability ϕ, the household avoids separation and enjoys housing services h. With probability $(1 - \phi)$, it must sell and buy, earning the sum of seller and buyer values.

Payoff With Renovation. If household i renovates, it pays cost c, receives idiosyncratic benefit ω_i, and obtains expected utility:

$$V_i^R = -c + \omega_i + \phi(h + b) + (1 - \phi)[B + O^R]$$

Renovation increases housing services by b for households that remain, while those who move earn the seller value O^R from selling a renovated house.

Renovation Threshold. Household i renovates if and only if $V_i^R \geqslant V_i^{NR}$, yielding the indifference condition:

$$\omega^* = c - \phi b - (1 - \phi)(O^R - O^{NR}) \tag{4.1}$$

The renovation threshold ω^* increases in cost c and decreases in both the direct benefit b and the seller value premium $(O^R - O^{NR})$.

4.2.2 Search, Matching, and Pricing

Reservation Services and Trading Decisions. We denote the seller's surplus from a given transaction as $S_O(\epsilon)$ and the buyer's surplus as $S_B(\epsilon)$. The seller earns the difference between the price $p^j(\epsilon)$, $j \in \{NR, R\}$ and his outside option r, which reflects rent income that could be earned if the house remains unsold. We assume that rent income does not depend on the renovation status.

The seller's surplus is given by:

$$S_O^j(\epsilon) = p^j(\epsilon) - r$$

The buyer earns the difference between the housing services and the price:

$$S_B^j(\epsilon) = \epsilon + b \times \mathbf{1}_{j=R} - p^j(\epsilon)$$

where $\mathbf{1}_{j=R}$ is an indicator that equals one if the house is renovated and zero otherwise.

Trade occurs if and only if the total surplus – the sum of $S_O^j(\epsilon)$ and $S_B^j(\epsilon)$ – is positive. This condition yields reservation levels of the housing services shock: $\epsilon^{NR} = r$ for unrenovated houses and $\epsilon^R = r - b$ for renovated houses. Renovation lowers the reservation threshold, making renovated houses more likely to sell.

Nash Bargaining and Equilibrium Prices. When trade occurs, prices are determined by Nash

bargaining with seller bargaining power $\theta \in (0, 1)$. This yields equilibrium prices:

$$p^{NR}(\epsilon) = \theta\epsilon + (1 - \theta)r \tag{4.2}$$

$$p^{R}(\epsilon) = \theta(\epsilon + b) + (1 - \theta)r \tag{4.3}$$

For any given match quality ϵ, renovated houses command a price premium of exactly θb—the seller captures fraction θ of the renovation benefit through bargaining.

Seller Values and Market Thickness. The expected value of selling depends on both the probability of sale and the expected price conditional on sale. Under our assumption that $F(\epsilon, \nu)$ is uniform on $[0, \nu]$, where $\nu = (1 - \phi)\overline{\nu}$ is the number of houses for sale, the seller values are:

$$O^{NR} = \frac{1}{2\nu}\left[\theta r^2 + \theta\nu^2 + 2(1 - \theta)r\nu\right] \tag{4.4}$$

$$O^{R} = \frac{1}{2\nu}\left[\theta r^2 + \theta\nu^2 + 2(1 - \theta)r\nu + \theta b\left(b - 2(r - \nu)\right)\right] \tag{4.5}$$

The key insight is that $O^R - O^{NR} > 0$[1]: renovated houses are both more likely to sell and command higher prices when sold, creating a seller value premium that increases with market thickness.

4.3 Model Results

We now derive the model's key predictions and show how they rationalize our empirical findings. The model generates three main results that directly correspond to patterns observed in the Lithuanian data.

Proposition 4.1 (Gross Price Effect)**.** *The gross price effect of renovation, measured as a percentage increase, decreases with market thickness ν.*

Renovation provides a fixed absolute benefit regardless of market conditions, but this represents a smaller percentage increase in thicker markets where baseline prices are higher. Under our uniform distribution assumption, the average price difference between renovated and unrenovated houses is $E[p^R(\epsilon)|\epsilon \geq \epsilon^R] - E[p^{NR}(\epsilon)|\epsilon \geq \epsilon^{NR}] = \theta b/2$. This absolute difference is independent of market thickness, consistent with our empirical finding in Table 6 column (7) that absolute price gains are similar across regions (€34 vs €31).

[1]We assume that $r < \nu$ to ensure that the matching probability for non-renovated houses $F(\epsilon^{NR}, \nu)$ is less than one.

However, expressing this as a percentage change – the average price difference relative to the expected conditional price of unrenovated houses – yields:

$$\text{Gross Price Effect} = \frac{\theta b/2}{\theta(r+\nu)/2 + (1-\theta)r}$$

We can show that $\frac{\partial \text{Gross Price Effect}}{\partial \nu} < 0$. Thicker markets generate higher baseline prices through better matching, but renovation benefits remain constant in absolute terms, so this mechanically reduces the percentage price gain from renovation, explaining why we observe a lower gross price effect in Lithuania's largest municipalities (2.8% vs. 11.0%).

Proposition 4.2 (Net Price Effect)**.** *When renovation costs exceed the seller's bargaining share of renovation benefits ($c > \theta b/2$), the net price effect increases with market thickness ν.*

While the gross price effect decreases with market thickness, the cost-price ratio falls even faster in thick markets. The net price effect is:

$$\text{Net Price Effect} = \text{Gross Price Effect} - \frac{c}{E[p^{NR}(\epsilon)|\epsilon \geq \epsilon^{NR}]}$$

Taking the derivative with respect to market thickness shows that when $c > \theta b/2$, the cost-price ratio effect dominates the gross price effect, making the net price effect increase with market thickness. This explains the second empirical fact: net returns to renovation are more favorable in Lithuania's largest municipalities (-10.6% vs. -27.0%) despite lower gross price effects. Since renovation costs are geographically uniform but apartment prices are higher in thick markets, renovation costs represent only 14% of apartment values in large cities compared to 42% elsewhere.

Proposition 4.3 (Renovation Incentives)**.** *When market thickness increases primarily through higher separation rates rather than housing stock, renovation activity decreases with market thickness.*

Higher separation probabilities create a hold-up problem where homeowners who are more likely to move cannot capture the full benefits of renovation due to limited bargaining power in resale markets. From equation (4.1), taking the derivative with respect to the probability to stay yields $\frac{\partial \omega^*}{\partial(1-\phi)} = (1-\theta)b > 0$ as $\theta < 1$. This implies ω^* increases with the increase in separation probability i.e. $1-\phi$. Higher separation rates increase the renovation threshold, making fewer households willing to renovate. This provides a novel explanation for why renovation activity is lower in Lithuania's largest municipalities despite better access to capital and contractors: higher labor mobility and family

turnover in urban areas reduce renovation incentives as households anticipate they may not capture the full value of their investments.

In short, the model successfully rationalizes all key empirical patterns. Lithuania's three largest municipalities exhibit smaller gross price effects but larger net price effects because thicker markets have higher baseline prices (reducing percentage gains) while lower cost-price ratios improve net returns. The framework is also consistent with absolute price gains across regions, lower urban renovation rates despite better infrastructure, and negative average returns of -22% when renovation costs exceed the seller's bargaining share of benefits.

4.4 Model Validation

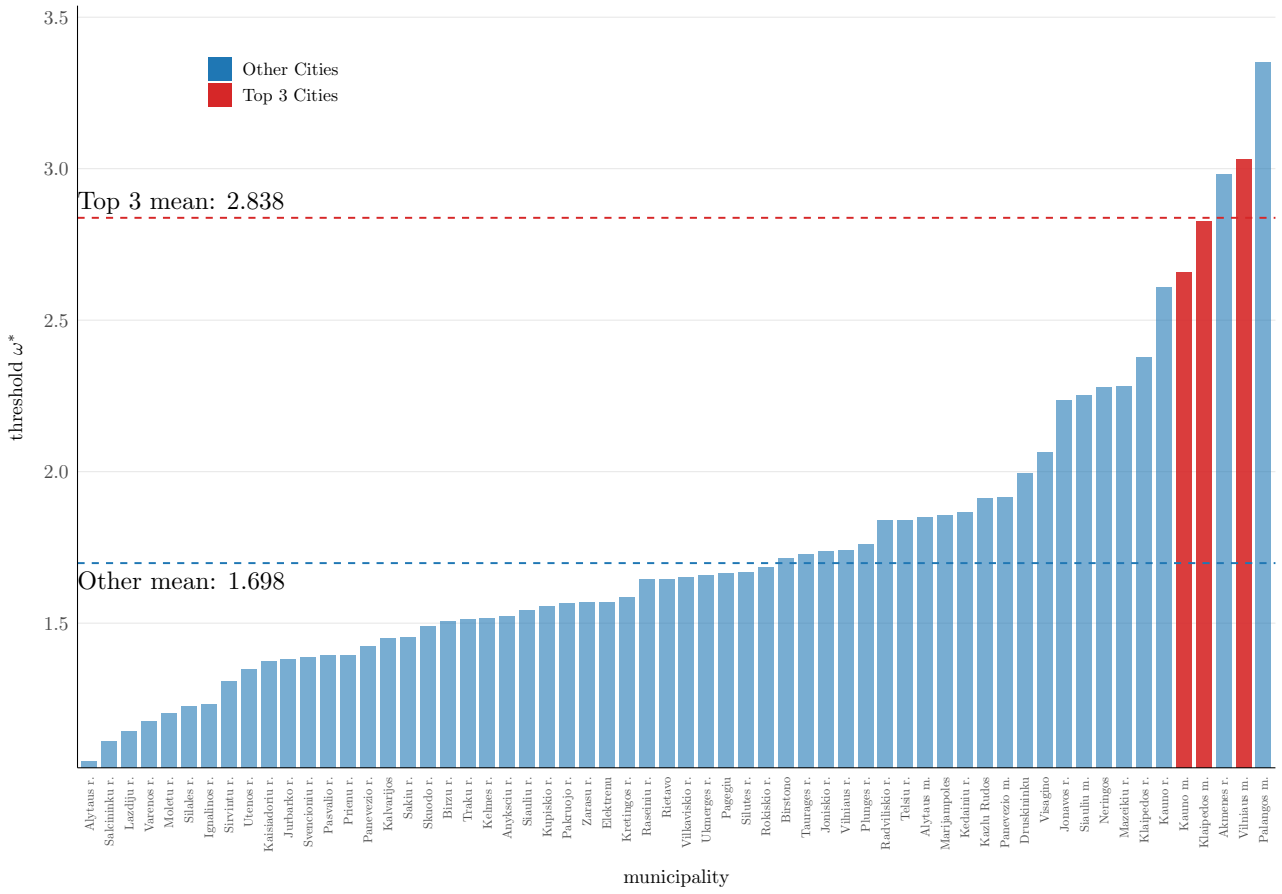
To validate our theoretical framework, we calibrate the model using housing market data from Lithuania and examine whether predicted renovation thresholds align with observed regional differences in renovation activity.

We calibrate key parameters using empirical magnitudes and standard assumptions. In Appendix we show that alternative calibration exercises lead to the same results. We normalize the outside option $r = 1$, and set $c = b = 0.12r$, based on the assumption that renovation reduces heating bills by 60% with heating comprising 10–20% of rent expenditure, and assume moderate seller bargaining power, i.e. $\theta = 0.5$.

Figure 5 presents the distribution of predicted renovation thresholds across Lithuanian municipalities. These thresholds are computed using the calibrated model parameters and municipality-level housing market characteristics, following equation (4.1).

We plot municipality-level thresholds in ascending order, distinguishing three largest cities (Vilnius, Kaunas, Klaipėda) from all other municipalities. Dashed horizontal lines indicate group means. In our theoretical framework, a higher threshold ω^* implies that only households with high idiosyncratic renovation benefits would choose to renovate; thus, municipalities with higher thresholds should exhibit lower renovation rates.

Figure 5: Predicted municipality-level renovation thresholds ω^*



Notes: The figure plots predicted renovation thresholds ω_i^* for all Lithuanian municipalities in ascending order. Thresholds are computed using calibrated model parameters and municipality-level housing market characteristics, following equation (4.1). Dashed horizontal lines denote mean thresholds for the three largest cities (Vilnius, Kaunas, Klaipėda) in red and for all other municipalities in blue.

The distribution of thresholds is highly dispersed. Across 60 municipalities, the mean threshold is 1.7552, with a standard deviation of 0.4949 and a coefficient of variation of 28.19%. Thresholds range from 1.0435 (Alytaus r.) to 3.3513 (Palangos m.), indicating substantial heterogeneity in the incentives to renovate.

Consistent with the model's prediction that thicker markets produce *higher* renovation thresholds, the three largest cities stand out sharply. Their mean threshold is 2.8378, compared to 1.6982 in other municipalities, a 67% difference. A two-sample t-test confirms that this difference is statistically significant at the 5% level ($t = 9.31$, $p = 0.0018$). These findings align with the theoretical mechanism: in large, highly liquid housing markets, homeowners face higher probabilities of moving before

capturing the full returns to renovation, which raises the threshold and can depress renovation activity.

While Figure 5 provides cross-sectional evidence that predicted renovation thresholds vary systematically across municipalities in a manner consistent with the theoretical mechanism, a more stringent validation requires testing whether these thresholds (and the market-thickness variables that drive them) actually predict observed renovation activity over time. To this end, we estimate a set of municipality-year panel regressions of the form

$$\text{RenovationRate}_{it} = \alpha + \beta X_{it} + \mu_i + \tau_t + \varepsilon_{it}, \tag{4.6}$$

where $\text{RenovationRate}_{it}$ is the number of renovated dwellings in municipality i during year t divided by its total housing stock, X_{it} includes our measures of market thickness and the theoretically predicted threshold ω_i^*, and μ_i and τ_t denote municipality and year fixed effects, respectively. All independent variables are standardized to facilitate coefficient interpretation, and regressions are weighted by housing sales.

Table 8 reports the results. Columns (1)–(3) use contemporaneous measures, while columns (4)–(6) employ one-year lags. The latter is important because renovation decisions require planning, financing, and coordination, and thus may respond more strongly to market conditions observed in prior periods.

Across all specifications, we find strong empirical support for the mechanism implied by the theoretical model. First, separation probability as measured by the ratio of annual housing sales to the housing stock in a municipality is negatively and significantly associated with renovation activity. A one-standard-deviation increase in the separation rate lowers the renovation rate by roughly 0.20–0.21 percentage points in the contemporaneous specification (columns (1)–(2)) and by 0.16–0.19 percentage points when lagged (columns (4)–(5)). Given that the average annual renovation rate is below 1%, these magnitudes are economically meaningful. Importantly, housing stock—the other component of market thickness in the model—is never statistically significant, suggesting that variation in separation probabilities, rather than variation in market size, is the primary driver of threshold heterogeneity.

Columns (3) and (6) test the model's central prediction by replacing reduced-form market-thickness variables with the theoretically derived renovation threshold ω_i^* , which aggregates the role of separation probability with other factors such as the housing stock, renovation costs and bene-

fits, the normalized rent income and the bargaining power. In both cases, the estimated coefficient is negative and statistically significant: municipalities with higher predicted thresholds indeed exhibit lower realized renovation rates. A one-standard-deviation increase in ω_i^* reduces the renovation rate by 0.0129 (contemporaneous) to 0.0151 (lagged) units. The lagged specification is more precisely estimated, consistent with the timing of renovation decisions.

Taken together, these regression results serve as a deeper validation of the model. The cross-sectional evidence from Figure 5 shows that predicted thresholds align with observed spatial differences in renovation activity, while the panel regressions in Table 8 demonstrate that the same mechanism holds over time and across changing market conditions. Municipalities where households face higher separation probabilities—and thus higher risks of not capturing the benefits of renovation before moving—are precisely those where renovation activity is lowest.

4.5 Counterfactual

The heterogeneity in predicted renovation thresholds across municipalities implies that a uniform subsidy scheme will not equalize renovation incentives geographically. To quantify how aggressive a differentiated policy would need to be, we consider a simple counterfactual experiment in which the government chooses municipality-specific subsidy rates so as to equalize the renovation threshold ω_i^* across the country.

For each municipality i, we take the benchmark to be the municipality with the lowest calibrated threshold,

$$\omega_{\min}^* = \min_i \omega_i^*,$$

and ask what additional subsidy rate s_i would be required to reduce the effective net cost of renovation so that the threshold in i matches $\omega_{\min}^*$. Under our specification, this implies

$$s_i \equiv \frac{\omega_i^* - \omega_{\min}^*}{c},$$

which we report in percentage points as the "required additional subsidy" for each municipality. Intuitively, s_i measures how much more generous the subsidy in municipality i would need to be, relative to the current calibration, in order to make landlords there just as willing to renovate as in the municipality with the strongest incentives.

Table 9 summarizes the distribution of s_i across municipalities. The mean required additional

subsidy is 5.93%, with a median of 5.05%, indicating that for a typical municipality only a moderate increase in the subsidy rate would be sufficient to align renovation incentives with the national benchmark. However, there is substantial dispersion: the maximum required subsidy is 19.23%, suggesting that some markets would need very large subsidies to catch up. The three largest cities (Vilnius, Kaunas, and Klaipėda) stand out in this respect. Their average required subsidy is 14.95%, compared to 5.46% for all other municipalities, implying a gap of 9.50 percentage points. In other words, equalizing renovation incentives would require disproportionately more support in the main urban centers than elsewhere.

Further, this proposed counterfactual aims to equalize renovation rate across municipalities, it does not produce high renovation activity in absolute terms. Renovation rate are low to begin with. Equalizing incentives therefore raises all municipalities to a level of *relatively low* renovation propensity. In other words, the exercise shows that substantial heterogeneity can be removed with moderate subsidies, but it also highlights the deeper challenge: additional subsidy will generate limited renovation.

This implies that, if the policy objective is to meaningfully increase nationwide renovation rates rather than merely eliminate spatial disparities, subsidies must exceed the levels reported in Table 9. The counterfactual therefore provides a lower bound on the subsidy required for a genuinely ambitious renovation program.

An additional policy concern emerges once we account for the distribution of the building stock. The municipalities requiring the highest subsidy rates are also the ones with the largest number of apartment blocks in need of renovation. Because the counterfactual subsidy is proportional to the renovation cost per building, but must be applied to a significantly larger stock in major cities, the fiscal burden of equalizing incentives is far from uniform. Even if smaller municipalities can be brought to the benchmark with only a modest subsidy increase, the large cities dominate the aggregate cost of any differentiated policy.

This interaction between *high required subsidy rates* and *large renovation volumes* underscores that spatially targeted renovation subsidies may not be fiscally cheap. Policymakers face a choice: (i) adopt a differentiated subsidy scheme that is economically well-targeted but potentially expensive, or (ii) implement a uniform subsidy at a higher level, which reduces spatial inequality but may still fall short of inducing sufficient renovation activity.

Taken together, the counterfactual highlights two key insights. First, substantial spatial heterogeneity in renovation incentives can be eliminated with moderate subsidies—except in large cities, where

thresholds are much higher. Second, eliminating heterogeneity does not solve the central problem: renovation rates are low everywhere, including in the benchmark municipality. This implies that a more ambitious national renovation strategy would require substantially higher subsidies than those implied by this equalization exercise.

5. Conclusions

This paper provide an explanation why energy efficiency renovations, despite substantial subsidies and environmental benefits, remain underutilized. Focusing on Lithuania, we showed that variation in housing market structure is central to understanding renovation patterns. While prior literature has emphasized financial constraints, coordination failures, and behavioral frictions, our analysis demonstrates that market thickness fundamentally shapes both the gross and net returns to renovation, and thus the willingness of households to invest.

Our empirical findings revealed three core facts. First, renovation activity is highly uneven across municipalities even under uniform national subsidy policies. Lithuania's largest cities – where access to credit and construction services should be more favorable – exhibit disproportionately low renovation activity. Second, repeated-sales estimates showed that while renovations do increase apartment values, by roughly 8-9% on average, this appreciation is insufficient to cover costs. Net returns remain negative, ranging between -19 and -22%, and varying substantially across regions. Third, the regional patterns are heterogeneous: gross price premia are smaller in thick urban markets, but net returns are less negative relative to thinner rural markets.

To rationalize these findings, we developed a search-and-matching model in which market thickness alters both capitalization and incentives. In thicker markets, higher separation probabilities raise the risk that households will sell before recouping renovation benefits, while greater buyer choice limits sellers' bargaining power.

The model validation provided two layers of support. First, the model predictions regarding gross versus net price effects and their relationship with market thickness map directly to our empirical findings. Second, when we calibrated municipality-level thresholds for renovation, we found that higher thresholds strongly correlated with lower observed renovation rates. A one-standard deviation increase in the threshold reduced renovation uptake by more than the mean annual renovation rate, underscoring the power of market structure in explaining observed regional variation.

Our counterfactual policy experiments highlight the implications of these findings. If policymakers ignore market thickness, subsidy programs risk systematically underperforming in certain regions. Equalizing renovation incentives across municipalities would require large adjustments: some rural markets would need minimal additional support, while large cities would require substantially higher subsidy rates, in some cases approaching 50%. These results underline that a uniform subsidy policy, while administratively simple, is unlikely to deliver equitable or efficient renovation outcomes across heterogeneous housing markets.

Three broader implications emerge from our study. First, renovation policies should be designed with an explicit awareness of market structure. Energy efficiency improvements are not only technological or financial decisions; they are part of market environments where the likelihood of capturing returns depends on transaction dynamics. Second, our findings suggest that thick-market effects – long studied in relation to price dispersion and transaction volumes – also matter for household investment decisions. By linking renovation choices to search frictions and separation risks, we extend the scope of search-and-matching models in housing economics. Third, our analysis speaks to the design of climate policy. If renovation programs are to meaningfully contribute to carbon reduction goals, they must not only subsidize costs but also align incentives with the structural realities of local housing markets.

References

Allcott, H. and M. Greenstone (2012): "Is There an Energy Efficiency Gap?" *Journal of Economic Perspectives*, 26, 3–28.

Allcott, H. and D. Taubinsky (2015): "Evaluating Behaviorally Motivated Policy: Experimental Evidence from the Lightbulb Market," *American Economic Review*, 105, 2501–2538.

Amaral, F., M. Dohmen, S. Kohl, and M. Schularick (2025): "Superstar Returns? Spatial Heterogeneity in Returns to Housing," *Journal of Finance*.

Amaral, F., M. Dohmen, M. Schularick, and J. Zdrzalek (2024): "Interest Rates and the Spatial Polarisation of Housing Markets," *American Economic Review: Insights*, 6, 1–18.

Andrusz, G. D. (1985): *Housing and Urban Development in the USSR*, State University of New York Press.

Anenberg, E. and P. Bayer (2020): "Endogenous sources of volatility in housing markets: The joint buyer–seller problem," *International Economic Review*, 61, 1195–1228.

Asmare, F., V. Giedraitis, J. Jaraitė, and A. Kažukauskas (2023): "Energy-related financial literacy and retrofits of Soviet-era apartment buildings: The case of Lithuania," *Energy Economics*, 120, 106583.

Aydin, E., D. Brounen, and N. Kok (2020): "The capitalization of energy efficiency: Evidence from the housing market," *Journal of Urban Economics*, 117, 103243.

Bisello, A., V. Antoniucci, and G. Marella (2020): "Measuring the price premium of energy efficiency: A two-step analysis in the Italian housing market," *Energy and Buildings*, 208, 109670.

Brounen, D. and N. Kok (2011): "On the economics of energy labels in the housing market," *Journal of Environmental Economics and Management*, 62, 166–179.

Burneika, D., R. Ubarevičienė, and A. Baranuskaitė (2019): "Soviet Housing Estates in Vilnius, Lithuania: Socio-ethnic Structure and Future(-Less?) Perspectives," in *Housing Estates in the Baltic Countries*, ed. by D. B. Hess and T. Tammaru, Springer, Cham, The Urban Book Series, 247–270.

Diaz, A. and B. Jerez (2013): "House prices, sales, and time on the market: A search-theoretic framework," *International Economic Review*, 54, 837–872.

European Commission (2020): "A Renovation Wave for Europe – Greening our Buildings, Creating Jobs, Improving Lives," https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0662.

Fuerst, F. and P. McAllister (2011): "Green Noise or Green Value? Measuring the Effects of Environmental Certification on Office Values," *Real Estate Economics*, 39, 45–69.

Fuerst, F., E. Oikarinen, and O. Harjunen (2016): "Green signalling effects in the market for energy-efficient residential buildings," *Applied Energy*, 180, 560–571.

Genesove, D. and L. Han (2012): "A search model of the housing market," *Journal of Urban Economics*, 72, 31–45.

Gerarden, T. D., R. G. Newell, and R. N. Stavins (2017): "Assessing the Energy-Efficiency Gap," *Journal of Economic Literature*, 55, 1486–1525.

Gillingham, K. and K. Palmer (2014): "Bridging the Energy Efficiency Gap: Policy Insights from Economic Theory and Empirical Evidence," *Review of Environmental Economics and Policy*, 8, 18–38.

Gyourko, J., C. Mayer, and T. Sinai (2013): "Superstar cities," *American Economic Journal: Economic Policy*, 5, 167–199.

Han, L. (2013): "Understanding the Puzzling Risk-Return Relationship for Housing," *Review of Financial Studies*, 26, 877–928.

Hess, D. B. and T. Tammaru (2019): "Modernist housing estates in the Baltic countries: formation, current challenges and future prospects," *Housing estates in the Baltic countries: The legacy of central planning in Estonia, Latvia and Lithuania*, 3–27.

Kahn, M. E. and N. Kok (2014): "The capitalization of green labels in the California housing market," *Regional Science and Urban Economics*, 47, 25–34.

Kažukauskas, A. and X. Li (2024): "Realized dynamic effect of retrofits on energy consumption in Soviet-era multi-apartment buildings," *Energy Economics*, 134, 107563.

Krainer, J. (2001): "A theory of liquidity in residential real estate markets," *Journal of urban Economics*, 49, 32–53.

Lithuania National Audit Office (2020): "Multi-apartment Building Renovation (Modernisation)," .

Myers, E. (2019): "Are Home Buyers Inattentive? Evidence from Capitalization of Energy Costs," *American Economic Journal: Economic Policy*, 11, 165–188.

Ngai, L. R. and S. Tenreyro (2014): "Hot and cold seasons in the housing market," *American Economic Review*, 104, 3991–4026.

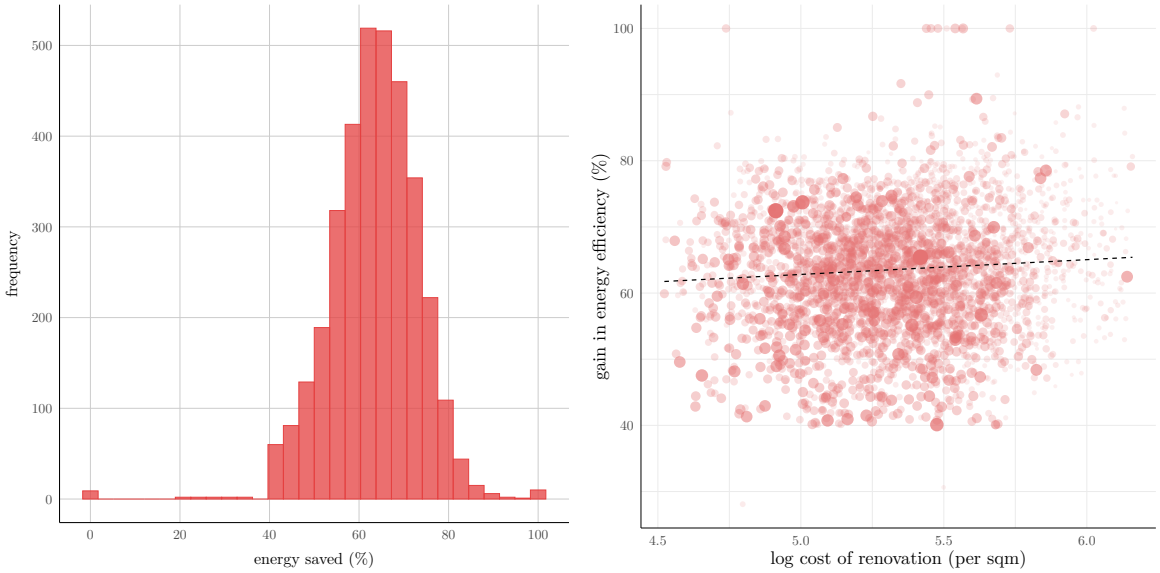
Van Nieuwerburgh, S. and P.-O. Weill (2010): "Why Has House Price Dispersion Gone Up?" *Review of Economic Studies*, 77, 1567–1606.

Wheaton, W. C. (1990): "Vacancy, search, and prices in a housing market matching model," *Journal of political Economy*, 98, 1270–1292.

A. Appendix

A.1 Additional Tables and Figures

Figure A1: Energy efficiency gains from renovation



(a) Energy saved due to renovation

(b) Cost of renovation and energy efficiency gain

Source: Real Property Cadastre and Register, APVA

Table 7: Repeated-sales model: the imputed loans effect

Dependent Variables:	log price change				price growth			
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Renovation dummy	0.1101***	0.1621***	-0.0195	0.9821***	0.1198**	0.1389	-0.3742***	1.943**
	(0.0181)	(0.0427)	(0.0333)	(0.2446)	(0.0483)	(0.0956)	(0.1316)	(0.9029)
Renovation dummy × top-3	-0.0824***	-0.0808**	0.0104	0.0212	-0.1479**	-0.1473**	0.2061**	0.0201
	(0.0309)	(0.0308)	(0.0330)	(0.0435)	(0.0570)	(0.0571)	(0.0847)	(0.1459)
Renovation dummy × costs		-0.0006				-0.0002		
		(0.0004)				(0.0009)		
Renovation dummy × costs-price ratio			0.2674***				1.020**	
			(0.1008)				(0.4207)	
log first-sale price				-0.3506***				-1.021***
				(0.0252)				(0.1063)
Renovation dummy × log first-sale price				-0.1442***				-0.2922*
				(0.0414)				(0.1552)
Fixed-effects								
first-sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
second-sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
postcode-first-sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
postcode-second-sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
postcode	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	28,356	28,356	28,356	28,356	28,356	28,356	28,356	28,356
Renovated apartments	1,819	1,819	1,819	1,819	1,819	1,819	1,819	1,819
R^2	0.17292	0.17297	0.17836	0.30769	0.12557	0.12557	0.13571	0.26911

Notes: The table presents baseline repeated-sales model estimates of renovation effects on apartment prices. Indicator variable "top-3" has value one for buildings in the three largest municipalities (Vilnius city, Kaunas city and Klaipeda city) and zero otherwise. The costs variable (in the independent variable list) is computed as imputed renovation loan costs per square meter. The costs-price ratio (in the independent variable list) is computed as imputed renovation loan costs divided by the first-sale price. All prices are deflated using a quarterly housing price index and winsorized at the 1st and 99th percentiles. Standard errors are clustered at the 2-digit postcode level.

Table 8: The Effect of Market Thickness on Renovation Activity

Dependent variable:	annual renovation rate					
Independent variables:	Contemporary			Lagged		
	(1)	(2)	(3)	(4)	(5)	(6)
Separation probability	-0.0021***	-0.0020***		-0.0016**	-0.0019*	
	(0.0006)	(0.0006)		(0.0007)	(0.0010)	
Log housing stock		-0.0010			0.0035	
		(0.0032)			(0.0044)	
Threshold ω^*			-0.0129*			-0.0151**
			(0.0067)			(0.0057)
Fixed effects						
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Mean dep. var.	0.0058	0.0058	0.0058	0.0063	0.0063	0.0063
Observations	827	827	827	767	767	767

Notes: The table reports panel regressions of municipality-year renovation rates on measures of housing market thickness and the model-predicted renovation threshold ω_i^*. Separation probability is defined as annual housing sales divided by the housing stock in a municipality. Thresholds are computed from equation (4.1) using calibrated parameters. All independent variables are standardized to have mean zero and unit variance. Regressions include municipality and year fixed effects and are weighted by housing sales. Standard errors are clustered at the municipality level are reported in parentheses.

Table 9: Counterfactual subsidy requirements to equalize renovation incentives

	mean	median	max	top-3 mean	others mean	difference
	(1)	(2)	(3)	(4)	(5)	(6)
Required additional subsidy	5.93%	5.05%	19.23%	14.95%	5.46%	9.50%

Note: This table reports the additional subsidy rates needed to equalize renovation thresholds across municipalities. The benchmark is the municipality with the lowest threshold. Required subsidy computed as $(\omega_i^* - \omega_{\min}^*)/c$ where $c = 0.12$. Based on theoretical model with $\theta = 0.5$, $b = 0.12$, $r = 1$.

Table A1: Subsidy rate for investments enhancing energy efficiency

	2009-12	2011-02	2013-08	2015-01	2015-07	2016-03	2016-12	2018-01	2022-11
at least class B is achieved									30%
additionally 20% for the heating system modernization expenses									Yes
at least class C and 20% of energy savings	15%								
at least class C and 40% of energy savings								30%	
additionally 10% for the heating system modernization expenses								Yes	
at least class D and 20% of energy savings			15%	15%	15%	15%	15%		
additionally at least class D and 40% of energy savings & investment project before Dec 31 2014									
−− the contract signed before Dec 31 2014 and the project finished before Oct 1 2015			25%	25%					
−− the contract signed Jan 1 2015 – Mar 31 2015 and the project finished before July 1 2016				25%					
−− the tender won before Mar 31 2015 and the project finished before July 1 2016					25%				
−− < ... > before Dec 31 2016						25%			

−− < ... > before July 1 2017							25%		
−− < ... > after July 1 2016					20%				
−− < ... > after Dec 31 2016						20%			
−− < ... > after July 1 2017							20%		
−− the tender won after Mar 31 2015 and the project finished before Dec 31 2017					20%	20%	20%		
−− the contract signed after Dec 31 2014 and/or the project finished after Oct 1 2015			15%	15%					
−− the contract signed Jan 1 2015 – Mar 31 2015 or after and/or the project finished before July 1 2016				15%					
at least class C and 40% of energy savings & investment project after Jan 1 2015									
−− the contract signed after Jan 1 2015 and the project finished before Dec 31 2017				20%	20%	20%	20%		
−− < ... > before Dec 31 2020				15%	15%	15%	15%		

Source: Resolutions of the Government of the Republic of Lithuania: Dec 16, 2009 (No. 1725), Jan 26, 2011 (No. 101), Jul 24, 2013 (No. 708); Dec 23, 2014 (No. 1505), Jul 1, 2015 (No. 724), Sep 30, 2015 (No. 1040), Mar 9, 2016 (No. 231), Dec 28, 2016 (No. 1277), Jan 17, 2018 (No. 54), Nov 23, 2022 (No. 1158). The policies are summarized by the authors.

Table A2: Repeated-sales model results with growth rates

Dependent Variables:	log price change		log net price change		price growth		net price growth		cost-price ratio	log cost	price change
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Renovation dummy	0.0875***	0.1102***	-0.2229***	-0.2696***	0.0789**	0.1198**	-0.2342***	-0.2569***			39.78***
	(0.0164)	(0.0182)	(0.0222)	(0.0277)	(0.0370)	(0.0486)	(0.0332)	(0.0435)			(5.543)
Renovation dummy × top-3		-0.0826***		0.1633***		-0.1490**		0.0793			-4.728
		(0.0310)		(0.0358)		(0.0575)		(0.0554)			(17.47)
top-3									-0.3844***	0.0318	
									(0.0873)	(0.0345)	
First sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Second sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode × First sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode × Second sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Renovation-end year									Yes	Yes	
Observations	28,356	28,356	28,259	28,259	28,356	28,356	28,259	28,259	1,819	1,819	28,356
Renovated apartments	1,819	1,819	1,722	1,722	1,819	1,819	1,722	1,722	1,819	1,819	1,819
R^2	0.17261	0.17289	0.18067	0.18167	0.12460	0.12471	0.12416	0.12419	0.07251	0.03497	0.20385

Clustered (postcode) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Source: Real Property Cadastre and Register, APVA.

Notes: The table presents baseline repeated-sales model estimates of renovation effects on apartment prices. Indicator variable "top-3" has value one for Vilnius city municipality, Kaunas city municipality and Klaipėda city municipality and zero otherwise. Net prices are computed by subtracting the relevant renovation costs for those apartments that got renovated before the sale. Models in columns (9) and (10) are estimated using the sample of only those apartments that got renovated between the two observed sales. The cost-price ratio is computed as the ratio of deflated renovation cost to deflated price of the first sale. The log cost variable is computed as log deflated renovation cost per square meter. The dependent variable in column (11) (price change) is computed as a difference in deflated price levels. Postcode fixed effects are constructed at the 2-digit postcode level. Standard errors are clustered at the 2-digit postcode level.

Table A3: Repeated-sales model results with 3-digit postcodes

Dependent Variables:	log price change		log net price change		price growth		net price growth		cost-price ratio	log cost	price change
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Renovation dummy	0.0885***	0.1155***	-0.2252***	-0.2738***	0.1158***	0.1589***	-0.1983***	-0.2243***			38.34***
	(0.0168)	(0.0193)	(0.0232)	(0.0290)	(0.0420)	(0.0568)	(0.0358)	(0.0473)			(5.451)
Renovation dummy × top-3		-0.0950***		0.1652***		-0.1513**		0.0882			-7.237
		(0.0357)		(0.0376)		(0.0678)		(0.0601)			(18.20)
top-3									-0.3844***	0.0318	
									(0.0666)	(0.0330)	
First sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Second sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode × First sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode × Second sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Renovation-end year									Yes	Yes	
Observations	28,356	28,356	28,259	28,259	28,356	28,356	28,259	28,259	1,819	1,819	28,356
Renovated apartments	1,819	1,819	1,722	1,722	1,819	1,819	1,722	1,722	1,819	1,819	1,819
R^2	0.17261	0.17289	0.18067	0.18167	0.12460	0.12471	0.12416	0.12419	0.07251	0.03497	0.20385

Clustered (postcode) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Source: Real Property Cadastre and Register, APVA.

Notes: The table presents baseline repeated-sales model estimates of renovation effects on apartment prices. Indicator variable "top-3" has value one for Vilnius city municipality, Kaunas city municipality and Klaipėda city municipality and zero otherwise. Net prices are computed by subtracting the relevant renovation costs for those apartments that got renovated before the sale. Models in columns (9) and (10) are estimated using the sample of only those apartments that got renovated between the two observed sales. The cost-price ratio is computed as the ratio of deflated renovation cost to deflated price of the first sale. The log cost variable is computed as log deflated renovation cost per square meter. The dependent variable in column (11) (price change) is computed as a difference in deflated price levels. Postcode fixed effects are constructed at the 3-digit postcode level. Standard errors are clustered at the 3-digit postcode level.

Table A4: Repeated-sales model results without Vilnius city municipality

Dependent Variables:	log price change		log net price change		price growth		net price growth		cost-price ratio	log cost	price change
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Renovation dummy	0.0908***	0.1102***	-0.2444***	-0.2696***	0.0854**	0.1198**	-0.2513***	-0.2569***			39.78***
	(0.0181)	(0.0182)	(0.0231)	(0.0277)	(0.0408)	(0.0486)	(0.0361)	(0.0435)			(5.548)
Renovation dummy × top-2nd and top-3rd		-0.0996***		0.1234***		-0.1764***		0.0276			-20.49
		(0.0368)		(0.0317)		(0.0634)		(0.0627)			(18.19)
top-2nd and top-3rd									-0.3584***	0.0491	
									(0.0872)	(0.0354)	
First sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Second sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode × First sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode × Second sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Renovation-end year									Yes	Yes	
Observations	22,623	22,623	22,526	22,526	22,623	22,623	22,526	22,526	1,667	1,667	22,623
Renovated apartments	1,667	1,667	1,570	1,570	1,667	1,667	1,570	1,570	1,667	1,667	1,667
R^2	0.18208	0.18240	0.19105	0.19150	0.14804	0.14818	0.14871	0.14871	0.05110	0.03463	0.22703

Clustered (postcode) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Source: Real Property Cadastre and Register, APVA.

Notes: The table presents baseline repeated-sales model estimates of renovation effects on apartment prices. The sample excludes apartments in Vilnius city municipality. Indicator variable "top-2nd and top-3rd" has value one for Kaunas city municipality and Klaipėda city municipality and zero otherwise. Net prices are computed by subtracting the relevant renovation costs for those apartments that got renovated before the sale. Models in columns (9) and (10) are estimated using the sample of only those apartments that got renovated between the two observed sales. The cost-price ratio is computed as the ratio of deflated renovation cost to deflated price of the first sale. The log cost variable is computed as log deflated renovation cost per square meter. The dependent variable in column (11) (price change) is computed as a difference in deflated price levels. Postcode fixed effects are constructed at the 2-digit postcode level. Standard errors are clustered at the 2-digit postcode level.

Table A5: Repeated-sales model results without "too low" prices

Dependent Variables:	log price change		log net price change		price growth		net price growth		cost-price ratio	log cost	price change
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Renovation dummy	0.0784***	0.0930***	-0.2222***	-0.2755***	0.0880***	0.1123***	-0.1932***	-0.2274***			35.92***
	(0.0112)	(0.0135)	(0.0234)	(0.0298)	(0.0185)	(0.0230)	(0.0195)	(0.0257)			(5.576)
Renovation dummy × top-3		-0.0511***		0.1819***		-0.0851***		0.1166***			2.972
		(0.0191)		(0.0335)		(0.0287)		(0.0294)			(13.16)
top-3									-0.2693***	0.0328	
									(0.0430)	(0.0334)	
First sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Second sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode × First sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode × Second sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Renovation-end year									Yes	Yes	
Observations	22,620	22,620	22,572	22,572	22,620	22,620	22,572	22,572	1,550	1,550	22,620
Renovated apartments	1,550	1,550	1,502	1,502	1,550	1,550	1,502	1,502	1,550	1,550	1,550
R^2	0.22704	0.22724	0.24249	0.24471	0.13363	0.13375	0.13180	0.13202	0.14535	0.04250	0.25154

Clustered (postcode) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Source: Real Property Cadastre and Register, APVA.
Notes: The table presents baseline repeated-sales model estimates of renovation effects on apartment prices. The sample excludes apartments for which the actual price is 50% or more below the predicted price. The predicted price is computed using a regression in which the log price per square meter at the first sale is regressed on the apartment's floor area, its squared term, and dummy variables for floor level, number of rooms, year of sale, and 2-digit postcode. Indicator variable "top-3" has value one for Vilnius city municipality, Kaunas city municipality and Klaipėda city municipality and zero otherwise. Net prices are computed by subtracting the relevant renovation costs for those apartments that got renovated before the sale. Models in columns (9) and (10) are estimated using the sample of only those apartments that got renovated between the two observed sales. The cost-price ratio is computed as the ratio of deflated renovation cost to deflated price of the first sale. The log cost variable is computed as log deflated renovation cost per square meter. The dependent variable in column (11) (price change) is computed as a difference in deflated price levels. Postcode fixed effects are constructed at the 2-digit postcode level. Standard errors are clustered at the 2-digit postcode level.

Table A6: Repeated-sales model results with buildings larger than 300 square meters

Dependent Variables:	log price change		log net price change		price growth		net price growth		cost-price ratio	log cost	price change
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Renovation dummy	0.0839***	0.1058***	-0.2246***	-0.2724***	0.0804**	0.1209**	-0.2314***	-0.2549***			38.58***
	(0.0164)	(0.0181)	(0.0225)	(0.0280)	(0.0369)	(0.0488)	(0.0332)	(0.0436)			(5.604)
Renovation dummy × top-3		-0.0790**		0.1652***		-0.1461**		0.0814			-3.429
		(0.0319)		(0.0365)		(0.0575)		(0.0552)			(17.77)
top-3									-0.3845***	0.0346	
									(0.0881)	(0.0346)	
First sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Second sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode × First sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode × Second sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Renovation-end year									Yes	Yes	
Observations	27,812	27,812	27,716	27,716	27,812	27,812	27,716	27,716	1,811	1,811	27,812
Renovated apartments	1,811	1,811	1,715	1,715	1,811	1,811	1,715	1,715	1,811	1,811	1,811
R^2	0.17706	0.17732	0.18524	0.18630	0.10447	0.10458	0.10352	0.10356	0.07268	0.03496	0.20617

Clustered (postcode) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Source: Real Property Cadastre and Register, APVA.

Notes: The table presents baseline repeated-sales model estimates of renovation effects on apartment prices. The sample excludes apartments in buildings whose total floor area is below 300 square meters. Indicator variable "top-3" has value one for Vilnius city municipality, Kaunas city municipality and Klaipėda city municipality and zero otherwise. Net prices are computed by subtracting the relevant renovation costs for those apartments that got renovated before the sale. Models in columns (9) and (10) are estimated using the sample of only those apartments that got renovated between the two observed sales. The cost-price ratio is computed as the ratio of deflated renovation cost to deflated price of the first sale. The log cost variable is computed as log deflated renovation cost per square meter. The dependent variable in column (11) (price change) is computed as a difference in deflated price levels. Postcode fixed effects are constructed at the 2-digit postcode level. Standard errors are clustered at the 2-digit postcode level.

Table A7: Repeated-sales model results without buildings renovated before 2013

Dependent Variables:	log price change		log net price change		price growth		net price growth		cost-price ratio	log cost	price change
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Renovation dummy	0.0872***	0.1103***	-0.2230***	-0.2693***	0.0789**	0.1210**	-0.2335***	-0.2548***			39.62***
	(0.0167)	(0.0185)	(0.0224)	(0.0280)	(0.0373)	(0.0491)	(0.0335)	(0.0441)			(5.554)
Renovation dummy × top-3		-0.0840***		0.1616***		-0.1530***		0.0743			-5.965
		(0.0314)		(0.0361)		(0.0578)		(0.0556)			(17.59)
top-3									-0.3844***	0.0318	
									(0.0873)	(0.0345)	
First sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Second sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode × First sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode × Second sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Postcode	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
Renovation-end year									Yes	Yes	
Observations	27,750	27,750	27,653	27,653	27,750	27,750	27,653	27,653	1,819	1,819	27,750
Renovated apartments	1,819	1,819	1,722	1,722	1,819	1,819	1,722	1,722	1,819	1,819	1,819
R^2	0.17479	0.17508	0.18286	0.18385	0.12642	0.12654	0.12591	0.12594	0.07251	0.03497	0.20581

Clustered (postcode) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Source: Real Property Cadastre and Register, APVA.

Notes: The table presents baseline repeated-sales model estimates of renovation effects on apartment prices. The sample excludes apartments in buildings which got renovated before 2013. Indicator variable "top-3" has value one for Vilnius city municipality, Kaunas city municipality and Klaipėda city municipality and zero otherwise. Net prices are computed by subtracting the relevant renovation costs for those apartments that got renovated before the sale. Models in columns (9) and (10) are estimated using the sample of only those apartments that got renovated between the two observed sales. The cost-price ratio is computed as the ratio of deflated renovation cost to deflated price of the first sale. The log cost variable is computed as log deflated renovation cost per square meter. The dependent variable in column (11) (price change) is computed as a difference in deflated price levels. Postcode fixed effects are constructed at the 2-digit postcode level. Standard errors are clustered at the 2-digit postcode level.

Table A8: Repeated-sales model results with imputed renovation loans

Dependent Variables:	log price change		log net price change (accounting for loans)		price growth		net price growth (accounting for loans)	
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Renovation dummy	0.0875***	0.1102***	-0.0381**	-0.0634**	0.0789**	0.1198**	-0.0555	-0.0654
	(0.0164)	(0.0182)	(0.0192)	(0.0242)	(0.0370)	(0.0486)	(0.0345)	(0.0461)
Renovation dummy × top 3		-0.0826***		0.0906**		-0.1490**		0.0355
		(0.0310)		(0.0349)		(0.0575)		(0.0554)
Fixed-effects								
first-sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
second-sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
postcode-first-sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
postcode-second-sale year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
postcode	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics								
Observations	27,783	27,783	27,783	27,783	27,783	27,783	27,783	27,783
R^2	0.17096	0.17123	0.18303	0.18359	0.12587	0.12599	0.13223	0.13263

Clustered (postcode) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Source: Real Property Cadastre and Register, APVA.
Notes: The table presents baseline repeated-sales model estimates of renovation effects on apartment prices. The dependent variables in columns (3)–(4) and (7)–(8) were adjusted by assuming that renovation loans were taken in the three largest municipalities and in a randomly selected half of renovated dwellings in other areas, so that the net price effect is equivalent to the gross price effect. Standard errors are clustered at the 2-digit postcode level.

A.2 Model results with renovation-dependent homeowner's outside option

In this subsection we describe the model results if the homeowner's outside option depends on renovation such that his outside option is denoted by r^j where $j \in \{NR, R\}$ and $r^R = r^{NR} + b$.

Reservation services. We denote the seller's surplus from a given transaction as $S_O(\epsilon)$ and the buyer's surplus from the transaction as $S_B(\epsilon)$. Since the seller would earn the difference between the price $p^j(\epsilon)$ and his outside option r^j, his surplus would be given by

$$S_O^j(\epsilon) = p^j(\epsilon) - r^j$$

The buyer would earn the difference between the housing services shock and the price, so that

$$S_B^j(\epsilon) = \epsilon + b \times \mathbf{1}\{j = R\} - p^j(\epsilon)$$

$\mathbf{1}\{j = R\}$ is an indicator that equals one if the house is renovated and zero otherwise. The sale will take place if the total surplus from the transaction – defined as the sum of $S_O^j(\epsilon)$ and $S_B^j(\epsilon)$ – is positive. We can show that, regardless of the renovation status, the reservation level of the housing services shock is given by $\epsilon^* = r^{NR}$.

The value for the seller when he is the owner of a non-renovated house would be given by the outside option if the sale does not happen and the price if the house gets sold, yielding

$$O^{NR} = F(\epsilon^*)r^{NR} + (1 - F(\epsilon^*))E\left(p^{NR}(\epsilon)|\epsilon \geq \epsilon^*\right)$$

Similarly, for a seller of a renovated house, the value is given by

$$O^{R} = F(\epsilon^*)r^{R} + (1 - F(\epsilon^*))E\left(p^{R}(\epsilon)|\epsilon \geq \epsilon^*\right)$$

Prices. We assume that the price is determined by bargaining and $\theta \in (0, 1)$ describes the seller's bargaining power. So we can solve for the price by maximizing the following objective for each $j \in \{NR, R\}$:

$$\max_{p^j(\epsilon)} \left(S_O^j(\epsilon)\right)^{\theta} \left(S_B^j(\epsilon)\right)^{1-\theta}, \quad \text{s.t.} \quad S_O^j(\epsilon), S_B^j(\epsilon) \geq 0$$

The equilibrium prices would be given by

$$p^j(\epsilon) = \theta\left(\epsilon + b \times \mathbf{1}\{j = R\}\right) + (1-\theta)r^j$$

It follows that for any level of ϵ, the price of a renovated house would be higher than the price of a non-renovated house by parameter b.

Now we can yield the first model result.

Gross Price Effect. Assuming that $F(\epsilon, \nu)$ follows a uniform distribution on $[0, \nu]$, we can show that the average price of the non-renovated house is lower than the average price of a renovated house:

$$\begin{aligned}\text{Gross Price Effect} = E\left(p^R(\epsilon)|\epsilon \geq \epsilon^*\right) - E\left(p^N(\epsilon)|\epsilon \geq \epsilon^*\right) &= \theta\frac{\epsilon^* + \nu}{2} + b + (1-\theta)r^{NR} \\ &\quad - \theta\frac{\epsilon^* + \nu}{2} - (1-\theta)r^{NR} \\ &= b > 0\end{aligned}$$

The fact the price difference does not depend on market thickness is in line with the empirical results (Table 6 column (7)). Expressing the price gain from renovation as a percentage change, we can yield the empirical result of the price gain decreasing in the market thickness:

$$\frac{E\left(p^R(\epsilon)|\epsilon \geq \epsilon^*\right) - E\left(p^N(\epsilon)|\epsilon \geq \epsilon^*\right)}{E\left(p^N(\epsilon)|\epsilon \geq \epsilon^*\right)} = \frac{b}{\theta\frac{r^{NR}+\nu}{2} + (1-\theta)r^{NR}} > 0$$

and clearly

$$\frac{\partial\frac{E\left(p^R(\epsilon)|\epsilon\geq\epsilon^*\right) - E\left(p^N(\epsilon)|\epsilon\geq\epsilon^*\right)}{E\left(p^N(\epsilon)|\epsilon\geq\epsilon^*\right)}}{\partial\nu} = -\frac{\frac{\theta}{2}b}{\left(\theta\frac{r^{NR}+\nu}{2} + (1-\theta)r^{NR}\right)^2} < 0$$

The last result is rather straightforward: if the renovation gain does not depend on the market thickness, comparing it to a relatively higher price level in thicker markets makes the gross price effect lower in thicker markets.

Net Price Effect. On average the net price gain from the renovation increases with market thickness.

After netting renovation costs from the price gain, we yield

$$\frac{\partial \frac{E\left(p^R(\epsilon)|\epsilon\geq\epsilon^*\right)-E\left(p^N(\epsilon)|\epsilon\geq\epsilon^*\right)-c}{E\left(p^N(\epsilon)|\epsilon\geq\epsilon^*\right)}}{\partial \nu} = -\frac{\frac{\theta}{2}(b-c)}{\left(\theta\frac{r^{NR}+\nu}{2}+(1-\theta)r^{NR}\right)^2}$$

If $b - c < 0$, the sign of the derivative would be positive, replicating the empirical results in Table 6 column (4).

The economic intuition would be the following: as long as the difference between the renovation benefit and the renovation costs is negative, the cost-price component dominates the gross price gain component and since a market with a higher level of market thickness would have a lower cost-price ratio, it would experience higher net price growth.

Renovation Incentives. We can show that $O^R - O^{NR} = b$, so substituting it into the renovation threshold equation (4.1) yields

$$\begin{aligned}\omega^* &= c - (1-\phi)\left(O^R - O^{NR}\right) - \phi b \\ &= c - (1-\phi)b - \phi b \\ &= c - b\end{aligned}$$

It follows that in this case the probability of renovation does not depend on market thickness.

A.3 Model results with proportional renovation benefits

Renovation benefits could also accrue proportionally to the property value, however, in this section we show that with this feature the model would not be able to replicate the key empirical findings.

The renovation decision. Suppose, after renovation, household's stochastic housing services ϵ_i are augmented by parameter $\gamma > 1$, so that the household receives $\gamma\epsilon_i$.

The household makes the renovation decision after learning his value of ω_i, but before learning the separation shock, so the household chooses the maximum of these two values:

$$\max\{(1-\phi)\left(B_i + O_i^{NR}\right) + \phi h, \quad -c + \omega_i + \left(1-\phi\right)\left(B_i + O_i^{R}\right) + \phi\left(\gamma h\right)\}$$

We assume that the housing services shock $\epsilon \sim F(\epsilon, \nu)$ does not depend on the renovation status

but depends on the total number of houses for sale, ν. This relationship will define the role of market thickness: the higher is the number of houses for sale, the more likely is the household to draw a higher housing services shock. Further, the buyer value and the seller value would be identical across households, so we remove the subindex i.

It follows that the threshold level of the renovation benefit ω^* which would make the household indifferent between renovating and not renovating is given by

$$\omega^* = -(1-\phi)\left(O^R - O^{NR}\right) + c - \phi\,(\gamma - 1)\,h \tag{A.1}$$

The threshold is increasing in the renovation cost c and decreasing in parameter γ which defines renovation benefits. Also, the higher is the value of selling a renovated house compared to the value of selling an non-renovated house, the lower is the threshold.

The total number of houses for sale ν will be equal to $(1-\phi)\overline{\nu}$. So the role of market thickness for the renovation decision occurs through parameters $\overline{\nu}$ and ϕ. We will determine this relationship after solving for the seller values O^{NR} and O^R.

Reservation services. Since the seller would earn the difference between the price and his outside option r which can be interpreted as rent income, his surplus would be given by

$$S_O(\epsilon) = p^j(\epsilon) - r$$

The buyer would earn the difference between the housing services shock and the price, so that

$$S_B^R(\epsilon) = \gamma\epsilon - p^R(\epsilon) \quad \text{and} \quad S_B^{NR}(\epsilon) = \epsilon - p^{NR}(\epsilon)$$

If the house is renovated, the buyer's surplus would also include the renovation benefit γ. The sale will take place if the total surplus from the transaction is positive, thus the reservation level of the housing services shock is given by $\epsilon^{NR} = r$ for non-renovated houses and $\epsilon^R = r/\gamma$ for renovated houses.

The seller's value when he is the owner of an non-renovated house would be given by the outside option if the sale does not happen and the price if the house gets sold, yielding

$$O^{NR} = F(\epsilon^{NR})r + (1 - F(\epsilon^N))E\left(p^{NR}(\epsilon)|\epsilon \geq \epsilon^{NR}\right)$$

Similarly, for a seller of a renovated house, the value is given by

$$O^R = F(\epsilon^R)r + (1 - F(\epsilon^R))E\left(p^R(\epsilon)|\epsilon \geq \epsilon^R\right)$$

Prices. We assume that the price is determined by bargaining and θ describes the seller's bargaining power. So we can show that the price of an non-renovated house $p^{NR}(\epsilon)$ and the price of a renovated house $p^R(\epsilon)$ would be given by

$$p^{NR}(\epsilon) = \theta\epsilon + (1 - \theta)r$$

$$p^R(\epsilon) = \theta\gamma\epsilon + (1 - \theta)r$$

Assuming that $F(\epsilon, \nu)$ follows a uniform distribution on $[0, \nu]$, we can show that the average price of the non-renovated house is lower than the average price of a renovated house:

$$E\left(p^{NR}(\epsilon)|\epsilon \geq \epsilon^{NR}\right) = E\left(\theta\epsilon + (1 - \theta)r|\epsilon \geq \epsilon^{NR}\right) = \theta\frac{\epsilon^{NR} + \nu}{2} + (1 - \theta)r \tag{A.2}$$

$$E\left(p^R(\epsilon)|\epsilon \geq \epsilon^R\right) = E\left(\theta\gamma\epsilon + (1 - \theta)r|\epsilon \geq \epsilon^R\right) = \theta\gamma\frac{\epsilon^R + \nu}{2} + (1 - \theta)r \tag{A.3}$$

Gross Price Effect. We can show that with this setup that the price differential for renovated dwellings compared to non-renovated dwellings is higher in markets with higher market thickness.

Having solved for average prices, we can show that the price differential for renovated dwellings compared to non-renovated dwellings is positive:

$$E\left(p^R(\epsilon)|\epsilon \geq \epsilon^R\right) - E\left(p^{NR}(\epsilon)|\epsilon \geq \epsilon^{NR}\right) = \theta(\gamma - 1)\frac{\nu}{2} > 0$$

Then

$$\frac{E\left(p^R(\epsilon)|\epsilon \geq \epsilon^R\right) - E\left(p^{NR}(\epsilon)|\epsilon \geq \epsilon^{NR}\right)}{E\left(p^{NR}(\epsilon)|\epsilon \geq \epsilon^{NR}\right)} = \frac{\theta(\gamma - 1)\frac{\nu}{2}}{\theta\frac{r+\nu}{2} + (1 - \theta)r}$$

and

$$\frac{\partial\frac{E\left(p^R(\epsilon)|\epsilon \geq \epsilon^R\right) - E\left(p^{NR}(\epsilon)|\epsilon \geq \epsilon^{NR}\right)}{E\left(p^{NR}(\epsilon)|\epsilon \geq \epsilon^{NR}\right)}}{\partial\nu} = \frac{\frac{\theta}{2}(\gamma - 1)r\left(1 - \frac{\theta}{2}\right)}{\left(\theta\frac{r+\nu}{2} + (1 - \theta)r\right)^2} > 0$$

Net Price Effect. We can show that the net price effect would still depend positively on market

thickness:

$$\frac{\partial \frac{E\left(p^R(\epsilon)|\epsilon\geq\epsilon^R\right)-E\left(p^{NR}(\epsilon)|\epsilon\geq\epsilon^{NR}\right)-c}{E\left(p^{NR}(\epsilon)|\epsilon\geq\epsilon^{NR}\right)}}{\partial \nu} = \frac{\frac{\theta}{2}\left((\gamma-1)r(1-\frac{\theta}{2})+c\right)}{\left(\theta\frac{r+\nu}{2}+(1-\theta)r\right)^2} > 0$$

Since in markets with a higher level of market thickness housing services are higher in expectation and since renovation affects housing services proportionally, the expected housing services value for the homeowner of a renovated house is higher too, resulting in a higher average price of renovated dwellings relative to non-renovated dwellings.

Renovation Incentives. In this case the probability of renovation is higher in markets with lower market thickness which contradicts the stylized facts.

Since in the model market thickness ν is determined by ϕ and $\overline{\nu}$, we will analyze their effect on the renovation threshold, and thus the renovation probability, separately.

A higher separation probability $(1-\phi)$ would affect the renovation threshold through three channels.

$$\omega^* = c - \underbrace{(1-\phi)}_{\text{(1): increases with } (1-\phi)} \times \underbrace{\left(O^R - O^{NR}\right)}_{\text{(2): increases with } (1-\phi)} - \underbrace{(\phi)}_{\text{(3): decreases with } (1-\phi)} \times(\gamma-1)\times h$$

First, a higher separation probability would imply a higher weight given to the differential in seller's values, $O^R - O^{NR}$. Since the seller's value is higher for renovated houses ($O^R - O^{NR} > 0$[2]), a higher separation probability would mean that the differential in seller's values for renovated and non-renovated houses becomes a more important factor in the renovation decision. However, the differential in seller's values for renovated and non-renovated houses affects the threshold value of renovation benefits negatively, so a higher weight given to the differential in seller's values would also reduce the renovation threshold.

Second, the separation probability would affect the differential in seller's values itself. Since

$$\frac{\partial(O^R - O^{NR})}{\partial\phi} = -\frac{\theta}{2}(\gamma-1)\left(\overline{\nu} + \frac{r^2}{\gamma\overline{\nu}(1-\phi)^2}\right) < 0$$

It follows that a higher separation probability increases the differential in seller's values and thus

[2]Having obtained the average prices in (A.2) and (A.3) and assuming that $r < \nu$ such that the probability of a successful match would be positive (i.e. $1 - F(\epsilon^{NR}) = 1 - r/\nu > 0$), we can show that $O^R - O^{NR} = \frac{\theta}{2}(\gamma-1)\nu\left(1-\frac{r^2}{\gamma\nu^2}\right) > 0$.

reduces the renovation threshold. The reason behind this effect is the same as with the difference in prices for renovated houses and non-renovated houses: renovation increases housing services proportionally, so the benefit is higher in thick markets where the expected level of housing services is higher.

Third, a higher separation probability would imply a lower weight given to the expected renovation gain in housing services: if the chances of having to reallocate are high, the renovation benefits have a lower value for the household. Since the expected renovation gain in housing services affects the renovation threshold negatively, through this term, a higher separation probability would increase the renovation threshold.

Since the effect of a higher separation probability is not unambiguous, we examine the total effect of a higher separation probability on the renovation threshold.

After substituting $O^R - O^{NR}$ into equation (A.1) and the functional form for the ϵ distribution, we can obtain

$$\begin{aligned}\omega^* &= c - (1-\phi)\frac{\theta}{2}(\gamma-1)\,\nu\left(1-\frac{r^2}{\gamma\nu^2}\right) - \phi\,(\gamma-1)\,h \\ &= c - \frac{\theta}{2}(\gamma-1)(1-\phi)^2\overline{\nu} + \frac{\theta}{2}(\gamma-1)\frac{r^2}{\gamma\overline{\nu}} - \phi\,(\gamma-1)\,h\end{aligned}$$

It follows that

$$\begin{aligned}\frac{\partial\omega^*}{\partial\phi} &= (\gamma-1)\left(\theta(1-\phi)\overline{\nu} - h\right) \\ &= (\gamma-1)(1-\phi)\overline{\nu}\left(\theta - \frac{h}{(1-\phi)\overline{\nu}}\right) \\ &= (\gamma-1)(1-\phi)\overline{\nu}\left(\theta - \frac{h}{\nu}\right)\end{aligned}$$

The sign of the derivative depends on several parameters. Assuming that non-separated homeowners should get at least their outside option r, then $\theta - \frac{h}{\nu} \leq \theta - \frac{r}{\nu}$. $\frac{r}{\nu}$ is equal to the non-matching probability for non-renovated houses. If this probability is lower than the seller's bargaining power θ, then the sign of the derivative is positive and a higher separation probability would actually decrease

the renovation threshold.

The effect of a higher housing stock $\overline{v}$ on the renovation threshold is unambiguously negative:

$$\frac{\partial \omega^*}{\partial \overline{v}} = -\frac{\theta}{2}(\gamma - 1)\left((1-\phi)^2 + \frac{r^2}{\gamma \overline{v}^2}\right) < 0$$