Understanding Housing Supply under Stringent Energy-efficiency Regulations

By

María Jimena Muzio

Master in Applied Economics
Universidad Torcuato Di Tella, 2018

Submitted to the Department of Urban Studies and Planning
in Partial Fulfillment of the Requirements for the Degree of

MASTER IN CITY PLANNING

at the
MASSACHUSETTS INSITUTE OF TECHNOLOGY

JUNE 2023

Authored by: María Jimena Muzio
Department of Urban Studies and Planning
May 17th, 2023

Certified by: Siqi Zheng
STL Champion Professor of Urban and Real Estate Sustainability
Thesis Supervisor

Accepted by: Ceasar McDowell
Professor of Practice of Civic Design
Department of Urban Studies and Planning
Chair, MCP Committee

Understanding Housing Supply under Stringent Energy-efficiency Regulations

By

María Jimena Muzio

Submitted to the Department of Urban Studies and Planning on May 17th, 2023, in Partial Fulfillment of the Requirements for the Degree of Master in City Planning at the Massachusetts Institute of Technology

ABSTRACT

Massachusetts's commitment to a 50% emissions reduction by 2030 and net-zero emissions by 2050 is reflected in the Green Communities Act of 2008, which requires the adoption of the Stretch Energy Code for every municipality that is designated as a Green Community. This appendix to the base building code adds more stringent energy-efficiency requirements, such as including the HERS Index rating system in every new residential construction. Despite their obvious environmental benefits, more stringent energy-efficiency building regulations can also lead to increased construction costs and negatively impact housing production and affordability. In this study, I investigate the tension in the housing supply resulting from the adoption of the Stretch Energy Code by analyzing municipalities' staggered designation as Green Communities to identify the causal mechanisms behind quantity and price effects in the residential real estate market. The results indicate that more energy-efficient properties command a positive sales price premium and that the Stretch Code adoption is associated with a decrease in the housing quantity and an increase in the average housing prices.

Thesis Supervisor: Siqi Zheng

STL Champion Professor of Urban and Real Estate Sustainability,

Department of Urban Studies and Planning,

ACKNOWLEDGMENTS

I want to express my sincere gratitude to my advisor, Siqi Zheng, for her invaluable guidance and support throughout my master's program. Her expertise and encouragement helped me to complete this research and write this thesis.

I would also like to thank Justin Steil for serving on my thesis committee and providing valuable feedback and suggestions. His insights and guidance were instrumental in helping me to shape this research project.

Finally, words cannot express my gratitude to Dongxiao Niu for all her time devoted to this research, her invaluable ideas, patience, and feedback. I could not have undertaken this journey without her generous support.

Table of Contents

Introduction

The scientific evidence is unequivocal: Climate change is no longer a distant threat but an ongoing disaster that continues to unleash deadly heat waves, intense droughts, floods, and devastating wildfires, putting lives and ecosystems in peril. In the race to adhere to the timeline put forward by the Paris Agreement to cut carbon emissions by 45% by 2030, decarbonizing the built environment will play a vital role in this complex and critical mission. In the United States, the building sector is responsible for 40% of the national energy demand and accounts for 40% of national CO2 emissions, according to the US Energy Information Administration (EIA). These levels represent the most significant energy and CO2 contributions of any sector. Furthermore, residential buildings account for 21% of US energy consumption, with over 60% attributed to space and water heating end-uses (Schwartz, E.K.; Krarti, M., 2022).

Green buildings represent a concerted effort to mitigate the negative impact of the building sector on the environment while stimulating positive impacts throughout the building life cycle (Zhang et al., 2018). This drive toward more sustainable designs gained momentum in 1990 with the launch of the Building Research Establishment's Environmental Assessment Method (BREEAM), the first-ever green building rating system globally. Subsequently, in 2000, the US Green Building Council (USGBC) developed and introduced Leadership in Energy and Environmental Design (LEED) criteria to improve the environmental performance of new construction projects. The ability to market LEED-certified new buildings to tenants proved instrumental in engaging the US real estate market (Ervin, C., 2011).

Since that first release, climate-related events have prompted an increase in climate change resilience efforts in the building sector, such as the creation of green building standards, certifications, and rating systems aimed at mitigating the impact of buildings on the natural environment through sustainable design. Developed nations have also made ambitious pledges to reduce carbon emissions and promote the adoption of energy-efficient technologies in the construction sector to make their engagement in buildings' decarbonization tangible. For instance, the United Kingdom was the first country to mandate Net Zero Energy Buildings (NZEBs) on a large scale, with the goal of producing zero-carbon homes by 2016[1]. Similarly, starting in January

[1]DEFRA, “UK Energy-efficiency Action Plan 2007”.

2021, the European Union Parliament has introduced a directive requiring all new buildings to be "nearly zero-energy" buildings.

In the United States, municipalities and states are taking significant strides to promote energy-efficient technologies, especially in the building sector. The US Department of Energy (DOE) has set ambitious goals of achieving marketable zero-energy homes by 2020 and commercial zero-energy buildings by 2025[2]. To support these objectives, California mandates that all new residences be net-zero by 2020 and all commercial buildings by 2030. Similarly, the Massachusetts Legislature enacted the Green Communities Act of 2008, which requires the state to update its building code every three years to align with the most recent version of the International Energy Conservation Code (IECC). This way, the Act ensures that new buildings are designed and constructed with energy efficiency in mind. In 2009, Massachusetts was the first state to adopt the Stretch Energy Code, an above-code appendix to the base building energy code that prioritizes energy performance over prescriptive requirements.

Furthermore, the Act of 2008 allows cities and towns to apply for a "Green Community" designation, which entitles them to receive financial and technical support to reduce energy use and costs by implementing clean energy projects in municipal buildings, facilities, and schools. Once municipalities are designated as Green Communities, they must adopt the Stretch Energy Code, which mandates that all new residential buildings meet a targeted HERS Index Score, a nationally recognized system for assessing and calculating a home's energy performance. For example, homes under 3,000 sqft must achieve a HERS Index Score of 70 or less, while houses over 3,000 sqft must score 65 or less. Participation in the Green Communities Program has been increasing steadily, with over 90% of the diverse cities and towns in the Commonwealth earning designation status since the first two municipalities joined the program in July 2010.

Regardless of the obvious environmental benefits of more stringent energy-efficiency building regulations, these can threaten housing supply and affordability. Developers face incentives and barriers when adopting greener building technology compared to traditional building codes and practices. While buildings with better energy performance can generate statistically significant price premiums in both transaction and rental markets (Miller et al., 2008; Hyland et al., 2013; Brounen & Kok, 2011; Chegut et al., 2014; Kahn & Kok, 2014; Walls et al.,

[2] DOE, “Building technologies program, planned program activities for 2008–2012,” 2008.

2017), design fees, construction costs, and maintenance rates may be higher as well (Chegut et al., 2019). Additionally, buildings with better energy performance may face longer construction duration and uncertain market demand (Deng and Wu, 2014).

Considering the above-mentioned in conjunction with the fact that the housing shortage in Massachusetts is a critical and rapidly evolving crisis, with one in ten homeowners and one in four renters spending over half of their income on housing costs in 2021 (Boston Foundation, 2021), it becomes crucial to empirically quantify the effect of stringent energy-efficiency building codes on housing supply. In 2022, the National Association of Home Builders reported that almost 70% of US households could not afford a new home priced at the national median of $412,505 (NAHB 2022). The problem is even more severe in Massachusetts, where housing production has been only about half of the level seen in the 1980s (Boston Foundation, 2021). Furthermore, the Massachusetts Taxpayers Foundation Report released in August 2022 revealed that the state had a net outmigration of 750,000 individuals over the past three decades, highlighting the urgent need for action to address the affordability crisis in the housing market.

The purpose of this paper is twofold. On the one hand, it aims at investigating the magnitude of the green price premium in Massachusetts' residential housing market after municipalities become designated as Green Communities. And on the other, this study intends to explore the tension in the housing supply resulting from the adoption of the Stretch Energy Code, which is required after the Green Community designation.

The quest for sustainability in the housing industry requires implementing effective strategies to optimize the energy efficiency of properties. However, despite their obvious environmental benefits, more stringent energy-efficiency building regulations can also lead to increased construction costs and negatively impact housing production and affordability. Therefore, by empirically quantifying both the quantity change (housing supply) and quality change (housing price) resulting from the adoption of the Stretch Energy Code by municipalities in the state, I believe this thesis project is one of the first efforts to provide insights into the critical question of how to pursue energy-efficiency in the building sector without harming housing affordability.

Background

The Green Communities Program and the Stretch Energy Code

The growing concern about climate change has led to a dramatic increase in public discourse about residential energy use in recent years. In this sense, state-wide building codes that set minimum efficiency standards for all new residential construction are one of the strategies that policymakers have used to improve the energy efficiency of residential homes. (Bruegge et al., 2016).

Massachusetts's commitment to meeting its ambitious greenhouse gas emissions goals, a 50% reduction by 2030 and net-zero emissions by 2050, is enshrined in the Green Communities Act of 2008, which requires updating the building code every three years to reflect changes made to the International Energy Conservation Code (IECC). This mandate seeks to guarantee that new buildings are designed and constructed with energy efficiency in mind. In 2009, Massachusetts went a step further by becoming the first state to adopt an above-code appendix to their "base" building energy code, known as the "Stretch Code." This optional appendix to the base code adds more stringent energy-efficiency requirements and is designed to emphasize energy performance rather than prescriptive requirements for all new residential and many new commercial buildings, as well as for those residential renovations that would typically trigger building permits.

Towns and cities' decision to adopt the Stretch Code appendix can be made by a vote of the appropriate elected officials, usually the town meeting for a town and the mayor and city council or aldermen for a city. Municipalities interested in adopting it are encouraged to hold a public hearing to gather input, increase awareness, and thus, ensure the adoption of the Stretch Code is a transparent and collaborative process that aligns with their constituents' needs and values. Concerning its implementation, in order to provide consistency among communities, once adopted, the Stretch Code can only go into effect on January 1st or July 1st, and there must be at least six months between adoption and when it becomes mandatory. For example, if Town A voted to adopt the Stretch Code in November 2010, it would become mandatory on July 1st, 2011. During the interim period, the Stretch Code would only be optional for builders[3].

In particular, the Stretch Code appendix allows developers to design buildings that surpass the energy-efficiency requirements of the base energy code by approximately 20%. Developers

[3] https://www.northfieldma.gov/sites/g/files/vyhlif991/f/uploads/qa_for_the_stretch_code.pdf

can select cost-effective and thoughtfully designed solutions to achieve their required energy reduction percentage. While the performance-based approach is mandatory for new residential construction, residential renovations, and most commercial buildings may opt for a "prescriptive" route that specifies minimum energy-efficiency requirements for different building materials and systems. These requirements result in an overall energy-efficiency improvement of 20% in both the commercial and residential sectors compared to the base code requirements.

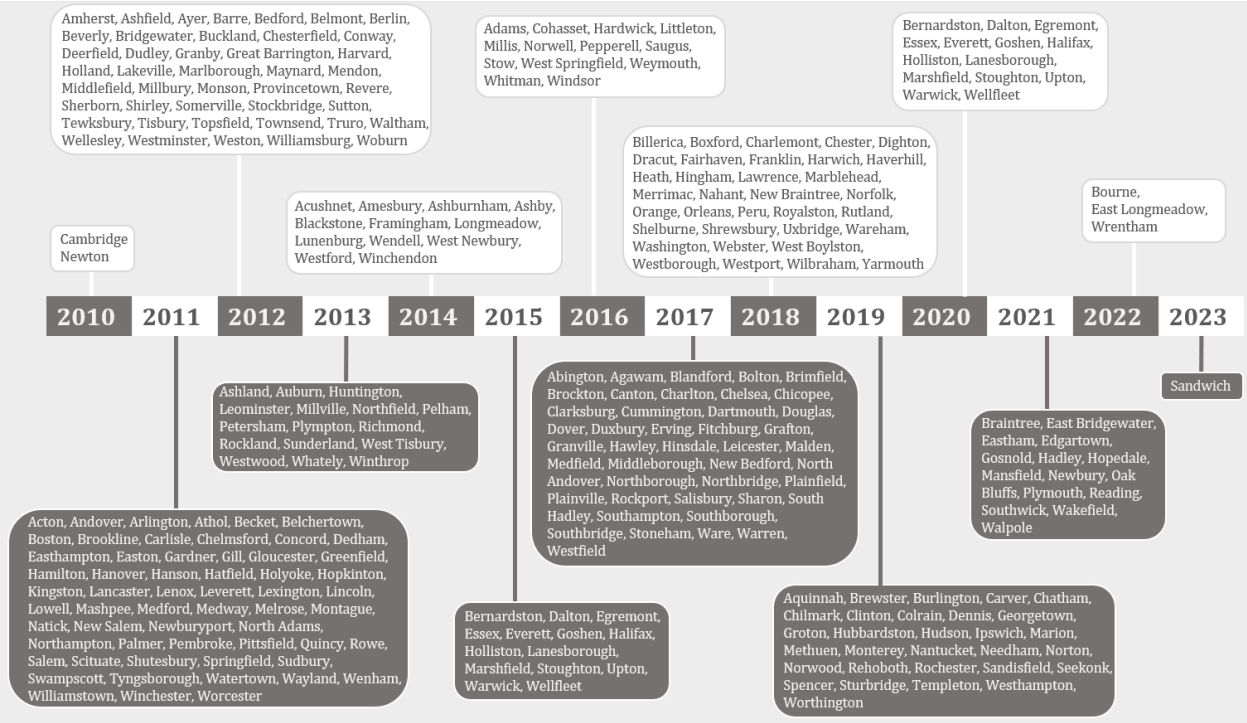
To comply with the residential Stretch Code, new residential homes, including multi-family dwellings of three stories or less, builders must show that each unit meets or is below a maximum HERS index score. For new homes larger than 3,000 sqft, the required HERS score is 65 or below, similar to Energy Star tier 2 requirements. For smaller houses under 3,000 sqft, however, the maximum allowed HERS score is 70. In addition, a duct leakage test is needed for homes with forced air heating and central air conditioning systems with ductwork running outside of the heated portion of a house. These tests help calculate how much energy is needed to heat and cool a home and help builders identify possible problems before a dwelling is completed when there is still time to fix them cost-effectively. Furthermore, duct testing using the Energy Star Thermal Bypass or Thermal Enclosure Checklist is also required. These inspections ensure that the home is well-air-sealed. In contrast, the HERS rating ensures that the house is designed to be well insulated with efficient heating, cooling, and lighting –all measures that save energy and reduce utility bills[4].

When it comes to implementing and enforcing the Stretch Code, the process is very similar to the existing building code. Residential buildings meeting the Stretch Code through a HERS rating and EPA Thermal Bypass or Thermal Enclosure Checklist require independent certification by a HERS rater. The rater will produce a report detailing the energy systems in the building and will provide a HERS Index score, together with proof of whether the home qualifies for any federal tax credits. Developers must submit the HERS report and a completed Energy Star Thermal Checklist to demonstrate compliance with the energy portions of the code. They must be submitted to the local building inspector, who will then conduct a plan and site review to guarantee the construction meets the requirements of the Stretch Code[5].

[4] https://www.northfieldma.gov/sites/g/files/vyhlif991/f/uploads/qa_for_the_stretch_code.pdf

[5] Ibid.

***Figure 1**. Timeline for municipalities' adoption of the Stretch Energy Code*



Source: Own elaboration.

RESNET-HERS Rating System

The Residential Energy Services Network (RESNET) is a nonprofit membership corporation founded in April 1995 by the National Association of State Energy Officials and Energy Rated Homes of America with the primary mission to promote energy efficiency in homes by developing an international market for home energy rating systems and mortgages. Managed by its board of directors, RESNET has earned national recognition as a standards-setting body for building energy-efficiency rating and certification systems throughout the United States[6].

RESNET's most notable contribution to energy efficiency is the HERS Index, introduced in 2006[7]. This system sets a national standard for inspecting and calculating a home's energy performance so that homeowners can compare different houses' efficiency more easily. The HERS Index score represents how much energy each rated home uses compared with a reference home

[6] https://www.resnet.us/about/us/
[7] Ibid.

constructed according to 2006 energy-efficiency standards. The lower the score, the more energy-efficient the home is.

The US Department of Energy has determined that a typical resale home in America receives a HERS Index score of 130, while new homes built to the International Energy Conservation Code (IECC) standards score 100. Therefore, a house with a HERS Index score of 70 is 30% more energy-efficient than the typical new home, while one scoring 130 is 30% less efficient than the standard new construction[8]. Conversely, a score of zero means that the house is a Net Zero Energy one –i.e., it uses no net purchased energy. Finally, a negative score means homes have achieved such energy efficiency that they generate more clean energy than they consume from the grid. This additional clean energy is returned to the system, with each negative point (-1, -2, -3) representing 1% of what a standard new home would use and instead put back into the grid[9].

To calculate a home's HERS Index score, a certified RESNET Home Energy Rater conducts an energy rating on the residence and compares its energy performance against that of a reference home to ensure that scores are always relative to house size, shape, and type.

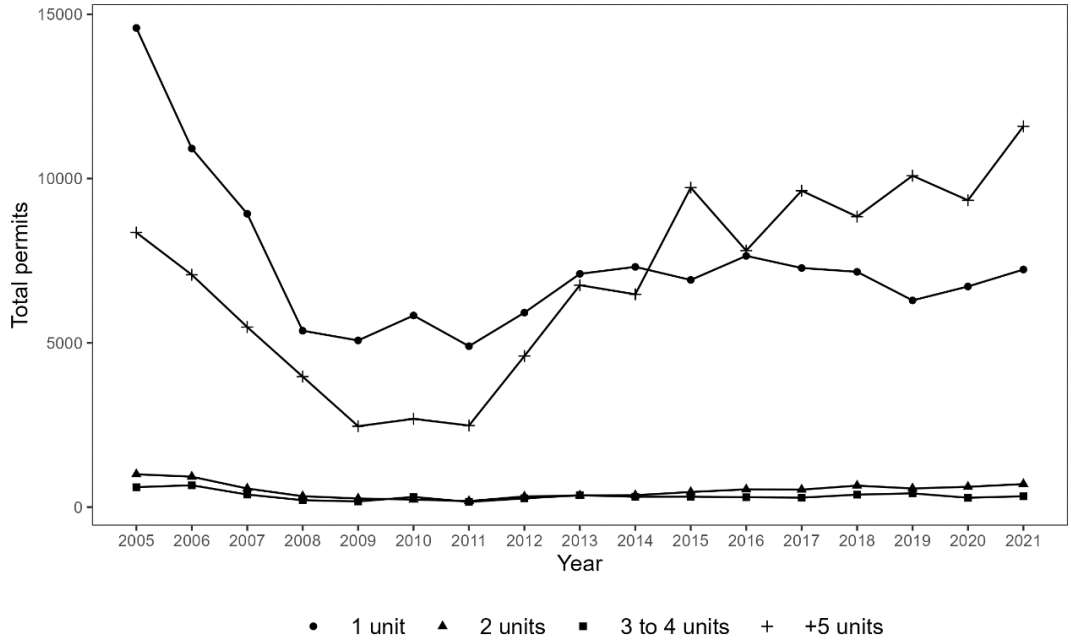
Housing prices and new construction

Over the past years, many US cities have experienced a combination of increases in housing prices and a decrease in new construction (Glaeser & Ward, 2009). Towns and cities in Massachusetts are no exception. Figure 2 shows the total number of permits issued in Massachusetts from 2005 to 2021 for different house types. The total number of permits for units in 2-units and 3 to 4-unit' buildings have remained relatively stable for over a decade. However, the number of permits for single-family and large multi-family developments displays a higher degree of variation. The steep decline that began before the 2008 financial crisis reverted in the crisis aftermath, in particular for developments of more than five units. Moreover, since 2016 large multi-family buildings are the only type of property that exhibits a clear upward trend.

[8] https://www.hersindex.com/hers-index/what-is-the-hers-index/

[9] https://www.bpcgreenbuilders.com/green-building/home-energy-rating-system-hers-scores/#:~:text=A%20negative%20rating%20represents%20the,being%20returned%20to%20the%20grid.

Figure 2. *Total permits in MA, 2005-2021*



Source: Own elaboration using the Building Permits Survey (US Census Bureau).

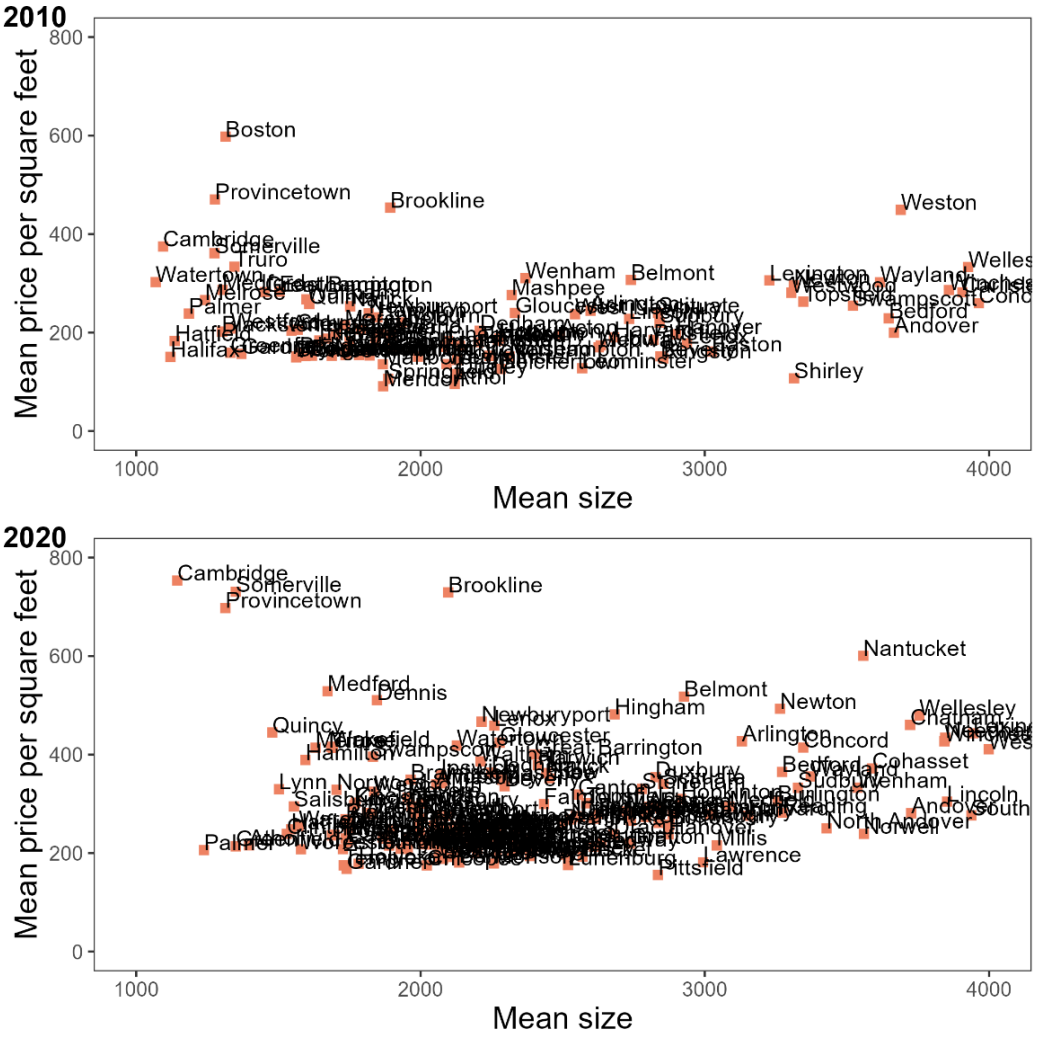
Figure 3 plots the mean home transaction price per sqft vs. properties' mean size for 2010 and 2020. While in 2010 the range of mean sizes appears to be more horizontally scattered, in 2020, the mean size seems to be more concentrated around 2300 sqft. Concerning housing prices, the case for cities such as Cambridge, Provincetown, Somerville, or Brookline is remarkable because they have experienced an almost entirely vertical shift; for nearly the same mean size, they exhibit much higher average prices after a decade. For instance, in 2010, the average home size was slightly above 1,000 sqft, and the mean price per sqft was slightly less than USD 400. Ten years later, the mean size remained the same, but the average price per sqft had almost doubled.

Local land-use regulations –including large minimum lot sizes, density restrictions, large minimum floor area requirements, minimum parking requirements, and aesthetic rules, among others– and more stringent building regulations decrease the housing supply, increasing the average level of housing prices. The decrease in the supply stems from the fact that stringent building codes can directly increase housing costs by raising construction standards in ways that increase the labor required or the cost of materials. In addition, code changes aimed at increasing energy efficiency can contribute to increased costs through administrative impediments if the

changes are associated with administrative delays, fees, or conflicts among administrative requirements.

Therefore, this thesis intends to better understand the implications of more stringent building codes, such as the Stretch Energy Code, on housing supply dynamics.

Figure 3. *Mean housing prices per sqft vs mean size, 2010 and 2020*



Source: Own elaboration using the Building Permits Survey (US Census Bureau).

State of the Art

Is there a higher willingness to pay for more energy-efficient homes?

In the current debate on the climate crisis, buildings are gaining increased attention as vehicles for achieving energy efficiency, carbon abatement, and corporate social responsibility (Chegut et al., 2014). The growing body of literature on these topics is evidenced by the increased interest from academia in environmental sustainability and the building and real estate sectors. In particular, special attention has been paid to the association between energy-efficiency certifications and the financial performance of commercial and residential properties. Indeed, several recent empirical studies conducted in different contexts have found that more energy-efficient and sustainable properties exhibit a positive and significant *green price premium* paid by consumers in both commercial and residential real estate markets.

On the commercial side, it is estimated that energy represents 30% of operating expenses in a typical office building, and yet, it is also the single largest and most manageable cost in the provision of office space; therefore, the design and operation of real estate do play an essential role in energy conservation (Eichholtz et al., 2010). Awareness of this fact is growing and has led to an increasing emphasis on green rating systems to provide owners and occupants with a solid yardstick for measuring building energy efficiency and sustainability (Eichholtz et al., 2010). Environmental labels, such as LEED and Energy Star, are one of the most popular pricing mechanisms to provide information to consumers about the energy footprint of properties aimed at altering their consumption choices, suppliers' production outputs, and, as a result, the level of environmental impact (Fuerst & McAllister, 2011b).

Quite a few studies have drawn upon the CoStar database of US properties to identify the effect of green certifications on commercial real estate sales and rental prices. For instance, Miller et al. (2008) is a pioneering study of green features in commercial buildings that use the US CoStar database to provide comparison data on Energy Star and LEED-certified buildings versus non-certified office property. Their findings suggest that the average LEED impact on sales price per sqft is a positive 10% and that the effect of Energy Star certification on selling price is roughly 6% on the positive side.

Eichholtz et al. (2010) report systematic evidence on the economic value of certification of green buildings. For each commercial building in the US that has a LEED or Energy Star

certification, they find comparable commercial properties to relate market rents or selling prices to a set of hedonic attributes. Their results suggest that an Energy Star certification will lead to a 3% increase in rent and a 7% increase in effective rent per sqft. Regarding sales prices, the evidence indicates that certified buildings transact for 16% higher prices. Likewise, by using data on office properties from the National Council of Real Estate Investment Fiduciaries (NCREIF), Pivo and Fisher (2010) find that Energy Star properties were worth 8.5% more per sqft than other comparable properties, thus confirming the existence of a positive price premium for energy-efficient buildings.

A similar effort by Fuerst and McAllister (2011a) reported the effect of eco-labeling on rental prices, sales prices, and occupancy rates by analyzing LEED and Energy Star-certified buildings in the US. Through standard hedonic regression modeling, they find that LEED certification leads to rental premia of 5% while the Energy Star label yields a premium of 4%. Further, their findings suggest a substantial sales price premium of 26% and 25%, respectively, for Energy Star and LEED-rated office buildings. Likewise, Chegut et al. (2014) investigate the financial performance of London's BREEAM-certified commercial buildings within a dynamic supply and demand framework. They find that BREEAM certification commands a 19.7% premium in rental prices and a 14.7% for sales transactions relative to non-certified buildings in the same neighborhood. More importantly, they show that the green building supply has an economically significant impact on certified real estate and the general prices of commercial real estate, meaning that there is a gentrification effect.

A slightly less established literature has examined the effect of energy ratings in the residential property market. Evidence of a positive association between home sales prices and energy-efficiency certifications has been found by, for instance, Brounen and Kok (2011). The authors are the first to provide empirical evidence on the market adoption and economic impact of energy performance certificates using a large-scale mandatory labeling program in the European Union. They study the Dutch housing market in particular since it was the first to adopt energy labels in the residential market in January 2008. Applying the Heckman two-step method, they find that green homes sell at a positive premium of 3.6% relative to comparable non-labeled homes. They also find evidence that ideology plays a role in the adoption of energy labels since adoption rates are higher among homeowners that voted for green political parties in the 2006 national elections.

Bruegge et al. (2015) examine how energy efficiency and the Energy Star label are capitalized into housing prices by using transaction data from the housing market in Gainesville, Florida, to estimate buyers' willingness to pay for both new and used Energy Star homes. With their more robust model specification, they find that the Energy Star price premium is about 1.2%, a magnitude that, according to the authors, is consistent with the present value of expected energy savings in the first years of homeownership. Interestingly, they also find that the price premium associated with Energy Star homes disappears over time in the resale market and that the first sale premium disappears with newer vintages of Energy Star homes suggesting that the Energy Star label may be unable to tackle the asymmetric information problem of making energy-efficiency more prominent in the resale housing market (Bruegge et al., 2016).

Following the above-mentioned, a study conducted by Zheng et al. (2012) examines the effect of promoting environmentally friendly features on the selling price of housing in Beijing, as formal rating systems in China have not been adopted yet. The authors created a Google Green Index that measures the search ranking of housing complexes based on their green characteristics between 2003 and 2008 to test the association between the initial asking price and the level of greenness of properties. The study reveals that the greenest building in the sample sells at a premium of 17.7% compared to the least sustainable one.

In line with Brounen and Kok (2011), Chegut et al. (2016) studied the value of Energy Performance Certificates (EPC) in the Dutch affordable housing market between 2008 and 2013. The authors document that dwellings with high energy efficiency, with an EPC A label, sell at a positive premium of 5.6% compared to a similar non-labeled affordable house. Interestingly, they also find that homes with a high primary energy demand (those with EPC labels in categories C to G) sell at a discount of 1.5% compared to non-labeled homes.

Aroul and Hansz (2012) investigate the price effects of green residential transaction prices in Frisco and McKinney, two similar cities in Texas. In particular, Frisco has implemented the country's first residential mandatory green building program, and even though McKinney has no green mandates, green properties have been voluntarily developed. The authors distinguish between price premiums in a mandatory green building context and contexts where green properties are developed by choice. Their findings suggest that green properties are transacted for 3-4.5% more in the former, and in the latter, the price premium falls to 1%.

Hyland et al. (2013) analyze the effect of BER energy-efficiency certificates on properties sale and rental prices in the Republic of Ireland. Their results show that energy efficiency is capitalized in house prices. For instance, and consistent with Chegut et al. (2016), relative to obtaining a D energy rating, an A-rated property receives a price premium of 9.3%, while a B rating increases the price by 5.2%. On the other hand, if the property receives an F or G rating, its price decreases by 10.6% relative to D-rated properties. Regarding the rental market, A-rated dwellings have rental rates that are 1.8% higher than D-rated properties. Counterintuitively, the premium is even higher for B-rated properties at 3.9%. On the low end of the scale, properties with ratings from D to G experience price discounts in the 2-3% range.

Likewise, Kahn and Kok (2014) use detailed data on a large sample of California single-family homes from 2007 to 2012 to study whether there is a price premium for energy-efficient homes. They conduct a hedonic pricing analysis and find that homes certified by the USGBC, EPA, and a state-wide rating agency, Build It Green, transact for about 2-4% more. Moreover, they present evidence of spatial variation in the capitalization of the green label such that both environmental ideology and local climate conditions affect the price of certified homes across regions.

Walls et al. (2017) analyze the effect of the Energy Star label and two local green certifications on sales prices of homes in three urban areas: Austin (Texas), Portland (Oregon), and the area of Durham-Raleigh-Chapel Hill (North Carolina). They study over 170,000 sales transactions for single-family homes from 2005 to 2011. Using matching techniques and a hedonic approach, they find that Energy Star certification is associated with higher home prices, about 2%, in the Portland and Durham-Raleigh-Chapel Hill markets. At the same time, there is no significant result for Austin. However, local green certifications appear to be more valuable than the Energy Star: in Austin, locally-certified homes sell at a premium of 7-8%, and in Portland, the premium is about 3%. The authors also conclude that Portland and Durham-Raleigh-Chapel Hill housing markets seem to capitalize accurately on the annual energy savings implied by the Energy Star label.

In slight contradiction, Yoshida and Sugiura's (2015) study on Tokyo green condominiums exhibits mixed results. They find that transaction prices of new green condominiums are lower than that of their non-green counterparts. However, this trend is reversed after two or more years

of condominium construction due to the fact that depreciation rates are lower for green buildings, thus, making their transaction price higher than their comparable non-green properties.

Do more energy-efficient homes have higher construction costs?

The empirical literature presented so far seems to draw an almost unanimous conclusion about the positive association between green certifications and a property's value. Additionally, the majority of published works consistently document the demand-side effects of green construction and focus on the benefits to building owners, society at large, the environment, and, in particular, building users (Rehm & Ade, 2013; Chegut et al., 2019).

However, a much smaller body of literature has thus far investigated the obstacles and barriers to building green such as higher construction costs and direct cost premiums rather than theoretical cost implications (Rehm & Ade, 2013). There is very limited rigorous empirical evidence quantifying the higher input costs (Dwaikat & Ali, 2016; Chegut et al., 2019), and, at least for now, the most enticing claims of green building cost-effectiveness are still inconclusive (Eichholtz et al., 2010; Circo, n.d.). In part, this is because performing a meaningful assessment of the green cost premium requires comparing conventional and green designs for the same building only (Kats, 2003), which is difficult to obtain. Existing research is still limited in scope and number, hampering the possibility of drawing more general conclusions regarding the cost premium of green construction (Chegut et al., 2019).

Kats et al. (2003) conducted the most comprehensive analysis of LEED construction costs to date, completed during the early adoption of LEED design and construction standards. The study aimed to compare the costs of constructing green buildings to those of conventional designs by analyzing the costs of 33 green buildings throughout the United States. Their findings suggest that the average premium for green buildings was approximately 2%, or $3 to $5 per sqft, compared to conventional designs. In addition, achieving the highest certification level of Platinum commanded a cost premium of 6%.

Matthiessen and Morris (2007) revisit the question of the cost of incorporating sustainable design features into projects expanding upon their earlier work "Costing Green: A Comprehensive Cost Database and Budget Methodology," released in 2004 and funded by Davis Langdon, a global construction consulting company. The authors analyzed 221 buildings, of which 83 were designed to meet some level of the USGBC's LEED certification. At the same time, the other 138 projects

were buildings of similar program types that did not have a goal of sustainable design. According to the results of this study, numerous projects are obtaining certification by implementing the same cost-effective strategies, while more advanced or expensive alternatives are frequently disregarded. Therefore, the conclusion of this report is essentially the same as the one they reached in 2004: "there is no significant difference in average costs for green buildings as compared to non-green buildings" (Matthiessen and Morris, 2007).

Rehm and Ade (2013) provide the first empirical analysis of detailed cost plan data in New Zeland to quantify the impact of green building practices on construction costs. Based on the comparison of 17 green buildings' actual cost data against modeled cost estimates, the authors find that, in particular, for 6 to 15 buildings and 4 Green Stars properties, there are differences between actual and modeled costs of around 8%. Thus, they conclude that more energy-efficient New Zealand buildings are not systematically more expensive than conventional buildings.

Dwaikat and Ali (2016) conducted an extensive literature survey to aggregate the green cost premiums reported in scientific journals (peer-reviewed), books, conference papers, and trade publications. They review 17 published works, of which more than 70% are trade publications, reflecting the lack of academic research. The authors do not reach any conclusive answer since there is a significant gap in the quantified cost premium range: "More than 90% of the results reported in the investigated empirical studies fall within the range from −0.4% to 21%" (Dwaikat & Ali, 2016).

Most recently, Chegut et al. (2019) provided the first systematic evidence on the cost and cost-effectiveness of investments to achieve green building certification. By assessing the marginal cost of construction for 336 commercial BREEAM-certified buildings relative to the non-certified counterparts, they find that the average difference in total costs between the two groups is 6.5.%. Interestingly, they identify that these higher costs stem from specific elements in construction costs. In particular, design fees are 32% higher for green projects while fitting and finishes costs are higher by 32% and 28%, respectively. Also, they report that the highest-rated green buildings are up to 31% more expensive to build and take, on average, 11% more time to complete than non-certified ones. The authors conclude that there is a positive gap between the average green price premium found in the empirical literature and the average green cost premium, suggesting that the slow take-up of green building practices may be due to both a market barrier and a market failure.

How do green building regulations impact the housing supply?

The construction and real estate development industry generally regards commercial green construction as costly, particularly when it pertains to renovating existing buildings (Rehm & Ade, 2013; Chegut et al., 2019), and even if the *green price premium* is large enough compared to the additional *green costs premium*, it might still not be financially viable for developers to build energy-efficient properties. In part, this is due to the fact that the profitability of a project hinges not only on its total expenses but also on its construction timeline; more extended construction periods increase the burden of construction loans and reduce the return on the developer's equity investment (Circo, 2008; Chegut et al., 2019). Moreover, theoretically-calculated financial benefits of commercial green buildings may not entirely equal the actual economic benefits that a specific project owner receives, especially if the owner is unable to fully capture the present value of calculated savings over the life-cycle or places a lower value on the estimated productivity and health benefits associated with green buildings (Circo, 2008). In addition, the extent to which calculations to evaluate the magnitude of the construction cost premium associated with green buildings are reliable depends on the accuracy of key assumptions and the context-specific nature of the project.

Even if there were significant and positive returns for green investors in the commercial real estate sector, such findings could not necessarily be extended to the green residential industry. In this line, Deng and Wu (2014) argue that the housing market's inefficiencies can impede the future expected benefits of green building techniques from being immediately and thoroughly reflected in properties' transaction prices. This mismatch between the occurrence of costs and realization of benefits is evidenced in Singapore's Green Mark case, where the authors find that, due to this discrepancy, even financially feasible green building investments (i.e., where the green price premium is large enough to offset the additional green costs) may not be pursued by developers in the residential green sector.

Moreover, the residential sector presents an additional challenge for developers as they may only receive a portion of the benefits associated with energy-efficient investments while paying all the construction costs if the green price premium is not fully revealed in the market until after the units are sold to households (Deng & Wu, 2014). Likewise, previous studies have documented the impact of the discrepancy between costs and benefits in the residential sector. For instance, Zheng and Kahn (2008) provide empirical evidence suggesting that newly-built home

units in Beijing, China, have incorporated the value of access to urban amenities into their prices, whereas residential land parcels have not.

Consequently, if, as discussed above, any misalignment, market barriers, or market failures exist in the green residential sector, it could discourage further development of more energy-efficient dwellings (Deng & Wu, 2014; Chegut et al., 2019). Indeed, the slow progress in the transition to cleaner technologies made by the construction industry seems to corroborate the idea that the current mismatch between long-term and short-term incentives is preventing developers from making investments that otherwise would be economically rational (Chegut et al., 2019). In the US, the homebuilding sector has a relatively low cost of entry. It is not dominated by a few large players, as evidenced by the economic censuses that report over 100,000 single-family construction companies, with the majority making less than $10 million per year (Gyourko & Molloy, 2015). However, if cities and municipalities were to impose more stringent building regulations that require all new constructions to be energy-efficient, developers facing any of the obstacles mentioned above may decide to exit the residential market. In turn, this could result in a shortage of housing supply and a consequent increase in home prices, harming even further housing affordability. Therefore, it is essential to provide empirical evidence on the quantity and price effects resulting from more stringent regulations on building practices.

Conceptual Framework

The theoretical considerations are based on the assumption that a comprehensive framework that accounts for all the factors and variables involved is needed to understand the effects of more stringent energy-efficiency regulations on housing supply. Thus, I consider it a better starting point to look for the determinants that drive municipalities to apply for the Green Community designation to uncover the driving forces that make cities join this program earlier than others. Secondly, I examine the marginal price effect of a single hedonic characteristic (HERS certification) to see if there is a higher willingness to pay for more energy-efficient homes. Finally, I analyze the overall market outcomes within a partial equilibrium framework under more stringent green building regulations.

What drives municipalities to apply to the Green Community Program?

Survival analysis examines and models the time it takes for events to occur. The typical event is death, from which the name "survival analysis" and much of its terminology derives, but its scope of application is much broader. Survival analysis focuses on the distribution of survival times and examines the relationship between survival and one or more predictors. In particular, the Cox proportional hazards model is a frequently used approach that allows us to study the association between variables and survival rate. It is instrumental in modeling state policy adoption (Knill & Tosun, 2009). One of its key advantages is that, as opposed to parametric models, it merely specifies a functional form for the influence of covariates and avoids the need to parameterize the baseline hazard function, making it much more attractive than the standard logit-probit approach (Jones & Branton, 2005; Knill & Tosun, 2009). Therefore, since this study focuses on understanding the magnitude and direction effects of key covariates included in the model, the Cox model represents a highly preferable estimation technique.

Under the Cox model, the hazard rate is given by:

$$h_i(t) = h_0(t)^{(\beta' x)}$$

Where $h_i(t)$ is the expected hazard at time t for i, $h_0(t)$ is the baseline hazard function when all predictors, x, are equal to zero, and β' is a vector of regression parameters. Although the baseline hazard rate is not directly estimated from the data, the covariate parameters are calculated

through a partial likelihood approach (Cox 1972). Thus, it is possible to test how theoretically significant covariates affect the chances that, for instance, a state adopts a particular policy without making assumptions about the shape of the baseline hazard rate (Jones & Branton, 2005). The quantities e^{β_i} are called hazard ratios. A value of β_i greater than zero, or equivalently a hazard ratio greater than one, indicates that as the value of the i^{th} covariate increases, the event hazard increases, and thus the length of survival decreases. In other words, a hazard ratio above one indicates a covariate is positively associated with the event probability and thus negatively associated with the length of survival. Therefore, I will use the Cox proportional hazards model to investigate the main factors influencing municipalities' decision to apply for the Green Community designation.

Willingness to pay for more energy-efficient homes

Green buildings differ from traditional ones because they require different technological and human capital resources. Therefore, the supply of green buildings is most likely to be driven by construction costs, other certified buildings' price signals, the prices and availability of raw materials and human capital necessary to construct them, advances in green technology, and government policies mandating energy-efficiency (Kok et al., 2011).

Assuming that green price premiums may reflect increased construction or renovation costs, then housing prices may experience increments after Massachusetts's municipalities are designated as Green Communities and, therefore, required to adopt the Stretch Energy Code. After its adoption, developers must incorporate the HERS rating system in every new residential construction and implement certain building practices to guarantee that they achieve the targeted HERS score according to the house type and size.

This first part of the analysis is adopted from Fuerst and McAllister's (2011) analytical framework. As the authors argue, the hedonic price function is based on the assumption that any good or service consists of a variety of utility-bearing characteristics ($z_1, z_2, \dots, z_n$), which, in the context of residential property transaction prices, can be thought of as structural and locational variables. Thus, "the empirically determined hedonic prices are indicative of an implicit market so that demand and supply functions can be derived for both short-run and long-run competitive equilibria" (Fuerst & McAllister, 2011a).

Fuerst and McAllister (2011) show that certified and non-certified properties may not be close substitutes in the marketplace but, if we assume that they are variations of a specific attribute i which represents the green certification then, the following function shows consumers' implicit willingness to pay for a given vector of housing attributes $\boldsymbol{z}$ at a given utility and budget level:

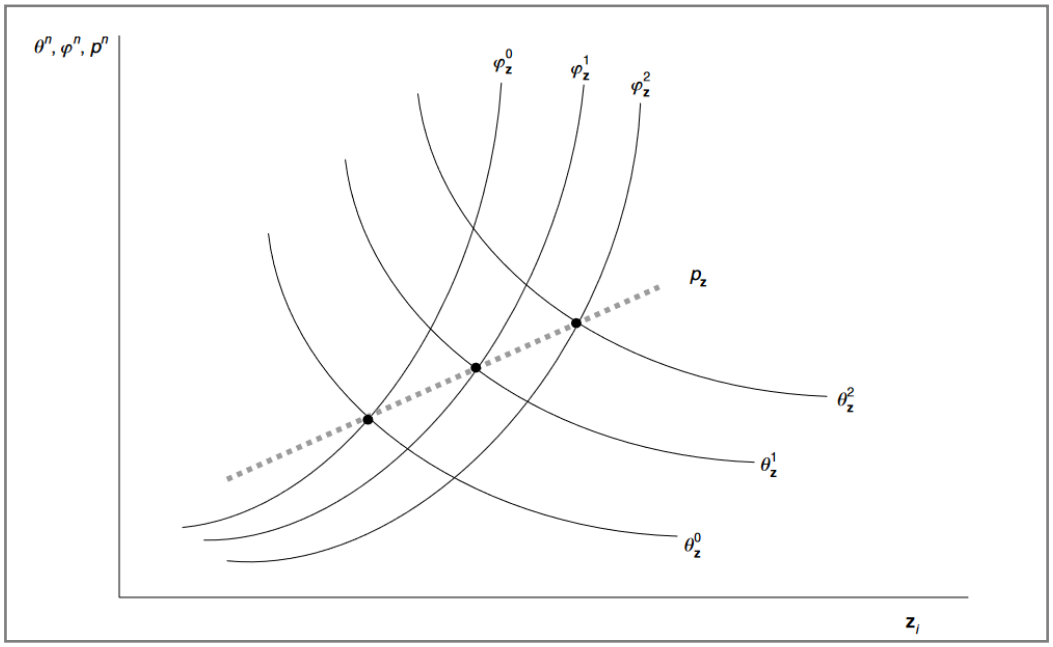
$$\theta_{\boldsymbol{z}_i} = {}^{U_{\boldsymbol{z}_i}}\!/_{U_x} > 0,$$

$$\theta_u = {}^{-1}\!/_{U_x} \; and,$$

$$\theta_y = 1$$

Where $\theta_{\boldsymbol{z}_i}$ is the bid or value function of a consumer, $U_{\boldsymbol{z}_i}$ is the utility of certification in the presence of all other housing attributes, U_x is the utility of all the other goods consumed, and y is the budget restriction. On the producers' side, the authors show that the supply function φ is determined by z_i, a profit-maximizing condition π and a shift parameter β that reflects the cost minimization of factor prices and production function parameters. Figure 4 below shows Fuerst and McAllister's theoretical analysis of the implicit equilibrium prices for the characteristic z_i representing green certifications. The marginal price of green labels is shown by $p_i(z)$ where the optimal level of z_i is defined as the intersection of the marginal value to the consumer and the marginal cost to the producer, demonstrating how higher levels of green certifications are associated with higher marginal prices.

Figure 4. *Marginal hedonic prices of eco-certification resulting from equilibrium reservation prices.*



Source: This Figure is adopted from Fuerst and McAllister (2011). It shows derivatives of a consumer's bid function θ_{z_i} representing demand reservation prices for buildings with various levels of eco-certification and the producer's function φ_{z_i} representing reservation supply prices of an increment in the level of eco-certification z_i.The resulting dashed line $p_i(z)$ is then the marginal price of incremental levels of eco-certification z_i where reservation demand prices and reservation supply prices intersect.

Drawing upon existing literature and the previous theoretical considerations regarding green price premiums, I anticipate that newly constructed homes, i.e., those built after the Stretch Code adoption, will exhibit positive price premiums. Therefore, my first hypothesis is as follows:

Hypothesis 1. All else equal, homebuyers will exhibit a higher willingness to pay for more energy-efficient homes in those communities that have adopted the Stretch Code.

The impact of green building regulations on the housing supply

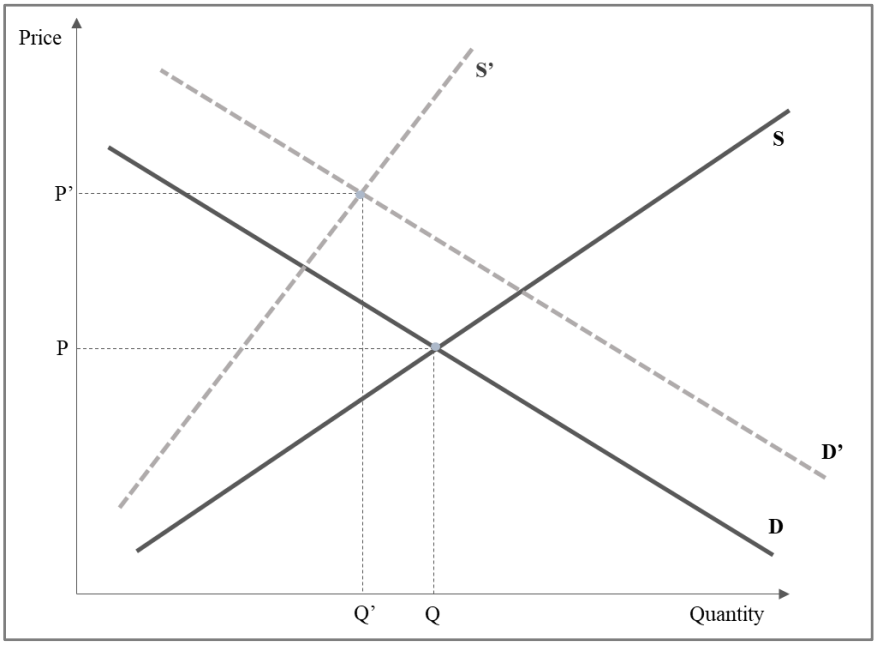
Then I proceed to analyze the effects of regulation on the housing market. Building codes do not directly restrict the housing quantity that can be built on any given amount of land. Still, they do impose other restrictions, such as the types of materials, construction methods, and inclusion of green certifications, among others, that tend to increase the cost of construction both directly through the fees and time costs and indirectly by requiring construction methods and adding uncertainty about project approval (Gyourko & Molloy, 2015). In this sense, the simplest

models predict that regulation will reduce the elasticity of housing supply, resulting in higher house prices and rents and a decrease in the quantity of housing (Fuerst & McAllister, 2011a; Gyourko & Molloy, 2015).

Figure 5 below displays the market expected response to the adoption of the Stretch Energy Code in any given municipality. The housing supply is given by ***S***, ***D*** represents the housing demand, and ***P*** is the equilibrium price. Assuming that the supply will not change by itself unless there is a change in demand, starting from the initial equilibrium point, any exogenous demand shock, such as population increase or inflow, will shift the demand curve upwards from ***D*** to ***D′***. Then, after municipalities are designated as Green Communities and, therefore, required to comply with the Stretch Energy Code, the supply will shift downwardly from ***S*** to ***S′.*** In addition, the slope of ***S′*** will become steeper since the elasticity of the supply will decrease due to the Stretch Code adoption. The rationale behind this change is that, most likely, after the Stretch Code adoption, developers will face an increase in construction costs since they need to pay for the HERS rating, and they will have to transition to more sustainable building practices to achieve the targeted HERS score, which will probably also increase their costs.

Thus, in the short run, the increase in demand coupled with a lower and more inelastic supply curve will result in less housing (from ***Q*** to ***Q′***) and higher average housing prices (from ***P*** to ***P′***) for all homes (new and existing).

Figure 5. *Model for the housing market dynamics after the Stretch Code adoption*



Source: Own elaboration.

Despite the apparent benefits of green regulations, they can also lead to higher prices and reduced housing stock (Brueckner, 2009; Gyourko and Molloy, 2015). In this sense, the Stretch Energy Code may exacerbate idiosyncratic uncertainty in the housing market, leading to a decrease in new home supply as developers face more uncertainty related to the future expected benefits and the processes required to transition to energy-efficient building practices (Ball, 2011). Additionally, the new building code may increase construction costs by placing restrictions on methods and materials used in construction, creating further friction within developers' business practices and potentially contributing to a decrease in supply. After taking into account all these elements, my second hypothesis is as follows:

Hypothesis 2. All else equal, after the Stretch Code adoption, the quantity of new construction will decrease, and the average housing price of all homes will increase. At the same time, the magnitudes will depend on the supply and demand elasticities of new homes in specific municipalities.

Furthermore, local residents' preferences may influence the demand for energy-efficient homes. Individuals who value environmental sustainability, such as those with higher educational levels or political preference for the Democratic Party, may be more inclined to live in or move

into greener homes and be willing to pay a premium for them. Previous studies have offered several potential explanations for why homeowners' perceptions of climate change can influence the equilibrium prices of climate-prone properties. For instance, Bernstein et al. (2019) provide one such explanation when they find that sophisticated buyers were more sensitive to sea-level rise exposure discounts than those less concerned about climate change. Thus, I suggest that residents' characteristics could influence developers' construction decisions. Municipalities with a higher proportion of highly educated citizens and a more significant percentage of Democrats voters may experience an increase in new construction. Therefore, I propose the following third hypothesis:

Hypothesis 3. After adopting the Stretch Code, all else equal, those municipalities with a larger proportion of higher educated citizens and a more significant Democrat vote share will see more new development activities.

Data

Data sources

To empirically address my three hypotheses, my analysis will draw upon five datasets: data on construction permits for new privately-owned housing units, data on housing transaction records, demographic information and political preference for towns and cities within Massachusetts, and data on the HERS Index score for a subsample of homes.

First, I draw data from the Building Permits Survey (BPS), conducted by the US Census Bureau, which collects data on new privately-owned authorizations for housing units. The survey encompasses all permit-issuing places or jurisdictions that issue building or zoning permits. Slightly less than half of permit-issuing sites are surveyed monthly, while the remaining are surveyed annually. In addition, it includes information about the type and number of buildings and housing units and the permit valuation, which is the estimated value of the residential structure as stated on its building permit. The whole BPS database has 5,967 observations for 351 MA municipalities over the 2005 to 2021 period.

Second, I obtained data from Warren Group, a real estate company that collects data on real estate transactions and property characteristics. This dataset covers property transactions in Massachusetts from 2010 to 2022. It provides information on the price at which each property was sold and detailed attributes like size, number of bedrooms, number of bathrooms, and property age, among others. I had an initial number of 13,993,161 observations. Then I proceeded to eliminate those that were not arm-length transactions, had a property use other than residential, were outliers in terms of transaction price and property size, or did not have census tract information. This procedure resulted in a dataset of 1,970,384 properties.

Third, I employed the American Community Survey (ACS) 5-year estimates from the Census Bureau to enrich the analysis by including demographic characteristics of towns and cities such as population, income level, educational attainment, unemployment rate, and home ownership. This dataset has a total of 4,563 observations over the period from 2009 to 2021 and provides a comprehensive view of the 351 MA municipalities.

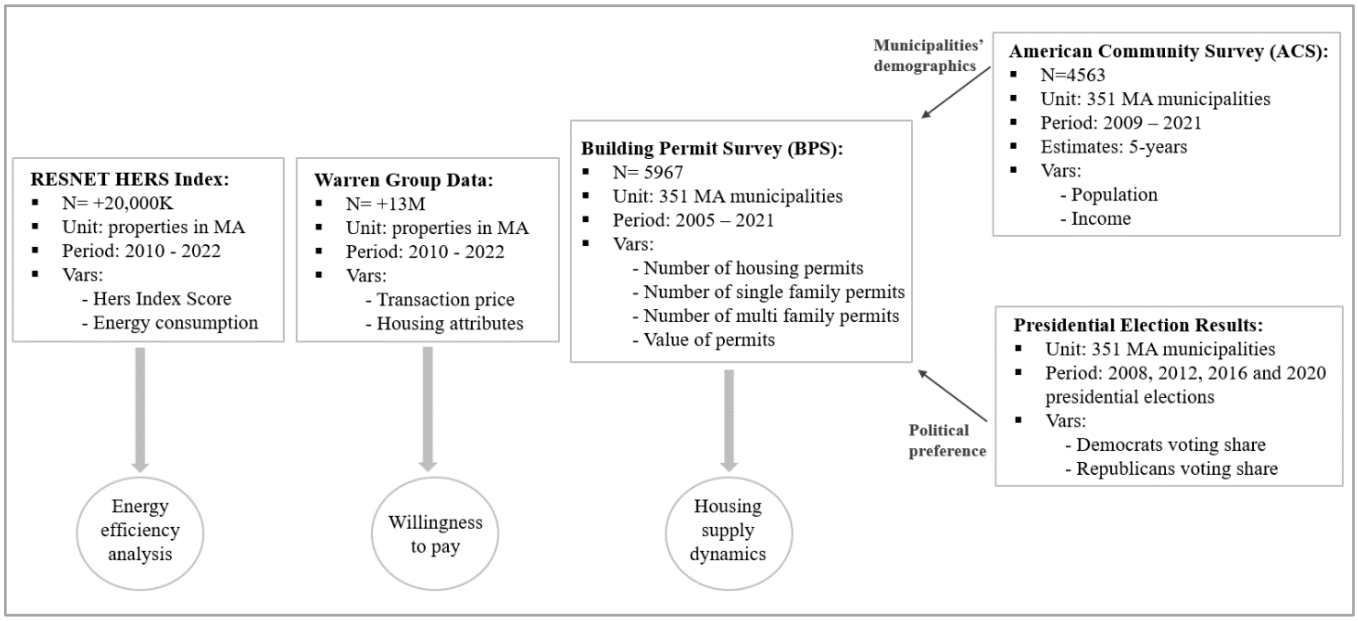
Fourth, I collected data on the 2008, 2012, 2016, and 2020 presidential election results. By doing so, I aim to investigate if political ideology influences buyers' willingness to pay for more energy-efficient homes in any given town or municipality. Including this information allows to

draw more accurate conclusions about the factors that influence consumers' preferences and behavior toward energy-efficient housing.

Fifth, I obtained a data set with the HERS Index score for more than 20,000 homes in Massachusetts. However, I could not merge this dataset with all the others due to inaccuracies in how properties' addresses were imputed. Yet, I used this information to better understand how the average HERS Index score and some energy consumption measures changed after the Stretch Code adoption.

Figure 6 below shows how all the above-mentioned datasets were combined. First, the Warren Group data is used to estimate the green price premium of more energy-efficient homes after the adoption of the Stretch Energy Code. Then the BPS, ACS, and Presidential Election datasets were combined in a resulting dataset of 5,967 observations used to examine the housing market and dynamics and energy-efficient construction practices' role in shaping them.

Figure 6. *Datasets used for analysis*

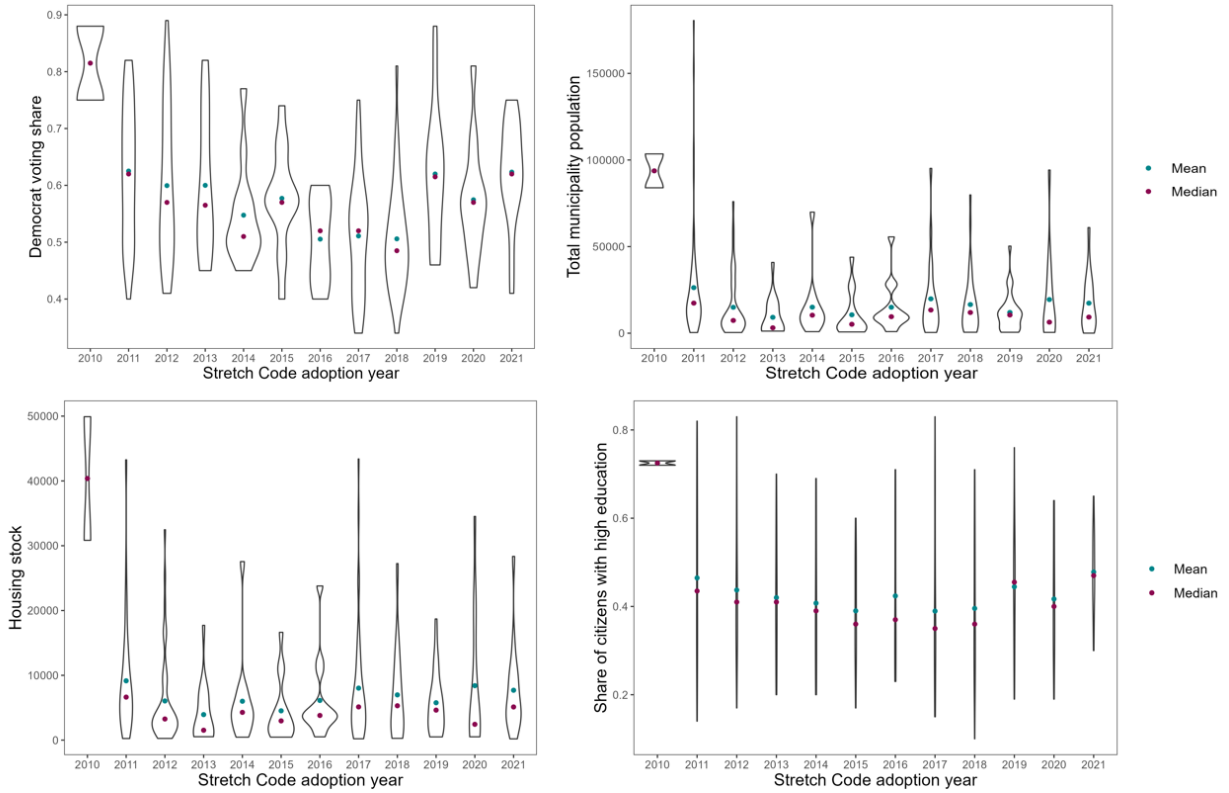


Source: Own elaboration.

Descriptive statistics

Figure 7 below shows distribution plots for demographic variables at the municipality level for each Stretch Code adoption year using ACS 5-year estimates. These variables are Democrat's voting share, total population, housing stock, and the proportion of highly educated citizens. Early adopters of the Stretch Code are municipalities that feature higher levels of educational attainment and a more significant percentage of Democrat party supporters.

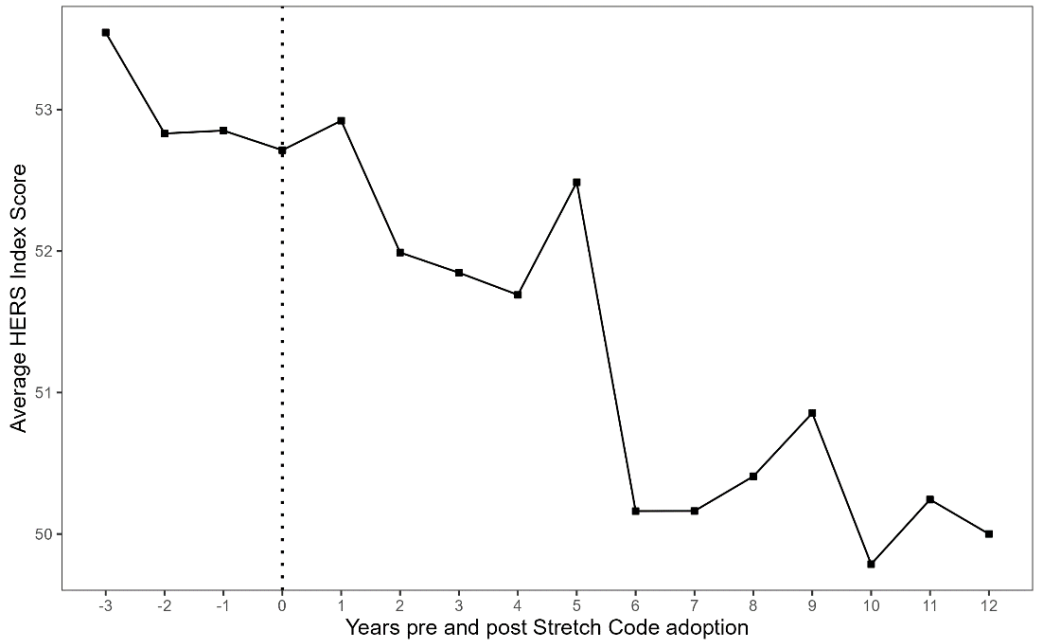
Figure 7. *Distribution plots of key demographic variables*



Source: Own elaboration using ACS 5-year estimates (US Census Bureau).

Concerning the issue of home energy performance, Figure 8 below shows the trend on the average HERS Index score across all MA municipalities before and after they are designated as a Green Community and, therefore, commanded to adopt the Stretch Energy Code. Given that lower scores in the HERS Index indicate higher energy-efficiency levels, the downward trend observed suggests that homes are built with higher energy-efficiency standards after adopting the Stretch Energy Code.

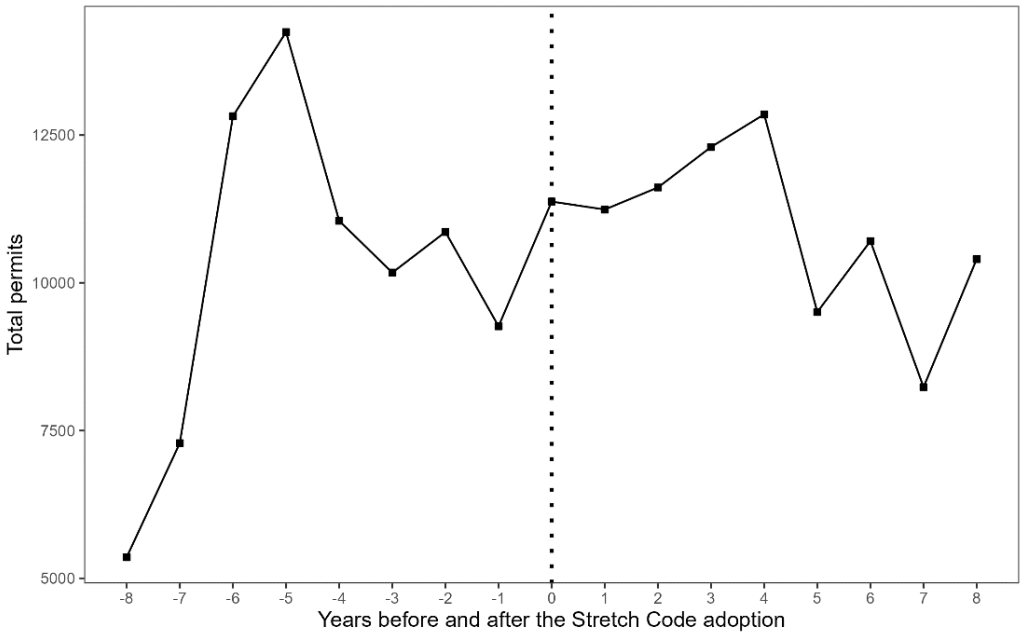
Figure 8. *Average HERS Index score before and after the Stretch Code adoption*



Source: Own elaboration using RESNET-HERS data.

To more systematically address the trend in housing production after a municipality adopts the Stretch Code, I assess the evolution of the number of housing permits before and after its adoption using the Building Permit Survey. Figure 9 shows that housing production slightly decreases immediately after the Stretch Code takes effect, but after one year of its adoption, the trend is reverted.

Figure 9. *Total number of new building permits before and after the Stretch Code adoption*



Source: Own elaboration using the Building Permits Survey (US Census Bureau).

In addition, Table 1 provides information on the total sample and the sub-samples of homes built before and after each municipality's Stretch Code adoption year, obtained from the Warren Group data. The first column shows that the average home in the sample sells for USD 331 per sqft, with an average size of approximately 2238 sqft divided over six rooms. Less than half of the properties in the sample have a parking spot. The remaining columns of Table 1 provide dwelling characteristics across homes built before their municipality adopted the Stretch Code and those homes constructed after it.

The most significant differences between the two groups in the second and third columns occur with regard to price and size. The average home built after the Stretch Code adoption has 380 sqft more and sells for USD 72 per sqft more than the average home built before its adoption. Comparing the other variables across the two groups shows no substantial differences when looking at the proportion of properties with a parking spot, the number of floors, fireplaces, or rooms.

Table 1. *Housing attributes descriptive statistics*

	Full sample		Built after SEC[1]		Built before SEC[2]		
Group	Mean	SD	Mean	SD	Mean	SD	t-test
Price per sqft	331.707	224.89	380.818	258.464	308.286	202.828	72.532***
Size	2238.73	1105.557	2496.427	1159.796	2115.833	1056.846	380.594***
NumRooms	6.451	8.813	7.125	12.024	6.13	6.741	0.995***
NumFireplace	0.51	0.715	0.59	0.74	0.472	0.7	0.118***
NumFloors	1.814	0.74	1.867	0.753	1.789	0.732	0.078***
Has parking	0.402	0.49	0.422	0.494	0.393	0.488	0.029***
Observations	53,169	53,169	15,126	15,126	38,043	38,043	53,169

** p < 0.05, ** p < 0.01, *** p < 0.001*
[1] Homes built after the Stretch Energy Code adoption by the municipality
[2] Homes built before the Stretch Energy Code adoption by the municipality

Finally, Table 2 below shows the mean values of the main variables of interest for the total sample and the sub-samples of municipalities that have adopted the Stretch Code and those that have not yet. This information was obtained using ACS and Building Permits datasets. The third and fifth columns show that municipalities that have adopted the Stretch Energy Code almost double the number of building permits. In particular, when considering the type of property, this difference is especially significant in the case of multi-family homes. Other substantial differences are given by the share of highly educated residents and the number of housing units built after 2010.

Table 2. *Municipalities descriptive statistics*

	Full sample		**Adopters[1]**		**Non-adopters[2]**		
Group	Mean	SD	Mean	SD	Mean	SD	t-test
Total permits	43.05	167.38	46.23	179.29	24.90	63.4	6.47***
SF permits	20.97	28.50	21.89	29.58	15.72	20.55	7.67***
MF permits	22.08	162.39	24.33	174.30	9.18	56.93	4.88***
Log(rent)	6.99	0.27	6.99	0.27	6.97	0.25	2.05*
Log(housing cost)	7.28	0.29	7.29	0.29	7.21	0.25	6.6***
Log(income)	11.28	0.32	11.29	0.33	11.25	0.27	2.86**
Log(housing stock)	8.25	1.25	8.35	1.19	7.68	1.41	11.61***
Log(population)	9.05	1.36	9.15	1.30	8.46	1.55	10.89***
Share of high educ	0.41	0.16	0.42	0.16	0.36	0.13	12.1***
Unemployment rate	0.04	0.01	0.04	0.01	0.04	0.02	-1.47
Share of detached houses	0.72	0.19	0.71	0.19	0.77	0.16	-9.56***
Q units built after 2010	339.67	896.55	361.72	957.06	212.89	374.72	7.07***
Poverty rate	0.06	0.04	0.07	0.04	0.06	0.03	6.41***
Democrat voting share	0.58	0.11	0.58	0.11	0.54	0.10	10.93***
Observations	5967	5967	5083	5083	884	884	5967

** $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$*

[1] Municipalities that have adopted the Stretch Energy Code

[2] Municipalities that have not adopted the Stretch Energy Code yet

Empirical Strategy

To investigate the tension in the housing supply resulting from more stringent energy-efficiency regulations, I propose first examining the main factors that drive municipalities to join the Green Communities Program using survival analysis techniques. Then, I will address the question of whether there is a higher willingness to pay for more energy-efficient homes through a standard hedonic model. And finally, I will analyze the staggered municipalities' designation as Green Communities to identify the causal mechanisms behind quantity and price effects in the residential real estate market.

What drives municipalities to apply to the Green Community Program?: Survival analysis

As mentioned in the theoretical considerations, to estimate the likelihood that a municipality joins the Green Community Program between time t and Δt, given that at time t it has not joined yet, I will estimate a Cox proportional hazards model of the following form:

$$h_m(t) = h_0(t)\exp(DiD_t + \beta_1 HousingStock_m + \beta_2 Pop_m + \beta_3 HighEduc_m + \beta_4 Income_m + \beta_5 Democrat_m \quad (1)$$

Where, DiD_t takes the value of 1 for municipalities that have adopted the Stretch Energy Code after the year of adoption, $HousingStock_m$ refers to the logarithm of the housing stock in municipality m; Pop_m to the logarithm of the population level; $HighEduc_m$ to the share of highly educated residents; $Income_m$ is the logarithm of the median income level in municipality m; and, $Democrat_m$ refers to the Democrat's voting share in municipality m.

Willingness to pay for HERS-rated residential homes

In his seminal paper, Rosen (1974) describes how implicit (i.e., hedonic) prices can be ascribed to non-market goods based on observed transactions in related markets (Bruegge et al., 2016). Given that the Green Community designation mandates the adoption of the Stretch Energy Code, every new construction after the code adoption must comply with the requirement of rating the property with the RESNET HERS Index. Therefore, I assume that after the Stretch Code adoption, every new house is a HERS-rated property. Thus, to estimate the higher energy-

efficiency sale price premium for residential homes that incorporate the HERS Index rating system, the hedonic model, as specified in Eq. (2), will be used. The HERS Index label is not directly sold or bought in the market, so its value cannot be observed as the equilibrium of supply and demand forces. Instead, it is always bought and sold in conjunction with an entire bundle of other housing characteristics, so the label's value can be determined using a hedonic model. This model assumes that each feature of a house (such as the HERS label, the size, the location, etc.) contributes to the market value of the entire home. The value of any particular feature, such as the HERS certification, can be implicitly identified by comparing houses that are similar except for the HERS label so that the average difference in market value for comparable homes with the HERS label and those without is the implied market value of the label (Bruegge et al., 2016).

Therefore, I analyze the relationship between energy efficiency and the transaction prices of HERS homes by employing a standard hedonic pricing model. To guarantee comparability, I restrict the sample to houses built no more than five years before the year the municipality adopted the Stretch Energy Code. Thus, the basic linear regression model takes the following form:

$$\log(P_{imt}) = \alpha + \beta_1 Stretch_i + \beta_2 X_{imt} + \gamma Age_i + \theta Location_m + \varphi YearMonth_t + \varepsilon_{imt} \quad (2)$$

The dependent variable is the logarithm of the transaction price of a house i in year t in municipality m. The primary explanatory variable of interest is $Stretch_i$, which takes the value of 1 for homes that are assumed to be HERS-rated properties and 0 otherwise. In line with the literature on the price premium of green buildings, a positive estimate of β_1 would be consistent with the idea that homeowners are willing to pay a higher price for a HERS-certified and, thus, more energy-efficient home. Further, I control for a rich set of housing attributes, including size, number of rooms, and parking space availability.

To obtain asymptotically consistent estimates from Eq. (2), a critical assumption that needs to be made is that the error term ε_{imt} must be uncorrelated with the covariates, implying that all factors that systematically affect equilibrium home prices are included in the regression (Bruegge et al., 2016). Therefore, to mitigate potential omitted variable bias, I allow individual effects to vary by time and neighborhood by including neighborhood and year-by-month time fixed effects. I also control for building age to disentangle the price effect of "being new" and "being green."

In this model specification, we cannot entirely rule out the possibility that unobserved quality differences between HERS homes and non-HERS homes determine the observed

differences in transaction prices. For instance, HERS homes might be coupled with other housing characteristics such as nicer kitchens or bathrooms. Nevertheless, by controlling for housing characteristics on the building level, I aim to reduce this possibility as much as possible.

Stretch Energy Code impact on the housing supply

The effects of land use restrictions on housing prices have been explored extensively. At the same time, relatively few studies have attempted to estimate how land use regulations suppress new residential development (Jackson, 2016). To assess the housing quantity and price effects resulting from the Stretch Energy Code adoption, I exploit the code's staggered adoption and estimate a fixed effect model to compare the changes in residential development in cities that have adopted the Stretch Energy Code to the changes in growth in towns that did not. The model for the quantity effect takes the following form:

$$NewBuilt_{mt} = \gamma + \mu_1 Stretch_m + \mu_2 DiD_{mt} + PopChange_m + \mu_4 X_{mt} + \varphi Year_t + \varepsilon \qquad (3)$$

The dependent variable, $NewBuilt_{mt}^{j}$ is the aggregate quantity of newly built houses in municipality m in year t, reflecting the supply of new homes. $Stretch_m$, indicates the Stretch Code adoption and takes the value of 1 if municipality m has adopted Stretch Code and 0 otherwise. DiD_{mt} is the primary variable of interest that takes the value of 1 if the outcome was observed in the treatment group ($Stretch_m$=1) and after the adoption year, and 0 otherwise. I also include $PopChange_m$, which is a time-invariant measure of population change between 1980 and 2010 and local residents' factors, X_{mt}, such as the municipality's housing stock, educational attainment, poverty, and unemployment rates. In order to avoid reverse causality, all explanatory variables take the lagged value of the previous year. Finally, fixed effects are included to control for yearly market trends and unobservable attributes. I refrain from including city-fixed effects following Duranton and Puga (2014). The main reason is that as the decision to adopt the Stretch Code or not is highly correlated with the municipality-level factors, the correlation between changes in building code stringency and housing supply residual (the error term) in the above model will be much stronger than the correlation between the level of building code stringency and the error term. In other words, fixed-effect estimations would lead to a larger bias (Duranton and Puga, 2014).

The key parameter μ_2 represents how much the average outcome of the Stretch adopters' group has changed after the adoption, compared to what would have happened to the same group had the code not been adopted. Based on my hypotheses, I expect a negative value of the coefficient μ_2 indicating that the quantity of new residential building permits decreases after the Stretch Code adoption in those municipalities that have adopted it and, therefore, mandated green residential building constructions.

Finally, turning to the relationship between the Stretch Energy Code adoption and the sales prices, Eq. (4) estimates the same model as Eq. (3) but with the logarithm of the average transaction price as the dependent variable. The model is as follows:

$$Price_{mt} = \gamma + \mu_1 Stretch_m + \mu_2 DiD_{mt} + PopChange_m + \mu_4 X_{mt} + \varphi Year_t + \varepsilon \qquad (4)$$

According to my hypothesis, I expect a positive value for the coefficient μ_2 indicating that the average housing price will increase after the Stretch Code adoption due to the decrease in housing supply that follows the more stringent building regulation implementation. Again, as mentioned above, I refrain from including city-fixed effects following Duranton and Puga (2014).

Results

First, the findings concerning the main factors that drive municipalities to apply for the Green Community designation are presented. Then, I assess the magnitude of the willingness to pay for more energy-efficient homes, and, finally, I turn to the effects of the Green Community designation coupled with the mandatory adoption of the Stretch Energy Code on the housing supply dynamics.

Primary factors driving municipalities to apply to the Green Community Program

Table 3 shows the Cox proportional hazards model (Eq. 1) estimates of the difference in time to application to the Green Community Program across municipalities which are part of the program and those that are not. Columns 1 to 4 display different models' specifications, varying depending on which covariates are included. The great majority of coefficients across models' specifications are not statistically significant except for $High\ Educ,$ which shows a positive, higher than one, and statistically significant coefficient every time this variable is included. The fact that this coefficient is bigger than one means that the share of high educated residents is positively associated with the probability of applying to the Green Communities Program and thus negatively associated with the length of survival. For instance, the coefficient in Column 1 implies that a one-unit increase in the share of $High\ Educ$ is associated with an approximate $e^{1.558}$ times higher hazard (risk) of adoption.

Similarly, Column 4 shows a model specification with four statistically significant coefficients. For instance, holding the other covariates constant, a one-unit increase in the population is associated with an approximate $e^{0.555}$ times higher hazard (risk) of adoption. Additionally, in Column 3, it is shown that an increase of 100 pp increase in the Democrat's voting share increases the hazard by a factor of $e^{1.243}$, which means that a 1 pp increase in this vote share is associated with a $0.01 * e^{1.243}$ times higher risk of adoption.

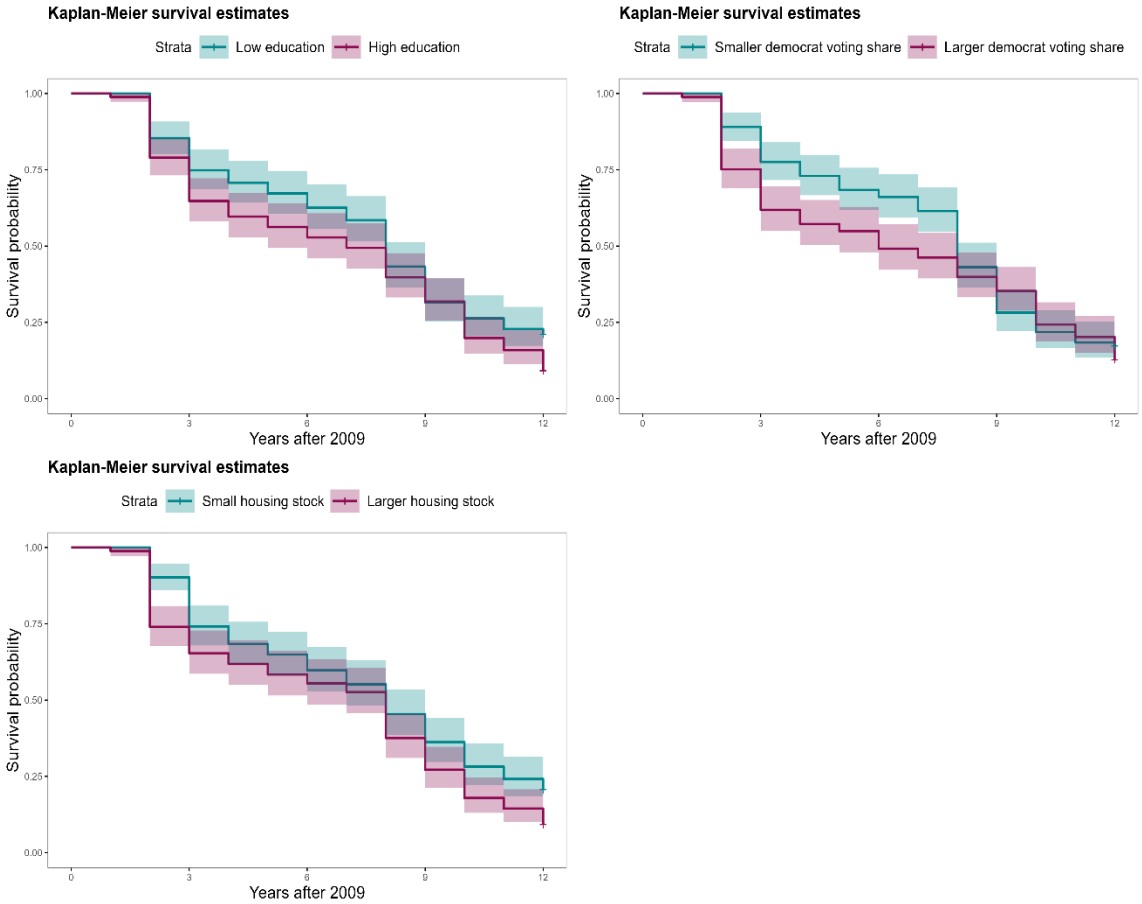
Table 3. *Regression results for the Cox proportional hazards model*

	Dependent variable:			
	time			
	(1)	(2)	(3)	(4)
Log(Housing stock)	0.047	0.065		-0.386*
	(0.196)	(0.208)		(0.228)
Log(Population)	0.125	0.103	0.170***	0.555***
	(0.178)	(0.191)	(0.043)	(0.212)
Share of high educ	1.558***			4.365***
	(0.372)			(0.654)
Log(Income)		-0.003	0.040	-1.797***
		(0.199)	(0.188)	(0.329)
Democrat voting share			1.243**	-0.714
			(0.551)	(0.692)
Observations	347	347	347	347
R^2	0.086	0.040	0.054	0.162
Max. Possible R^2	1.000	1.000	1.000	1.000
Log Likelihood	-1,514.507	-1,523.096	-1,520.638	-1,499.523
Note:				*p<0.1; **p<0.05; ***p<0.01
				Standard errors in parentheses

Figure 10 shows the estimated survival functions for specific covariates while the others are fixed at their average values. The horizontal axis indicates the years it would take any given municipality to adopt the Stretch Energy Code since 2009, while the vertical axis shows the survival probability, i.e., one minus the probability of the Stretch Code adoption. For instance, the first plot displays the estimated survival functions for municipalities with high education attainment levels (a given municipality's share of highly educated residents is bigger than the mean share across all municipalities) and those with lower levels.

In sum, higher education-level municipalities are more likely to adopt the Stretch Energy Code. Similarly, municipalities with more extensive housing stock and larger Democrats voting share are also more likely to adopt the Stretch Code earlier. However, these coefficients are not statistically significant.

Figure 10. *Kaplan-Maier survival estimates*

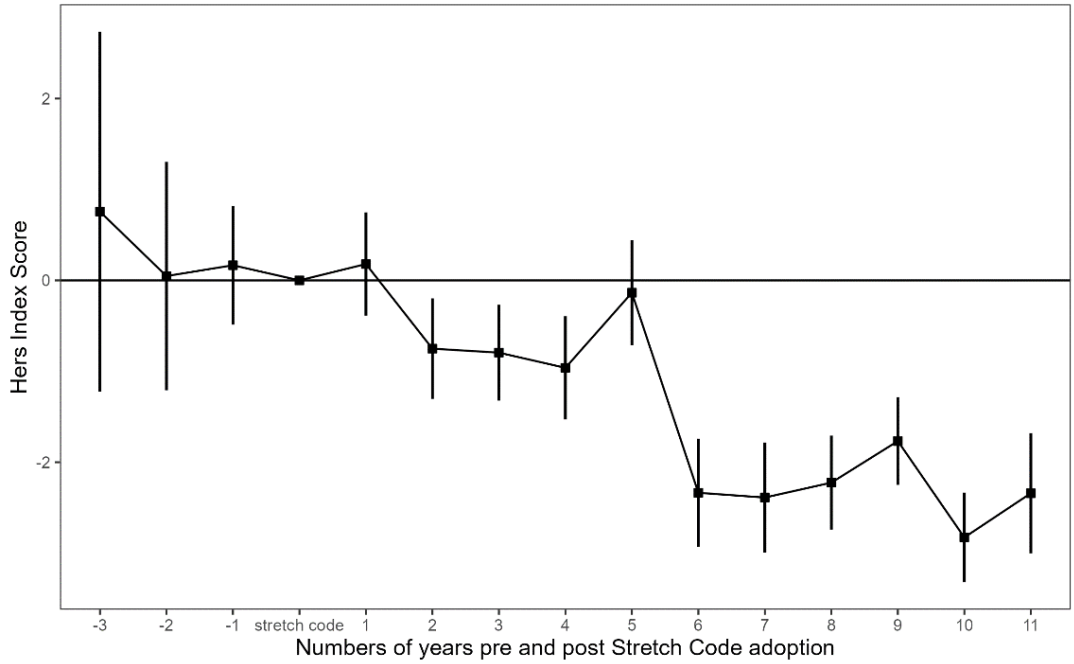


Source: Own elaboration using ACS 5-year estimates data (US Census Bureau).

Willingness to pay for HERS-rated residential homes

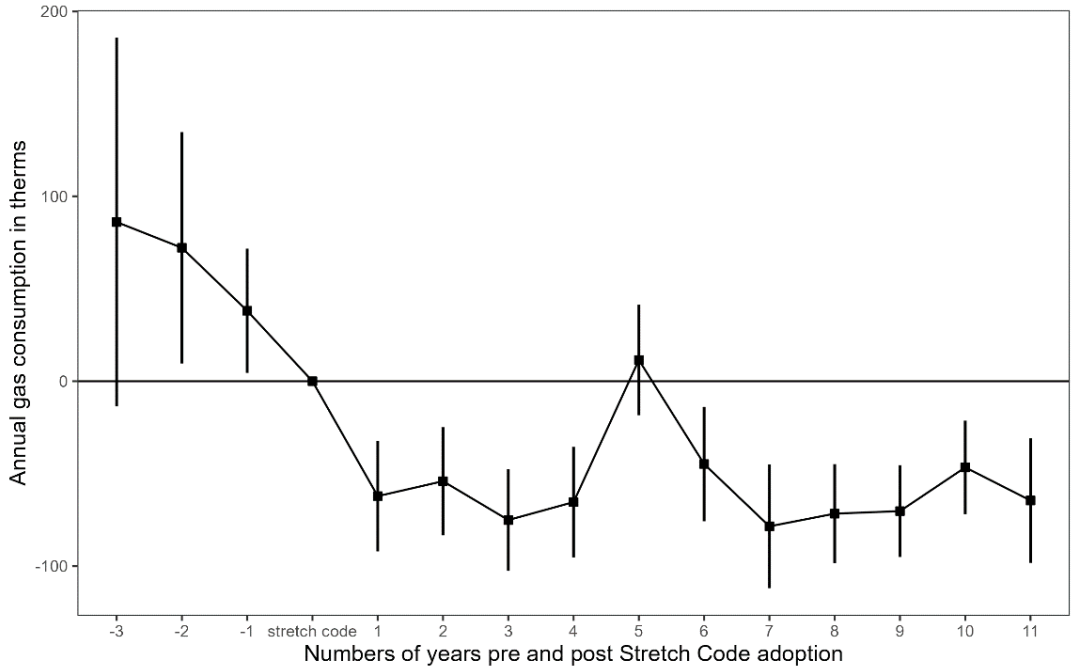
To begin analyzing the issue of whether there is a higher willingness to pay for more energy-efficient properties, I propose empirically assessing if homes built after the Stretch Code adoption are performing better in terms of energy efficiency. Using the RESNET-HERS Index dataset, I estimate two regressions with the Hers Index score and the annual gas consumption as dependent variables on the difference in years between the HERS rating date and the Stretch Code adoption date across municipalities. Figures 11 and 12 plot the regression coefficients of both regressions. Indeed, both graphs indicate that after the Stretch Code adoption, homes exhibit lower HERS scores (i.e., higher energy efficiency) and lower gas consumption levels.

Figure 11. *Effect of Stretch Code adoption on the HERS Index score*



Source: Own elaboration using RESNET-HERS data.

Figure 12. *Effect of Stretch Code adoption on annual gas consumption in therms*



Source: Own elaboration using RESNET-HERS data.

Next, the regression analysis results using the model in Eq. (2) are presented in Table 4. All the specifications use the natural logarithm of the sales price per sqft as the dependent variable related to a set of hedonic housing attributes that serve as control variables. Gradually more fixed effects are added from Columns 1 to 4. Importantly, keeping constant the observable characteristics, the Stretch Code adoption dummy is positive and significant in all four model specifications meaning that there is a higher willingness to pay for more energy-efficient homes. In accordance with the literature, these greener properties command a sales price premium of about 3.7 to 5.5 percent.

Table 4. *Effect of the Stretch Energy Code adoption on willingness to pay*

	Price per sqft			
	(1)	(2)	(3)	(4)
StretchCode	0.233***	0.224***	0.037***	0.055***
	(0.007)	(0.006)	(0.009)	(0.008)
Log(Size)	-0.377***	-0.288***	-0.376***	-0.366***
	(0.007)	(0.006)	(0.007)	(0.006)
NumRooms	0.002***	0.001***	0.001***	0.001***
	(0.0003)	(0.0003)	(0.0002)	(0.0002)
NumFireplace	0.135***	0.143***	0.056***	0.065***
	(0.004)	(0.004)	(0.003)	(0.003)
NumFloors	-0.099***	-0.092***	-0.031***	-0.031***
	(0.004)	(0.004)	(0.004)	(0.003)
Parking	0.042***	0.033***	0.031***	0.032***
	(0.006)	(0.005)	(0.006)	(0.005)
Intercept	8.651***	7.272***	7.495***	7.911***
	(0.056)	(0.109)	(0.216)	(0.222)
Bldg age FE	Yes	Yes	Yes	Yes
Year-month FE	No	Yes	Yes	Yes
Location FE	No	No	Block gr.	C.tract
Observations	59,488	59,488	59,488	59,488
R^2	0.114	0.296	0.672	0.634
Note:		*p<0.1; **p<0.05; ***p<0.01		
		Standard errors in parentheses		

Table 5 below shows the regression results for the same model for two different sub-samples. Columns 1 and 2 report the results for the logarithm of transaction prices per sqft for single-family units. At the same time, Columns 3 and 4 have the logarithm of transaction prices per sqft for multi-family units as the dependent variable. The aim was to investigate if there was a differential price premium for both home types. The coefficients in Columns 2 and 4 do not differ substantially, so it might be difficult to argue that there is a sizeable difference between the price premiums for both home types.

Table 5. *Effect of the Stretch Energy Code adoption on the willingness to pay – by property type*

	Price per sqft			
	Single-Fam		Multi-Fam	
	(1)	(2)	(3)	(4)
StretchCode	0.045***	0.041***	0.011	0.046***
	(0.012)	(0.011)	(0.015)	(0.013)
Log(Size)	-0.372***	-0.335***	-0.191***	-0.220***
	(0.012)	(0.011)	(0.009)	(0.008)
NumRooms	0.008***	0.008***	0.001***	0.001***
	(0.002)	(0.001)	(0.0002)	(0.0002)
NumFireplace	0.050***	0.061***	0.065***	0.063***
	(0.005)	(0.004)	(0.007)	(0.006)
NumFloors	-0.033***	-0.032***	-0.032***	-0.028***
	(0.006)	(0.006)	(0.004)	(0.004)
Parking	-0.017**	-0.015*	0.058***	0.065***
	(0.009)	(0.008)	(0.008)	(0.007)
Intercept	8.246***	7.009***	6.841***	7.685***
	(0.278)	(0.439)	(0.310)	(0.333)
Bldg age FE	Yes	Yes	Yes	Yes
Year-month FE	Yes	Yes	Yes	Yes
Location FE	Block gr.	C.tract	Block gr.	C.tract
Observations	22,597	22,597	23,094	23,094
R^2	0.605	0.558	0.819	0.788
Note:		*p<0.1; **p<0.05; ***p<0.01		
		Standard errors in parentheses		

Stretch Energy Code impact on the housing supply

Finally, I now analyze the effect of the Stretch Energy Code adoption on the housing supply. Table 6 reports the regression coefficients resulting from estimating Eq. (3). Column 1 shows the model with the total number of new permits at the municipality level as the dependent variable, while Columns 2 and 3 use the number of single-family new permits and multi-family new permits at the municipality level as dependent variables respectively. The coefficient of DiD, the main variable of interest, exhibits the expected sign in the case of the single-family developments, and its magnitude implies that the adoption of the Stretch Energy Code is associated with a decrease of 12 percent in the number of new permits. However, for the case of multi-family (Column 3), the coefficient has the opposite expected sign in the sense that municipalities that adopt the Stretch Code experience an increase of almost 18 percent in the quantity of multi-family new building permits.

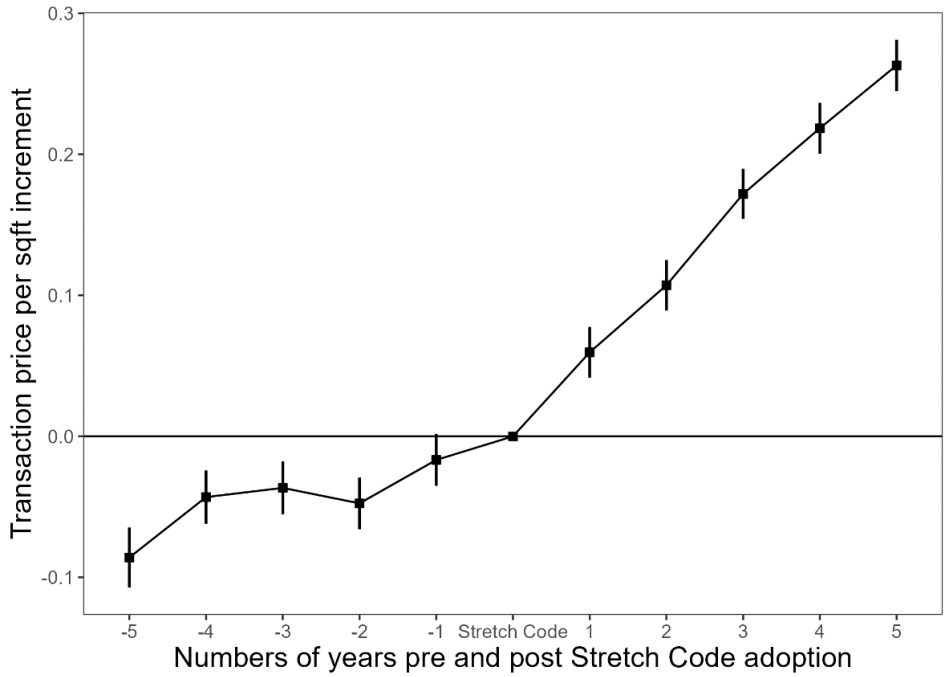
In addition, the population change variable has the expected sign. It is statistically significant for Columns 1 and 2, indicating that a 10 pp increase in the population growth rate leads to an increase in the new permits of 6.8 and 8.4 percent, respectively. The rest of the statistically significant covariates also exhibit signs in the expected direction.

Table 6. *Effect of Stretch Energy Code adoption on housing supply*

	Quantity of new building permits		
	All types	Single-F	Multi-F
	(1)	(2)	(3)
Treatment	0.085*	0.080**	-0.053
	(0.044)	(0.041)	(0.066)
DiD (Treat x Post)	-0.012	-0.120***	0.179***
	(0.037)	(0.035)	(0.056)
Pop increase 1980-2010	0.680***	0.840***	-0.101
	(0.044)	(0.041)	(0.066)
Log(Housing stock)	0.882***	0.709***	0.542***
	(0.012)	(0.011)	(0.018)
Share of high educ	0.798***	0.337***	0.956***
	(0.106)	(0.098)	(0.158)
Unemployment rate	-0.772	-1.499	1.416
	(1.075)	(0.997)	(1.605)
Poverty rate	-4.053***	-5.586***	2.047***
	(0.375)	(0.348)	(0.561)
Intercept	-5.018***	-3.520***	-4.301***
	(0.121)	(0.112)	(0.180)
Year FE	Yes	Yes	Yes
Observations	4,200	4,200	4,200
R^2	0.594	0.527	0.237
Note:	*p<0.1; **p<0.05; ***p<0.01		
	Standard errors in parentheses		

Before turning to the effect of the Stretch Code adoption on municipal-level average housing prices, it is worth noting the coefficients plotted in Figure 13, which were obtained by running the regression of the municipal-level average transaction price per sqft on the difference in years between the transaction date and Stretch Code adoption date across municipalities. Indeed, all coefficients except one are statistically significant, and, particularly after the Stretch Code adoption, the curve has a markedly upward trend which could be taken as evidence of an increase in the average transaction price.

Figure 13. *Transaction price per sqft increment after Stretch Code adoption*



Source: Own elaboration using Warren Group transaction data.

Table 7 shows the results of estimating the model in Eq. (4). The six columns differ in the sub-samples used for estimating the effect of the Stretch Code adoption on the average housing price at the municipality level. For instance, in Column 1, all properties in the Warren Group transaction database are used to calculate the dependent variable, i.e., price per sqft per year per municipality. In Columns 2 and 3, single-family and multi-family properties are considered respectively. Finally, the last three columns report the results for non-HERS-rated properties: homes built before the Stretch Code adoption. This sub-sample is further divided between single-family homes (Column 5) and multi-family properties (Column 6).

The coefficient of DiD, the primary variable of interest, is always positive, as expected, and statistically significant across all the models except for the last one. The average transaction price of all properties increases by about 5.1% as a result of the Stretch Code adoption. Furthermore, when only single-family homes are considered, the average price increase rises to 5.7%, and, in the case of multi-family homes, it drops to 4.7%.

Similarly, those non-HERS-rated homes are also subject to an overall price increase equal to 4.3%, stemming from the fact that, as demonstrated in the quantity model, the introduction of

the Stretch Energy Code leads to a supply decrease in the housing quantity which, in turn, raises the average sales prices of all homes, including those non-HERS-rated. For this last group, the increase is even more pronounced in the case of single-family homes, 6.2%, but is not statistically significant for multi-family developments.

Finally, it should be noted that the coefficient of $Pop\ increase\ 1980-2010$ has the opposite expected sign since it should be positive given that all else equal, any exogenous demand shock, such an increase in population, will drive the average housing price up.

Table 7. *Effect of Stretch Energy Code adoption on housing supply*

	Prices per sqft					
	All homes	SF	MF	NH	NH-SF	NH-MF
	(1)	(2)	(3)	(4)	(5)	(6)
DiD (Treat x Post)	0.051***	0.057***	0.047**	0.043***	0.062***	0.024
	(0.015)	(0.015)	(0.022)	(0.016)	(0.016)	(0.024)
Pop increase 1980-2010	-0.040**	-0.001	-0.097***	-0.036*	-0.023	-0.069**
	(0.018)	(0.018)	(0.025)	(0.019)	(0.019)	(0.027)
Log(Housing stock)	0.131***	0.094***	0.161***	0.143***	0.107***	0.172***
	(0.008)	(0.008)	(0.012)	(0.009)	(0.009)	(0.013)
Share of high educ	1.176***	1.175***	1.164***	1.229***	1.243***	1.154***
	(0.043)	(0.042)	(0.063)	(0.045)	(0.047)	(0.068)
Unemployment rate	-0.898	-0.086	-0.848	-0.599	-0.170	-0.696
	(0.580)	(0.571)	(0.860)	(0.611)	(0.626)	(0.959)
Poverty rate	-0.055	-0.243	-0.612**	-0.281	-0.551***	-0.679**
	(0.176)	(0.175)	(0.250)	(0.184)	(0.191)	(0.268)
Intercept	3.676***	3.898***	3.495***	3.548***	3.788***	3.393***
	(0.079)	(0.083)	(0.112)	(0.083)	(0.090)	(0.123)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,835	1,771	1,430	1,811	1,666	1,311
R^2	0.556	0.568	0.431	0.542	0.555	0.402

Note: *p<0.1; **p<0.05; ***p<0.01
Standard errors in parentheses

Heterogeneous effects

Finally, this section presents heterogeneous effects on the housing quantity effect by income and education level. Table 8 shows the result of estimating the model in Eq. (3) with the inclusion of the interaction term between DiD and the $High\ Income$ dummy variable that takes the value of 1 when the municipality has an income level that is higher than the average income level of 2015 across all municipalities, and 0 otherwise. This interaction term is only significant for the single-family model, and, as expected, its positive sign means that higher-income municipalities observe a smaller decline in the supply of single-family units.

Table 8. *Effect of Stretch Energy Code adoption on housing supply by income level*

	Quantity of new building permits		
	All types	Single-F	Multi-F
	(1)	(2)	(3)
Treatment	0.092**	0.075*	-0.034
	(0.044)	(0.042)	(0.066)
DiD (Treat x Post)	-0.061	-0.235***	0.224***
	(0.047)	(0.044)	(0.070)
High income	0.350***	0.300***	0.050
	(0.041)	(0.039)	(0.062)
DiD x High inc	0.064	0.163***	-0.044
	(0.057)	(0.054)	(0.086)
Pop increase 1980-2010	0.640***	0.837***	-0.153**
	(0.045)	(0.042)	(0.068)
Log(Housing stock)	0.843***	0.659***	0.557***
	(0.012)	(0.011)	(0.018)
Unemployment rate	-3.151***	-4.788***	2.693*
	(1.049)	(0.987)	(1.570)
Share high educ	0.558***	0.257**	0.703***
	(0.115)	(0.108)	(0.172)
Intercept	-4.936***	-3.442***	-4.272***
	(0.122)	(0.114)	(0.182)
Year FE	Yes	Yes	Yes
Observations	4,200	4,200	4,200
R^2	0.594	0.514	0.234
Note:	*p<0.1; **p<0.05; ***p<0.01		
	Standard errors in parentheses		

Table 9 presents the results of the heterogeneity analysis by education level. Similarly, an interaction term between DiD and the $High\ Education$ dummy variable is included. The $High\ Education$ variable takes the value of 1 when the municipality has a share of highly educated residents that is larger than the average share of highly educated residents in 2015 across all municipalities, and 0 otherwise. Unlike the previous results, the interaction term is statistically significant across the three models. Its positive sign implies that even though there is a decrease in the supply of housing units, evidenced by the negative sign of the DiD coefficient, those municipalities that have a more significant proportion of highly educated residents are less affected.

Table 9. *Effect of Stretch Energy Code adoption on housing supply by education level*

	Quantity of new building permits		
	All types	Single-F	Multi-F
	(1)	(2)	(3)
Treatment	0.103**	0.095**	-0.038
	(0.044)	(0.041)	(0.066)
DiD (Treat x Post)	-0.098**	-0.150***	0.039
	(0.048)	(0.045)	(0.072)
High educ	0.111***	-0.015	0.205***
	(0.039)	(0.037)	(0.059)
DiD x High educ	0.219***	0.091*	0.315***
	(0.058)	(0.054)	(0.087)
Pop increase 1980-2010	0.676***	0.836***	-0.100
	(0.044)	(0.041)	(0.066)
Log(Housing stock)	0.890***	0.715***	0.547***
	(0.012)	(0.011)	(0.018)
Unemployment rate	-1.733	-2.490**	1.080
	(1.063)	(0.987)	(1.583)
Poverty rate	-4.454***	-5.910***	1.820***
	(0.361)	(0.335)	(0.537)
Intercept	-4.777***	-3.379***	-4.059***
	(0.115)	(0.107)	(0.172)
Year FE	Yes	Yes	Yes
Observations	4,200	4,200	4,200
R^2	0.594	0.526	0.242
Note:	*p<0.1; **p<0.05; ***p<0.01 Standard errors in parentheses		

Discussion

Having discussed the results of the green price premium and quantity and price effects resulting from the Stretch Energy Code adoption in the preceding section, I now incorporate estimations of the increase in construction costs due to more energy-efficient building practices. In this regard, the 2023 MIT-WIT report titled "Public Policy for Net Zero Homes and Affordability"[10] determines the incremental cost of building net zero housing at different efficiency levels across Massachusetts. To that end, the WIT principal investigators, Payam Bakhshi, Afshin Pourmokhtarian, and John Cribbs, reviewed past studies of the cost premium of high-efficiency (e.g., Net-Zero and Passive House) residential buildings; conducted interviews with architects, engineers, and contractors; identified parameters and developed model houses; performed energy modeling and Manual J calculations to define specifications for the model houses; prepared quote sheets, obtained written prices from subcontractors, and performed cost estimates based on those quote sheets and RS Means data; and analyzed the collected data and calculated the cost implications.

Table 10 below shows the results of the cost deltas obtained for single-family and small multi-family (4 units). Thus, in the case of single-family homes, the specialized Stretch Energy Code is likely to increase the construction cost by between $10,000 and $20,000 depending on the chosen pathway to compliance. For 4-unit multi-family developments, the cost increase ranges between $34,000 and $82,000 again, depending on some construction features. In addition, the table also incorporates the mean permit value obtained from the US Census Bureau Building Permit Survey, which reports the estimated value of the residential structure as shown on the building permit at the time of its submission. I consider this value a proxy of the construction cost for each type of home to calculate the proportion of these costs increments from the total average construction cost. However, I also acknowledge that the building permit value could be lower than the actual construction cost of a given property. Therefore, the analysis that follows should be regarded as on the conservative side. Considering the mean permit value as a proxy of the average construction cost, it can be argued that building greener bear a higher cost increment in the case of multi-family developments (4.6 -11%). Although not insignificant, the cost delta for single-family homes is much lower and lies in the 2.8 – 5% range.

[10] Working paper that will be released on June 2023.

Table 10. *Increment in construction costs*

	Single-family	**Multi-family (4 units)**
Construction cost delta	$10,846 - $19,188	$34,230 - $82,257
Mean permit value	$384,671	$750, 712
Cost delta as % of permit value	2.8% - 5%	4.6% - 11%

Table 11 reports a summary of the findings presented in the Results section. The first column shows the results of the property-level analysis to estimate people's willingness to pay for more energy-efficient homes, that is, the green price premium that HERS-rated houses exhibit in contrast to non-HERS-rated properties. As discussed, the price premium is slightly higher for multi-family homes, which aligns with the fact that multi-family homes exhibit higher increments in construction costs. In addition, the fact that there is an increase of 18%, as shown in Column 4, in the supply of multi-family could be considered counterintuitive concerning the hypothesis stated in this document. However, it could also indicate that developers are transitioning from building single-family homes to multi-family residential properties, which might stem from the fact that it is easier and less expensive to incorporate greener building practices in the case of multi-family homes. For instance, in these developments, better insulation is easier to achieve due to shared walls. Needless to say, more evidence should be gathered to confirm or not this potential explanation.

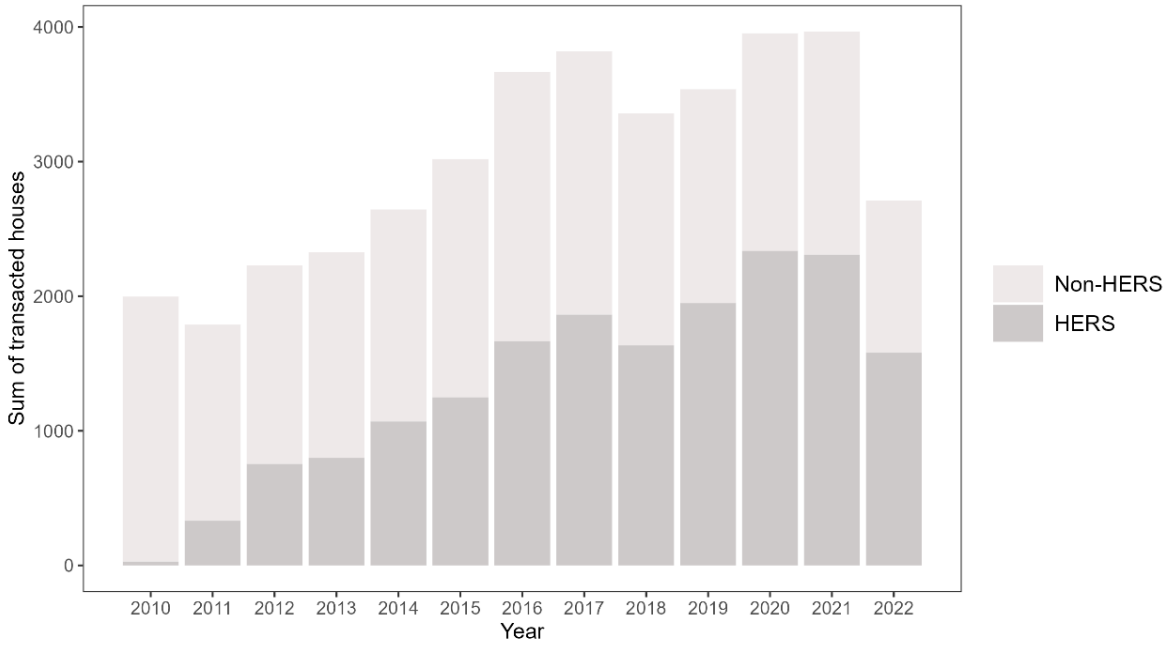
Table 11. *Summary of results*

	Property level	**Municipality level**		
	HERS homes price premium	Non-HERS homes mean price increase	Average home price increase	Average quantity change
All type of homes	5.5%	4.3%	5.1%	-1.2%*
Single-family	4.1%	6.2%	5.7%	-12%
Multi-family	4.6%	2.4%*	4.7%	+18%

*Not statistically significant

Additionally, the second and third columns in Table 11 display the average price increments obtained from the analysis at the municipality level. In this sense, the findings show that the aggregate price level increases by 5% on average after the Stretch Code adoption. This municipality-level 5% increase could be decomposed into two effects. The first is the green price premium found for HERS-rated homes, which becomes more relevant as municipalities gradually adopt the Stretch Energy Code and require every new construction to incorporate the HERS Index. Thus, the proportion of HERS-rated houses among all transacted properties in any given year will be progressively more prominent. Figure 14 shows that, indeed, this is the case. In 2019, HERS-rated homes represented 55% of all transacted homes. This proportion has been steadily increasing, and in 2022, HERS-rated homes represented 60% of all transacted properties. Then, the second component affecting the municipality-level average price increase stems from the supply decrease. The second column in Table 11 shows the average price increase for non-HERS-rated homes, i.e., homes built before the municipality's Stretch Code adoption year. The increase in the municipality-level average price for these properties can be attributed to the decrease in the supply since it is assumed that these homes are not energy-efficient and, therefore, are not subject to any green price premium.

Figure 14. *Proportion of HERS and non-HERS transacted homes, 2010-2022*



Source: Own elaboration using Warren Group transaction data.

Moreover, the comparison between Table 10 and Table 11 indicates that cost deltas are passed on to some extent to the price of HERS-rated homes. For instance, the case of single-family is relatively straightforward since the cost increase lies in the range of 2.8 to 5%, and the green premium that this type of properties command is approximately 4.1%. Then, the case of multi-family developments follows a similar reasoning. The cost delta is between 4.6 and 11%. If 4.6% is assumed as the actual increase, the observed price premium of 4.6% for multi-family homes will imply that the rise in the construction cost is entirely passed on to the price and, therefore, fully bearded by the homeowner.

Finally, further in-depth exploration is needed to robustly capture how and in which proportion the green price premium of HERS-rated properties and the housing supply decrease contribute to the municipality-level average price increase. Being able to decompose this general price effect in those two components will be particularly helpful in drawing more insights about the overall impact of more stringent energy-efficiency regulations.

Conclusion

In this study, I use panel data to empirically assess the effects at the property and municipality level resulting from the adoption of the Stretch Energy Code when municipalities are designated as Green Communities.

First, the results show that the share of highly educated residents is crucial in determining which municipalities join the Green Communities Program earlier than others.

Secondly, the analysis at the property level using transaction data sheds light on the willingness to pay for more energy-efficient homes. In accordance with the literature, HERS-rated homes command a sales price premium of about 3.7 to 5.5 percent.

Third, the analysis at the municipality level shows that adopting the Stretch Energy Code is associated with a decrease of 12 percent in the number of new single-family permits. However, multi-family developments experienced an increase of almost 18 percent after the code was adopted. More research would be needed to determine whether this increment could indicate that developers are transitioning from building single-family homes to multi-family residential properties.

With regard to the municipality-level average price effects, this study shows that the average transaction price of all properties increases by about 5.1% as a result of the Stretch Code adoption. Furthermore, the average price increase of single-family homes rises to 5.7% and, in the case of multi-family homes, drops to 4.7%. Furthermore, those non-HERS-rated homes are also subject to an overall price increase equal to 4.3%, which stems from the fact that introducing the Stretch Energy Code leads to a supply decrease in the housing quantity and an increase in the average sales prices of all homes.

As climate change continues to be a major global concern, increasing the energy efficiency of new residential construction in Massachusetts is an urgent imperative for the health and well-being of all Massachusetts residents. However, despite their obvious environmental benefits, more stringent energy-efficiency regulations in the building sector can also lead to increased construction costs and harm housing affordability. Thus, policymakers must identify environmentally sustainable solutions that do not impose an excessive financial burden on citizens and balance energy-efficiency regulations with the need for accessible and affordable housing.

References

Aroul, R., & Hansz, J. A. (2012). The Value of "Green:" Evidence from the First Mandatory Residential Green Building Program. *Journal of Real Estate Research*, *34*(1), 27–50. https://doi.org/10.1080/10835547.2012.12091327

Ball, M. (2011). Planning Delay and the Responsiveness of English Housing Supply. *Urban Studies*, *48*(2), 349–362. https://doi.org/10.1177/0042098010363499

Bernstein, A., Gustafson, M. T., & Lewis, R. (2019). Disaster on the horizon: The price effect of sea level rise. *Journal of Financial Economics*, *134*(2), 253–272. https://doi.org/10.1016/j.jfineco.2019.03.013

Brounen, D., & Kok, N. (2011). On the economics of energy labels in the housing market. *Journal of Environmental Economics and Management*, *62*(2), 166–179. https://doi.org/10.1016/j.jeem.2010.11.006

Bruegge, C., Carrión-Flores, C., & Pope, J. C. (2016). Does the housing market value energy-efficient homes? Evidence from the energy star program. *Regional Science and Urban Economics*, *57*, 63–76. https://doi.org/10.1016/j.regsciurbeco.2015.12.001

Chegut, A., Eichholtz, P., & Holtermans, R. (2016). Energy-efficiency and economic value in affordable housing. *Energy Policy*, *97*, 39–49. https://doi.org/10.1016/j.enpol.2016.06.043

Chegut, A., Eichholtz, P., & Kok, N. (2014). Supply, Demand and the Value of Green Buildings. *Urban Studies*, *51*(1), 22–43. https://doi.org/10.1177/0042098013484526

Chegut, A., Eichholtz, P., & Kok, N. (2019). The price of innovation: An analysis of the marginal cost of green buildings. *Journal of Environmental Economics and Management*, *98*, 102248. https://doi.org/10.1016/j.jeem.2019.07.003

Circo, C. J. (n.d.). *Using Mandates and Incentives to Promote Sustainable Construction and Green Building Projects in the Private Sector: A Call for More State Land Use Policy Initiatives*. *112*.

Deng, Y., & Wu, J. (2014). Economic returns to residential green building investment: The developers' perspective. *Regional Science and Urban Economics*, *47*, 35–44. https://doi.org/10.1016/j.regsciurbeco.2013.09.015

Dwaikat, L. N., & Ali, K. N. (2016). Green buildings cost premium: A review of empirical evidence. *Energy and Buildings*, *110*, 396–403. https://doi.org/10.1016/j.enbuild.2015.11.021

Eichholtz, P., Kok, N., & Quigley, J. M. (2010). Doing Well by Doing Good? Green Office Buildings. *American Economic Review*, *100*(5), 2492–2509. https://doi.org/10.1257/aer.100.5.2492

Fuerst, F., & McAllister, P. (2011a). Green Noise or Green Value? Measuring the Effects of Environmental Certification on Office Values: Green Noise or Green Value? *Real Estate Economics*, *39*(1), 45–69. https://doi.org/10.1111/j.1540-6229.2010.00286.x

Fuerst, F., & McAllister, P. (2011b). Eco-labeling in commercial office markets: Do LEED and Energy Star offices obtain multiple premiums? *Ecological Economics*, *70*(6), 1220–1230. https://doi.org/10.1016/j.ecolecon.2011.01.026

Glaeser, E. L., Gyourko, J., & Saiz, A. (2008). Housing supply and housing bubbles. *Journal of Urban Economics*, *64*(2), 198–217. https://doi.org/10.1016/j.jue.2008.07.007

Glaeser, E. L., Gyourko, J., & Saks, R. (2005). Why Is Manhattan So Expensive? Regulation and the Rise in Housing Prices. *The Journal of Law and Economics*, *48*(2), 331–369. https://doi.org/10.1086/429979

Glaeser, E. L., Gyourko, J., & Saks, R. E. (2006). Urban growth and housing supply. *Journal of Economic Geography*, *6*(1), 71–89. https://doi.org/10.1093/jeg/lbi003

Glaeser, E. L., & Ward, B. A. (2009). The causes and consequences of land use regulation: Evidence from Greater Boston. *Journal of Urban Economics*, *65*(3), 265–278. https://doi.org/10.1016/j.jue.2008.06.003

Gyourko, J., & Molloy, R. (2015). Regulation and Housing Supply. In *Handbook of Regional and Urban Economics* (Vol. 5, pp. 1289–1337). Elsevier. https://doi.org/10.1016/B978-0-444-59531-7.00019-3

Hyland, M., Lyons, R. C., & Lyons, S. (2013). The value of domestic building energy-efficiency—Evidence from Ireland. *Energy Economics*, *40*, 943–952. https://doi.org/10.1016/j.eneco.2013.07.020

Jackson, K. (2016). Do land use regulations stifle residential development? Evidence from California cities. *Journal of Urban Economics*, *91*, 45–56. https://doi.org/10.1016/j.jue.2015.11.004

Jones, B. S., & Branton, R. P. (2005). Beyond Logit and Probit: Cox Duration Models of Single, Repeating, and Competing Events for State Policy Adoption. *State Politics & Policy Quarterly*, *5*(4), 420–443. https://doi.org/10.1177/153244000500500406

Kahn, M. E., & Kok, N. (2014). The capitalization of green labels in the California housing market. *Regional Science and Urban Economics*, *47*, 25–34. https://doi.org/10.1016/j.regsciurbeco.2013.07.001

Knill, C., & Tosun, J. (2009). Hierarchy, networks, or markets: How does the EU shape environmental policy adoptions within and beyond its borders? *Journal of European Public Policy*, *16*(6), 873–894. https://doi.org/10.1080/13501760903088090

Kok, N., McGraw, M., & Quigley, J. M. (2011). The Diffusion of Energy-efficiency in Building. *American Economic Review*, *101*(3), 77–82. https://doi.org/10.1257/aer.101.3.77

Kristl, Ž., Senior, C., & Temeljotov Salaj, A. (2020). Key challenges of climate change adaptation in the building sector. *Urbani Izziv*, *31*(1), 101–111.

Lall, S. V., Freire, M., Yuen, B., Rajack, R., & Helluin, J.-J. (Eds.). (2009). *Urban Land Markets*. Springer Netherlands. https://doi.org/10.1007/978-1-4020-8862-9

Mapp, C., Nobe, M., & Dunbar, B. (2011). The Cost of LEED—An Analysis of the Construction Costs of LEED and Non-LEED Banks. *Journal of Sustainable Real Estate*, *3*(1), 254–273. https://doi.org/10.1080/10835547.2011.12091824

Matisoff, D. C., Noonan, D. S., & Flowers, M. E. (2016). Policy Monitor—Green Buildings: Economics and Policies. *Review of Environmental Economics and Policy*, *10*(2), 329–346. https://doi.org/10.1093/reep/rew009

Mayer, C. J., & Somerville, C. T. (2000). Land use regulation and new construction. *Regional Science and Urban Economics*, *30*(6), 639–662. https://doi.org/10.1016/S0166-0462(00)00055-7

Meltzer, R., Ellen, I. G., & Li, X. (2021). Localized commercial effects from natural disasters: The case of Hurricane Sandy and New York City. *Regional Science and Urban Economics*, *86*, 103608. https://doi.org/10.1016/j.regsciurbeco.2020.103608

Miller, N., Spivey, J., & Florance, A. (2008). Does Green Pay Off? *Journal of Real Estate Portfolio Management*, *14*(4), 385–400. https://doi.org/10.1080/10835547.2008.12089822

Olaussen, J. O., Oust, A., & Solstad, J. T. (2017). Energy performance certificates – Informing the informed or the indifferent? *Energy Policy*, *111*, 246–254. https://doi.org/10.1016/j.enpol.2017.09.029

Parkinson, A., Hill, S., & Wheal, R. (2016). An income-based analysis of the value premise for property energy performance. *Energy*, *106*, 162–169. https://doi.org/10.1016/j.energy.2016.03.019

Pivo, G., & Fisher, J. (2010). Income, Value, and Returns in Socially Responsible Office Properties. *Journal of Real Estate Research*, *32*(3), 243–270. https://doi.org/10.1080/10835547.2010.12091281

Quigley, J. M., & Raphael, S. (2005). Regulation and the High Cost of Housing in California. *American Economic Review*, *95*(2), 323–328. https://doi.org/10.1257/000282805774670293

Rehm, M., & Ade, R. (2013). Construction costs comparison between 'green' and conventional office buildings. *Building Research & Information*, *41*(2), 198–208. https://doi.org/10.1080/09613218.2013.769145

Schill, M. H. (2023). *Regulations and Housing Development: What We Know*.

Somerville, C. T. (2023). *The Contribution of Land and Structure to Builder Profits and House Prices*.

Tsai, I.-C. (2022). Value capitalization effects of green buildings: A new insight through time trends and differences in various price levels. *Building and Environment*, *224*, 109577. https://doi.org/10.1016/j.buildenv.2022.109577

Walls, M., Palmer, K., Gerarden, T., & Bak, X. (n.d.). *Is Energy-efficiency Capitalized into Home Prices? Evidence from Three US Cities*.

Yoshida, J., & Sugiura, A. (2015). The Effects of Multiple Green Factors on Condominium Prices. *The Journal of Real Estate Finance and Economics*, *50*(3), 412–437. https://doi.org/10.1007/s11146-014-9462-3

Zheng, S., & Kahn, M. E. (2008). Land and residential property markets in a booming economy: New evidence from Beijing. *Journal of Urban Economics*, *63*(2), 743–757. https://doi.org/10.1016/j.jue.2007.04.010

Zheng, S., Wu, J., Kahn, M. E., & Deng, Y. (2012). The nascent market for "green" real estate in Beijing. *European Economic Review*, *56*(5), 974–984. https://doi.org/10.1016/j.euroecorev.2012.02.012