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The diffusion of "green" buildings in the housing market: empirics on the long run effects of energy efficiency regulation

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February 19, 2016

Abstract

The impact of environmental regulation on market diffusion and market entry of "green", innovative buildings in the housing market is studied using a unique data set of German residential buildings. Particularly, we analyze how energy efficiency regulation, in terms of minimum standards, affects energy-requirements in newly constructed buildings over time in both, the high and low quality housing segment. The data we use consists of a large sample of German apartment houses built between 1950 and 2005. We develop a new measure for regulation intensity and apply a panel-error-correction regression model to energy requirements of low and high quality housing. Our findings suggest that regulation is effective and significantly impacts technology adoption in low quality housing. Moreover, we find that regulation indirectly also positively affects energy efficiency in the high quality housing markets. This suggests that tighter building codes have a substantial impact on both, the entry and the diffusion of "green" buildings in the housing market.

JEL Codes: D2, Q4, R5

Keywords: environmental regulation, market entry, technology diffusion, residential real estate, energy efficiency

1 Introduction

In the light of the warnings about the accelerating pace of global climate change, politicians are paying increased attention to sustainability, resource and energy efficiency issues. Many countries are seeking to restructure their energy supply systems and stimulate energy efficiency investment. In this context, residential housing plays an important role, since, according to IEA-data, it accounts for up to 40% of final energy needs in developed countries. The lion's share of residential energy demand stems from heating and cooling (for a comprehensive overview about global energy use patterns, see, Johansson & Nakićenović 2012). Politicians in the European Union (EU) are especially focused on the potential savings in the real estate sector and are seeking to implement the "Nearly Zero-Energy Buildings" (NZEB) standard by the end of 2020. Numerous policy measures and initiatives are being introduced in order to achieve this goal. Although their effectiveness and efficiency is controversially debated (Parry et al. 2014, Tsvetanov & Segerson 2013), building energy codes are probably the oldest and most frequently used instrument designed to increase the energy efficiency of real estate (Jacobsen & Kotchen 2013, Annunziata et al. 2013, Iwaro & Mwasha 2010, Moore & Wilson 2009, Imrie & Street 2009).

In this context, politicians often emphasize the twofold importance of such regulations: First, to reduce actual energy demand and to force investors to adopt existing, and market-proofed energy efficiency technologies, which is mainly motivated by the idea that cost effective "green" technologies are underutilized (for a discussion of the different barriers to invest, see Schleich 2009). Second, regulation is expected to create a market for inventions, i.e. to change the institutional framework in a way that stimulates market entry and adoption of new "green" building materials, techniques and building designs in the high quality housing market segment (see, Horne & Dalton 2014, Saheb et al. 2013, European Commission & European Parliament 2012). The idea to open the market for new technologies by environmental regulation entered the political arena in the early 1990s, most prominently emphasized by the former US vice

president Al Gore (1992). This approach goes back to the well received articles by Porter (1991) and Porter & Van der Linde (1995). In a nutshell, the so called *"Porter Hypothesis"* states that environmental regulation can result in Pareto-optimal outcomes. While effectively protecting the environment, regulation creates incentives to innovate and to bring new products in the market (Ambec et al. 2013).

While building energy codes are generally assumed to be effective in reducing energy requirements and to stimulate the market entry of "green" buildings, empirical knowledge on their actual impact is relatively scarce (see section supplementary material for a comprehensive review of the literature; for a more general overview, see, van den Bergh (2008)). As pointed out by Jacobsen & Kotchen (2013), empirical assessment is important for several reasons. First, the effectiveness of regulation crucially depends on the actual level of energy requirements. If regulation is not tight enough, the construction industry's good building practice will remain unaffected. Second, actual energy savings often lag far behind engineers' promises (Metcalf & Hassett 1999, Michelsen & Müller-Michelsen 2010, Schröder et al. 2009, Brounen et al. 2012) due to either technical flaws or end-user behavior that partly offsets the increased technical energy efficiency of housing (Sunikka-Blank & Galvin 2012, Galvin 2015, Sorrell & Dimitropoulos 2008). Thus, engineers' calculations do not necessarily reflect real energy (cost) savings, which are the actual measure of interest for investors and policy-makers. Indeed, the few empirical studies available indicate that energy efficiency regulation is an effective instrument to increase the average real energy performance of newly constructed buildings (see, for an overview, Jacobsen & Kotchen 2013). But there is only weak empirical evidence to date how building codes affect energy efficiency at the tails of the distribution, i.e. in the low and high quality housing market segment. The specific studies available are small in number, concentrate on the aspect of innovation of building materials and mostly use qualitative methodologies (see, Beerepoot & Beerepoot 2007, Gann et al. 1998, Vermeulen & Hovens 2006, Noailly 2012, Fischer & Guy 2009).

In the present study, we address this gap in the empirical literature and explicitly assess

whether environmental regulation has an impact on the energy performance of high and low quality housing. Specifically, we address three key aspects that have not been analyzed so far: first, we assess the long-run effects of regulation on the diffusion of "green" buildings throughout the housing market. Borrowing from quantile regression method, we focus on the directly affected market segment of low-quality housing and demonstrate, that—as expected—building codes have a significant and direct impact on the energy performance. This lets us conclude, that building energy codes positively affect technology adoption. Secondly, we demonstrate that minimum standards also indirectly affect the high quality housing market segment, i.e. the market segment where no immediate influence of the regulation can be expected. "Innovators" or "early adopters" (Rogers 1962) in the high end segment respond to increased energy efficiency in low quality housing by investing in a broader range of energy saving technologies and building designs. We interpret this as the impact of regulation on the market entry of new, innovative "green" buildings. At least we find granger causality for a lagged and indirect effect. Finally, taking the long run perspective allows us to analyze a variety of regulatory regimes, each with a specific regulatory intensity. We show that real regulatory intensity matters for both, technology adaptation and the market entry. Particularly quantitative, longitudinal evidence is claimed to be in general missing from the debate (Ambec et al. 2013).

The remainder of the paper is structured as follows. Section 2 introduces our data and presents some stylized facts on energy efficiency in German residential housing. The empirical model is outlined in Section 3 and the results are discussed in Section 4. Section 5 concludes.

2 Empirical strategy, data and stylized facts

In the present study, we address both, the effects of regulation on the diffusion of existing technologies and the market entry of "green", more energy efficient buildings. Further, we consider the time dimension and the real regulatory intensity. We analyze these issues in a novel

approach by further developing the methodologies and measurement concepts in four key points.

First, as in the study by Aroonruengsawat et al. (2012), we follow a panel analysis approach and take a long run perspective on the effects of regulation. In contrast to Aroonruengsawat et al. (2012), we introduce a measure for regulatory intensity, which is, instead of a qualitative assessment proposed in the previous literature, endogenously computed as the share of actually affected house building projects.

Second, instead of using top-down, aggregate regional energy demand as dependent variable, we ground our analysis on micro-data gathered from energy consumption bills, as proposed recently by Jacobsen & Kotchen (2013) and Michelsen & Rosenschon (2012). However, our micro data does not allow a traditional difference in differences approach because the standards are defined on a federal level, which means that there are no *untreated* houses which are built after the introduction of a new regulation. Therefore, we aggregated the information and gathered time series of energy efficiency by years of construction.

Third, in contrast to the existing literature, we concentrate on the tails of the distribution instead on the entire sample, borrowing from quantile regression methods. This allows us to study the behavior of investors in the low and high quality segments of the housing market in terms of energy efficiency. In the low quality segment (e.g. the least efficient 10% of buildings), investors are forced to *adopt* existing energy efficiency technologies by a tighter building code. In the literature around technology diffusion, these types of investors are named as "laggards" (Rogers 1962). In contrast, investors in the high quality segment (e.g. the most efficient 10% of buildings), are not directly affected by tighter building codes. They can be considered as "innovators" or "early adopters" (Rogers 1962) as they open the market for "green" buildings with higher energy efficiency levels. Our approach allows us to disentangle the effects between both groups of investors.

Fourth, we combine the advantages of micro data information with the specific methodological capabilities of an aggregate panel data analysis. Employing an error correction type

panel setup allows us not only to draw findings on the effectiveness of building energy codes; it also allows us to study the diffusion process of existing technologies, the market uptake of "green" buildings and, moreover, on the interaction of both aspects. In the following the data and methods used are documented in detail.

2.1 Measuring energy efficiency, technology diffusion and market entry of "green" buildings

Micro-data The aim of this study is to identify the dynamics of the energy efficiency of buildings under different regulatory regimes, and—most importantly—to disentangle the effects of regulation on market entry and technology diffusion. To study the first aspect, a measure for the energy performance of buildings is needed. These measures are typically provided by engineers. However, historical data and a systematical, official assessment on the energy performance of buildings is missing, on the microlevel as well as a time series on an aggregate level. Yet, it is possible to gain insights on the market entry and diffusion of energy efficiency technologies from a cross-section of todays energy consumption of buildings by associating the current energy performance with the year of construction. That is, we use the current energy efficiency of a building as proxy for the "natural" energy efficiency of the building at the time of construction. This, however, necessitates that we can rule out *ex post* changes in energy efficiency, i.e. refurbishment of the facilities.[1]

Our data[2] allows for such an approach: we use information contained in official "Energy Performance Certificates" (EPCs), as they are, since 2009, compulsory for each home for rent or for sale within the European Union (see, Poel et al. 2007). The EPC used in this study include information on the refurbishment status of, from the energy efficiency perspective, five most

[1] Although some studies control for refurbishment and find substantial effects (e.g. Brounen et al. (2012) or Leth-Petersen & Togeby (2001)), other studies do not consider refurbishment in their analysis of vintage class specific energy performance of real estate (e.g. Costa & Kahn (2011) or Chong (2012)).

[2] Data is provided by one of the leading energy billing service providers Germany, *ista Germany GmbH.*

important building components: roof, facade, windows, basement ceiling and heating system. The EPC report whether these parts of the building have been refurbished or replaced within the past 15 years, more than 15 years ago, whether they are non-refurbished or the status is unknown. Observations are only included in the analysis, if none of those construction parts is reported as "refurbished" and at most one part is reported as "unknown". The EPC of these buildings should, provided that refurbishments are correctly reported, quite well proxy housing quality at the time of construction.

Market entry and diffusion processes can be tracked in the distribution of energy requirements of the housing stock over time: the lower tail of the distribution should reflect innovative "green" buildings, while the upper tail should in first place reflect the adoption of existing technologies. In our empirical strategy, we therefore borrow from quantile regression and identify the buildings that belong to the high end housing market segment (the most efficient buildings—the 10th percentile of energy performance in our sample) and low quality buildings (the 90th percentile). To study the effect of regulation on technology diffusion, the most affected market segment should be low quality housing. If regulation is tight enough, investors in this segment would be forced to adopt more efficient building technologies. The effects of regulation on the market entry of innovative "green" buildings should be observable most easily in the high end segment. This strategy does not allow us to observe the diffusion and market uptake of specific technologies. However, we are able to identify general trends that can most likely be attributed to the market entry of new or improved technologies, materials and building designs or the adoption of proven technologies, triggered by command-and-control regulation.

The EPC are calculated according to the German regulation ("Energieeinsparverordnung 2009" (EnEV)) and based on information on real energy consumption. The inputs of raw energy for each fuel type (e.g. oil in litres, natural gas in kilowatt-hours) for space heating are multiplied by their "heat value" to derive consistent energy consumption measures in kWh per year. These measures are adjusted by regional "climatic parameters", that are available for

8,400 postal-code districts. These parameters normalize the energy requirements to the climatic conditions of the German city Würzburg in the year 2002[3]. Further, the EPCs are standardized by living space of the dwelling in square-meters. To mitigate the potential bias due to consumer behavior, a three year average is reported in the certificates. Thus, the EPCs include comparable information on the annual energy requirements of buildings, which is consistent over time and space.

Because of data availability restrictions, the sample is limited to apartment buildings. The apartment housing stock in Germany comprises approximately 21 million flats, which equals roughly 54% of the housing market[4]. In this market segment, the share of rental apartments is relatively high: about 80% of the dwellings are, according to official figures, for rent. The rental market is dominated by private landlords and small housing companies. Large real estate companies and institutional investors play, in contrast to other countries, an ancillary role (see figure 1).

Our micro-data comprises roughly 300,000 buildings which equals about three million flats. Thus, we cover about 14% of the apartment housing market segment. However, as we are interested in the "natrual" energy efficiency of buildings, we restrict our sample to only those observations that we can identify as non-refurbished. This is the case for approximately 40,000 buildings. These buildings contain, on average, 12 flats and have a size of 850 m^2 residential space (see Figure 2).

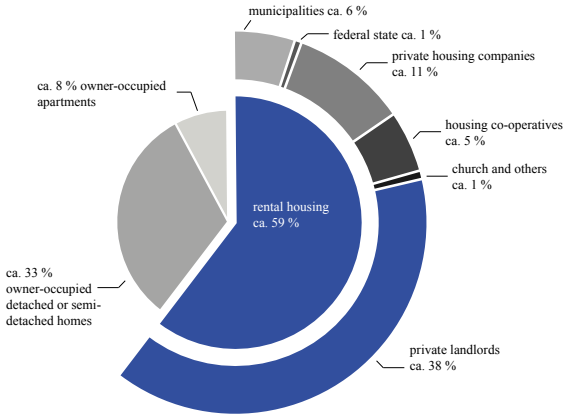
Approximately one third are owned by small and private landlords. 43.4% percent are owned by small housing companies (with a portfolio of up to 1,000 flats) and 23.6% are owned by large housing companies (>1,000 flats in portfolio). Moreover, the buildings are spread quite equally across Germany: the distribution reflects the relative size of federal states quite well (see figure 4). About 43% of the buildings are located in urban areas. The average Energy

[3]For a more detailed description of the climatic parameters, see, www.dwd.de/klimafaktoren.

[4]Detailed figures on the German housing market were recently published by the German Federal Statistical Office: https://www.destatis.de/zensuskarte/index.html

Figure 1: Structure of the German housing market and distribution of owners in the sample

Homeowners in Germany*



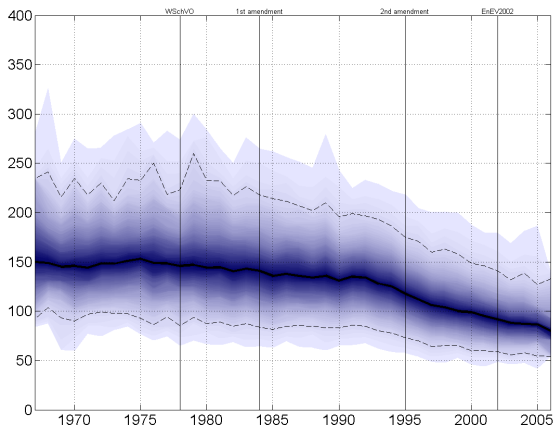
Types of Homeowners in the sample

Owner	Buildings in sample	Share
Private landlords (up to 20 flats)	12918	32.94%
Small housing companies (21 to 1000 flats)	17047	43.42%
Large housing companies (>1000 flats)	9280	23.64%

*Source: adopted from Veser et al. (2006); Unfortunately, the most recent numbers on the ownership structure stem from 2006. However, while the role of larger companies and also the share of owner-occupied dwellings has increased in recent years, the general structure should be still quite well reflected.

Figure 2: Descriptive statistics of building characteristics

Distribution of energy coefficients by year of construction



Characteristics of buildings in sample

	Mean	SD
No. of flats	12.0	16.2
Residential space	852.1	1054.1
EPS	125.4	40.2
Partly commercial (%)	14.4	35.1
Year of construction	1988	22
Urban (%)	43.0	49.5

Performance Score (EPS) of the non–refurbished buildings is 125 kWh/m^2. Overall, our sample has a slight bias towards larger buildings and, moreover, professional housing companies are over-represented. However, this has no direct implications for our empirical strategy since we are interested in the development of energy performance over time rather than the levels of energy consumption, which might be potentially biased by these factors.

At first glance the empirical data suggests that the energy performance of apartment buildings in Germany has improved substantially since the middle of the 20th century. The distribution of EPS by year of construction in our sample is illustrated in Figure 2; the darker the color of the fan–chart, the larger the number of observations in this range. Since energy requirements (in the type of houses analyzed in our sample) have a natural lower bound, the distribution has a positive skew for any construction year. We observe a general decline of EPS over time. Also, while energy efficiency improves, the gap between the most efficient and the most inefficient houses narrows. Moreover, we detect a decline in both the upper and lower percentiles of EPS over time, indicating technological progress and diffusion of market proven energy efficiency technologies. The median house build in 2007 has an energy performance roughly identical to the most energy efficient houses built 40 years earlier. That is, when it comes to fostering energy efficiency, creating incentives to adopt seems to matter more than creating incentives improve potential energy efficiency through innovation.

Since the energy efficiency standards in Germany are implemented on a national basis, we cannot apply common micro-econometric techniques such as difference-in-differences estimations to identify the causal effects of regulation. Therefore, we employ macro-econometric methods and analyze aggregate time series for the energy performance of buildings. To keep as much information as possible, we consider both, the time and the panel dimension of the data and generate time series by regions.

The sample analyzed in this paper covers apartment houses constructed between 1950 and 2005. With this sample, we are able to observe EPS of buildings constructed under five different

Figure 3: Regions and regional distribution

Regions

Distribution of obs. in the panel

Federal state	% of sample	Region
Schleswig-Holstein	2.18	North
Hamburg	1.92	
Bremen	0.91	
Hesse	11.42	
Rhineland-Palatinate	4.03	Rhine-
Saarland	0.88	Hesse
Brandenburg	2.53	
Meck.-W. Pommerania	1.89	
Saxony	4.76	East
Saxony-Anhalt	1.94	
Thuringia	1.66	
Baden-Wuerttemberg	17.99	
Bavaria	15.74	
Berlin	4.23	
Lower Saxony	7.85	
North Rhine-Westfalia	20.08	

regulatory regimes - ranging from unregulated buildings until the end of 1977 to EnEV 2002 standards. As Germany was divided until 1990, we drop all apartment houses constructed under GDR housing market regulation (built before 1990 and located in Saxony, Thuringia, Saxony-Anhalt, Brandenburg, Berlin and Mecklenburg-West Pomerania) to ensure identical institutional settings.

To the extent possible, our regions coincide with the German federal states (Länder). However, to generate sufficiently large entities where the percentiles of the empirical distributions in our sample are meaningful approximations of the entire population, smaller Länder are combined to larger units. Hamburg, Bremen and Schleswig-Holstein form the "North" region, the Saarland, Rhineland-Palatinate and Hesse form Rhine-Hesse, and the former GDR Länder of Brandenburg, Mecklenburg-West Pomerania, Saxony, Saxony-Anhalt, and Thuringia form the

"East" group (for the spatial dimension, see Figure 4).

We generate separate high and low quality housing time series for each region, defined as the 10th and the 90th percentile of EPS for houses of a specific year of construction in the respective region. Variables controlling for the attributes of the housing stock are computed as region/year mean values of the corresponding building features.

2.2 Regulation regimes and regulation intensity

Energy efficiency regulation in Germany In Germany building codes have a relatively long tradition of being used as a policy instrument to affect energy efficiency standards (Geller et al. 2006). The first, the "Heat Insulation Ordinance" (WSchV), came into force in November 1977. In the light of the first oil crisis in the early 1970s, politicians decided to define minimum standards for the energy efficiency for both residential and commercial buildings. Based on so called U-values, measures for the thermal conductivity of construction parts, this regulation defined an aggregate maximum level of annual (a) energy requirement of 250 kilowatt-hours (kWh) per square meter living space (m^2) for newly constructed homes. This regulation was amended twice, in 1984 and 1995. In 2002 WSchV was replaced with the "Energy Saving Ordinance" (EnEV), which is still in force. The regulatory steps and the maximum energy requirements are summarized in Figure 4.

The motivation for regulation changed over time. While WSchV was introduced against the background of strategic trade policy (i.e. to reduce the dependency on fossil fuel imports), EnEV was developed in response to sustainability issues and concerns about global warming (Geller et al. 2006, p. 567f). Since 2002, the EnEV has been amended twice: 2009 and 2013. The recent change in regulation is also associated with a switch in the guidance regime: while previous building codes were issued without stating exact validity periods and without information on further regulatory steps, EnEV 2013 is the first that outlines a stepwise tightening of construction law to a carbon neutral standard by 2021.

Measuring regulation intensity Instead of capturing regulation through a set of shift and slope dummies, as in most of the previous literature, we aim to actually measure regulation intensity in the present study. However, using the level of regulation itself (in terms of maximum allowed energy requirements) is difficult for a number of reasons. First, because energy building codes are amended over time, regulation is instationary by construction. Since economic reasoning suggests a relation between the level of regulation and the level of energy efficiency, this could not be solved by simply taking first differences, but requires some error correction type of indicator. Concerning energy regulation this, however, creates a new set of problems. Regulation is supposed to affect the behavior of economic agents, if it is binding to at least some agents, but is supposed to be neutral when irrelevant for every agent. In econometric terms this type of phenomenon is commonly treated using regime switching models. Both commonly used versions are problematic in our case: When using the difference between the maximum of the empirical distribution and the regulation level as indicator, we can use the sign of this error correction term as a plausible regime indicator in a model with deterministic regime switching. This indicator turns negative whenever a regulation does not affect any agent. However, this induces further noise into the model since this indicator is strongly affected by outliers. Using a more stable indicator, such as the difference between the median of the empirical distribution and regulation, requires an endogenous identification of regimes as done in threshold or Markov switching models. However, these models also come at the cost of substantial uncertainty, since regimes are often only weakly identified. To overcome these issues we propose to use a regulation index r at time t that is defined as the share F of houses built in $t-1$ that would have been affected by the regulation R relevant at time t:

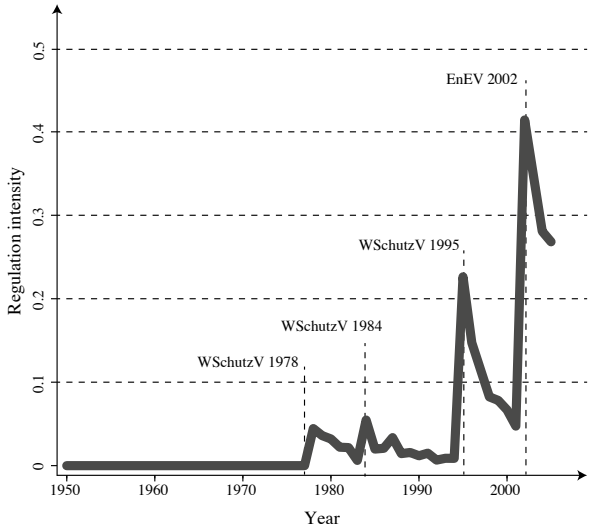
$$r_t = F_{H(t-1)}(R_t), \tag{1}$$

Figure 4: Regulatory steps and regulation intensity

Regulatory steps of energy building codes

year	regulation	max. kwh/m^2a
until 1978	no regulation	∞ kWh
1978	Heat Insulation Ordiance (WSchV)	250 kWh
1984	amendment of WSchV	230 kWh
1995	amendment of WSchV	150 kWh
2002	Energy Saving Ordinance (EnEV)	100 kWh
2009	amendment of EnEV	60 kWh
2016	amendment of EnEV	45 kWh
2021	amendment of EnEV	0 kWh

Real regulation intensity



where $H(t)$ is the set of houses build at time t. R is scaled in $kWh/(m^2a)$. r_t indicates immediately when any agent is affected by regulation, while not being prone to outliers. The real regulation intensity, as described above, is depicted in figure 4.

2.3 Macroeconomic, attitudinal and other control variables

Energy prices Energy prices are proven to be important predictors for the energy performance of buildings. As Costa & Kahn (2011) demonstrate for residential housing in the USA, electricity prices at the time of construction determine to a large extent current heating energy needs. For the German case, the most important heating fuels are oil and natural gas. As implemented in long-term cross-border delivery contracts, the price of gas is to some extent tied to the price of oil. Therefore, we include the oil price as a proxy for heating energy costs[5].

[5]Due to data constraints, the price for natural gas cannot be included. Only the price of oil is available for almost the entire period of observation

One might argue that forward looking agents consider price expectations rather than the past energy price development when deciding on long term investments (such as real estate) (Quigley 1984, Nesbakken 2001), however, most institutional oil price forecasts are essentially flat (in real terms), taking past movements of the oil price as granted. Therefore, we account for lagged changes in the logged oil price measured as the US Dollar price of Brent crude oil (free on board).

Green attitude There are several studies on green technology diffusion addressing the roles of behavior and "green" attitudes, e.g. in the decision to adopt an innovative energy efficient heating system. It is found that people who perceive environmental issues to be important are more likely to adopt environmentally friendly technologies (Kahn 2007) and, moreover, have a greater willingness to pay for such technologies (Michelsen & Madlener 2012, Claudy et al. 2011). To differentiate whether it is truly the regulation that matters, or a generally more supportive attitude towards "green" ideas in society that might also be highly correlated to ecologically motivated regulation, we control for green support in the population using opinion polls. In the context of "green" buildings, this measure is also used by Brounen & Kok (2011) and Kahn (2007). Our attitude control is based on a monthly, representative political survey conducted by *"Forschungsgruppe Wahlen"* to forecast German parliamentary elections. We include the first difference of vote shares for the green party differentiated by year and region to our estimations. As the green party was founded in January 1980, information on green support is only available from the survey since 1979. We assume a vote share of 0 for the respective earlier years. Although this appears to be a odd decision, this is a quite plausible approximation: the environmental movement and the green party in Germany have their roots in the anti-nuclear movement, that became socially acceptable in the mid 1970s (Kitschelt 1986). However, the support for the green party was still quite low in their founding year.

Spatial controls Several studies address the role of local market conditions on real estate investor's decisions to adopt energy efficient technologies. Kok et al. (2012, p.562), for example, find that, for the case of green office space, *"the diffusion has been more rapid in metropolitan areas with higher incomes, and in those with sound property market fundamentals....."* In general, compared to rural areas, economic conditions tend to be better in urbanized agglomerations. To capture this effect, we control for urbanized housing markets by including the share of apartments in our sample that is located in or the direct surrounding of a town with at least 50,000 inhabitants.

Building characteristics The building size affects housing's "natural" energy efficiency due to differences in the ratio between interior space and the outer shell of a building. As for example demonstrated by Leth-Petersen & Togeby (2001) for Danish apartment blocks, the smaller the house, the higher are energy requirements. We control for size including the average living space in m^2 and the average number of flats per building. Further, we include the share of buildings used for residential as well as commercial purposes. Variable definitions and descriptive statistics are given in table 1.

Table 1: Descriptive Statistics

Variable	Definition	obs	mean	std.	min	max
Year	Year of construction	368	1979.2	16.5	1950	2005
q^{90}	90th percentile of energy performance measures (adoption series)	368	190.3	41.3	102.0	305.1
q^{10}	10th percentile of the energy performance measures (innovation series)	368	97.2	20.1	50.9	169.2
Regulation (r)	Share of buildings that would have been affected by the regulation in $t-1$	368	0.05	0.1	0.0	0.4
No. flats	Average of number of flats per building	368	13.4	9.8	3.0	118.3
Living space	Average living space in m^2 per building	368	929.4	578.5	187.6	6152.1
Commercial	Share of buildings which are partly in commercial use	368	0.2	0.1	0.0	0.7
City	Share of buildings located in the core of a city $>$ 50,000 inhabitants	368	0.5	0.3	0.0	1.0
Oil price	log oil price in US $	368	0.05	0.2	-0.6	1.0
No oil price	missing data of oil price expectations (dummy)	368	0.2	0.4	0.0	1.0
Green attitudes	Share of supporters of the green party	368	0.05	0.05	0.0	0.2

3 Model and methods

3.1 Estimation

Model setup Our panel setup essentially is an error correction type model taking the form:

$$\begin{aligned}\Delta q^{90}_{j,t} = \alpha_1 + \alpha_2(q^{90}_{t-1} - q^{10}_{t-1}) + \alpha_3 \Delta q^{90}_{j,t-1} + \alpha_4 \Delta q^{10}_{j,t-1} \\ + \alpha_5 r_t + \sum_{m=1}^{M} \psi_m \bar{c}^m_{j,t} + \sum_{k=1}^{M} \phi_k C_k + u_j + \varepsilon_{j,t} \end{aligned} \tag{2}$$

$$\begin{aligned}\Delta q^{10}_{j,t} = \beta_1 + \beta_2(q^{90}_{t-1} - q^{10}_{t-1}) + \beta_3 \Delta q^{90}_{j,t-1} + \beta_4 \Delta q^{10}_{j,t-1} \\ + \beta_5 r_t + \sum_{m=1}^{M} \xi_m \bar{c}^m_{j,t} + \sum_{k=1}^{M} \chi_k C_k + v_j + \eta_{j,t}, \end{aligned} \tag{3}$$

where $q^p_{j,t}$ is the natural logarithm of the pth percentile of the energy performance measures of buildings in region j constructed in year t, $\bar{c}^m_{j,t}$ is the mean of the building specific control variable c^m for region j and year of construction t, and C_k are non construction specific control variables. u_j and v_j are region specific effects, and $\varepsilon_{j,t}$ and $\eta_{j,t}$ the idiosyncratic error terms. Essentially, this model is a version of a fixed effects panel cointegration model, where the cointegration relation is restricted to one. An unrestricted version of the model has been tested and yields similar results. The key difference between our approach and conventional panel cointegration models is the use of an error correction term relying on the entire sample rather than the specific region. Thereby, we avoid carrying the uncertainty in the quantile estimates in regions with few observations into the error correction term.

For our analysis we are mostly concerned about the coefficients estimates for the impact of regulation on energy efficiency (α_5 and β_5), and the adjustment coefficients (α_2 and β_2). While the first describe the initial impact of the "shock" to regulation intensity, the latter describe the mutual interaction of energy efficiency between the high and low quality segments. Significant adjustment coefficients (with the correct sign), indicate that an exogenous shock to regulation

will eventually be transmitted through the entire market, affecting both market segments in a similar fashion in the long run. However, to truly understand the interaction of both market segments completely, we have to look of at the interaction of the adjustment coefficients and the autoregressive terms (α_3, α_3, β_3, and β_3). That is why we focus on the interpretation of impulse response functions for the sake of clarity of our exposition.

We use a bootstrap rather than analytic confidence bounds to account for cross sectional correlation and heteroscedasticity. Although this bootstrap does implicitly model the uncertainty in our measures for the energy efficiency of early adopters and laggards, we add a second layer bootstrap that explicitly models the uncertainty in the quantile estimates as a robustness test.

To allow simulation that is required for both our bootstrap and to derive impulse response functions, we need to model the regulation intensity (given the fixed regulation level) endogenously. Do to so, we need some distributional assumptions. For simplicity we go for a normality assumption for the results reported in the papers[6].

4 Results

The estimated models have substantial explanatory power, as indicated by the F-statistics in table 2. The first model on low quality housing explains about 42%, the model for high quality market segment about 30% of total variation.

Our estimations confirm the general finding of the previous literature that regulation successfully affects energy efficiency of the housing stock rather than merely reinforcing developments already initiated by private actors. However, it sheds some new light on the propagation of regulation throughout the economy. We find that regulation strongly affects the adoption of existing technologies in the low quality housing market segment (see table 2).

[6]Further details on methodological aspects of the estimation can be found in the technical supplement attached to this paper.

Figure 5: Impulse response to regulation

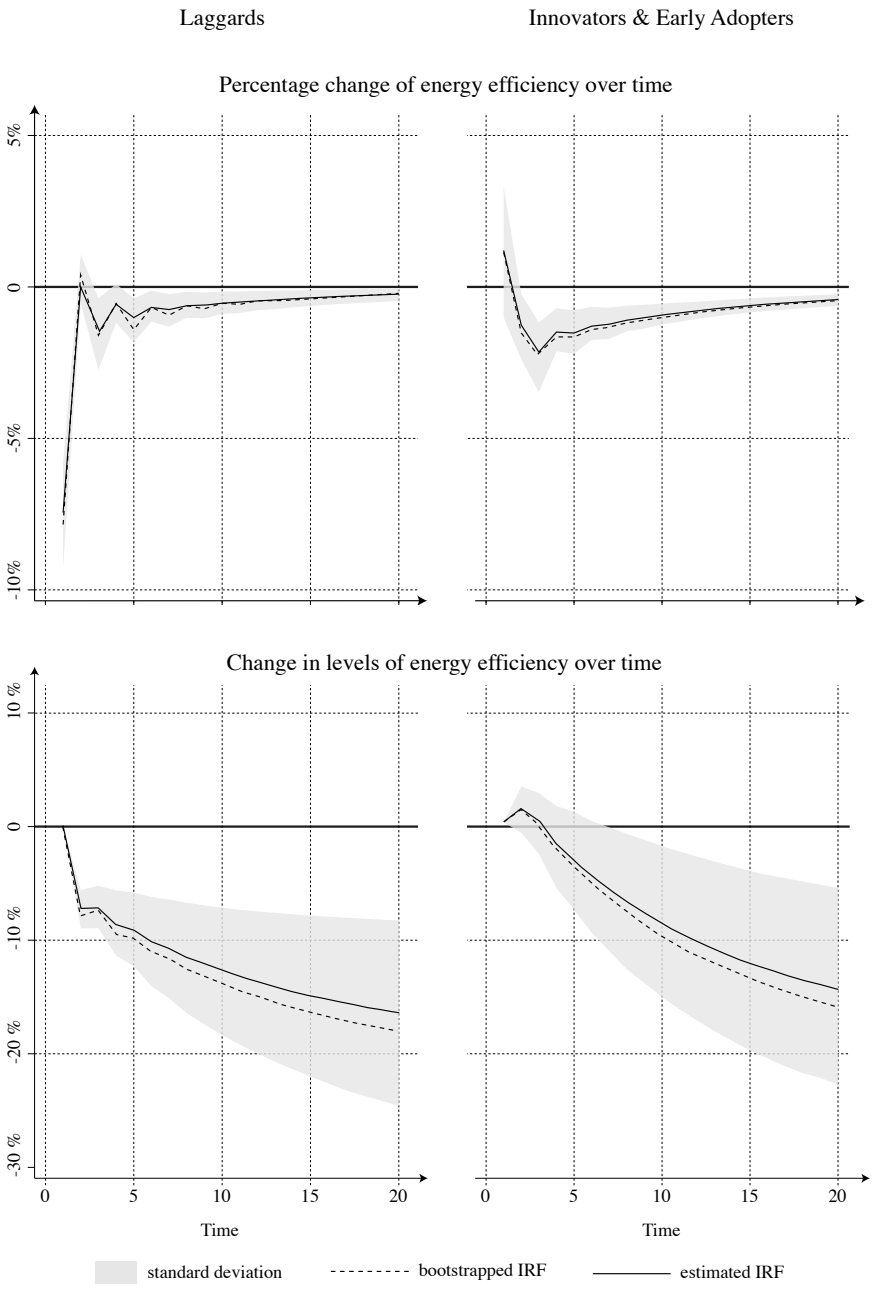


Table 2: Estimation results

	double-bs coefficient		p-val.	single bs coefficient		p-val.	orig. estimates coefficient		Pr(> |t|)
Model 1: Laggards									
Constant	0.37167	***	0.000	0.38902	***	0.000	0.38682	***	0.000
$q^{90}_{t-1} - q^{10}_{t-1}$	-0.56644	***	0.000	-0.58894	***	0.000	-0.58896	***	0.000
$\Delta q^{90}_{j,t-1}$	-0.24082	***	0.000	-0.22947	***	0.000	-0.23142	***	0.000
$\Delta q^{10}_{j,t-1}$	-0.24136	***	0.000	-0.26269	***	0.000	-0.25860	***	0.000
Regulation r_t	-0.15949	**	0.047	-0.16006	**	0.018	-0.15896	**	0.026
Δ Green attitude	-0.23905		0.203	-0.23424		0.152	-0.22574		0.148
Δ oil price$_{t-1}$	0.01202		0.704	0.01229		0.364	0.01282		0.352
No oil price$_{t-1}$	-0.00266		0.900	-0.00317		0.931	-0.00266		0.941
No. flats	0.00322		0.217	0.00318		0.320	0.00322		0.278
Living space	-0.00006		0.190	-0.00006		0.340	-0.00006		0.304
Commercial	0.13735	**	0.039	0.13552		0.102	0.13863		0.100
City	0.01034		0.855	0.00389		0.969	0.01221		0.881
North Rhine-Westphalia	0.00912		0.788	0.01248		0.803	0.00858		0.893
Baden-Wrttemberg	-0.03284		0.257	-0.03372		0.240	-0.03464		0.268
Bavaria	-0.03940		0.160	-0.04149		0.276	-0.04166		0.294
Berlin	0.00320		0.959	0.00762		0.945	0.00111		0.999
North	-0.00458		0.913	-0.00028		0.979	-0.00703		0.907
Rhine-Hesse	0.00154		0.954	0.00203		0.937	0.00073		0.973
East	0.01761		0.673	0.01960		0.659	0.01721		0.699
Model 2: Early adopters/Innovators									
Constant	-0.24027	***	0.000	-0.26054	***	0.000	-0.25988	***	0.000
$q^{90}_{t-1} - q^{10}_{t-1}$	0.43613	***	0.000	0.46750	***	0.000	0.46463	***	0.000
$\Delta q^{90}_{j,t-1}$	-0.23502	***	0.000	-0.25316	***	0.000	-0.25784	***	0.000
$\Delta q^{10}_{j,t-1}$	-0.16824	***	0.003	-0.15325	*	0.058	-0.15218	*	0.080
Regulation r_t	0.02611		0.760	0.02642		0.601	0.02779		0.617
Δ Green attitude	-0.29874		0.137	-0.28909	*	0.070	-0.28781	*	0.090
Δ oil price$_{t-1}$	0.00052		0.988	-0.00086		0.925	0.00091		0.971
No oil price$_{t-1}$	-0.01650		0.464	-0.01877		0.569	-0.01837		0.543
No. flats	0.00675	**	0.016	0.00665	**	0.010	0.00672	***	0.006
Living space	-0.00012	**	0.014	-0.00012	***	0.004	-0.00012	***	0.004
Commercial	-0.17578	**	0.014	-0.17729	**	0.042	-0.17967	**	0.028
City	-0.04672		0.439	-0.04323		0.649	-0.04489		0.627
North Rhine-Westphalia	-0.00463		0.898	-0.00552		0.913	-0.00541		0.911
Baden-Wrttemberg	0.02814		0.363	0.02873		0.430	0.02989		0.408
Bavaria	0.03169		0.290	0.03326		0.302	0.03326		0.292
Berlin	0.07069		0.288	0.06910		0.446	0.07291		0.380
North	0.03476		0.437	0.03497		0.613	0.03453		0.639
Rhine-Hesse	-0.01186		0.675	-0.01220		0.753	-0.01217		0.747
East	-0.02717		0.543	-0.02685		0.464	-0.02762		0.440
Diagnostics Model 1	F=13.44*** (N=352, DF=18, 333)					adj. R-Squared=0.4209			
Diagnostics Model 2	F=8.203*** (N=352, DF=18, 333)					adj. R-Squared=0.3072			

***, **, * indicate significance at 1%, 5% or 10% level of confidence

However, the results for the 10th percentile show an entirely different picture: we find no direct impact of regulation on the market entry of innovative "green" buildings in the high quality market segment. At the same time, we find a strongly positive impact of the error correction term, i.e. the spread between the considered time series. That is, while regulation is only Granger causing the market diffusion but not market entry of "green" buildings, the series for early adopters/innovators and laggards are mutually Granger causing each other, both through the error correction term and the lagged first differences. This implies that the impact of regulation on the market entry of innovative "green" buildings that has been found in the micro-data, is entirely of an indirect nature. Regulation reinforces the incentive to adopt existing technologies, thereby reducing the spread between laggards and early adopters/innovators. The reduction of the spread—or in other words: the shrinking technological advantage of the innovators over laggards—is, in turn, fostering the market entry of innovative "green" buildings.

Figure 5 shows the joint dynamics of the series for laggards and early adopters/innovators in both percentage changes and accumulated level changes after the introduction of higher energy standards that affect 50% of the current construction. While the effect in the low quality segment is spread over several years (with a significantly negative impulse response function over almost a decade) the vast majority of the impact happens right after the introduction of the regulation. Surprisingly early adopters and innovators do not react at all in the first year. Starting two years after the new energy standards were established, the EPS in the high quality housing market segment start to decrease, maintaining a highly improved speed of the market entry of innovative "green" buildings for two decades. After 20 years, energy consumption in both the low and high quality housing market segments is almost 20% below the level where it would have been without the new energy standard.

Since the regulation considered in our study works through fixed limits rather than incentives that scale with the energy efficiency, the results meet the theoretical expectations. Only laggards have an immediate incentive to adapt their behavior, thus reducing the risk of an apartment

house construction permit not being approved by the authorities. This stimulates the diffusion of market proven construction techniques, building designs and materials fostering energy efficiency. The indirect effect on innovators' behavior is also intuitively traceable. As innovators are not directly affected by regulation, they most likely respond to market signals—thus after the introduction of new energy efficiency standards.

All our results hold when controlling for oil price changes or lagged oil price changes as a proxy of energy price movements and green attitude. Oil prices are not significant in neither the adaption nor the innovation equations, which contrasts with the findings of previous studies on housing quality in the USA. In this context, it must be noted that residential real estate in the US is, in most cases, owner occupied. We analyze apartment housing in Germany, of which roughly 80% refer to the rental segment. There is an ongoing discussion about the incentives to invest in energy efficiency, since landlords bear the costs of investment but cannot typically pass the costs on to the tenants who benefit from reduced energy bills. In the literature this is referred to as the so-called *"landlord tenant dilemma"* (Stull 1978, Rehdanz 2007) and might serve as an explanation for the observations in this study.

The share of green voters, albeit having a sizable coefficient, is only significant in the high quality equation and even there only at the 10% level. Quantitatively the coefficients of green attitude in both equations are very similar. The coefficients bear the expected negative sign. However, these estimates might downplay the role of green attitudes in the change of energy efficiency. The volatility of green voting might be much higher than the volatility of the underlying attitudes.

5 Conclusions

The present paper evaluates the effects of building energy codes in the German apartment housing sector. Based on our analysis, we can draw two main conclusions.

In line with previous studies, we find that energy building codes effectively decrease energy requirements in residential real estate. More precisely, energy efficiency standards successfully affect technology adoption in the low quality housing market segment. Our results show that regulatory intensity is important in this context; the tighter the regulation, the higher the technology adoption and the faster the adoption of existing technologies by laggards in the low quality housing market segment.

Regulation has no direct impact on "innovators" or "early adopters" investments. However, there is a strong indirect effect of regulation on innovation. Investors in the high end housing market segment strongly react to a narrowing technology gap compared to adopters, even if their own performance is far from being in risk of being affected by regulation in the near future. Although this effect is merely indirect, our results constitute strong empirical indication for the effectiveness of building codes to change the behavior of early adopters and thus to foster the market entry of innovative "green" buildings in the high quality housing market segment.

Unfortunately, the methodology applied does not allow for exact conclusions about the communication channels between the housing market segments. But the indirect link between regulation and innovation favors explanations that emphasize shifts in production technology or the importance of market trends. A new energy efficiency framework might motivate real estate investors in the high quality segment to readjust their 'signaling' of outstanding quality to tenants; for example by developing more energy efficient buildings. At the same time, the improvement in general energy efficiency increases the credibility of the imminent threat of more rigid future regulation. Both aspects are associated with a higher demand for energy efficiency innovations. Alternatively, the manufacturing processes might increase efficiency as a result of scale economies in production; cost reductions potentially allow for the market-uptake of previously economically non-feasible inventions. Altogether these factors favour the market entry of innovative "green" buildings. However, a detailed analysis should be subject to future research.

At first glance, our results seem to encourage the application of building energy codes in

general. Policy makers, however, should read the presented insights carefully. Although we find that past policy has been effective, this does not necessarily imply that this success can be improved upon with future rounds of regulation. In the German case, for example, regulation is already very tight, narrowing the room for future regulatory interventions. Applying our results to the announced regulatory steps in 2014 and 2016 an—in terms of $kWh/(m^2 \cdot a)$—only small indirect impact on energy efficiency in the innovative segment can be expected. Moreover, it must be noted that our analysis did not evaluate the "optimal" level of regulatory intensity. For example, policy makers should take into account drawbacks on aggregate construction activity (Burfurd et al. 2012). This potentially decelerates technology diffusion and market entries, which in turn might offset the positive effects from regulation.

Over all regulation seems to be a valid policy option in countries with relatively poor housing quality, i.e. high energy requirements. For countries like Germany, the impact of regulation is less important. Especially against the background of the targeted NZEB housing standard by 2020, other activities to stimulate energy efficiency investments and energy efficiency innovations must supplement the legal setting. In this context, the results on "green attitude" provide an alternative option to speed up innovation. Rising awareness for energy saving technologies and communicating the positive effects of energy efficiency can be one such supplemental strategy.

Supplementary material I

Methodology

This technical appendix outlines some of the more technical aspects of the paper in slightly more detail. For a full mathematical exposition of the techniques we combine, please refer to the papers mentioned below.

Account for heteroscedasticity and cross sectional correlation

To account for heteroscedasticity, the estimation is made using an adjusted wild bootstrap (Wu 1986) that accounts for cross sectional correlation, cross equation correlation and heteroscedasticity. When resampling for a wild bootstrap, the original residuals are multiplied with a factor v drawn from a distribution that guarantees that the moments of the distributions of ε and εv resemble each other. Most importantly, mean and variance should be identical for ε and εv. Contrary to the residual bootstrap the wild bootstrap maintains fluctuations of variance over time from the original sample.

Following Davidson & MacKinnon (2010), we apply the same multiplier v to residuals from both equations, allowing cross equation correlation similar to SUR estimation approaches. Similarly, we apply the same v to observations in the same period, thereby accounting for cross sectional correlation in the residuals. This leaves us with a fairly low number of possibilities to resample. To allow a large number of distinct bootstrap samples (and thereby prevent statistical artifacts in the results), we draw the multipliers from Webb's six point distribution (Webb 2013) instead of the more commonly used two-point distributions proposed by Mammen (1993) and Davidson & Flachaire (2008).

Generated regressor problem An additional advantage of using a bootstrap in our application is that it simultaneously accounts for the generated regressor problem that occurs since

our measures for market entry and diffusion of "green" buildings are quantile estimates based on the available subsample. Since the entire process is simulated in our bootstrap, resampling the endogenous variable implies resampling the lagged endogenous that is used as predetermined explanatory variable at the same time. Since the measurement error in the left hand side variable is a (substantial) part of the error term, this measurement error is automatically considered by the bootstrap with respect to the lagged endogenous, which is our only variable where a generated regressor problem matters.

Derivation of the impulse response functions

As a robustness test, we also apply a two step bootstrap where we explicitly consider the uncertainty in the quantile estimates. To do so, we resample the micro-data before aggregating to the panel level before each iteration of our wild bootstrap. For each state and year specific subsample we draw (with replacement) $N_{i,t}$ buildings from the original corresponding subset of the micro-data. This resampled micro-data is used to create a new panel dataset. Equation 3 is estimated based on that data. The coefficients and residuals obtained thereby are then used for a single wild bootstrap iteration. Since the uncertainty coming from the estimation of quantiles from our sample is accounted for twice in this procedure, the standard errors of the coefficients are larger when applying the double bootstrap by construction. However, all results remain stable quantitatively and mostly significant, also at lower significance level.

Deriving impulse response functions

Since our sample includes periods without regulation, we cannot capture the impact of regulation through the level of regulation itself but instead rely on the regulation index proposed in the paper. Contrary to regulation that might be treated as exogenous, the regulation index is merely predetermined since it includes past information on the distribution of energy coefficients. While this is sufficient for the estimation of unbiased regression coefficients, it poses a problem when

computing impulse response functions where changes of the regulation index due to changes in energy efficiency have to be treated as endogenous.

For the impulse responses presented in Section 4 we assume that energy coefficients at any point in time are normally distributed. If this assumption holds, the two points of the distribution considered in our estimation, i.e. the 10th and the 90th percentile, describe the entire distribution of EPS for a given year. That is, we can compute the share of houses affected by the regulation for any given period endogenously.

Following Fry & Pagan (2007) we do not report the median impulse response function, but the individual impulse response (generated by the bootstrap) that is closest to the median. This guarantees that the IRF as reported is actually consistent with a potential parameter constellation.

Supplementary material II

Empirical evidence on the effects of building energy codes

As pointed out by Jacobsen & Kotchen (2013), there are few empirical studies on the real energy saving effects of building codes in the real estate sector. For a long time, it was generally claimed that adequate data, especially to analyze the supply side of housing, was not available (Gyourko 2009, Eichholtz et al. 2011). This has changed with the availability of new micro-data sources, like e.g. energy billing data or information on environmental certification schemes like the Energy Star label (see, e.g., Chegut et al. (2013)). The first studies on building energy codes, based on detailed micro-data gathered from consumption bills, were published starting in 2012.

The first paper to use energy billing information is Jacobsen & Kotchen (2013). The sample consists of 2,239 homes in Gainesville, Florida (USA). Based on this data, the authors evaluate the effects of the 2002 modified state wide energy building code. Monthly electricity and gas bills for the period of 1999-2005 serve as basis for a twofold empirical strategy, consisting of (i) a set of linear regressions to test whether level effects can be identified on average and in a seasonal perspective; and (ii) a difference-in-difference approach to analyze the performance of regulated vs. unregulated dwellings. While controlling for observable housing characteristics and heating degree days, the authors conclude that building energy codes are an effective instrument for reducing energy consumption in residential real estate. Moreover, they find that, in the case of the Florida state regulation, engineer's calculations and empirical observations are almost identical.

Another micro-data based study, Koirala et al. (2013), analyzes the effects of adopting the "International Energy Conservation Code" (IECC) in the US. The study combines an impressive amount of housing records (containing energy performance measures, housing attributes and individual information on residents) collected from the American Community Survey (the sample consists of 1% of US residences) with aggregate data on regulation, heating degree days and

energy prices on the state level. They find that the application of IECC allows households to save about 1.8 % on electricity, 1.3 % on natural gas, and 2.8 % on heating oil compared to dwellings in states without this regulation.

Evidence from outside the US is presented by Michelsen & Rosenschon (2012). They analyze the effects of German regulation from a long term perspective, 1967 to 2006, using energy billing information for a sample of 41,496 apartment houses. Standardized energy consumption of explicitly non-refurbished homes is modeled as a function of building characteristics, spatial controls and, most importantly, housings' age interacted with dummies for the regulation regime at the time of construction. They find evidence for two effects of tighter building codes: first and in line with the findings of Jacobsen & Kotchen (2013), the authors present level effects in energy consumption induced by changes in the legal setting. Secondly, they find regulation regime specific differences in energy consumption over time, which they interpret as differing trends in technological progress.

Other studies use aggregate information from US states to assess the impact of regulation. Aroonruengsawat et al. (2012) find significant effects of energy efficiency standards in US states based on panel data analysis. They conclude that regulation decreased electricity consumption by up to 5 % in states with high construction activity. Deason & Hobbs (2011) demonstrate, based on a set of panel regressions, that building codes decreased residential primary energy consumption by 1.3 % compared to states without regulation. In the first and frequently cited study on the impact of regulation, Jaffe & Stavins (1995) conclude that building codes did not affect observed building practice. Moreover, the adoption of energy efficiency measures is not affected by regulation.

To our knowledge, there is only little evidence how building energy codes affect the market entry of innovative "green" buildings. However, there is reason to believe that tighter building codes also affect the application of energy efficiency innovations in the high quality housing market segment. As proposed by Porter (1991), because regulation can rise the awareness of

Table 3: Empirical studies on the effects of building energy codes

Study	**Region**	**Period**	**Data**	**Methods**	**Key findings**
Jacobsen & Kotchen (2013)	USA	1999-2005	micro; gas and electricity billing data; N=2,239	linear OLS; Dif.-dif.	Regulation is effective; 4-6% decreases in energy consumption can be observed which corresponds to building codes requirements.
Koirala et al. (2013)	USA	2007	micro & aggregate data; American Community Survey 2007; N=1,137,886	IV; Hierarchical regression	The application of building codes can save up to 1.8 % of electricity, 1.3% natural gas and 2.8% oil.
Aroonruengsawat et al. (2012)	USA	1970-2006	aggregate data	panel regression	Introduction of building codes reduced electricity consumption in regions with dynamic construction activity.
Michelsen & Rosenschon (2012)	Germany	1967-2006	micro; heating energy bills of German apartment housing; N=41,496	linear OLS	Introduction and amendment of energy building codes comprise two effects: reduced level of energy consumption and decreasing energy requirements over time.
Deason & Hobbs (2011)	USA	1986-2008	aggregate data	panel regression	Primary energy consumption is by 1.3% lower in states that implemented building codes.
Beerepoot & Beerepoot (2007)	Netherlands	1996-2003	micro-data; energy performance calculations; N=352	Logistic regression	Building codes did not affect innovation at large but lead to incremental innovation in energy saving techniques.
Jaffe & Stavins (1995)	USA	1979-1988	aggregate; based on national association of home builders annual survey	OLS	Building codes did not affect observed building practice; adoption of energy efficiency measures is not affected by direct regulation.

investors for environmental issues and thereby increase demand for "green" buildings. But also the supply side might be positively affected: new products, like innovative insulation materials, heating systems or thermal glazed windows might be developed. It is also possible, that production of housing becomes cheaper due to process innovation or scale economies, which allows investors to increase the energy efficiency of buildings at constant costs. Finally, there might also be progress in the design of buildings (see, e.g., Fischer & Guy 2009), which results in decreased energy requirements.

In the few studies available in this context, only the product innovation channel has been analyzed so far. Beerepoot & Beerepoot (2007) research the impact of building codes on new technology development in the context of the Dutch residential building industry's innovation system. The authors assess a small sample of Dutch housing records and conclude that regulation does not provide sufficient incentives to create "really new innovations"(Beerepoot & Beerepoot 2007). However, the authors argue that standards at least induce some incremental energy efficiency improvements in the Netherlands.

Based on 35 Dutch commercial office building projects Vermeulen & Hovens (2006) analyze the diffusion of 'mature' and the uptake of 'young' innovations. They find that 'young' innovations, in addition to other factors, are adopted because they were needed in order to comply with the Dutch Energy Performance Standards (EPS). Based on the additional finding that EPS did not increase the adoption rates of 'mature' innovations, the authors conclude that, *"the instrument of Energy Performance Standards will, at best, be effective if it is regularly made more stringent and if it addresses more recently emerging appliances"* (Vermeulen & Hovens 2006, p. 2735).

Gann et al. (1998) analyzed the British "Building Regulation Part L, Conservation of Fuel and Power." Based on 21 expert interviews, the authors discuss various channels how regulation enters the innovations process in the housebuilding sector. Overall, Gann et al. (1998) find evidence that the shift from a "prescriptive" regulatory regime (in terms of allowed construction

materials and techniques) to a "performance-based" approach increased innovation activities.

The only quantitative evidence in this context is presented by Noailly (2012), who analyzes the effect of building codes on patenting activity in seven european countries in the period 1989 through 2004. Noailly (2012) arrived at the conclusion that a 10% tighter building code for wall insulation would increase patenting activities by 3%. According to this study, energy prices have no effect on inventions while public R&D expenditures slightly positively impact patent applications.

In summary, knowledge on the effectiveness of building energy codes and the incentives that such regulation create to bring "green" buildings on the market can be characterized as being far from comprehensive. The consensus appears to be that, in general, building codes, by accelerating the adoption of energy efficiency measures, decrease energy consumption in the housing sector. But in absence of longitudinal studies almost nothing can be said about regulatory intensity. Existing literature except—the study by Aroonruengsawat et al. (2012)—focuses largely on the mere introduction, not the amendment of energy efficiency regulation over time. This is an important limitation of studies centered on addressing the question of whether environmental regulation stimulates the market uptake of heating energy saving materials and building designs.

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