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The Power of Mandatory Quality Disclosure: Evidence from the German Housing Market

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Manuel Frondel, Andreas Gerster, and Colin Vance[1]

The Power of Mandatory Quality Disclosure: Evidence from the German Housing Market

Abstract

Many countries have introduced Energy Performance Certificates to mitigate the information asymmetry with respect to the thermal quality of houses. Drawing on a stylized theoretical model that is coupled with comprehensive data on real estate advertisements in the German housing market, this paper investigates the causal effect of disclosing energy information on the offer prices of houses. We are particularly interested in testing whether house sellers who would not voluntarily disclose the house's energy consumption decrease the offer price upon a shift to a mandatory disclosure scheme. Employing both within-variation from panel data and an instrumental-variable approach to cope with the endogeneity of disclosure decisions, our analysis demonstrates the power of mandatory disclosure rules to increase market transparency and to reduce prices.

JEL Classification: D82, L15, Q58

Keywords: Information asymmetry; mandatory disclosure; environmental certification

March 2017

1 Manuel Frondel, RUB and RWI; Andreas Gerster, RGS Econ and RWI; Colin Vance, Jacobs University Bremen and RWI. - *We are grateful for invaluable comments and suggestions by participants of the 31st Annual Congress of the European Economic Association in Geneva, the 22nd Annual Conference of Environmental & Resource Economics in Zurich, the Fifth Mannheim Energy Conference in Mannheim, the Ninth RGS Doctoral Conference and the Economics Seminar, both at Ruhr University Bochum, as well as the 21th Spring Meeting of Young Economists in Lisbon. This work has been partly supported by the Collaborative Research Center "Statistical Modeling of Nonlinear Dynamic Processes" (SFB 823) of the German Research Foundation (DFG), within Project A3, "Dynamic Technology Modeling".* *– All correspondence to: Manuel Frondel, RWI, Hohenzollernstr. 1-3, 45357 Essen, Germany, e-mail: manuel.frondel@rwi-essen.de*

1. Introduction

Ever since Akerlof's (1970) seminal contribution on markets for lemons, it is widely recognized that information asymmetries are pervasive. For example, purchasers of used cars typically know less about the car quality than the sellers. The purchase of used houses is another particularly relevant example, as the financial consequences are large and learning effects are limited due to the typically small number of purchases over an individual's lifetime.

To alleviate information asymmetries with respect to the thermal quality of houses, many countries have introduced Energy Performance Certificates (EPCs), with labeling schemes ranging from voluntary certification, such as the U.S. Energy Star program, to mandatory schemes that prescribe the disclosure of thermal qualities for all buildings to be sold. For example, as of May 1, 2014, Germany's legislation obliges sellers to disclose a building's energy consumption per square meter in real estate advertisements and to always present the EPC to potential buyers, not just on demand. Prior to May 2014, the German legislation just implied the weak obligation "to make available an EPC [...] as soon as a potential buyer asks for it" (EnEV, 2007), yet the absence of an EPC did not carry legal sanctions. To enforce compliance, heavy fines for non-compliance were introduced, ranging up to 15 thousand euros (EnEV, 2014). With these legal changes, the nature of the labeling scheme shifted substantially, from an effectively voluntary disclosure of energy information originally to an enforced disclosure today.

Using data on real estate advertisements that cover large parts of the German housing market and the years 2013 to 2015, this paper investigates the consequences of such a shift in legislation on the housing market. We are particularly interested in identifying the causal effect of disclosing energy information of the offer prices of houses. Motivated by a stylized theoretical model, three hypotheses are tested: First, in the absence of mandatory disclosure rules, real estate advertisements present the energy consumption per square meter more often for houses fulfilling high energy-efficiency standards than for those of low energy quality. Second, offer prices should decrease for houses whose owners would not voluntarily disclose in the absence of more stringent disclosure rules. Third, the drop in prices should be correlated with energy quality, that is, sellers whose homes have the worst energy qualities will lower their offer prices the most upon a shift in disclosure rules. Employing both within variation from panel data and an instrumental variable approach to cope with the endogeneity of disclosure decisions, our analysis demonstrates that mandatory disclosure rules for energy information in the housing market increase market transparency and reduce prices.

Our first hypothesis accords with early theoretical work stressing the potential of voluntary disclosure for sellers of good-quality products to escape the pooling with bad qualities, thereby possibly achieving higher selling prices (Milgrom, 1981; Grossman, 1981). In fact, there is ample empirical evidence that sellers successfully employ voluntary disclosure as an instrument to overcome adverse selection problems in numerous fields as diverse as food qualities (Ippolito and Mathios, 1990) and online auctions of used cars (Lewis, 2011).

That the best-quality seller is the first to disclose as a means to distinguish from low-quality sellers can trigger an iterative process called "market unraveling", in which further sellers are induced to disclose information on their product as well, trying to escape a pool of non-disclosing sellers with ever worse average quality. In theory, all but the worst-quality seller would disclose, an outcome called the "unraveling result" that hinges on several strong assumptions, such as costless disclosure (Dranove and Jin, 2010).

In reality, however, there are many markets in which voluntary disclosure is incomplete (Dranove and Jin, 2010), casting doubt on the efficacy of voluntary disclosure to overcome information asymmetries. As an alternative, mandatory rules to disclose quality have been found to improve consumers' welfare in a wide variety of applications, including schooling (Figlio and Lucas, 2004) and health plan report cards (Beaulieu, 2002; Bundorf et al., 2009; Dafny and Dranove, 2008; Jin and Sorensen, 2006; Scanlon et al., 2002).

Studies that investigate the *shift* from a voluntary to a mandatory disclosure regime are scarce, though. Exploring the impacts of labeling on the fat content of salad dressings, one of the few such studies is Mathios (2000). He finds that under a voluntary regime, the producers of high-fat dressings did not disclose information on the fat content and, moreover, the sales of high-fat dressings dropped after introducing mandatory disclosure rules.

With respect to energy labels, previous research has largely focused on the market value of energy efficiency. Eichholtz et al. (2010), for example, present empirical evidence that the U. S. Energy Star label is associated with an average price premium of some 16% for office buildings, while for the EU label, Brounen and Kok (2011) and Hyland et al. (2013) analyze the extent to which different energy efficiency classifications of buildings are capitalized into prices. Yet, to our knowledge, empirical evidence on the effect of mandatory disclosure rules for energy information is unavailable so far.

Our study contributes to the literature on information disclosure in at least two respects: First, given that both theoretical and empirical articles stress that the extent of market unraveling under voluntary disclosure rules is context-specific and depends on a confluence of factors, such as the market structure, the kind of quality differentiation, and consumer preferences (Dranove and Jin, 2010), we are the first to analyze the potential of voluntary disclosure rules to overcome information asymmetries in the housing market with respect to energy quality.

Second, we analyze whether it is desirable to go beyond voluntary information disclosure by invoking mandatory disclosure rules. Many theoretical articles argue that mandatory disclosure can raise consumer surplus. Whether this argument holds true for energy information in the housing market, though, has largely escaped empirical scrutiny. By finding that mandatory disclosure rules trigger price reductions for homes of otherwise non-disclosing sellers, our analysis indicates positive welfare effects for consumers.

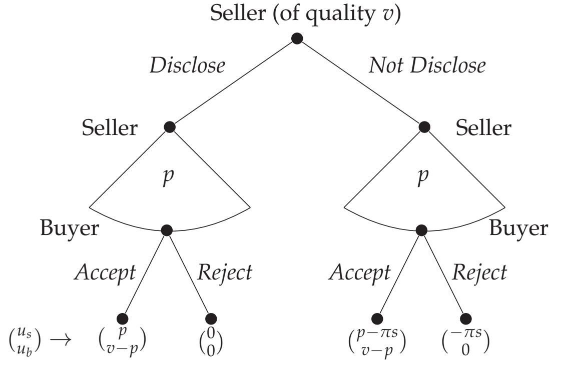
In the subsequent section, we present a stylized model based on game theory to derive theoretical predictions about the impact of a mandatory disclosure policy on prices. Drawing on data from Germany's largest online platform for real estate advertisements, Section 3 describes the data set and presents summary statistics, followed by a discussion of our empirical strategy in Section 4. In Section 5, we present the estimation results. The last section summarizes and concludes.

2. Theoretical Model

In this section, we propose a stylized model of house purchases under asymmetric information that serves to guide our empirical approach by illustrating the three testable hypotheses presented in the introduction. Inspired by the early work of Milgrom (1981) on voluntary disclosure, we extend his model by two features: (1) limited rationality of buyers and (2) cost of non-compliance with disclosure rules.

As summarized by Dranove and Jin (2010), most empirical situations are characterized by incomplete "market unraveling", which is commonly explained by the existence of limited rationality of buyers, disclosure cost or strategic interactions between sellers. Because the cost of disclosing energy information on real estate platforms are marginal and the vast number of sellers make Germany's real estate market very competitive, our model focuses on the limited rationality of buyers. Furthermore, the introduction of non-compliance cost reflects the key

Figure 1: A Model of House Purchases under Imperfect Quality Information



insight from the enforcement literature (e.g. Polinsky, 2000) that compliance with mandatory disclosure rules is determined as the result of a seller's profit maximization, taking into account the possibility of sanctions.

The structure of the model, as well as its outcomes, are briefly explained here, with the details being presented in Appendix A. Let a seller possess a house with quality v, which, for the sake of simplicity, is assumed to be uniformly distributed on the unit interval $[0, 1]$. Quality v is purely private information of the seller, whereas potential buyers are assumed to be only able to observe the distribution of qualities in the population, given here by density $f(v) = 1$ for $v \in [0, 1]$. When posting a real estate advertisement, the seller can decide to either disclose quality or to abstain from disclosure (Figure 1). Upon deciding on disclosure, the seller proposes a house price p, an offer that a potential buyer can either accept or reject.

In case of a buyer's acceptance, the house is sold and the seller's pay-off is determined by the house price $u_s = p$, whereas the buyer's pay-off equals $u_b = v - p$, the value of the house, reflected by quality v, less its price. If instead the transaction does not take place, the seller's pay-off is zero in case of quality disclosure, whose cost is assumed to be negligible, and $-\pi s$ in case of non-disclosure, where s denotes the level of sanctions, such as fines, legal and reputation cost, and π designates a detection probability, so that $-\pi s$ reflects the expected cost of non-compliance.

Following the concept of "cursed equilibrium" introduced by Eyster and Rabin (2005) to operationalize limited rationality of buyers, we employ parameter $\chi \in [0, 1]$ to capture the extent to which the buyer makes rational inferences on qualities. A fully naive buyer, indicated by $\chi = 1$, does not recognize that sellers of low-quality houses have particularly strong incentives to refuse disclosure and thus wrongly believes that the quality of a house for which no energy information is disclosed equals the population average. In contrast, relying on Bayesian updating, a fully rational buyer ($\chi = 0$) forms rational beliefs over qualities and takes the seller's strategic considerations into account.[1]

Table 1: Equilibrium Pricing and Disclosure Strategies of Sellers

Equilibrium Price		Who discloses?
v	if $v > v^*$	House Owners with $v > v^* = \frac{\chi - 2\pi s}{1+\chi}$
$\bar{v} = \frac{\chi}{2} + \frac{(1-\chi)v^*}{2}$	if $v \leq v^*$	

Table 1 presents the pricing and disclosure strategies that follow from the subgame perfect χ-cursed equilibrium of the game. It illustrates that sellers act strategically in disclosing only good qualities, while hiding others: when a house's quality v exceeds a threshold value v^*, which discriminates between disclosure and non-disclosure, a seller voluntarily opts for disclosure and sets the price p equal to quality v. Sellers of houses with $v \leq v^*$ decide against disclosure and demand a price $\bar{v}$ that does not depend on house quality.

When sanction level s or detection probability π equal zero and buyers do not form fully rational beliefs ($\chi > 0$), "unraveling" remains incomplete, indicated in the model by a disclosure threshold $v^* > 0$. It is intuitive that this threshold increases in a buyer's naivety χ, allowing a seller to achieve higher prices. In contrast, by raising the cost πs of non-compliance, mandatory disclosure rules decreases the threshold value v^* and thus increases the share of disclosing sellers.

To gauge the price impact of a policy change that mandates disclosure, we define policy compliers as sellers of houses with $v \in [v_1^*, v_2^*]$, where v_1^* and v_2^* indicate the threshold values prior to and after the policy change, respectively. As demonstrated in Appendix A, the equilibrium strategies presented in Table 1 imply that such policy compliers reduce housing prices in response to mandatory disclosure. This reflects sellers' ability to exploit buyers' limited strategic thinking by demanding prices above their house's quality v prior to mandatory disclosure.

To sum up, this stylized model has served to rationalize the following three hypotheses: First, we expect sellers to disclose energy information more often for houses with good thermal

[1]Behavioral failures that imply a buyer's inability to correctly interpret a seller's strategic behavior with regard to the implications that they have on unobserved qualities ("conditional failures") have been found to be relevant in both the laboratory (Jin et al., 2015) and using observational data on movie openings with and without previous reviews (Brown et al., 2012).

qualities. Second, we anticipate that a policy that mandates quality disclosure should imply a decrease in offer prices for houses whose owners would choose to not disclose in the absence of the policy. Third, as sellers of bad quality houses profit disproportionately from a pooling equilibrium, the model suggests that price decreases are particularly pronounced for houses of bad quality.

3. Data

Drawing on data from Immobilienscout24, Germany's largest online platform for real estate advertisements, we focus on the market for used houses, thereby ignoring both newly built houses, as well as unbuilt houses that are already offered on the platform. Our focus owes to the fact that in markets for used goods, information asymmetries are particularly prevalent. The data set comprises 312,899 houses that were for sale between January 2013 and October 2015. The data contains detailed information on housing characteristics, the heat energy consumption per square meter for those advertisements in which it is disclosed, as well as the offer price.[2]

In the majority of cases, the house appears one time in the data, but for a subset of 65,486 houses, we additionally have monthly recordings, thereby producing a panel structure with which to track changes in the price of the house over time, as well as changes in the status of whether the seller discloses the heat energy consumption per square meter. This inter-temporal variation comes by way of a professional content management software that is often used by real estate agents and banks, which automatically updates changes in the ad posting during the house's time on the market. As private sellers, which comprise about 6% of the full sample, do not have access to such software, they are not included in the panel data. The analyses that follow draw on both the full data set and the subset of panel data to control for fixed effects. As we demonstrate in Appendix D, houses for which panel information is available are very similar to those that appear only one time in the data. Hence, restricting the analysis to the panel data set should not have any bearing on our conclusions.

As our primary interest is on systematic differences between houses for which energy information is disclosed in the advertisement and those for which this information is not provided,

[2] In Appendix B, we provide details on energy performance certificates in Germany, the calculation of their central measure of the heat energy consumption per square meter, and the introduction of mandatory disclosure rules. Furthermore, the preparation of the data set used for our analyses is discussed in Appendix C.

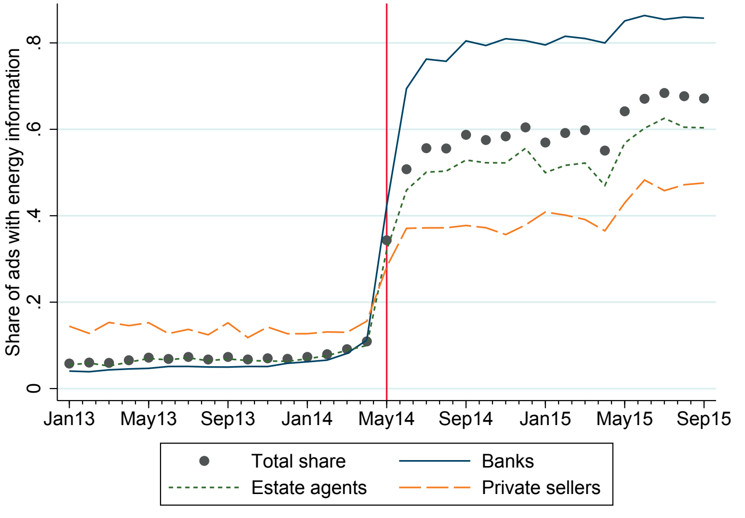
Table 2: Summary Statistics

	Ads with energy information			Ads without energy information		
	Mean	**Std. Dev.**	**# of Obs.**	**Mean**	**Std. Dev.**	**# of Obs.**
Price, in 1,000 EUR	270.8	157.7	127,434	238.5	148.8	223,315
Duration, in months	5.4	6.4	127,434	6.6	9.2	223,315
Living space, in m^2	165.6	67.8	127,434	165.6	70.0	223,315
Lot size, in m^2	729.1	594.0	127,434	757.2	642.9	223,315
# of rooms	6.1	2.5	127,434	6.1	2.6	223,315
Years since construction	45.6	27.8	127,434	48.0	29.4	223,315
Years since last modernization	9.0	9.0	37,677	8.8	9.1	49,697
House category:						
Multi-family house	0.16	0.36	118,553	0.15	0.36	192,209
One-family house	0.55	0.50	118,553	0.57	0.50	192,209
Row house	0.29	0.46	118,553	0.28	0.45	192,209
Self-rated house condition:						
Basic	0.09	0.28	47,296	0.12	0.32	80,698
Normal	0.51	0.50	47,296	0.52	0.50	80,698
Superior	0.40	0.49	47,296	0.37	0.48	80,698
In need for renovation:						
Yes	0.15	0.35	89,913	0.19	0.39	138,385
No	0.85	0.35	89,913	0.81	0.39	138,385
Heating system:						
Central	0.93	0.25	89,765	0.92	0.28	142,086
Floor	0.04	0.19	89,765	0.04	0.21	142,086
Oven	0.03	0.18	89,765	0.04	0.19	142,086
Seller type:						
Bank	0.34	0.48	127,434	0.24	0.43	223,315
Agent	0.60	0.49	127,434	0.66	0.47	223,315
Private Seller	0.06	0.23	127,434	0.10	0.30	223,315
Heat energy consumption in kWh/m^2	172.9	83.7	127,434	–	–	–

Table 2 compares the summary statistics for both these subsamples. While for the majority of characteristics, there are small differences in the means, a quite substantial discrepancy can be observed for house prices. The average price for houses for which energy information is disclosed is about 14% higher than for the remaining houses, although mean living space is virtually identical and the mean lot size is even somewhat larger for those houses for which energy information is unavailable. Another notable distinction from Table 2 is that the shares of seller types, i. e. banks, real estate agents and private sellers, differ across both subsamples: For instance, with 34%, the share of banks is 10 percentage points larger among advertisements including energy information than among those without it.

This distinction and, most notably, the fact that banks responded differently than real estate agents and private sellers when disclosure became mandatory, is exploited in our empirical

Figure 2: Shares of Advertisements in Immobilienscout24 including Energy Information across Seller Types.

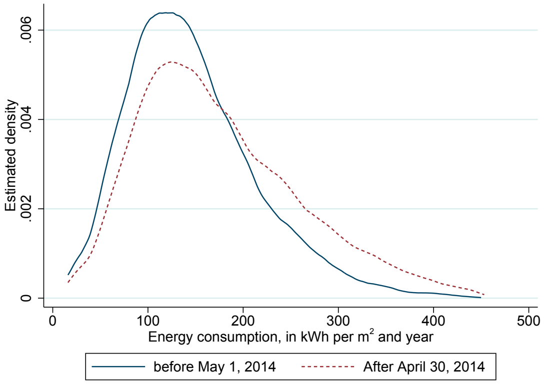


strategy to identify the causal effect of disclosing energy information on house prices. In fact, as Figure 2 reveals, after April 2014, the share of sales advertisements that include energy information was substantially larger for banks than for real estate agents and private sellers, whereas prior to May 2014, the opposite was true. Overall, the share of advertisements that displayed information on energy efficiency increased substantially, from some 10% prior to May 2014 to about 60% at the end of 2014.

That sellers comply only imperfectly with the policy can be traced back to three major reasons: First, sellers that have not yet received an already ordered energy performance certificate are nevertheless allowed to post the advertisement. Second, as suggested by our stylized model, sellers that expect the benefits of non-disclosure to exceed its cost may deliberately decide to violate the law. Third, the penalty of € 15,000 was only effective from May 2015 onwards. However, as illustrated by Figure 2, disclosure increased only little after May 2015, so that the fear of those penalties does not influence a sizable share of sellers.

The heterogeneity in the degree of compliance across seller types appears to be plausible given the different institutional characteristics of these groups (for a detailed discussion of seller type differences, see Appendix E). As the costs associated with non-disclosure, such as image and reputation losses, are particularly high for banks, it is presumably in their interest

Figure 3: Distribution of Heat Energy Consumption per Square Meter before May 1, 2014, and after April 30, 2014.

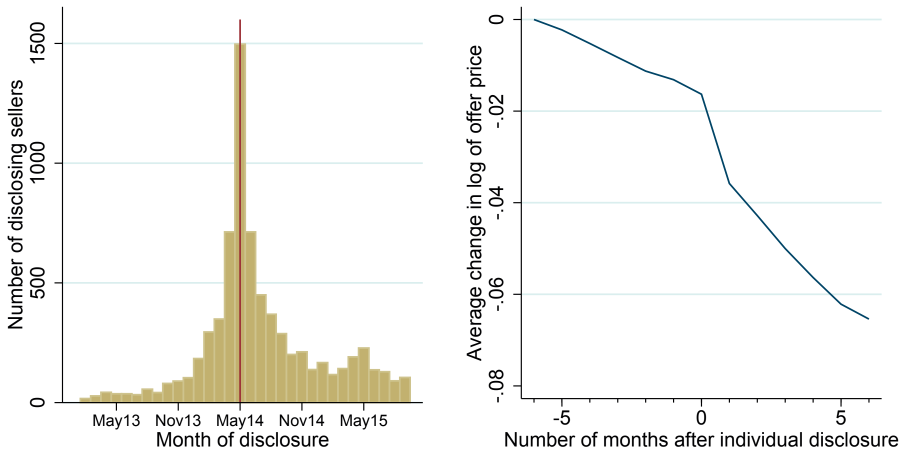


that employees comply with legal rules. Indeed, most banks operate specialized compliance departments to ensure that awareness about law changes and their consequences is high for their employees. In contrast, mechanisms to ensure compliance with the law are far less common for estate agencies and private sellers.

In sum, on the basis of this discussion, it seems to be highly warranted to assume that the change in disclosure rules as of May 2014 created exogenous variation in the provision of energy information in real estate advertisements across sellers types. In the subsequent section, the heterogeneous response of banks and estate agents is exploited to instrument the likely endogenous choice of disclosing energy information. After all, it is likely that energy information is more often included in real estate advertisements for buildings fulfilling high energy-efficiency standards than for houses of low energy quality.

To provide empirical support for our assumption that the disclosure decision is often strategic in nature, in other words, endogenous, we use the full sample to plot the distribution of the heat energy consumption per square meter before May 1, 2014, and after April 30, 2014, expecting that this distribution would shift to the right, as the share of houses with low thermal qualities among those whose consumption value is disclosed would increase as a consequence of the change in legal rules that mandates quality disclosure. Our expectation of a rightward shift is confirmed by Figure 3 and a Kolmogorov-Smirnov test that clearly rejects the equality of distributions for both subgroups (test statistic: 0.14, p-value = 0.000). In contrast, the distribution should have remained unaltered if the disclosure of energy consumption values would

Figure 4: Distribution of Energy Information Disclosure Dates (Left Panel) and Price Changes Relative to the First Offer Price, by Month of Disclosure (Right Panel)



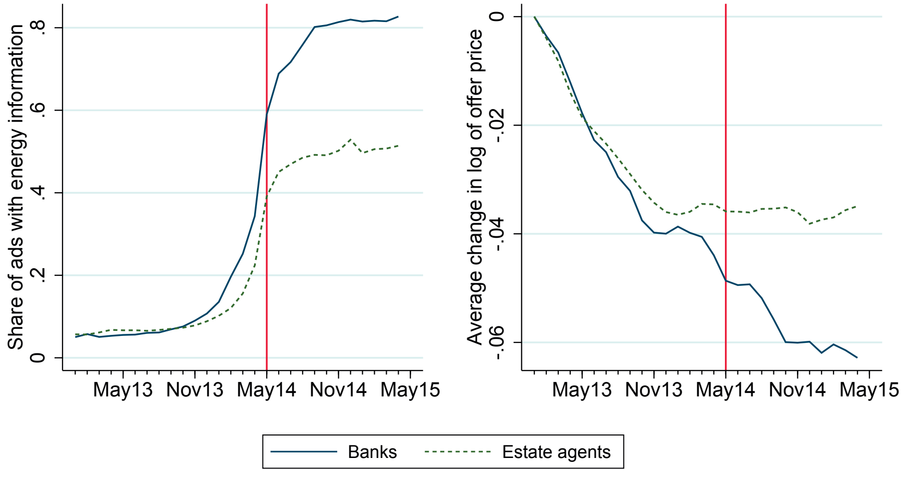
Notes for Right Panel: To normalize price changes to zero in the first period, the graph displays price changes for houses that disclosed within 6 months after they were first offered on the market.

have been a matter of chance or sellers' inattention, rather than strategic decisions.

Turning to the repeated observations from the panel data allows the identification of sellers who provided the energy information only at some point after the advertisement had been posted for the first time. By illustrating that these sellers disclosed predominantly around May 2014, the left panel of Figure 4 demonstrates that the policy change induced substantial "within variation" with respect to the disclosure of energy consumption information. The right panel of Figure 4 provides some first graphical evidence that sellers reduce prices upon disclosure. A particular pronounced price drop is evident in the month immediately following disclosure.

We can also use the panel data to illustrate how differences in policy compliance between banks and estate agents affected pricing decisions. While the left part of Figure 5 reconfirms that banks complied more strongly with the policy, the right part displays the average change in prices relative to the first offer price, and demonstrates that before May 2014, both price adjustments and disclosure rates are similar for banks and estate agencies. However, as soon as banks disclosed more often when disclosure became mandatory, on average, banks reduced prices more strongly.

Figure 5: **Share of Advertisements with Energy Information (Left Panel) and Price Changes Relative to the First Offer Price, by Month (Right Panel)**



4. Methodological Issues

Our main aim is to empirically identify the causal impact of the binary treatment variable EPC_i on the offer price of a house, with $EPC_i = 1$ indicating the disclosure of the heat energy consumption per square meter. Recognizing that disclosure is an endogenous outcome, we begin with an investigation of the determinants of disclosure by estimating the following linear probability model on the full data set:

$$\begin{aligned} EPC_i &= \alpha_0 + \boldsymbol{\alpha}_{\mathbf{x}}^T \mathbf{x}_i + \alpha_P PostApril2014 + \alpha_A Agent_i + \alpha_B Bank_i \\ &\quad + \alpha_{AP} Agent_i \cdot PostApril2014 + \alpha_{BP} Bank_i \cdot PostApril2014 + \mu_z + \epsilon_i, \end{aligned} \tag{1}$$

where $\mathbf{x}_i$ captures a suite of housing characteristics, μ_z denotes zip-code fixed-effects and ϵ_i the error term. *PostApril2014* is a dummy variable designating that the advertisement on house i appeared in Immobilienscout24 after April 30, 2014, that is, after disclosure became mandatory, and $Bank_i = 1$ and $Agent_i = 1$ indicate that advertisement i owes to a bank or a real estate agent, respectively, with private sellers representing the reference group in Equation 1. Motivated by Figure 2 and the discussion in the previous section, we have included interaction terms to capture seller-type-specific differences in the disclosure of energy consumption values after April 2014.

In examining the impact of treatment EPC_i on the offer price, we follow the framework of Rubin (1974), where the potential offer price for house i is denoted by $p_i(1)$ if energy information is disclosed and by $p_i(0)$ otherwise. For an individual house i, the causal effect of disclosure is given by the difference between potential outcomes: $p_i(1) - p_i(0)$. This difference, however, is principally unobservable, as we either observe $p_i(1)$ or $p_i(0)$, yet not both, giving rise to the well-known evaluation problem (Holland, 1986).

As researchers are commonly interested in average impacts, rather than in individual effects, the empirical literature typically focuses on the average treatment effect (ATE): $E(p_i(1)) - E(p_i(0))$, where $E(.)$ denotes the expectation operator. The ATE can be readily estimated with a standard hedonic model in which the house price p_i is regressed on a set of house characteristics, including EPC_i. However, identification of the effect of EPC_i rests crucially on the conditional independence assumption (CIA), which requires that all house characteristics that influence disclosure decisions and may be related to house prices are observable. It is conceivable, though, that sellers of homes with poor but unobservable energy efficiency would refrain from disclosing energy information, thereby violating the CIA and likely resulting in an upward bias in the estimate of the EPC's effect (see the first column of Table 4).

To estimate average treatment effects under less restrictive assumptions, we exploit within-variation at the house level using the panel data, thereby eliminating the influence of all time-constant observable and unobservable house characteristics that may underlie sellers' strategic disclosure decisions. Using ordinary linear regression, the following fixed-effects model is estimated:

$$\ln p_{it} = \gamma_{EPC} EPC_{it} + \nu_t + \tau_i + \epsilon_{it}, \tag{2}$$

where p_{it} designates the price of house i in month t, ν_t and τ_i correspond to month- and house-fixed effects, and u_{it} denotes the error term. Equation 2 does not encompass the vector $\mathbf{x}$ that appears in Equation 1 and includes only time-invariant housing characteristics, as these are captured by the fixed effects. It also excludes the interaction terms comprising seller types and the post-April dummy, as these are argued below to exclusively determine disclosure, but not the house price.

Coefficient γ_{EPC} yields the average treatment effect on the treated (ATT). It corresponds to the effect among those households that changed treatment status over the observation period.

Identification of the ATT is subject to a common trends assumption, requiring that – in the absence of disclosure – houses of disclosing and non-disclosing sellers would follow the same price trends. The ATT reflects two possible motivations for disclosure: It captures the average treatment effect for policy compliers, i.e. sellers of houses who strategically disclosed only in response to more stringent disclosure policy of May 2014, but it also captures this effect for those who added the EPC information for reasons other than the policy change.

In addition to the ATT, we isolate the local average treatment effect (LATE), that is, the estimate of the average treatment effect for policy compliers, which are those sellers who disclose energy information only in response to the mandatory disclosure policy. To isolate the LATE, we exploit the difference in the response across seller types before and after the regulatory change in May 2014 by specifying an instrumental variable (IV), $Bank_i \cdot PostApril2014_t$, which is assumed to exogenously determine sellers' choice to disclose the energy quality of house i, but should not be correlated with the house price. The IV estimator identifies the local average treatment effect (LATE) (Imbens and Angrist, 1994), which in our case corresponds to the average treatment effect for policy compliers.

IV-Estimation follows from a panel-approach using the method of two-stage least squares, with the first stage specified as:

$$EPC_{it} = \delta Bank_i \cdot PostApril2014_t + \nu_t + \tau_i + \epsilon_{it}, \tag{3}$$

The specification of Equation 3 is similar to Equation 1 but, being estimated with fixed effects, again excludes the vector $\mathbf{x}_i$. As private sellers are not included in the panel data, another distinction is that Equation (3) does not include the term $Agent_i \cdot PostApril2014_t$, as this term is perfectly collinear with the time dummies, ν_t. The second-stage model is identical to Model 2, but replaces EPC_{it} with the predicted value obtained from Equation 3.

Identification of the LATE using an IV approach hinges on several identifying assumptions, the first being that the instrument is correlated with the treatment, but uncorrelated with potential outcomes. While the correlation between the instrument and the treatment variable can easily be assessed, the requirement that instrumental variables are unrelated to potential outcomes (the "validity" of the instrument) is in principle untestable. In the following, we argue why we consider our instrumental variable to be valid.

First, the inclusion of time-fixed effects into our model absorbs all changes in the macroeconomic environment that may influence housing prices, which therefore cannot challenge the validity of the instrument. Second, time-constant differences between house characteristics, as well as selling strategies for a specific house, are not of concern as they are captured by the house-fixed effects. What is more, our IV approach can even accomodate time-varying house characteristics or selling strategies, as long as they are the same for both estate agents and banks. Indeed, we find empirical support for this requirement: price changes are indistinguishable for banks and estate agents prior to the policy change, as illustrated in the right panel of Figure 5.

Besides the validity of the instrument, "monotonicity" (Imbens and Angrist, 1994) is required to identify the LATE, which implies that the instrument can only influence treatment uptake in the same way, so that the instrument should not simultaneously increase treatment probabilities for some sellers and decrease them for others. In our case, this means that the legal obligation to disclose energy information should not have decreased the disclosure probabilities for some sellers – which does not seem to be a critical assumption.

Finally, identification requires a stable-unit-treatment-value assumption (SUTVA), implying that the treatment solely exerts a direct effect on the unit being treated, thereby excluding indirect effects. Specifically, SUTVA rules out the existence of general equilibrium effects and treatment externalities. With respect to our empirical example, one might argue that disclosure of energy information in an advertisement may affect other house sales by, for instance, increasing the attention of buyers to energy efficiency attributes. While we cannot deny the possibility of such spill-over effects, we argue that for two reasons it is highly unlikely that they are of critical magnitude. First, compliance with the new disclosure rules is far from being perfect, rendering substantial shares of non-compliers. Second, taking the weak response of private sellers as a benchmark, the awareness of potential buyers about new disclosure rules seems limited.

5. Empirical Results

The results of the ordinary least squares (OLS) estimation of Linear Probability Model 1 reveal that information on energy efficiency is disclosed more often for more recently constructed houses than for older buildings (Table 3), with the propensity to disclose energy consumption values being highest for houses constructed between 2002 and 2015. Although partly driven by the fact that EPCs and, hence, energy information are less readily available for older houses than for more recently constructed homes, this finding may also reflect strategic behavior to obscure poor thermal quality. In a similar vein, disclosure is less frequent for those houses that are in need of modernization and self-rated as being of only basic quality. These results lend support to our first hypothesis that sellers of houses with better thermal qualities are more likely to disclose energy information than those of low-quality houses.

Table 3: OLS Regression Results for Linear Probability Model 1 of the Determinants of Energy Consumption Disclosure in Real Estate Advertisements

		Coeff. s	Std. Errors
Year of construction	1977-2002	0.029**	0.002
(base category: Pre 1930)	2002-2015	0.032**	0.003
Year of modernization	1977-2001	0.024*	0.011
(base category: Pre 1977)	2002-2015	0.022*	0.011
	n.a.	-0.014	0.010
Self-rated house condition	Normal	-0.024**	0.003
(base category: Superior)	Basic	-0.041**	0.004
	n.a.	-0.035**	0.002
Need for modernization	Yes	-0.051**	0.002
(base category: No)	n.a.	-0.058**	0.002
Heating type	Floor heating	-0.013**	0.004
(base category: Central heating)	Oven	-0.020**	0.005
	n.a.	-0.070**	0.002
Seller type	Bank	0.002	0.004
(base category: Private sellers)	Agent	-0.012**	0.003
Appearance after April 30, 2014	PostApril2014	0.268**	0.005
Interactions terms	Bank*PostApril2014	0.452**	0.005
	Agent*PostApril2014	0.212**	0.005
House category	Multi-family house	-0.009**	0.003
(base category: Row house)	One-family house	-0.001	0.002
	n.a.	-0.127**	0.003
Further house characteristics	Lot size, in 1000 m^2	0.002	0.003
	Lot size (squared)	-0.002**	0.001
	Living space, in 100 m^2	0.015**	0.004
	Living space (squared)	-0.005**	0.001
	% of rooms	0.005**	0.000
Constant	–	0.124**	0.012
Zip code fixed-effects	✓		
Number of observations	312,899		
R^2	0.37		
F-Statistic	6,956.02		

Note: ** and * denote statistical significance at the 1% and 5% level, respectively.

Confirming the conclusions drawn from Figure 2, the estimation results reported in Table 3 indicate that the obligation to disclose energy consumption values as of May 2014 increased the

Table 4: Estimates of the Effect (ATE, ATT, LATE) of Energy Information Disclosure on House Prices

	Hedonic Model	Fixed-Effects	Fixed-Effects	Panel IV
	ATE (Std. Err.)	ATT (Std. Err.)	ATT (Std. Err.)	LATE (Std. Err.)
EPC	0.052** (0.001)	-0.018** (0.001)	-0.003 (0.002)	-0.117** (0.018)
$EPC \times 1(125 \leq \text{EC} < 190)$	-	-	-0.010** (0.003)	-
$EPC \times 1(\text{EC} \geq 190)$	-	-	-0.030** (0.003)	-
House fixed effects	-	✓	✓	✓
Month fixed effects	✓	✓	✓	✓
Number of house-month obs.	-	412,637	412,637	412,637
Number of houses	312,899	65,486	65,486	65,486

Note: Standard errors are in parentheses. ** denotes statistical significance at the 1% level, * at the 5% level. The full model results for the hedonic model are presented in Appendix F.

share of advertisements including this information by some 27 percentage points after April 2014 for private sellers. Even more pronounced is the reaction to this obligation of other seller types: conditional on zip-code fixed-effects and other covariates, the disclosure rate of estate agents is some 21 percentage points higher than for private sellers, with the disclosure rate of banks even exceeding that of private sellers by 45 percentage points.

To provide for a reference point for our estimates on the price effects of disclosure, in the first column of Table 4, we present the results of a hedonic model obtained by estimating Equation 2 by OLS using the full data set, thereby ignoring the potential endogeneity of disclosure. The OLS estimates suggest that the average treatment effect (ATE) of disclosure is positive and amounts to 5.2%. This result should be interpreted with great caution owing to the endogeneity of the disclosure decision: the owner of a house with a good thermal quality is likely to disclose energy information more often than other market agents. The OLS estimate on the coefficient of EPC_i is thus likely to be biased upwards as a consequence of unobserved thermal quality being part of the error term, ultimately resulting in an omitted-variable bias.

Contrary to the OLS estimate, the fixed-effects estimate of the coefficient on EPC_i presented in the second column of Table 4 has a negative sign. It reflects the average treatment effect on the treated (ATT), indicating that upon the disclosure of energy efficiency information house prices decrease by around 1.8% – a finding that is in accord with our second hypothesis. To investigate whether price decreases are particularly strong for houses with poor thermal qualities, we interact the disclosure variable from Equation 3 with two dummy variables that indicate whether a house's heat energy consumption (*EC*) is either higher than 190 kWh per square meter and, hence, lies within the highest tercile or lies within the middle tercile, where the energy consumption per square meter is between 125 and 190 kWh.

The estimates from third column of Table 4 show that the ATT is very close to zero for the base category of good energy quality houses. In contrast, houses with energy consumptions within the middle tercile reduce prices by an additional 1 percentage point, while the additional decrease for houses in the highest tercile amounts to some 3 percentage points, which confirms our third hypothesis that bad quality houses reduce prices more strongly.[3]

The panel IV estimate of the coefficient on EPC_i presented in the last column of Table 4 reflects the local average treatment effect, indicating that upon the disclosure of energy efficiency information house prices decrease on average by 11.7% for the subgroup of compliers, i. e. for owners of houses that have only disclosed the information in response to the mandatory disclosure rule. The standard error on the estimate is rather large, resulting in a 95% confidence interval for the LATE that spans from -15.2 to -8.1%, reflecting a high uncertainty about the magnitude of the price reductions for policy compliers remains. Even at the lower bound of this interval, the LATE estimate is considerably larger than the ATT of -1.8%, which may reflect that policy compliers reduce prices more strongly, compared to sellers that add energy information for reasons other than the policy change.

Although the magnitude of the IV-estimate is large, we can exclude bias owing to weak instruments. We gauge the strength of our instrument using Stock et al.'s (2002) rule of thumb, which requires that the F statistic for the coefficient of the instrument exceeds the threshold of 10. With an F statistic of 195 resulting from the first-stage estimation, we clearly reject the hypothesis that the second-stage equation is only weakly identified.

6. Summary and Conclusions

Based on a comprehensive data set that covers large parts of the German housing market for the years 2013 to 2015, this paper has investigated the causal impact of the decision to disclose a house's heat energy consumption on the offer price of the house, a decision that was influenced by a policy change that mandates such disclosure in real estate advertisements as of May, 2014. Prior to this policy change, energy information had only been voluntarily provided in some 10% of the advertisements, a share that increased to more than 60% after disclosure

[3] In Appendix G, we show that both the panel and the IV estimates remain virtually unchanged when controlling for a set of 18 duration dummy variables.

became mandatory.

Motivated by a stylized theoretical model, we tested the hypothesis that house sellers who would not voluntarily disclose the house's heat energy consumption decrease the offer price upon a shift to a mandatory disclosure regime. To cope with the endogeneity of the disclosure decision, our empirical identification strategy rests on two pillars. First, we exploit changes in disclosure decisions and prices for houses over time, with this within variation helping to eliminate time-constant confounding factors. Second, taking advantage of the fact that banks complied with the disclosure obligation to a much larger extent than real estate agents, we pursued an instrumental variable approach to estimate the causal effects of disclosure on policy compliers, that is, those sellers who disclose energy information only in response to the mandatory disclosure policy. Our estimation results demonstrate that policy compliers tend to reduce the houses' offer prices. Consistent with our theoretical predictions, these price reductions are particularly pronounced for houses with poor energy qualities.

In sum, our findings suggest that "market unraveling" – the central result from information economics according to which voluntary disclosure regimes may be sufficient to overcome information asymmetries – is only of limited empirical relevance for the German housing market. Instead, to address information asymmetries with respect to the thermal quality of houses, our study underlines the power of mandatory disclosure rules. This is particularly important from a policy perspective, as, ultimately, house buyers may benefit from mandating disclosure through higher market transparency and lower prices.

Appendix A Derivation of Model Results

A.1 Derivation of Equilibrium Strategies

In this section, we solve the disclosure game presented in Section 2 for its χ-cursed equilibrium. The equilibrium strategy of the seller is denoted by $\sigma_s^*(v) = (DISC(v)^*, P_D^*, P_{ND}^*)$, where $DISC(v)^*$ represents the decision to either disclose (D) or to not disclose (ND) and P_j^*, $j \in \{D, ND\}$, corresponds to the decision of setting the offer price, after having disclosed (P_D^*) or not disclosed (P_{ND}^*). Furthermore, the strategy of the buyer is given by $\sigma_b^* = (BUY_D^*, BUY_{ND}^*)$, where $BUY_j^* \in \{A, R\}$, that is, buyers can either accept (A) or reject the offer price (R).

We first focus on the subgame that follows the decision of the seller to disclose. In this subgame, quality information is revealed. Accordingly, the buyer acts under perfect information and his best response to a seller's price offer P_D^* is:

$$BUY_D^* = \begin{cases} A & \text{if } v \geq P_D^* \\ R & \text{if } v < P_D^*. \end{cases}$$

Anticipating this, the profit maximizing strategy of the seller implies $P_D^* = v$ and profits of the seller correspond to v.

Next, we consider the subgame that follows the decision of the seller not to disclose. In this situation, quality information is private, so that a buyer has to form beliefs over the quality. Following Eyster and Rabin (2005), we assume that the belief of the buyer over qualities, given the seller's actions a_s and equilibrium strategy σ_s^*, $\widehat{prob}(v_j|a_s, \sigma_s^*)$, is of the form:

$$\widehat{prob}(v_j|a_s, \sigma_s^*) = \left((1-\chi) \frac{\sigma_s^*(a_s|v_j)}{\sum_{v_j \in V_j} prob(v_j)\sigma_s^*(a_s|v_j)} + \chi \right) prob(v_j),$$

where χ denotes the degree of naivety of the buyer, v_j represents one of J non-overlapping intervals on the unit interval $[0, 1]$ with $\sum_{j=1}^{J} prob(v_j) = 1$ and $prob(v_j)$ corresponds to the probability that v falls into the interval v_j. In our setting, we focus on the two intervals $[0, v^*)$ and $[v^*, 1]$, where v^* is a constant cutoff value for disclosure that occurs if $v \geq v^*$.

Accordingly, the belief of the buyer that $v \geq v^*$, given that the seller acts according to the equilibrium strategy σ_s^*, is:

$$\begin{aligned}
&\widehat{prob}(v \geq v^*|a_s = ND, \sigma_s^*) \\
&\quad = \left((1-\chi) \frac{\sigma_s^*(ND|v \geq v^*)}{prob(v \geq v^*)\sigma_s^*(ND|v \geq v^*) + prob(v < v^*)\sigma_s^*(ND|v < v^*)} + \chi \right) prob(v \geq v^*) \\
&\quad = \left((1-\chi) \frac{0}{(1-v^*)0 + v^*1} + \chi \right) (1-v^*) \\
&\quad = \chi(1-v^*).
\end{aligned}$$

Similarly, we obtain for $v < v^*$:

$$\begin{aligned}
&\widehat{prob}(v < v^*|a_s = ND, \sigma_s^*) \\
&\quad = \left((1-\chi) \frac{\sigma_s^*(ND|v < v*)}{prob(v \geq v^*)\sigma_s^*(ND|v \geq v^*) + prob(v < v^*)\sigma_s^*(ND|v < v^*)} + \chi \right) prob(v < v^*) \\
&\quad = \left((1-\chi) \frac{1}{(1-v^*)0 + v^*1} + \chi \right) v^* \\
&\quad = (1-\chi) + \chi v^*.
\end{aligned}$$

At the last decision node, the buyer decides under uncertainty and maximizes expected utility. Given the beliefs over the type of the seller, the buyer accepts the offer as long as the buyer's expected utility is larger than zero. In our case this condition reads:

$$\begin{aligned}
E\left(u_b(\sigma_s^*(v), BUY_{ND} = R)\right) \leq & E\left(u_b(\sigma_s^*(v), BUY_{ND} = A)\right) \\
\Leftrightarrow \quad 0 \leq & \widehat{prob}(v < v^*|a_s = ND, \sigma_s^*) E(v - P_{ND}^*|v < v^*) \\
& + \widehat{prob}(v \geq v^*|a_s = ND, \sigma_s^*) E(v - P_{ND}^*|v \geq v^*), \qquad (4)
\end{aligned}$$

where $u_b(\cdot)$ denotes the buyer's utility function. By inserting the beliefs of the buyers from above and taking advantage of closed form solutions for the truncated means of a random variable that is uniformly distributed on the unit interval, $E(v|v < v^*) = v^*/2$ and $E(v|v \geq v^*) = (1+v^*)/2$, Inequality 4 can be rearranged as follows:

$$\frac{\chi}{2} + \frac{(1-\chi)v^*}{2} \geq P_{ND}^*.$$

Accordingly, the best response to a price offer $P_{s,ND}^*$ is:

$$BUY_{ND}^* = \begin{cases} A & \text{if } \frac{\chi}{2} + \frac{(1-\chi)v^*}{2} \geq P_{ND}^* \\ R & \text{if } \frac{\chi}{2} + \frac{(1-\chi)v^*}{2} < P_{ND}^*. \end{cases}$$

Anticipating this, the seller adopts the following pricing strategy:

$$P^*_{ND} = \frac{\chi}{2} + \frac{(1-\chi)v^*}{2}.$$

Having solved the two subgames for their unique sequential (Bayesian) Nash Equilibrium allows to consider the decision of the seller at her first decision node. Anticipating the utility levels that are implied by equilibrium strategies, the seller's strategy implies the following decision rule on disclosure:

$$DISC(v)^* = \begin{cases} D & \text{if } v \geq \frac{\chi}{2} + \frac{(1-\chi)v^*}{2} - \pi s \\ ND & \text{if } v < \frac{\chi}{2} + \frac{(1-\chi)v^*}{2} - \pi s. \end{cases}$$

Accordingly, the seller discloses the quality a house with a quality weakly above a certain cutoff value v^*, which is determined by $v^* = \frac{\chi}{2} + \frac{(1-\chi)v^*}{2} - \pi s$, and, hence:

$$v^* = \frac{\chi - 2\pi s}{1+\chi}.$$

A.2 Derivation of Price Effect for Policy Compliers

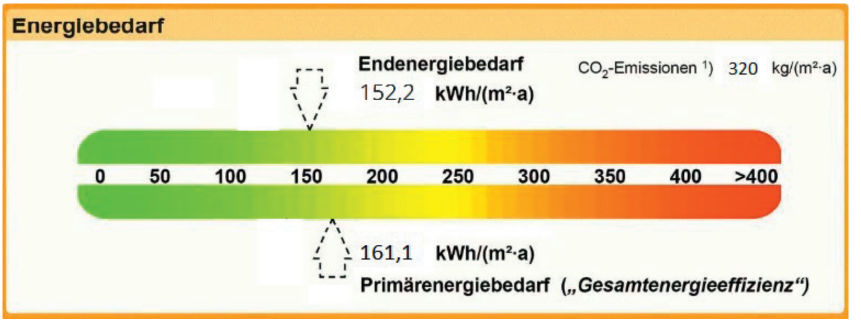
We claim that in equilibrium, policy compliers decrease prices after disclosing, i.e. $P^*_{ND,1} \geq P^*_{D,2} \; \forall \; v \in [v^*_2, v^*_1]$, where the subscripts 1 and 2 mark equilibrium prices or threshold values prior to and after the policy, respectively. Because disclosure always leads to prices that equal quality v, i.e. $P^*_{D,1} = P^*_{D,2} = v$, the inequality $P^*_{ND,1} \geq P^*_{D,2}$ is equivalent to $\bar{v}_1 \geq v$.

To show that $\bar{v}_1 \geq v \; \forall \; v \in [v^*_2, v^*_1]$, it is sufficient to prove that $\bar{v}_1 \geq v$ for the highest value of v, which is given by $v = v^*_1$. Substituting v^*_1 for v and v^* in $\bar{v}_1 \geq v$ yieds: $((1-\chi)(\chi - 2\pi s))/(2(1+\chi)) \geq (\chi - 2\pi s)/(1+\chi)$, where πs constitute the costs of non-compliance prior to the policy change. Rearranging gives $\pi s \geq 0$, which is true with certainty as both sanctions s and detection probabilities π are non-negative.

Appendix B Institutional Background of EPCs

In 2002, energy performance certificates (EPCs) were introduced in Germany, with the goal to mitigate asymmetric information between sellers and buyers of a house by providing a standardized measure for its energy quality. The central element of an EPC is a continuous

Figure 6: Example for the Element of an Energy Performance Certificate Presenting the Energy Use for Heating Purposes (in kWh/m^2a)



energy consumption value that gives the amount of heating energy in kWh per square meter and year (Figure 6). Furthermore, the certificate summarizes information on the construction year of a house, its heating system and main fuel type. Information on the energy consumption of houses is economically important: a one standard deviation change by 85 kWh/m^2a implies additional (undiscounted) heating cost of around 19,000 or 27,000 EUR over 30 years, given today's energy prices for oil and gas, respectively.

EPCs can be issued by a wide range of professions, including craftsmen and construction engineers, after some basic training. For newly built houses, energy comsumptions are determined based on engineering calculations, while for existing houses, they can be also calculated based on heating bills for the three preceeding years. In the latter case, EPCs cost around 75 EUR. An EPC based on engineering calculations is more expensive, about 400 EUR, but still a small share of the overall cost of a house.

Prior to May 2014, the German legislation just implied the weak obligation "to make available an EPC [...] as soon as a potential buyer asks for it" (EnEV, 2007) – an obligation that could neither be tracked nor enforced. Furthermore, even after completion of the selling process, the EPC did not have to be handed over to a buyer, which allowed sellers to completely withhold the information without fear of sanctions.

As of May 1, 2014, Germany's legislation has substantially strengthened the disclosure rules, obliging sellers to disclose a building's energy consumption per square meter in real estate advertisements and to always present the EPC to potential buyers, not just on demand. This change has allowed sellers to identify non-compliant competitors and to sue them for unfair competition, requiring non-compliant sellers to disclose the information and to pay all legal expenses. Furthermore, authorities can impose heavy fines for non-compliance, ranging up to 15 thousand euros as of May, 2015 (EnEV, 2014).

Appendix C Data Preparation

Our dataset originates from Immobilienscout24, the largest German online real-estate platform. The dataset comprises all houses that have been offered for sale between January 2013 and October 2015. We identify houses using their geocoordinates and drop all cases where this information is missing (283,543 observations) or not unique (163,537 observations), leaving us with a sample of 630,537 distinct houses.

Owing to our focus on used houses, we remove all houses that are sold by construction companies (84,004 observations) or that have not been completed at the time of posting the ad (18,604 observations). We also exclude particular houses such as castles, farm houses, mansions, holiday homes and historical monuments (57,967 observations). Furthermore, we do not consider houses with 10 or more bedrooms or bathrooms, 30 or more rooms, more than 5 stories (5,615 observations) or houses that are classified as uninhabitable (8,220 observations).

Moreover, we delete all observations that have missing values for one of the following characteristics: lot size, living space, number of rooms, year of construction and zip code (82,597 observations). Furthermore, we remove outliers that fall into the top or bottom 1% of either living space, lot size, the purchasing price or the annual energy consumption (25,745 observations).

As a result, we are left with 350,749 observations on used houses that form the basis for our analyses. To investigate disclosure decisions, we focus on ad characteristics prior to ad withdrawal. As we can observe ad withdrawals only for observations that end prior to the last month in our dataset (October 2016), we do not consider ads in this month (37,850 observations), so that the analysis of disclosure decisions is based on 312,899 observations. When we analyze the within variation of offer prices, we focus on houses of sellers with content management systems that have at least once updated their ad (65,486 houses), irrespective of whether the ad has been withdrawn by October 2016.

Appendix D Comparison of Sellers With and Without Content Management Systems

In this section, we investigate whether houses from sellers with a content management system (CMS) in the panel dataset are systematically different from those we observe only once. Content management systems facilitate the process of putting ads online and track all changes that occur when sellers change prices or disclose energy information, enabling us to analyze price adjustments in response to disclosure.

Table 5: Differences in Characteristics, by Availability of a Content Management System (CMS)

	Sellers with CMS			Sellers without CMS			
	Mean	**Std. Dev.**	**Numb. of Obs.**	**Mean**	**Std. Dev.**	**Numb. of Obs.**	**Norm. diff.**
Price, in 1,000 EUR	251.2	161.9	65,486	250.0	150.7	285,263	0.8
Duration, in months	7.2	5.9	65,486	5.9	8.8	285,263	17.4
Living space, in m^2	172.1	72.4	65,486	164.1	68.3	285,263	11.4
Lot size, in m^2	784.2	663.0	65,486	738.5	616.5	285,263	7.1
# of rooms	6.2	2.6	65,486	6.1	2.5	285,263	2.8
Years since construction	48.3	29.9	65,486	46.9	28.6	285,263	5.1
Years since last modernization	8.8	8.7	12,285	8.9	9.1	75,089	-1.1
House category:							
Multi-family house	0.16	0.37	51,440	0.15	0.36	259,322	4.0
One-family house	0.58	0.49	51,440	0.56	0.50	259,322	5.0
Row house	0.25	0.44	51,440	0.29	0.46	259,322	-8.8
Self-rated house condition:							
Basic	0.10	0.30	19,813	0.11	0.31	108,181	-1.6
Normal	0.52	0.50	19,813	0.52	0.50	108,181	-0.1
Superior	0.38	0.49	19,813	0.38	0.48	108,181	1.1
In need for renovation:							
Yes	0.16	0.37	37,983	0.18	0.38	190,315	-3.3
No	0.84	0.37	37,983	0.82	0.38	190,315	3.3
Heating system:							
Central	0.92	0.26	40,005	0.92	0.27	191,846	1.1
Floor	0.04	0.20	40,005	0.04	0.20	191,846	-0.7
Oven	0.03	0.18	40,005	0.04	0.19	191,846	-0.8
Seller type:							
Banks	0.18	0.38	65,486	0.30	0.46	285,263	-29.2
Estate agents	0.82	0.38	65,486	0.59	0.49	285,263	51.7
Private	0.00	0.00	65,486	0.10	0.31	285,263	-48.3
EPC disclosed	0.33	0.47	65,486	0.37	0.48	285,263	-9.8
Annual energy cons. in kWh/m^2	168.8	80.8	21,307	173.7	84.2	106,127	-5.8
Regional characteristics at the zip code level							
Population density in persons/km^2	725.9	1,049.8	65,186	735.5	1,058.2	283,773	-0.9
Purchasing power in 1,000 EUR	21.3	3.2	65,186	21.4	3.0	283,773	-0.9
Percentage of retirees	0.21	0.03	65,186	0.21	0.03	283,773	1.7
Percentage of foreign household heads	0.06	0.04	65,186	0.06	0.04	283,773	-2.2

Note: Regional characteristics are drawn from microm (2015a), microm (2015b) and microm (2015c).

As Table 5 illustrates, the houses sold by sellers who use a CMS are very similar to those who do not for a wide range of characteristics, such as offer prices, the number of rooms, the age of the house, the number years since last modernization, the house category, the self-rated house condition and the heating system. Furthermore, regional characteristics at a zip code level, such as the population density, the average purchasing power, the percentage of retirees and the percentage of foreign household heads are very similar for both subgroups.

Reflecting the fact that private households do not use CMS, we cannot observe panel data for this seller group. Furthermore, houses with smaller living spaces and longer durations on the market are slightly more frequent for sellers without CMS. However, as these differences are rather small, we do not suspect that they pose a major challenge to the generalizability of our results.

Appendix E Comparison of Seller Types

Three seller types are active on the German housing market: banks, real estate agents and private sellers. The seller type of "banks" consists mostly of home loan banks that complement their financing activities by large real estate agencies (Table 6). On average, a bank offers 43 houses over the study period on Immobilienscout24. Typically, selling activities are bound by strict rules and the banks' compliance departments ensure law abidence by informing their estate agents about law changes.

The seller type of "estate agents" consists of smaller real estate agencies, which sell about 10 houses on average over the study period (Table 6). Agencies can vary largely in size, ranging from self-employed agents to large agencies with multiple employees. Selling processes are less regulated, compared to banks, ranging from ad-hoc procedures for small self-employed agents to more standardized procedures in large agencies. Both banks and real estate agencies recruit their employees from an integrated labor market of real estate agents. Typically, the importance of monthly fixed salaries is more pronounced for banks, while estate agencies rely more strongly on commissions. The last seller type represents private sellers, who offer their houses without support of estate agencies or banks, typially selling only their own house (Table 6).

The portfolios of houses offered by either private sellers, estate agents, or banks are quite homogeneous, with some notable differences (Table 7). For instance, houses offered by banks are cheaper, on average, than those sold by real estate banks and private sellers, they are more likely to be situated in regions with slightly lower population densities and average per-capita incomes, have less living space and somewhat worse energy efficiency ratings. Private sellers tend to sell row-houses more often than banks and real estate agents, and the houses offered are on average a few years younger compared to both estate agents and banks and energy efficiency ratings of the houses seem to be slightly better. In general, however, differences between the seller types are rather small and all lie below 33% in terms of normalized differences, i.e. differences in means, normalized by the average standard deviation.

Table 6: Number of Sales on Immobilienscout24 in 2013 and 2015 across Seller Types.

	Banks	Estate Agents	Private Sellers
Number of objects	97,695	223,300	29,754
Number of sellers	2,290	21,926	28,868
Average number of sales	42.7	10.2	1.0
Std. Dev.	110.6	82.7	0.3
p10	1	1	1
p90	106	22	1

Table 7: Differences in Characteristics, by Seller Type.

	Banks	Estate Agents	Private Sellers	Banks - Agents	Agents - Private
	Mean	**Mean**	**Mean**	**Normalized Difference**	
Price, in 1,000 EUR	214.4	262.5	275.5	-33.0	-8.6
Duration, in months	5.8	6.5	4.9	-9.6	19.6
Living space, in m^2	156.7	170.0	162.0	-19.5	11.9
Lot size, in m^2	755.8	753.6	668.7	0.4	14.2
# of rooms	5.9	6.2	6.3	-9.1	-4.8
Years since construction	49.9	46.7	41.4	11.3	18.6
Years since last modernization	11.2	8.7	7.1	26.6	18.2
House category:					
Multi-family house	0.17	0.15	0.11	4.4	12.9
One-family house	0.57	0.56	0.51	2.8	10.5
Row house	0.26	0.29	0.38	-6.7	-20.
Self-rated house condition:					
hspace0.5cm Basic	0.16	0.11	0.06	14.5	17.0
Normal	0.59	0.52	0.46	12.9	11.9
Superior	0.25	0.37	0.47	-24.6	-21.
In need for renovation:					
Yes	0.22	0.17	0.11	14.1	15.4
No	0.78	0.83	0.89	-14.1	-15.
Heating system:					
Central	0.92	0.92	0.93	-1.8	-3.7
Floor	0.03	0.05	0.04	-6.0	1.9
Oven	0.05	0.03	0.03	8.6	3.4
EPC disclosed	0.45	0.34	0.24	22.3	21.8
Annual energy cons. in kWh/m^2	190.1	165.8	142.2	28.8	30.6
Regional characteristics at the zip code level					
Population density in persons/km^2	582.5	791.1	801.5	-20.8	-1.0
Purchasing power in 1,000 EUR	20.9	21.5	21.7	-19.3	-6.1
Percentage of retirees	0.21	0.21	0.21	-0.6	5.6
Percentage of foreign household heads	0.06	0.06	0.07	-12.8	-5.5
Number of observations	97,695	223,300	29,754		

Notes: Normalized differences equal the differences in means, normalized by the average of the standard deviation in the two sub-samples. Regional characteristics are drawn from microm (2015a), microm (2015b) and microm (2015c).

Appendix F Comprehensive Estimation Results for Hedonic Model

Table 8: OLS Regression Results for the Hedonic Model of the Effect of Energy Consumption Disclosure on Offer Prices

		Coeff. s	Std. Errors
EPC		.052**	.0014
Year of construction	1977-2002	.25**	.0013
(base category: Pre 1930)	2002-2015	.37**	.0021
Year of modernization	1977-2001	.065**	.0086
(base category: Pre 1977)	2002-2015	.11**	.0084
	n.a.	.08**	.0083
Self-rated house condition	Normal	-.11**	.002
(base category: Superior)	Basic	-.22**	.0034
	n.a.	-.092**	.0019
Need for modernization	Yes	-.27**	.002
(base category: No)	n.a.	-.12**	.0014
Heating type	Floor heating	-.065**	.0035
(base category: Central heating)	Oven	-.21**	.0037
	n.a.	-.025**	.0013
Seller type	Banks	-.068**	.0023
(base category: Private sellers)	Agents	-.046**	.002
House category	Multi-family house	.0025	.0023
(base category: Row house)	One-family house	.094**	.0015
	n.a.	-.019**	.0021
Further house characteristics	Lot size, in m^2	.00034**	2.5e-06
	Lot size (squared)	-5.7e-08**	6.0e-10
	Living space, in m^2	.0059**	.000035
	Living space (squared)	-6.7e-06**	7.1e-08
	% of rooms	-.0053**	.00037
Constant	Constant	11.267**	.0097
Zip code fixed-effects	✓		
Number of observations	312,899		
R^2	0.26		
F-Statistic	6794.30		

Note: ** and * denote statistical significance at the 1% and 5% level, respectively.

Appendix G Estimation Results (with Duration Dummies)

Table 9: Estimates of the Effect (=ATE, ATT, LATE) of Energy Information Disclosure on House Prices

	Hedonic Model	Panel	Panel, interacted with energy quality	Panel IV
Estimand	(=ATE)	(=ATT)	(=ATT)	(=LATE)
EPC	0.089**	-0.013**	0.002	-0.117**
Standard Errors	0.004	0.001	0.002	0.018
95% Conf. Interval	[0.082,0.096]	[-0.016,-0.011]	[0.002,0.006]	[-0.152,-0.082]
$EPC \times 1(125 \leq ES < 190)$	-	-	-0.010**	
Standard Errors	-	-	0.003	
95% Conf. Interval	-	-	[0.016,-0.004]	
$EPC \times 1(ES \geq 190)$	-	-	-0.032**	
Standard Errors	-	-	0.003	
95% Conf. Interval	-	-	[0.037,-0.026]	
House fixed effects	-	✓	✓	✓
Month fixed effects	✓	✓	✓	✓
Duration dummies	✓	✓	✓	✓
Number of house-month obs.	-	412,637	412,637	412,637
Number of houses	65,486	65,486	65,486	65,486

Note: Standard errors are in parentheses. ** denotes statistical significance at the 1% level, * at the 5% level. The regressions include 18 dummies that capture the duration in months that ad i is available on the online platform (durations larger than 17 months are jointly captured by one dummy variable).

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