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INCENTIVES FOR INFORMATION PROVISION: ENERGY EFFICIENCY IN THE SPANISH RENTAL MARKET

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Abstract

We build a search model with asymmetric information regarding houses´ energy efficiency. The objective is to shed light on the house owners` incentives to obtain and disclose energy certificates (ECs) in the rental market. Such incentives depend not only on the rent premium for more efficient houses - as has been widely documented - but also on the rent penalty for unlabeled houses. Interestingly, we show that such a penalty is higher the greater the disclosure rate of ECs. The theoretical predictions are empirically quantified in the context of the Spanish rental market.

JEL Classification: N/A

Keywords: asymmetric information, energy efficiency, adoption rate, rental market

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Incentives for Information Provision: Energy Efficiency in the Spanish Rental Market

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March 2, 2020

Abstract

In this paper we build a search model with asymmetric information regarding houses' energy efficiency. The objective is to shed light on the house owners' incentives to disclose energy certificates (ECs) in the rental market. Such incentives depend not only on the rent premium for more efficient houses - as previously documented - but also on the implicit rent penalty for unlabeled houses. Interestingly, we show that such a penalty is higher the greater the disclosure rate of ECs in the local market. This suggests that the enforcement of the EC regulation should be more stringent during the early phases, as the boost in the initial disclosure rate would strengthen the incentives for later adoption. We illustrate the theoretical predictions with empirical evidence from the Spanish rental market.

Keywords: Asymmetric information, energy efficiency, adoption rate, rental market.

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1. Introduction

Improvements in energy efficiency are expected to be key in reducing energy consumption and global carbon emissions. Yet, and despite substantial policy supports to energy efficiency programs,[1] the energy savings actually achieved lag behind expectations. This applies to a broad range of settings, including schools (Burlig et al., 2017), commercial buildings (Kok et al., 2011), or the residential sector (Fowlie et al., 2018), among others. The literature on the so-called energy-efficiency gap (Allcott and Greenstone, 2012; Gerarden et al., 2017) has highlighted imperfect information as one important reason for why agents fail to exploit profitable investments in energy efficiency.[2] For instance, in the rental market, landlords face weak incentives to invest in energy efficiency whenever lack of reliable information about the house's energy efficiency makes tenants unwilling to pay more for more efficient houses. Thus, failure to capitalize energy efficiency investment leads landlords to underinvest (Myers, 2015).

In order to address this market failure, most jurisdictions have introduced energy certificate (EC) programs that provide reliable information about the dwellings' energy efficiency. Several empirical studies have confirmed the existence of an efficiency rent premium that allows landlords to cash in the returns of their investments. This is true for the commercial building sector (Kok et al., 2011; Eichholtz et al., 2010) as well as for the residential sector (Ramos et al., 2015; Dressler and Cornago, 2017; Fuerst and Warren-Myers, 2018). Yet, despite the gains that many landlords would obtain from disclosing their ECs, disclosure rates remain low in most residential markets, even in those in which disclosure is mandatory. In this paper, we build a model that helps explain the link between the low disclosure rates of ECs and the weak incentives to obtain and disclose them. More specifically, our model combines search frictions with asymmetric information over the houses' energy efficiency to create predictions about the owners' incentives to obtain and disclose the energy certificates. The theoretical predictions are illustrated with empirical evidence from the Spanish rental market, with emphasis on two issues (i) the reasons underlying the low disclosure rates of ECs in the rental market, and (ii) the link between the initial disclosure rates and the incentives for further disclosure.

Most of the existing papers on this topic focus on the incremental rents obtained by more efficient houses relative to the less efficient ones. This type of analysis measures the landlords' incentives to improve energy efficiency *conditional on* having an EC. However, even if compulsory, landlords (i) may not be aware of the EC regulation (particularly so in the first phases of its implementation), or (ii) may have incentives to hide the EC whenever it would reveal low energy efficiency. Hence, when assessing the impact of ECs, it is important to take into account the potential selection bias that these incentives create. Fuerst and Warren-Myers (2018) show that correcting for this selection bias gives rise to an increase in the estimated efficiency premia. In their empirical analysis of the Australian residential rental market, the rental prices for the most efficient houses are, after

[1] For instance, the European Union relies on the "energy efficiency first" principle that requires all energy-related policy-making and investment decisions to prioritize energy saving solutions over any other.

[2] Other explanations include capital market imperfections, split incentive problems, and behavioral biases.

controlling for all other relevant factors, 3.5% higher as compared to a reference average rating. In contrast, houses with no EC are rented with a 1.13% penalty as compared to houses with the reference rating. Our model helps explain the factors underlying both the premium as well as the implicit penalty.

From a theoretical perspective, one needs to relax the assumption that all owners are aware of the EC regulation to obtain the coexistence of labeled and unlabeled houses (equivalently, one may assume that it is costly to obtain an EC so that some landlords decide not to obtain one before knowing what the EC would reveal). Otherwise, Milgrom (1981)'s unraveling equilibrium would prevail, resulting in full disclosure: no individual household would have incentives to hide the EC as doing so would signal that the house has the lowest energy efficiency rate in the market. However, Milgrom (1981)'s equilibrium with full disclosure breaks down whenever there is no full awareness of the EC regulation. The reason is that not displaying the EC need not necessarily signal low energy efficiency but rather lack of awareness. In turn, since this avoids full unraveling, the disclosure rate affects the incentives to display the certificates through the rent penalty faced by those who do not disclose them.

In this paper, we uncover these effects through the lens of a simple model that captures the incentives for the disclosure of energy certificates (ECs) in the rental market, including the impact on rental prices of both the labeled as well as the unlabeled houses. We combine (i) a search model for price formation under monopolistic competition, with (ii) a model of asymmetric information between landlords and tenants regarding the house's energy efficiency. Our search model builds upon the model by Armstrong et al. (2009) (AVZ thereafter), which extends the seminal work of Wolinsky (1986) to allow for differences in quality among firms. We assume monopolistic competition in the rental market since (i) there are typically many differentiated houses for rent, (ii) each house is negligible on its own, so that landlords ignore their impact on the market-level variables, and (iii) each landlord faces a downward sloping demand and hence retains significant market power. We use this model to derive predictions about the rental prices of the houses with and without ECs, shedding light on the landlords' incentives to disclose them.

First, we analyze the case of search frictions but perfect information regarding the houses' energy efficiency: all landlords are assumed to comply with the EC regulation, so that tenants can perfectly observe the energy efficiency of the houses once they visit them. We find that more energy efficient houses are rented at a premium, which is not affected by search costs nor the average energy efficiency in the housing market. Even if an increase in search costs and a reduction in the average energy efficiency of the houses in the local market increases rental prices, the energy efficiency premium remains constant because the price effects are uniform across houses.

Second, we assume that some landlords do not display the ECs because they are unaware of the EC regulation. In turn, this implies that owners with low ECs now have incentives to hide them in order to be pooled with other more efficient houses that do not have the EC simply because their owners are unaware of the EC regulation. In this case, the average efficiency of the houses in the local market affects the search process, and through this, it has an impact on the rent efficiency premium of houses with and without ECs.

Our model predicts that an exogenous increase in compliance (e.g. through increased awareness of the regulation) would trigger a reduction in the rental prices of those houses whose landlords endogenously decide not to show their ECs. In turn, this rent effect would increase the fraction of houses that disclose their ECs.

In this context, an increase in awareness is more effective in encouraging the disclosure of ECs than in standard models. Disclosure rates increase for two reasons: (i) the direct awareness effect, and (ii) as highlighted in this paper, the increase in the rent premia and implicit penalties as awareness affects the pool of houses that do not comply with the regulation. Eventually, if awareness is sufficiently high, the market unravels and all houses comply with the EC regulation. Therefore, in order to encourage energy efficiency investments through higher efficiency premia, policymakers should provide richer information about the EC regulation in the early phases, when awareness is low and the incentives for the disclosure of ECs are still weak.

We illustrate the findings of the model in the context of the Spanish housing rental market. Exploiting detailed information about the houses for rent from the commercial website Idealista, we fit modified hedonic models using Heckman's two-step method (Heckman, 1979) to deal with potential selection bias. As suggested by the theoretical model, our empirical analysis incorporates characteristics of the local housing market as these affect the incentives to disclose the ECs, as well as the prices at which labeled and unlabeled houses can be rented. We find that the most efficient houses (with A or B labels) obtain a 7% rent premium as compared to the least efficient houses (with F or G labels), while the efficiency rent premium of houses with labels C, D or E is 5%. Interestingly, we find that the rental prices for unlabeled houses significantly decrease with the disclosure of ECs in the local market. In particular, a 1% increase in the disclosure rate triggers a 6% reduction in the rental price of the labeled houses. In sum, this evidence supports our main theoretical findings regarding the interplay between rent premia and rent penalties in shaping the incentives for the disclosure of ECs.

The reminder of the paper is organized as follows. In section 2, we build and solve a search model with asymmetric information to study the incentives for the disclosure of ECs. In section 3, we provide suggestive evidence of the Spanish rental market in support of our theoretical predictions. Section 4 of the paper concludes.

2. The Model

Consider a rental market in which there is a unit mass of consumers searching for houses to rent, and infinitely many available houses. The consumers' net utility from renting a house i with rental price p_i, is given by $u_i - p_i$. The term u_i captures the consumer's idiosyncratic utility (or *match utility*) from renting the house, which is assumed to be an *i.i.d.* draw from a uniform distribution in the interval $[0, \theta]$, where the parameter θ measures the house's energy efficiency. Therefore, when θ is known, the higher the house's energy efficiency, the higher the consumer's expected utility from renting it (thus capturing the fact that higher energy efficiency implies lower energy bills). In turn, the distribution of energy efficiency θ in the population of houses is uniform in the interval $[\underline{\theta}, 1]$. Hence, the average energy efficiency of the houses in the market, denoted $\widetilde{\theta}$, is increasing in $\underline{\theta}$.

When θ is not known, all the houses are ex ante identical from the point of view of consumers (as match utilities and energy efficiencies are drawn from common distributions). However, houses are ex-post differentiated as, once the customer has visited a house, he is able to observe his realized match utility. At each visit, the consumer incurs a search cost $s > 0$. Throughout the analysis, we will assume that search costs are sufficiently low in order to guarantee that a solution always exists.

The consumer visits houses sequentially: he visits houses randomly until he decides to stop searching.[3] The consumer has the option to rent any of the houses he has visited. For simplicity, we assume that when a tenant visits a house, she is sure to be able to rent it in case she decides to do so.[4]

Landlords have to certify the energy efficiency of their houses by obtaining and disclosing their Energy Certificates (ECs). We first analyze the case in which all owners comply with this regulation, thus allowing tenants to perfectly observe the energy efficiency of the houses which they have visited. We will then consider the case in which not all owners comply with this regulation, either because they are not aware of it or because they decide not to disclose their ECs.

Equilibrium pricing when all owners comply with the EC regulation First, we assume that all houses display their ECs, allowing tenants to observe θ upon visiting a house. Let V denote the consumer's equilibrium expected value from searching in this market. The consumer optimally stops searching as soon as he finds a house that gives him utility $u - p \geq V$, where V is implicitly

[3] In online platforms, such as Idealista, the order in which houses are displayed might affect the order of search. However, from the point of view of the landlords, search can be regarded as approximately random if e.g. tenants use different settings for search/display preferences. An alternative model would be one with ordered search, in which consumers would first visit the house they anticipate would give them a higher expected utility, as in Armstrong (2017) and Armstrong and Zhou (2011). As shown by Armstrong et al. (2009), with infinitely many houses, prominence has no impact on equilibrium prices even in the case of asymmetric houses. A full understanding of the implications of ordered search in our context is nevertheless out of the scope of this paper, as it would require investigating whether landlords with higher energy certificates have stronger incentives to pay for prominence.

[4] The implicit assumption is that the landlord holds the house for the tentant during some time until he has made completed his search. However, if this assumption does not hold in reality, a given house might no longer be available once a tenant decides to come back to it after. Relaxing this assumption is out of the scope of this paper as it would highly increase the complexity of the search model.

defined so that the search cost s equals the expected gain from an additional visit,

$$s=\frac{1}{1-\underline{\theta}}\int_{\underline{\theta}}^{1}\left(\frac{1}{\theta}\int_{p+V}^{\theta}\left(u-p-V\right)du\right)d\theta. \tag{1}$$

Each landlord has a single house. He chooses the rental price p so as to maximize his expected profits, given by the rental price times the probability of renting the house, $p\Pr\left(u-p\geq V\right).$ Our first Proposition characterizes the equilibrium rental price and the equilibrium value from searching in this market.

PROPOSITION 1: *Suppose all houses display their ECs. The rental price of a house with efficiency θ is given by*

$$p\left(\theta\right)=\frac{\theta-V}{2}\cdot \tag{2}$$

For s low enough, there exists a unique equilibrium value from search V, given by

$$V=\left(\frac{1}{1-\underline{\theta}}\ln\frac{1}{\underline{\theta}}\right)^{-1}\left(1-\sqrt{1-\frac{\frac{1+\underline{\theta}}{2}-8s}{1-\underline{\theta}}\ln\frac{1}{\underline{\theta}}}\right)\cdot \tag{3}$$

Proof. See the Appendix. □

In equilibrium, rental prices (2) are increasing in θ, i.e., more energy efficient houses are rented at higher prices. More energy efficient houses are also more likely to be rented out given that tenants are more likely to stop searching when they visit a highly energy efficient house. Hence, equilibrium profits (conditionally on having a visit) are also increasing in θ,

$$\pi\left(\theta\right)=\frac{1}{\theta}\left(\frac{\theta-V}{2}\right)^{2}\cdot \tag{4}$$

The equilibrium value from searching in this market, V, is found by plugging the equilibrium price (2) into the search equation (1). Inspection of equation (3) shows that V is decreasing in the search cost s and increasing in the energy efficiency of the least efficient house, $\underline{\theta}$. The first result is intuitive: the higher the search cost, the higher are the rental prices and the less it pays to continue searching. The second result derives from the interplay of two confounding effects. On the one hand, a higher $\underline{\theta}$ means that the average energy efficiency of the houses in the market $\widetilde{\theta}$ is higher, which implies that consumers expect to obtain higher utility from search. However, a higher $\underline{\theta}$ also reflects less heterogeneity across houses, which induces consumers to search less. Since the former effect dominates, there is a positive relationship between V and $\underline{\theta}$.

The energy efficiency premium, i.e., the difference in the rental prices of two houses with energy efficiencies θ' and θ, with $\theta'>\theta$, is simply given by $\left(\theta'-\theta\right)/2>0$. Notably, the energy efficiency premium does not depend on s or $\underline{\theta}$ given that V cancels out when taking the price differences. However, through V, search costs and the distribution of θs in the market affect prices and profits. In particular, a lower s and a higher $\underline{\theta}$ lead to lower prices and profits. Intuitively, the lower the search cost and the higher the expected energy efficiency of the other houses in the market, the lower is the market power of each individual landlord.

Equilibrium pricing when not all owners comply with the EC regulation So far, we have assumed that all owners obtain and disclose their ECs. However, we know this is rarely the case in reality. Indeed, landlords might either not have an EC, or if they have one, they might have incentives to hide it. What do these incentives depend on and how does this affect the equilibrium in the rental market?

Let α measure the degree of awareness of the EC regulation. Some owners (a fraction $1-\alpha$) do not have ECs simply because they are not aware of the regulation.[5] The remaining owners (a fraction α) are aware of the regulation but some of them might decide not to disclose their ECs. In this case, if a tenant visits a house without an EC, through Bayesian updating he forms rational beliefs about the house's energy efficiency.[6]

Just as in the previous section, the consumer optimally stops searching as soon as he finds a house that gives him utility $u - p \geq V$, where V denotes the consumer's equilibrium expected value from searching. The expression that implicitly defines V is now different from (1) as the tenant only observes the θs of houses that display their ECs. Therefore, since V now depends on the landlords' disclosure decisions, we first need to characterize such optimal decisions. In turn, this requires characterizing prices and profits for houses with and without ECs, an issue which we analyze next.

For those houses with an EC, since the tenant observes the true value of θ, prices are as in Proposition 1.[7] For the houses without an EC, the tenant does not observe the true value of θ but expects it to be equal to the average efficiency of the houses without an EC, denoted $\widehat{\theta}$. Hence, rental prices for houses without an EC are as in Proposition 1, with θ replaced by $\widehat{\theta}$.

In order to find the value of $\widehat{\theta}$, we need to characterize the optimal disclosure decisions of the ECs. In line with Grossman and Hart (1980) and Jovanovic (1982), if the EC reveals that the house's energy efficiency is low $\theta < \widehat{\theta}$, the landlord is better off not showing it and making tenants believe that the house's energy efficiency is equal to the one expected for the houses without EC, $\widehat{\theta}$. This follows from the fact that equilibrium profits (4) are increasing in θ. Accordingly, $\widehat{\theta}$ is implicitly defined by

$$\widehat{\theta} = \alpha \int_{\underline{\theta}}^{\widehat{\theta}} \frac{\theta}{1-\underline{\theta}} d\theta + (1-\alpha)\, \widetilde{\theta}. \tag{5}$$

The first term of the above equation reflects the expected efficiency of the houses with an EC (a fraction α of all houses) whose owners optimally decided to hide it (those with $\theta < \widehat{\theta}$). The second term reflects the expected efficiency of the houses without an EC (a fraction $1-\alpha$), i.e.,

[5] An equivalent interpretation would be that a fraction α of the landlords find it costless to obtain the EC, while the other fraction find it prohibitly costly to obtain one (e.g. the opportunity costs of devoting time to complete the EC paperwork is very high).

[6] Frondel et al. (2017)'s model assumes that a fraction of consumers are naive, i.e., they believe that the energy efficiency of the houses without an EC is equal to the population average.

[7] Note, however, that the endogenous value of V need not be the same as in the previous section.

the population average $\widetilde{\theta}$. Clearly, if an interior solution exists, $\widehat{\theta}$ must be below $\widetilde{\theta}$ because of the selection bias among the houses without the EC. If no interior solution exists, the corner solution $\widehat{\theta} = \underline{\theta}$ applies. The following Lemma characterizes the equilibrium value of $\widehat{\theta}$.

LEMMA 1: *(i) If* $\alpha \geq \frac{1-\underline{\theta}}{1+\underline{\theta}}$, $\widehat{\theta} = \underline{\theta}$. *(ii) If* $\alpha \in \left(0, \frac{1-\underline{\theta}}{1+\underline{\theta}}\right)$, *there exists a unique* $\widehat{\theta} \in \left(\underline{\theta}, \widetilde{\theta}\right)$. *The solution is strictly decreasing in* α *and increasing in* $\underline{\theta}$.

Proof. See the Appendix. □

If sufficiently many landlords are aware of the EC regulation, the houses without ECs are mostly owned by owners who decide to hide them. Hence, $\widehat{\theta}$ is so low that it does not pay to hide the EC, i.e., there is market unravelling. Otherwise, for lower values of α, the solution is interior, with $\widehat{\theta}$ decreasing in α in the interval $\left(\underline{\theta}, \widetilde{\theta}\right)$. On one extreme, when only an infinitesimally small fraction of landlords are aware of the EC regulation, $\widehat{\theta}$ tends to the population average $\widetilde{\theta}$. On the other extreme, when α is close to $(1-\underline{\theta}) / (1+\underline{\theta})$, there is almost full market unravelling. In turn, the interior solution for $\widehat{\theta}$ is increasing in $\underline{\theta}$. Intuitively, the average house that is pooled with the non-labeled houses has higher efficiency the higher $\underline{\theta}$.

Using the equilibrium price in Proposition 1, the difference in rental prices of two houses with and without EC, is given by $\left(\theta - \widehat{\theta}\right)/2 > 0$. It follows that the houses with ECs are rented at a premium, which is larger the higher θ and the lower $\widehat{\theta}$. Since $\widehat{\theta}$ is decreasing in α (Lemma 1), it follows that the efficiency rent premium is larger in markets where a greater fraction of landlords are aware of the EC regulation. Similarly, since $\widehat{\theta}$ is increasing in $\underline{\theta}$ (Lemma 1), the efficiency rent premium is larger in markets with low $\underline{\theta}$ (and hence a low average efficiency, $\widetilde{\theta}$).

It only remains to characterize V, which we have so far taken as given. As before, V is implicitly defined so that the search cost s equals the expected gain from an additional visit. The latter is now decomposed in two terms: the expected gain from visiting a house with or without an EC, times the probability of each event. If the house displays the EC, which occurs when the landlord is aware of the EC regulation and the house has high efficiency $\theta > \widehat{\theta}$, the expected gain from search is similar to (1), but the distribution of the θs is truncated at $\widehat{\theta}$ from below. If the house does not display the EC, the expected gain from an additional visit is similar to (1) but θ is now replaced by $\widehat{\theta}$. This event occurs when the owner is not aware of the regulation or when he is but decides to hide the EC. Formally, the condition that determines the tenant's optimal search is given by

$$\begin{aligned} s &= \frac{\alpha}{1-\underline{\theta}} \int_{\widehat{\theta}}^{1} \left(\frac{1}{\theta} \int_{p(\theta)+V}^{\theta} \left(u - p(\theta) - V\right) du \right) d\theta \\ &\quad + \left[(1-\alpha) + \alpha \frac{\widehat{\theta} - \underline{\theta}}{1-\underline{\theta}} \right] \left[\frac{1}{\widehat{\theta}} \int_{p(\widehat{\theta})+V}^{\widehat{\theta}} \left(u - p\left(\widehat{\theta}\right) - V \right) du \right], \end{aligned} \tag{6}$$

where the endogenous objects, $p(\theta)$ and $\widehat{\theta}$, have been defined in Proposition 1 and Lemma 1, respectively.

The RHS of equation (6) is decreasing in V. Hence, the equilibrium value from search, V, is decreasing in s. It follows that rental prices and profits are higher in markets with higher search costs. However, just as before, this does not affect the rent premium as V cancels out when taking the price differences across houses with and without ECs.

The above results are summarized in our next Proposition.[8]

PROPOSITION 2: *Among the owners who are aware of the EC regulation, only those with* $\theta > \widehat{\theta}$ *display the EC. The rental price of houses with and without EC is* $p(\theta)$ *and* $p\left(\widehat{\theta}\right)$, *where prices are defined in Proposition 1 and* $\widehat{\theta}$ *is defined in Lemma 1. If* s *is sufficiently low, there exists a unique solution to (6) which is decreasing in* s.

Proof. See the Appendix. □

Empirically, it is not possible to test the predicted negative correlation between the rent premium and the average energy efficiency of the houses without the EC (the latter is non-observable). However, the fraction of houses in the market which disclose their ECs provides a good proxy for $\widehat{\theta}$. In particular, the *observed* disclosure rate of ECs can be expressed as

$$A = \alpha \frac{1-\widehat{\theta}}{1-\underline{\theta}}, \tag{7}$$

as only a fraction α of houses obtain ECs and, among these, only a fraction $(1-\widehat{\theta})/(1-\underline{\theta})$ disclose them. Since this expression is decreasing in $\widehat{\theta}$, and the rent efficiency premium is also decreasing in $\widehat{\theta}$, we predict a positive correlation between the *observed* disclosure rates of ECs and the efficiency rent premium. The *observed* disclosure rate A is more informative about the average energy efficiency of the houses without EC in markets where the average energy efficiency (as proxied by $\underline{\theta}$) is higher.[9]

It follows that a boost in disclosure (e.g. triggered by an increase in overall awareness of the EC regulation) would imply a stronger implicit penalty for the houses that hide their ECs. The resulting increase in compliance would further strengthen the incentives for disclosure, giving rise to a virtuous circle as the unlabeled houses are increasingly penalized with lower rents. Hence, the regulatory enforcement should be more stringent when and where disclosure rates are low and hence the incentives for information provision are still weak.

To summarize our testable predictions, more efficient houses are rented at higher prices than less efficient houses, and houses with an EC obtain a premium over houses without. An increase in search costs and a reduction in the average energy efficiency in the housing market lead to higher

[8] It is possible to include an expected penalty for non-compliance, ρF, where F denotes the fine and ρ the probably of being detected. The critical value of θ below which landlords would hide the EC is lower than $\widehat{\theta}$. Intuitively, a landlord is willing to give up some rent instead of facing the fine. In turn, this would reduce the expected energy efficiency of the houses without EC, contributing to unravelling and increasing the rent premium of the houses with EC. Hence, the effects of increasing the expected fine would go beyond the pure cost related effects.

[9] This result in is line with Frondel et al. (2017)'s prediction and empirical findings regarding the effects of moving from a regime of voluntary disclosure to a mandatory one.

rental prices and higher expected profits. However, since these effects are uniform across houses, the energy efficiency premium is not affected by search costs nor the average energy efficiency. In markets with higher observed disclosure rates of ECs, the rent premium of the houses with ECs is relatively higher. This effect is more pronounced the higher the observed energy efficiency.

In the next section we explore these testable implications in the context of the Spanish housing rental market.

3. Empirical Analysis

To promote investments in energy efficiency, the European Parliament has made it mandatory that all buildings disclose information on their energy efficiency (Directive 2002/91/EC). This has given rise to the Energy Performance Certificate (EPC), which assesses heating systems, ventilation and insulation quality, among others, with a common standard across all member states: houses and buildings are certified with an index that ranges from A to G according to the dwellings' energy efficiency.[10] Landlords who do not comply with these standards are subject to fines.[11]

In this paper we use data from the Spanish rental market to empirically illustrate our previous theoretical findings. We first describe the data, and then provide evidence regarding the existence and determinants of an energy efficiency premium and an energy efficiency penalty. As discussed at the end of the section, the empirical exercise has some limitations, mainly due to the fact that it exploits cross-sectional variation across a limited number of medium-sized Spanish cities.

3.1. Data

We have downloaded cross sectional data of rental advertisements from the main Spanish commercial housing website (Idealista) during April 2016. Being the most popular real estate website in Spain, Idealista has the largest number of advertisements and website visits in this field.[12] It is thus reasonable to believe that our data sample does not suffer from selection bias. The advertisements available on Idealista provide us information about the dwellings' rental price, their location, their advertisement type, their characteristics, and their EC ratings (if they have one). According to the theoretical model presented in the previous section, the disclosure rate of ECs and the distribution of energy efficiency of the houses in a local market affect the rent premium. To obtain the variation of these determinants, we focus on eight relatively small Spanish cities with an average of 100,000 inhabitants each. These cities are treated as eight separate markets. Our sample consists of 8,009 ads that are spread across these cities.

[10] Spain adhered to this certification procedure in June, 2013 (BOE, 2013).

[11] The fines for hiding an EC are as follows. Minor infringements receive a fine of 300-600 Euro. These include: publicize the sale or rental of a building without mentioning the energy rating obtained, or failure to display the energy efficiency label in cases resulting mandatory. Serious infringements receive a fine of 601-1000 Euro. These include the sale or rental of a property without giving the buyer or lessee EC registered.

[12] For instance, a recent study of the rental market by the Bank of Spain also relies on Idealista data, arguing that it is "the website with the largest coverage of the rental market for the whole of Spain". See Banco de España (2019).

The disclosure rate of ECs in each city is computed as the percentage of houses in the city that display the EC information online. To calculate the mean and variance of the EC ratings within each city, we have assigned numbers from 7 to 1 to the ratings A to G, with higher values indicating more energy efficient houses. The summary statistics of ECs are shown in Table 1. With only 1,506 out of 8,009 ads including EC information, the mean disclosure rate is 19%.[13] Pamplona has the highest disclosure rate, 47%, and Cádiz has the lowest, 13%. The average EC rating (denoted as $AverageLabel$) is 4.35, i.e., dwellings with a C or D label on average. According to our data, the variance of ECs (denoted as $VarianceLabel$) ranges from 3.30 to 5.52. The mean and variance help us characterize the distribution of ECs in each local market. The annual income per capita in each city is also shown in Table 1.

Furthermore, we have constructed the variable $GreenVote$ to capture the green ideological heterogeneity of the homeowners in each city.[14] We have measured this variable as the fraction of votes for the green parties in the Spanish 2016 General Election. This fraction has remained fairly stable across time, i.e., using data for the Spanish elections in 2015, 2016 and 2019, the mean of $GreenVote$ is 1.335% and the average variance is only 0.028%.[15] As it will be later explained, we will use this variable as a determinant of the decision to obtain and disclose energy certificates.

Table 1 City Characteristics

	Total	Cadiz	Jaen	Pamplona	Soria	Huesca	Oviedo	Salamanca	Valladolid
No. of Observations	8,009	3,536	614	540	173	470	963	1,186	527
Adoption Rate	19%	13%	18%	47%	14%	17%	23%	20%	23%
AverageLabel	4.35	4.62	4.71	3.30	5.52	4.79	3.75	4.12	4.08
VarianceLabel	3.85	5.02	5.02	0.90	3.08	2.85	3.90	3.17	3.04
Income per Capita (Euro)	25,923	25,994	23,999	29,807	24,498	25,088	27,339	24,462	25,624
GreenVote	1.91%	2.88%	1.59%	1.07%	0.81%	1.16%	1.30%	0.95%	0.92%

Table 2 provides descriptive statistics of the ads on the labeled and non-labeled samples. Relative to the unlabeled dwellings, the rental prices of the labeled dwellings are slightly higher on average. Also, the labeled houses are smaller in size and tend to be in a better condition on average relative to those houses without certificates. The percentage of houses needing renovation is higher among the unlabeled houses.

As shown in Table 3, one fifth of the 1,506 houses with EC information are very energy efficient (A label), while 10.82% of them are very energy inefficient (G label). In our empirical analysis, we have divided labels into three groups: the most efficient group (A or B), the group with average energy efficiency (C, D or E) and the inefficient group (F or G).

[13] This number is in line with those reported in other studies. In Holland, the adoption rate is even lower 17% (Brounen and Kok, 2011).

[14] See also Brounen and Kok (2011) and Dressler and Cornago (2017), who use the same approach.

[15] We have considered "Recortes Cero-Grupo Verde" and "Pacma" as the green parties. We have also performed the estimation with different definitions for green party (e.g., also including "Unidos Podemos", or only including "Recortes Cero-Grupo Verde"), and results are very robust. Recortes Cero-Grupo Verde is the Spanish green party, Pacma is a party that defends animals' rights, and Unidos Podemos is a left-wing party.

Table 2 Descriptive Statistics: Houses

	All Dwellings		Labeled Dwellings		Non-labeled Dwellings	
	Mean	St.Dev	Mean	St.Dev	Mean	St.Dev
Adoption rate	0.19	0.09				
Price (Euro/square meter)	6.81	4.69	6.83	4.47	6.80	4.73
Size (square meters)	104.93	137.03	98.36	61.14	106.46	149.16
Bedrooms	2.64	1.20	2.62	1.22	2.65	1.19
WC	1.60	0.78	1.57	0.71	1.61	0.79
Storeroom	0.21	0.40	0.23	0.42	0.20	0.40
Fitted wardrobe	0.57	0.50	0.58	0.49	0.56	0.50
Parking	0.33	0.47	0.31	0.46	0.33	0.47
Lift	0.59	0.49	0.71	0.45	0.56	0.50
Second hand/good condition	0.96	0.18	0.98	0.15	0.96	0.19
Second hand/needs renovating	0.005	0.07	0.003	0.05	0.006	0.08
Fully furnished/Equipped	0.59	0.49	0.63	0.48	0.57	0.49
Fully furnished/Unequipped	0.09	0.29	0.10	0.30	0.09	0.28
Unfurnished	0.04	0.20	0.04	0.20	0.04	0.20
Lift	0.59	0.49	0.71	0.45	0.56	0.50
Advertisement Type						
Private	0.49	0.50	0.52	0.50	0.48	0.50

Table 3 Descriptive Statistics: ECs

	Total	A	B	C	D	E	F	G	Not available
Sample Size	1506	315	76	123	233	386	70	146	157
Percentage		20.91%	5.04%	8.16%	15.47%	25.63%	4.64%	10.82%	10.42%

3.2. Is there an energy efficiency premium?

According to our theory model, we expect that more energy efficient homes charge a positive energy efficiency rent premium. To measure it in the context of the Spanish rental market, we use a hedonic model, according to which a product is decomposed into its attributes, with the price of a product being a function of such attributes (Rosen, 1974). Our basic hedonic regression takes the following form:

$$log(price/m_i^2) = \beta_0 + \beta_1 Label_i + \beta_k X_i + \Lambda_n + \epsilon_i \quad (8)$$

where the dependent variable, $log(price/m^2)$, is the natural logarithm of the rental price per square meter of dwelling i. $Label_i$ includes two dummy variables, which capture the houses' energy efficiency levels. We divide them into three groups: the dummy $A+B$ equals one for houses with the most efficient labels A and B, and it equals zero otherwise; the dummy $C+D+E$ equals one for houses labeled as C, D, or E. The estimated coefficients for $A+B$ and $C+D+E$ thus measure the energy efficiency premium as compared to the most inefficient houses, labeled as E or F. X_i is a vector of dwelling's characteristics, including size, number of bedrooms, and the house condition, among others.[16] Additionally, Λ_n represents city-level variables, including income per capita and average energy efficiency, which control for potential heterogeneity across local markets. The error term is denoted as ϵ_i.

The disclosure of ECs is likely not random, as the theory section showed. Owners of more efficient houses have greater incentives to obtain and disclose their ECs, and houses which are in better condition tend to be more energy efficient. Landlords also take the average adoption rate into consideration when making their certification and disclosure decisions. This may be a source of selection bias as we only observe the efficiency labels of those houses whose owners decided to obtain and disclose the certificate.

To correct for this, we use a Heckman two-step method (Heckman, 1979) using three exogenous determinants of label adoption: the local share of votes for the green parties ($GreenVote$), the local adoption rate of ECs ($AdoptionRate$), and whether the house is advertised by the landlord himself or by an agency ($Private = 1$ in the first case and $Private = 0$ otherwise). We expect landlords to be more likely to obey to the energy efficiency regulation in cities with a higher environmental awareness (as reflected in the share of green votes).[17] We also expect landlords to be more likely to comply with the regulation in cities with high adoption rates. Indeed, our theory model predicts that the rent of unlabeled houses is negatively related to the local adoption rate of ECs. Still, once the energy efficiency information has been released, the local adoption rate should have no impact on the rental price. Last, in our model the decision to obtain an EC depends on the landlord's opportunity cost of time. Accordingly, taking the decision to hire an agency as a proxy for the landlord's opportunity cost of time, we expect that landlords who decide to rent the house without intermediaries have a lower opportunity cost. Hence, they should also be more likely to obtain an EC.

Under the assumption that these three variables are not directly related to the rental price, they could help us correctly identify the potential selection bias. As supporting evidence, the correlation between the rent per square meter and these three variables is very low: the correlation between rent and $GreenVote$ is 0.13; the correlation between rent and $AdoptionRate$ is 0.01, and the correlation between rent and $Private$ is 0.03.

Firstly, we use a Probit model to estimate the probability of obtaining and disclosing the ECs using the full sample of houses:

$$Pr(EC_i) = \beta_0 + \gamma GreenVote_n + \rho Private_i + \sigma AdoptionRate_n + \beta_k X_i + \Lambda_n + \epsilon_i \tag{9}$$

where EC_i is a dummy variable that takes the value one if the house displays an EC, and zero otherwise. X_i captures the house's characteristics, while Λ_n includes the city's characteristics. Among these, $AverageLabel_n$ and $VarianceLabel_n$, which measure the mean and variance of ECs

[16] Due to the collinearity issue, we cannot control all the house characteristics. For example, in terms of house condition, we only control dummy variable *Good Condition* which is equal to one if house is advertised with good condition indicator. As for furniture condition, we control for two dummy variables: $Unfurnished$ and $FullyFurnished/Unequipped$.

[17] Label adoption is positively related to the local environmental ideology in Brounen and Kok (2011)'s study.

in the city n where the house is located, might affect the incentives to obtain and disclose the ECs through the effects on the consumers' value from search and, ultimately, through the effects on prices. Following our theory model, we assume that landlords take these market-level variables as given when they make their decisions on whether to obtain and disclose the certificates. The implicit assumption is that the individual decisions are negligible in the aggregate, so they do not affect the market-level variables in the rental market. $Income_n$ represents the average income per capita in city n. Due to potential collinearity, we do not control for city-fixed effects as these are captured by the aforementioned city-level control variables.

Table 4 presents the results of the Probit estimation with three different sets of exogenous variables. All three specifications report similar results.

The probability of obtaining and displaying an EC increases with environmental awareness, as reflected by $GreenVote$. The estimated coefficient on $GreenVote$ is larger when the advertisement type is also controlled for. Consistent with our reasoning, landlords who advertise their house by themselves are more likely to obtain ECs relative to those who resort to an agency. Moreover, in cities with higher adoption rates, landlords are significantly more likely to obtain and disclose their ECs in all three specifications. In line with our theoretical model, in local markets where consumers' expected value from searching is higher (which in turn is positively correlated with the mean and variance of the ratings), the rent efficiency premium shrinks down, leading landlords to be more reluctant to obtain and disclose their ECs. Indeed, the estimates on the mean and variance of the ECs in our Probit model are negative in the last specifications. The average income level is negatively related to the probability of obtaining ECs, but the effect is non-significant. As expected, houses in good condition are more likely to disclose the EC information, and this effect is significant in all three specifications. Also, those dwellings with lifts, fitted wardrobe and storerooms are significantly more likely to be labeled. In contrast, the size of the dwellings, number of WCs, and number of bedrooms do not seem to be correlated with the incentives to adopt and disclose the EC information.

With the estimated Probit model in the first stage, we construct consistent estimates of the inverse Mills ratio $\hat{\lambda}$. The inverse Mills ratio is added as an instrumental variable in the basic hedonic model to deal with the self-selection issue.

$$log(price/m^2)_i = \beta_0 + \beta_1 Label_i + \beta_k X_i + \tau \hat{\lambda}_i + \Lambda_n + \epsilon_i \tag{10}$$

Table 5 reports the estimated results for the basic hedonic model. In the columns with odd numbers, we cluster the ECs into three groups. As explained above, $Label_i$ captures the houses' energy efficiency levels according to the three groups, $A+B$, $C+D+E$ and the excluded category F. According to our model, we expect a positive rent premium for those houses that are more energy efficient, indicating that the coefficients on $Label_i$ should be ranked as $A + B > C + D + E > 0$. To show the robustness of our results, we also utilize the variable $LabelRating$, which assigns numbers from 7 to 1 to labels A to G. In the columns with even numbers, we include $LabelRating$ instead of the efficiency dummy variables. In the first two columns, we control for $AdoptionRate$

and $GreenVote$ as exogenous variables in the first step; in column (3) and (4), $AdoptionRate$ and $Private$ are included in the first step; and the last two columns refer to specifications that include the three exogenous variables as controls in the Probit model.

Based on the 1,348 labeled dwellings in the sample, our model explains about 25% of the natural logarithm of the rental price per square meter. Compared with those houses labeled as E or G, the estimated energy efficiency rent premium associated with the most efficient labels (A or B) is 8% - 9%, which is significant at the 5% level when we include advertisement type as an exogenous variable. In turn, the energy efficiency premium for those houses labeled as C, D or E is around 5%, which is significant at the 10% level in all three specifications. The magnitude is similar to those found in other countries.[18] In terms of the test with $LabelRating$, there is about a 1% increase in rent on average if the certificate is upgraded to a higher level, controlling for other factors. This result is significant at the 10% level when we include advertisement type as an exogenous variable. In sum, all the estimates of all six specifications give support to our first result; namely, that energy efficiency improvements can be at least partly capitalized through higher rents.

As shown in all six specifications, the coefficients on the inverse Mills ratio $\hat{\lambda}$ are all significantly positive, implying a positive correlation between the error term in the selection equation and the primary equation in the subsample with labels. The unobserved factors, which make landlords more likely to obtain and disclose their ECs, tend to have a positive and significant impact on the rent for the labeled houses.

As for the houses' characteristics, smaller dwellings tend to have a higher rent per square meter. Having an additional WC is associated with a significantly higher rent. An additional bedroom has a minor effect on the rental price, and the rent per square meter is significantly higher for those houses with fitted wardrobes, parking area and lift. Last, tenants are willing to pay more for houses in good condition, while they pay less for houses that are not equipped or not fully furnished. Last, the rent tends to be higher in cities with a higher average income.

To conclude, efficient labels are associated with a higher rent per square meter, lending empirical support to the claim that energy efficiency certificates help alleviate the information asymmetry between landlords and tenants.

3.3. Is there an energy efficiency penalty?

There are several reasons for landlords to comply with the EC regulation. Most of the literature has focused on the rental premium obtained by the more efficient houses, as we have also documented in the previous section. In this paper, we have identified another reason for compliance: the implicit penalty for not disclosing the certificate, which depends on the adoption rate of ECs in the local market. In this section we provide empirical evidence for this claim.

We focus on the sample of houses without ECs. In order to deal with the potential selection bias, and similarly to what we did before, we use Heckman's two-step method. However, we can no longer take the $AdoptionRate$ as an exogenous determinant of label adoption, as tenants might

[18] See the empirical evidence reviewed by Ramos et al. (2015).

take it into account to update their beliefs about the energy efficiency of the unlabeled houses. In the first stage, we use three different specifications with $GreenVote$, $Private$, or the combination of the two as exogenous variables. In the first stage, we estimate the probability of not showing the EC with a Probit model over the full sample:[19]

$$Pr(1 - EC_i) = \beta_0 + \gamma GreenVote_n + \rho Private_i + \beta_1 AdoptionRate + \beta_k X_i + \Lambda_n + \epsilon_i \qquad (11)$$

In the second stage, we regress the hedonic model for the unlabeled houses. The inverse Mills ratio $\hat{\lambda}$ is added to deal with the potential selection bias:

$$log(price/m^2)_i = \beta_0 + \beta_1 AdoptionRate + \beta_k X_i + \tau\hat{\lambda}_i + \Lambda_n + \epsilon_i \qquad (12)$$

Table 6 reports the results of the estimates of the second step for each of the three first step specifications. As shown in column (1), a 1% higher disclosure rate is associated with a 13.6% reduction in the rental price of the unlabeled houses when we only for *Greenvote* as exogenous variable of label adoption. Column (2) presents the results when we only use *Private*. In this specification, the magnitude of the second-stage coefficient on $AdoptionRate$ is much smaller, but the estimated effect of the local adoption rate on rent is still significant negative. Column (3) reports the results for the specification that includes $GreenVote$ and $Private$ in the first stage. A 1% higher disclosure rate is associated with a 1.93% reduction in the rental price. In sum, the estimated coefficient on $AdoptionRate$ is negative and significant at the 1% level in all specifications, even though the magnitudes of the penalty differ. This result is consistent with our model's prediction: in markets with higher disclosure rates, tenants are willing to pay less for the unlabeled houses as they expect their energy efficiency to be lower.

In the last two specifications, the dwellings' characteristics have a similar impact on the rental price as in the previous section. The fact that the good condition variable now takes a different sign could be explained by the heterogeneity in landlords' subjectivity when defining what good condition means, but it is in any case non-significant. There exists a significant price discount for those houses that are not equipped or not furnished. Consumers are willing to pay more for those apartments with parking area, lift as well as for houses with more WCs. The estimates on unobserved factors (as captured by $\hat{\lambda}$), which make the landlords more reluctant to disclose ECs, are negatively related to the rent. In the first specification, however, most of the estimates on house characteristics take the opposite sign, probably indicating that $Private$ is better than $GreenVote$ as an exogenous variable of the adoption decision.

In terms of market characteristics, the second moment of the EC ratings shows the sign predicted by the model. As explained in section 2, the value of search increases with the heterogeneity across houses. The negative relationship between the price and the value of search implies that the rent decreases with the variance of the energy efficiency rating. Additionally, rental prices significantly

[19] For the sake of brevity, we omit the empirical results of the first step, which are nevertheless available upon request.

increase with the average income of the city, as expected.

3.4. Limitations of the empirical strategy

Arguably, and despite the robustness of the results, our empirical strategy faces some limitations. Firstly, to deal with the potential selection bias, we have used the Heckman two-step method. This method requires the inclusion of exogenous variables that affect the adoption and disclosure decisions while being unrelated to the rental price. As already argued, our exogenous variables ($GreenVote$, $Private$ and $AdoptionRate$) show low correlation with the rental prices, but this does not mean the strict satisfaction of the exogenous condition. For instance, $GreenVote$ might be correlated with the average education level or with the population density, which in turn could be correlated with rental prices. Nevertheless, $GreenVote$ seems to be stable across cities of various sizes and locations, which again suggests that it is not correlated with other variables that might be affecting the rental prices.

Secondly, our sample is limited to the cross-sectional data downloaded within one month. The variation thus relies on differences across Spanish cities. Our estimations are based on the assumption that the omitted variables that could potentially affect the rental price are not correlated with $Label$ or with any other independent variables. If panel data were available, we could further control for the heterogeneity of cross-sectional units to also study the dynamic changes in adoption rates. For this purpose, further research could expand the sample to panel data across a larger number of cities.

4. Conclusions

There is consensus on the need to improve energy efficiency in order to achieve the desired reductions in carbon emissions. Even though investments in energy efficiency could provide net-positive gains, the evidence points at the existence of an energy efficiency gap which is driven, among other causes, by information asymmetries. This applies to the housing market, in which lack of information regarding the houses' energy efficiency prevents landlords from cashing in the gains from improving energy efficiency. By reducing such asymmetries, energy efficiency certificates have the potential of restoring the incentives to invest in energy efficiency.

In this paper we have constructed a model of price formation in the rental market that sheds light on the scope of the energy certificates regulation to achieve the intended goal. The model, which incorporates search frictions and asymmetric information about the houses' energy efficiency, delivers two main predictions. First, more energy efficient houses are rented at higher prices, i.e., there is an efficiency rent premium among houses with ECs. This premium is unaffected by search costs or by the average energy efficiency in the housing market, as the effects are uniform across all houses regardless of their energy efficiency level. However, the average energy efficiency in the housing market does affect the energy efficiency premium of houses with and without the energy certificate, given that it affects the pool of houses that decide to hide their ECs and hence their perceived energy efficiency. Second, all else equal, the incentives to comply with the energy certificate regulation are stronger in local markets in which there is greater compliance. Such incentives are driven by the discount at which unlabeled houses are rented, which is bigger the higher the compliance rate in the local rental market. These theoretical predictions have been illustrated in the context of the Spanish rental market.

Our results suggest important policy implications regarding the promotion of investments in energy efficiency in the rental market. In particular, a push in the disclosure rate (e.g. through policies that promote awareness of the EC regulation), would increase disclosure, which would in turn reduce the rent of the unlabeled houses, further encouraging landlords to disclose their energy certificates. Hence, if regulators could choose to devote their resources to enforce the EC policy, they should be more stringent in the first phase, when disclosure rates are low and hence the incentives for information provision are still weak.

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Appendix: Proofs and Tables

Proof of Proposition 1: Expected profits are

$$\pi(\theta) = p \Pr(u - p \geq V) = p \frac{\theta - (p + V)}{\theta}.$$

Maximization with respect to the price implies

$$\frac{\partial \pi(\theta)}{\partial p} = -\frac{1}{\theta}(V + 2p - \theta) = 0 \Rightarrow p(\theta) = \frac{\theta - V}{2}.$$

The second order condition is always satisfied.

Plugging the equilibrium price into the profit function, the expected profits (conditionally on a consumer visiting the house) are given by

$$\pi(\theta) = \frac{1}{\theta}\left(\frac{\theta - V}{2}\right)^2.$$

Plugging the equilibrium price (2) into expression (1),

$$\frac{1}{1-\underline{\theta}}\int_{\underline{\theta}}^{1}\left(\frac{1}{\theta}\int_{\frac{\theta-V}{2}+V}^{\theta}\left(u - \left(\frac{\theta - V}{2}\right) - V\right)du\right)d\theta = s.$$

Simplifying,

$$\frac{1}{8(1-\underline{\theta})}\int_{\underline{\theta}}^{1}\frac{(\theta - V)^2}{\theta}d\theta = s,$$

and integrating by parts,

$$\frac{1}{8(1-\underline{\theta})}\left[\frac{1-4V}{2} - (V-\underline{\theta})^2\ln\underline{\theta} + \underline{\theta}\left(2V - \frac{\underline{\theta}}{2} - (2V - \underline{\theta})\ln\underline{\theta}\right)\right] = s.$$

The positive root is given by

$$V = \left(\frac{1}{1-\underline{\theta}}\ln\frac{1}{\underline{\theta}}\right)^{-1}\left(1 - \sqrt{1 - \frac{\frac{1+\underline{\theta}}{2} - 8s}{1-\underline{\theta}}\ln\frac{1}{\underline{\theta}}}\right).$$

For this solution to be valid, we require that $u - p(\theta) - V > 0$ for all θ. Using expression (2) for the equilibrium price, this requires $V < \underline{\theta}$. This, together with the condition that V is non-negative, imposes a lower bound on $\underline{\theta} \geq 16s - 1$, or equivalently, an upper bound on s given $\underline{\theta}$. □

Proof of Lemma 1: Equation (5), can be re-written as

$$\widehat{\theta} = \frac{1}{2}\frac{\alpha}{1-\underline{\theta}}\widehat{\theta}^2 + \frac{1}{2}\frac{1-\alpha-\underline{\theta}^2}{1-\underline{\theta}}.$$

The LHS of the above equation is linear in $\widehat{\theta}$; the RHS is quadratic in $\widehat{\theta}$. For them to cross, it has to be the case that the RHS is greater than the LHS evaluated at $\widehat{\theta} = \underline{\theta}$. Since the RHS is decreasing in α, it follows that the solution to (5) is interior if and only if $\alpha < \frac{1-\underline{\theta}}{1+\underline{\theta}}$. In this case, solving for $\widehat{\theta}$ in equation (5),

$$\widehat{\theta} = \frac{1}{\alpha}\left(1 - \underline{\theta} - \sqrt{\alpha^2 + \underline{\theta}^2\alpha - \alpha + \underline{\theta}^2 + 1 - 2\underline{\theta}}\right).$$

This solution is decreasing in α and increasing in $\underline{\theta}$.

Otherwise, if $\alpha \geq \frac{1-\underline{\theta}}{1+\underline{\theta}}$, the corner solution $\widehat{\theta} = \underline{\theta}$ applies. □

Proof of Proposition 2: All the results have been proven in Proposition 1, Lemma 1 and the main text, except for the existence and uniqueness of the V solution. The derivative of the RHS of equation (6) with respect to V is given by

$$-\frac{1}{8}\frac{2\left[1-\underline{\theta}-\alpha\left(1-\widehat{\theta}\right)\right]\left[\widehat{\theta}-V\right]+2\widehat{\theta}\alpha\int_{\widehat{\theta}}^{1}\frac{\theta-V}{\theta}d\theta}{y\left(1-\underline{\theta}\right)}<0.$$

All the terms in the ratio are positive. This is clearly the case for the denominator. To check the sign of the numerator, note two issues. First, for the solution to be valid, we require that $u-p\left(\theta\right)-V>0$ for all θ. Using expression (2) for the equilibrium price, this requires $V<\widehat{\theta}$. Second, using Lemma 1,

$$1-\underline{\theta}-\alpha\left(1-\widehat{\theta}\right)>1-\underline{\theta}-\frac{1-\underline{\theta}}{1+\underline{\theta}}\left(1-\widehat{\theta}\right)=\left(1-\underline{\theta}\right)\left(1-\frac{1-\widehat{\theta}}{1+\underline{\theta}}\right)>0.$$

Since the above derivative is preceding by a minus sign, the RHS of equation (6) is strictly decreasing in V. It follows that the RHS of equation (6) equals s at a single point as long as s is sufficiently small (otherwise, the RHS would not cross s). This critical s is implicitly defined by replacing V by $\underline{\theta}$ in equation (6) (note that none of the variable on the RHS of equation below depend on s),

$$\begin{aligned} s \quad \leq \quad & \frac{\alpha}{1-\underline{\theta}}\int_{\widehat{\theta}}^{1}\left(\frac{1}{\theta}\int_{\frac{\theta+\underline{\theta}}{2}}^{\theta}\left(u-\frac{\theta+\underline{\theta}}{2}\right)du\right)d\theta \\ & +\left[\left(1-\alpha\right)+\alpha\frac{\widehat{\theta}-\underline{\theta}}{1-\underline{\theta}}\right]\left[\frac{1}{\widehat{\theta}}\int_{\frac{\widehat{\theta}+\underline{\theta}}{2}}^{\widehat{\theta}}\left(u-\frac{\widehat{\theta}+\underline{\theta}}{2}\right)du\right]. \end{aligned} \tag{13}$$

Last, since the RHS of (6) is decreasing in V, it follows that the V solution is decreasing in s. □

Table 4 The Determinants of EC Adoption

	(1)	(2)	(3)
Advertisement Type			
Private		0.221***	0.224***
		(0.000)	(0.000)
City Characteristics			
GreenVote	0.604		3.920
	(0.907)		(0.458)
Adoption Rate	3.573***	3.319***	3.353***
	(0.000)	(0.000)	(0.000)
AverageLabel	-0.00889	-0.0689	-0.100
	(0.910)	(0.316)	(0.218)
VarianceLabel	0.0157	0.00388	-0.0149
	(0.702)	(0.905)	(0.720)
Income	-0.0306	-0.0222	-0.0379
	(0.267)	(0.232)	(0.174)
House Characteristics			
Dwelling Size	-0.0412	-0.0474	-0.0484
	(0.546)	(0.489)	(0.481)
Bedroom	-0.0349	-0.0323	-0.0330
	(0.145)	(0.177)	(0.168)
WC	-0.00987	0.000678	0.000911
	(0.770)	(0.984)	(0.978)
Storeroom	0.108**	0.0893**	0.0943**
	(0.014)	(0.039)	(0.032)
Parking	0.0106	0.00353	0.00146
	(0.793)	(0.930)	(0.971)
Fitted Wardrobe	0.104***	0.0735**	0.0716**
	(0.003)	(0.040)	(0.046)
Lift	0.164***	0.180***	0.185***
	(0.000)	(0.000)	(0.000)
Good Condition	0.289***	0.206**	0.203**
	(0.004)	(0.041)	(0.044)
Fully Furnished/Unequipped	0.0108	0.0269	0.0280
	(0.852)	(0.644)	(0.630)
Unfurnished	-0.0194	-0.0252	-0.0223
	(0.813)	(0.760)	(0.787)
N	8001	8001	8001
Adjusted R^2	0.0522	0.0570	0.0571

p-values in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5 Energy Certificates and Rental Prices

	(1)	(2)	(3)	(4)	(5)	(6)
EC						
A or B	0.0681*		0.0928**		0.0856**	
	(0.070)		(0.015)		(0.025)	
C, D or E	0.0517*		0.0532*		0.0526*	
	(0.083)		(0.076)		(0.080)	
Label Rating		0.00757		0.0124*		0.0109*
		(0.252)		(0.067)		(0.106)
City Characteristics						
AverageLabel	-0.00597	-0.00406	0.0194	0.0225	0.0338	0.0368
	(0.870)	(0.911)	(0.580)	(0.520)	(0.338)	(0.297)
VarianceLabel	-0.0667***	-0.0693***	-0.0475***	-0.0486***	-0.0382**	-0.0397***
	(0.000)	(0.000)	(0.002)	(0.001)	(0.012)	(0.007)
Income	0.0880***	0.0877***	0.0853***	0.0851***	0.0830***	0.0827***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
House Characteristics						
Dwelling Size	-0.551***	-0.552***	-0.558***	-0.558***	-0.556***	-0.557***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Bedroom	-0.0104	-0.0101	-0.00678	-0.00596	-0.00524	-0.00457
	(0.545)	(0.559)	(0.691)	(0.728)	(0.759)	(0.791)
WC	0.163***	0.163***	0.171***	0.171***	0.172***	0.172***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Storeroom	-0.0118	-0.0117	-0.0267	-0.0273	-0.0330	-0.0334
	(0.711)	(0.715)	(0.407)	(0.396)	(0.304)	(0.297)
Parking	0.0870***	0.0893***	0.0823***	0.0838***	0.0832***	0.0850***
	(0.003)	(0.002)	(0.005)	(0.004)	(0.004)	(0.003)
Fitted Wardrobe	0.146***	0.145***	0.135***	0.134***	0.129***	0.128***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Lift	0.142***	0.145***	0.118***	0.119***	0.105***	0.107***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Good Condition	0.176***	0.175***	0.134**	0.132**	0.115*	0.113*
	(0.010)	(0.010)	(0.038)	(0.040)	(0.075)	(0.079)
Fully Furnished/Unequipped	-0.124***	-0.125***	-0.128***	-0.129***	-0.127***	-0.128***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Unfurnished	-0.264***	-0.265***	-0.263***	-0.265***	-0.259***	-0.260***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Selection $\hat{\lambda}$	0.536***	0.534***	0.360***	0.352***	0.266**	0.258**
	(0.000)	(0.000)	(0.001)	(0.001)	(0.010)	(0.012)
N	1348	1348	1348	1348	1348	1348
Adjusted R^2	0.253	0.252	0.252	0.251	0.249	0.248

p-values in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6 Adoption Rate and Rental Price

	(1)	(2)	(3)
City Characteristics			
Adoption Rate	-13.27***	-1.522***	-1.931***
	(0.000)	(0.000)	(0.000)
AverageLabel	-0.216***	-0.0271	-0.0336*
	(0.000)	(0.123)	(0.057)
VarianceLabel	-0.149***	-0.0738***	-0.0763***
	(0.000)	(0.000)	(0.000)
Income	0.146***	0.127***	0.127***
	(0.000)	(0.000)	(0.000)
House Characteristics			
Dwelling Size	-0.462***	-0.562***	-0.559***
	(0.000)	(0.000)	(0.000)
Bedroom	0.0899***	0.000652	0.00353
	(0.000)	(0.950)	(0.734)
WC	0.196***	0.181***	0.182***
	(0.000)	(0.000)	(0.000)
Storeroom	-0.296***	-0.0334**	-0.0426***
	(0.000)	(0.025)	(0.004)
Parking	0.0542***	0.0857***	0.0842***
	(0.000)	(0.000)	(0.000)
Fitted Wardrobe	-0.194***	0.0816***	0.0726***
	(0.000)	(0.000)	(0.000)
Lift	-0.295***	0.0876***	0.0746***
	(0.000)	(0.000)	(0.000)
Good Condition	-0.675***	-0.0168	-0.0393
	(0.000)	(0.602)	(0.222)
Fully Furnished /Unequipped	-0.0587***	-0.0281*	-0.0301*
	(0.000)	(0.089)	(0.068)
Unfurnished	-0.0356	-0.0929***	-0.0914***
	(0.140)	(0.000)	(0.000)
Selection $\hat{\lambda}$	6.270***	-0.467***	-0.236**
	(0.000)	(0.000)	(0.031)
N	6496	6496	6496
adj. R^2	0.291	0.269	0.268

p-values in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$