Is Mandatory Disclosure Really Mandatory? An Evaluation of the Home Energy Score Program

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Abstract

To address asymmetric information about energy efficiency in the housing market, cities across the United States have begun to adopt voluntary and mandatory disclosure policies. I study a mandatory disclosure policy in Portland, Oregon. This policy requires sellers to (1) obtain an energy assessment and (2) publish the assessment in real estate listings. Similar to other settings with mandatory disclosure, this policy suffers from non-compliance: 64% of sellers obtain an assessment, and 72% of these sellers publish the assessment (46% in total). To understand the causes of non-compliance, I develop a theoretical model, evaluating this two-stage disclosure decision. Using administrative assessment data and proprietary housing data, I test hypotheses from the model. Consistent with the theory of asymmetric information, I find that sellers act strategically, as they are more likely to publish the assessment if their home is efficient. This behavior was exacerbated with the COVID-19 pandemic when the city reduced enforcement activity, suspending fines for non-compliance. Surprisingly, there is not full compliance among the most efficient homes. This suggests that there is a coordination problem between sellers and realtors. I find that there is substantial heterogeneity across realtors, as experienced realtors are more likely to comply with the policy. Together, these results demonstrate the limitations of the use of mandatory disclosure polices as a way to mitigate asymmetric information.

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In a residential setting, sellers tend to have more information than buyers about the energy efficiency level of a home, as they have lived in the home, consuming energy and paying utility bills. While buyers may make assumptions based on observable housing attributes (e.g., appliances, cooling/heating system, windows, etc.), they are unable to measure energy efficiency with accuracy. This asymmetric information causes a variety of issues. Without the disclosure of information, the value of energy efficiency is determined by the average efficiency in the market. If a home is more or less efficient than the average, then it will result in economic losses or rents, respectively. Ultimately, this may lead to issues of moral hazard in which sellers do not make investments in energy efficiency prior to selling a home.[1] Meanwhile, buyers may not be able to accurately sort into homes based on their preferences for energy efficiency.[2] After the purchase of a home, these new homeowners may make sub-optimal investments in energy efficiency.[3] Together, this contributes to the "energy efficiency gap," in which homeowners do not make cost-effective investments in energy efficiency (Gillingham and Palmer, 2014).

To mitigate these issues, there have been attempts to increase information prior to the sale of a home. A common disclosure mechanism is utility bills. While utility bills provide information about historical energy consumption, these bills are not a great proxy of energy efficiency, as they cannot separate consumer behavior that is different between households. In recent years, cities and states have begun to adopt voluntary and mandatory disclosure policies, requiring sellers to disclose an energy assessment at the time of sale. In this paper, I examine a mandatory disclosure policy in Portland, Oregon. In 2018, the City of Portland established the Home Energy Score program, which requires sellers to obtain a home energy score assessment and publish the results in real estate listings.

[1]Myers et al. (2022) show that sellers are more likely to make investments in energy efficiency when they are required to disclose an energy audit at the time of sale.

[2]Brewer (2022) studies sorting behavior in the rental market when the renter is and is not required to pay utility bills.

[3]Gilbert et al. (2022) examine two forms of sub-optimal investment behavior under a rebate program. They find that a rebate may induce some homeowners to make investments that they would otherwise make on their own accord later in the tenure of their home. Meanwhile, other homeowners make investments that are not cost-effective.

To study this program, I combine administrative data on the assessments with proprietary housing transaction data. With this data, I am able to construct individual measures of compliance for obtaining and publishing an assessment. Although a mandatory policy, there are issues of non-compliance. From 2018 to 2021, 64% of sellers obtained an assessment and 72% of these sellers published the assessment (46% in total). To understand the causes of non-compliance, I construct a two-stage decision model, evaluating the seller's decision to obtain and publish an assessment. From this model, I derive comparative statics, formulating hypotheses about factors that influence disclosure. I consider both internal factors that are unique to a home (e.g., housing attributes and energy efficiency) as well as external factors (e.g., enforcement and realtors). Because there is non-compliance, this research setting provides a unique opportunity to study strategic behavior under mandatory disclosure. While the focus of this paper is energy efficiency, my findings can be abstracted to other settings of asymmetric information (e.g., durable goods, entertainment, food, healthcare, etc.).

By looking at these internal factors, I am able to explore issues of selection. The model predicts that, for homes in which there is greater uncertainty about energy efficiency, sellers are more likely to obtain and publish an assessment. I proxy for uncertainty by the age and size of a home.[4] I find that sellers with older homes are more likely to obtain an assessment. This, however, is not the case for publishing the assessment. Meanwhile, I find mixed results for the size of a home. Together, these results suggest that, when publishing the assessment, there is not selection on the housing attributes. Instead, there is selection on energy efficiency, as sellers are more likely to publish the assessment if their home is efficient. This result is consistent with strategic behavior in the presence of asymmetric information.[5] Surprisingly, I find that there is not full compliance even among the most efficient homes. While this may

[4]I use an absolute measure of energy efficiency. Thus, a larger home will, all else equal, will be less efficient, as it requires more energy to heat and cool the area of the home. This results in greater uncertainty in larger homes.

[5]In settings with asymmetric information, sellers of high quality goods have an incentive to disclose the quality of their good, distinguishing themselves from other low quality goods in the market.

occur for several reasons, it possibly suggests that there is a coordination problem between sellers and realtors. These results indicate that sellers respond to the information that is revealed through the assessment. Moreover, they do so strategically.

I further explore this research setting, considering the role of external factors like enforcement and realtors. The model predicts that sellers are less likely to obtain and publish an assessment when enforcement decreases. During the COVID-19 pandemic, the City of Portland announced that they would reduce enforcement activity, suspending fines for non-compliance. Since this was an exogenous shock to enforcement, I use the pandemic as a natural experiment to study how sellers respond to changes in enforcement. While sellers are less likely to obtain an assessment during the pandemic, I am unable to determine how much of this effect is driven by enforcement, rather than the pandemic itself. Conditional on obtaining an assessment, sellers are less likely to publish the assessment during the pandemic. Relative to before the pandemic, these sellers are less likely to publish the assessment if their home is inefficient; meanwhile, they are about equally as likely to publish the assessment if their home is efficient. These results imply that, without enforcement, strategic behavior is exacerbated. Outside of the model, I study how realtors influence the seller's disclosure decision. I find substantial heterogeneity across realtors, as experienced realtors are more likely to comply with the policy. Not only may there be a coordination problem, as eluded to earlier, the results suggest that there may also be heterogeneity in the cost of compliance and/or the perceived fine for non-compliance. Ultimately, the results suggest that the seller's disclosure decision is likely to be a multi-agent decision between them and their realtor.

With this paper, I contribute to a nascent literature on mandatory disclosure policies in the energy sector. At the time the policy was established in Portland, there were two other cities in the United States that had a similar policy: Austin, Texas and Berkeley, California.[6] While recent research examines the policy in Austin (Cassidy, 2022; and Myers et al., 2022),

[6]Since the establishment of the Home Energy Score program in Portland, additional cities in the metropolitan statistical area have adopted a similar policy, including Hillsboro and Milwaukie.

other research examines policies abroad, for example, energy performance certificates in Europe (Aydin et al., 2018; Frondel et al., 2019; and Fuerst et al., 2015).[7] While each of these papers study the capitalization of energy efficiency, few look at non-compliance.[8]

My paper fills this void, tackling issues of non-compliance. In doing so, I make several contributions. First, I construct a two-stage decision model, evaluating the seller's decision to obtain and publish an assessment. While other policies only require sellers to obtain an assessment, this policy also requires sellers to publish the assessment in real estate listings. By looking at both of these stages, I am able to elicit additional information about strategic behavior. For example, I show that sellers act strategically, as they are more likely to publish the assessment if their home is efficient. Second, I examine the causes of non-compliance, considering the role of external factors. I show that sellers are more likely to engage in strategic behavior when there is a lack of enforcement. Meanwhile, I find heterogeneity in compliance across realtors. To the best of my knowledge, my paper is the first to consider the role of these external factors. These results highlight the limitations of mandatory disclosure policies. While these policies improve the degree of information, they are unlikely to unravel, resulting, instead, in strategic behavior. Third, I use a comprehensive proxy of energy efficiency. Created by the U.S. Department of Energy, the home energy score is a discrete metric (1-10) of energy efficiency. Since the score is based on home assets, rather than consumer behavior, it provides more accurate information than other proxies of energy efficiency (e.g., utility bills). To motivate the decision model, I estimate the price for energy efficiency using a revealed preference model. I find that a per unit increase in the score is associated with about a 0.5% ($3,000) increase in price. This estimate is roughly equivalent to the energy cost savings from a 30-year mortgage ($2,700). These findings suggest that previous estimates based on stated-preference models are overstated (Sussmen et al., 2022).[9]

[7] The energy performance certificate is an alphabetical label (A-G), indicating the energy efficiency level of a home.

[8] Myers et al. (2022), for example, suggest that sellers may not be fully informed about the energy efficiency level of their home, resulting in non-compliance.

[9] Sussman et al. (2022) estimate that a per unit increase in the score is associated with a 5% ($19,698) to 11% ($47,102) increase in price, depending on the manner in which the information was shared.

The remainder of the paper proceeds as follows. First, I provide background on the Home Energy Score program, highlighting institutional details that are unique to the program. Second, I discuss the sources of data. Third, I present stylized facts about the program, motivating the theoretical setting. Here, I consider the relationship between energy efficiency and sales price. Fourth, I develop a two-stage decision model, looking at the seller's decision to obtain and publish an assessment. From this model, I draw multiple hypotheses based on comparative statics. Fifth, I test the hypotheses in the data. And, sixth, I conclude, noting possible extensions.

1 Background

The Home Energy Score program was established in 2018. Effective in Portland, the program requires a seller to (1) obtain a home energy score assessment and (2) publish the assessment in real estate listings prior to selling a home. The seller is responsible for the cost of obtaining an assessment, which typically ranges from \$100 to \$250 depending on the home energy score assessor.[10] Meanwhile, the fine for non-compliance is \$500.[11] Although a seller may obtain an exemption, for example, in the case of a foreclosure, such an exemption is rarely pursued.[12]

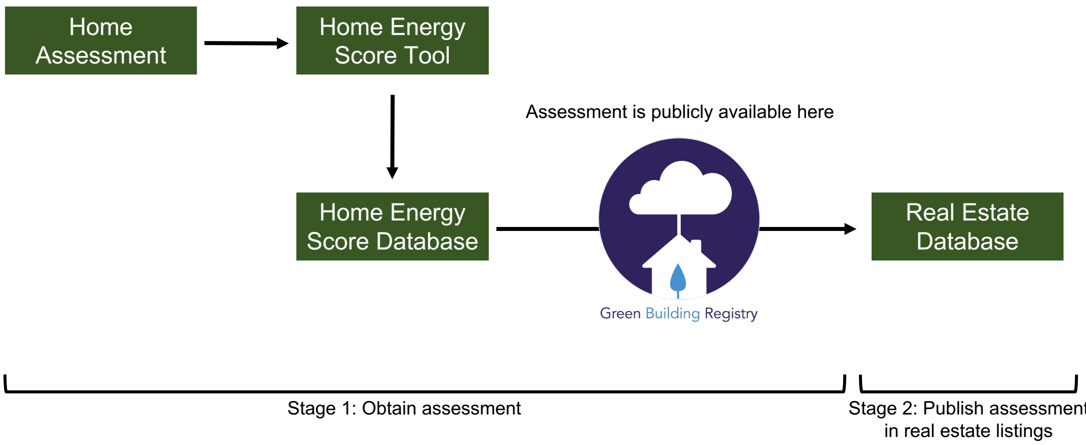
Figure 1 illustrates the two stages of disclosure. Stage 1 requires the seller to obtain a home energy score assessment. Here, the seller seeks out a qualified home energy score assessor who performs an in-home assessment, documenting home assets such as insulation. These assets are put into an engineering calculator that produces the home energy score. Upon completion of an assessment, the assessment is stored in a central database by the U.S. Department of Energy, denoted in the figure as the home energy score database.

[10]Low-income households (i.e., households with income at or below 60 percent of median family income) qualify for a free home energy score assessment.

[11]The City of Portland may issue additional fines for every subsequent 180-day period in which the violation continues (see Bureau of Planning and Sustainability, City of Portland, 2017).

[12]A seller may obtain an exemption if any of the following apply: foreclosure sale; trustee's sale; deed-in-lieu of foreclosure sale; pre-foreclosure sale where sales price is less than current mortgage; sale at public auction; under control of court appointed receiver; subject to notice of default; deemed uninhabitable due to casualty; condemned by action of government; or compliance would cause undue hardships on seller (see Bureau of Planning and Sustainability, City of Portland, 2017).

Figure 1: Stages of Disclosure



Notes: The figure illustrates the two stages of disclosure. Stage 1 requires the seller to obtain a home energy score assessment. And, stage 2 requires the seller to publish the assessment in real estate listings.

Earth Advantage, a non-profit organization in Portland, collects these assessments and provides them to the public via the Green Building Registry. This registry is an online portal that allows individuals to search for an assessment by street address. Stage 2 then requires the seller to publish the assessment in real estate listings, which are stored in a real estate database. The assessment remains publicly available in the Green Building Registry, regardless of whether the seller publishes the assessment. If a seller chooses to withhold their assessment from real estate listings for whatever reason, a buyer can access the assessment through this registry. I observe data at two points, the home energy score database and real estate database. As a result, I am able to construct individual measures of compliance for obtaining and publishing an assessment.

The home energy score assessment is a nationally accredited assessment created by the U.S. Department of Energy. The assessment presents a variety of information regarding residential energy use (see appendix figure 1). While other energy metrics are presented in the assessment (e.g., expected annual energy consumption, costs, and carbon emissions), I focus on the home energy score, since it is the metric that is emphasized in the real estate listings. The home energy score is a discrete metric (1-10) of energy efficiency. Note that a more energy efficient home that consumes less energy receives a higher score. As illustrated in appendix figure 2, the score strictly considers the home's assets, including attributes (e.g., age), envelope (e.g., insulation), and equipment (e.g., heating equipment).[13] By construction, the score does not take into consideration heterogeneous consumption from behavioral choices and electrical load. Instead, the engineering calculator used to create the score applies multiple modeling assumptions.[14] This provides an "apples-to-apples" comparison between homes, removing consumer behavior that is difficult to separate in other proxies of energy efficiency (i.e., utility bills). About 50 home assets go into the engineering calculator, estimating expected annual energy consumption for heating, cooling, and hot water use, measured in terms of British Thermal Units (MBTU). This continuous metric is then converted into the score with thresholds defined by the U.S. Department of Energy (see appendix figure 3). These thresholds vary by weather station, allowing homes to be compared across climate zones.[15]

2 Data

To conduct this analysis, I combine two sources of data. First, I receive the housing data from the Regional Multiple Listing Service (RMLS). I prefer the RMLS database to other real estate databases, such as CoreLogic and Zillow, since it is the only database that has a field for the home energy score. A link to the assessment is often provided as well. Moreover, the data provided to the RMLS is used to populate other real estate platforms such as Redfin and Trulia. Thus, the information from the assessment is publicly disseminated to prospective buyers, becoming a housing attribute that enters into the purchasing decision. This data set includes 39,439 housing transactions in Portland from 2018 to 2021. It contains the usual set of housing attributes (e.g., acres, bathrooms, bedrooms, sqft, year of construction, etc.),

[13]For more details regarding the home assets, including a full list of the inputs used in the calculation of the score, see U.S. Department of Energy (2017).

[14]Modeling assumptions include the following: occupancy; appliance fuel type; building length and width aspect ratio; thermostat settings; and electrical load (see U.S. Department of Energy, 2017).

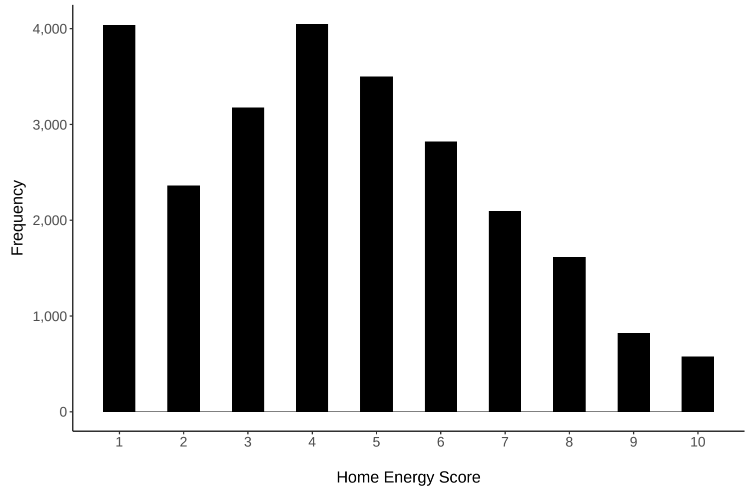
[15]The weather stations are identified in accordance with TMY3 weather data. There are three weather stations that service Portland: Portland Hillsboro; Portland International Airport; and Portland Troutdale.

Table 1: Summary Statistics: Housing Attributes

Attribute	**Mean (Standard Deviation)**	**N**
Sales Price	604,254	39,439
	(293,893)	
Year of Construction	1,956	39,439
	(67)	
Bedrooms	3.33	39,439
	(0.94)	
Full Baths	1.95	39,439
	(0.80)	
Total Sqft	2,171	39,430
	(972)	
Levels	2.04	39,439
	(0.77)	
Garages	1.34	39,439
	(0.89)	
Acres	0.21	37,781
	(0.77)	
Property Condition		39,439
New	0.06	
Fixer	0.04	
Remodel	0.21	
Restored	0.02	
Other	0.67	
Cooling System		39,439
Central Air	0.43	
Heat Pump	0.05	
Wall / Window Unit	0.03	
Other	0.06	
None	0.11	
Missing	0.33	
Heating System		39,439
Forced Air	0.89	
Baseboard	0.02	
Heat Pump	0.01	
Wall Furnace	0.01	
Other	0.08	
Fuel Type		39,439
Gas	0.73	
Electric	0.11	
Electric and Gas	0.11	
Other	0.05	
Observations	39,439	

Notes: The table reports the mean (standard deviation in parentheses) of housing attributes for homes transacted in Portland from 2018 to 2021.

Figure 2: Distribution of the Home Energy Score



Notes: The figure plots a histogram of the home energy score for assessments in Portland from 2018 to 2021..

which are used as controls in the empirical analysis. It also contains the home energy score. The housing outcome of interest is sales price. Table 1 displays the summary statistics for these transactions. In this sample, the average sales price is $604,254.

Second, I receive the home energy score data from Earth Advantage. They maintain the Green Building Registry that allows individuals to search for an assessment. This data set includes 31,157 assessments obtained in Portland from 2018 to 2021. It contains the energy metrics, including the home energy score, as well as other property characteristics like address. Note that a score of 5 represents the "average home."[16] In the sample, however, the distribution is skewed right with an average score of 4.38 (see figure 2). This is likely the case because the housing stock in Portland is relatively old. It is important to note that the home energy score is an absolute measure of energy efficiency, as it is not normalized by any housing attribute. For example, consider the size of a home (sqft). All else equal, a larger home will require more energy to heat and cool the area of the home, resulting in a lower score. This is observed in the data, as energy efficient homes are more likely to be smaller (see appendix table 1). These homes are also newer. This is expected given developments in

[16]The distribution of expected annual energy consumption that the U.S. Department of Energy uses to create the score varies by weather station, accounting for local climate conditions. Thus, the "average home" is unique to a specific location.

building codes and technology. Because of this, it becomes even more important to control for the housing attributes in the empirical analysis. To combine these data sets, I merge on street address.[17] For each housing transaction, I then select the most recent assessment that has occurred prior to the close date. Through this process, I am able to match 23,886 (77%) assessments to a housing transaction.[18,19] In the analysis that follows, I consider the full sample of housing transactions (39,439). In doing so, I construct individual measures for obtaining and publishing an assessment. About 64% of sellers obtain an assessment.[20] Here, there is selection on observables, as sellers with newer and larger homes are less likely to obtain an assessment (see appendix table 2). Conditional on obtaining an assessment, 72% of sellers publish the assessment in real estate listings. Now, there is little selection on observables. There is, however, selection on the home energy score, as sellers with energy efficient homes are more likely to publish the assessment. Figure 3 documents changes in compliance across time.[21] The figure also documents periods of enforcement, which I will discuss in more detail later in the paper. The compliance rate, both for obtaining and publishing an assessment, remains relatively unchanged between 2018 and 2020. This, however, changes with the COVID-19 pandemic, as the compliance rate decreases, before returning toward pre-pandemic levels at the end of 2021. From the data, it is evident that there are issues of non-compliance. In the remainder of the paper, I examine the factors that influence the seller's disclosure decision. To do so, I construct a two-stage decision model, looking at the seller's decision to obtain and publish an assessment. I then use this model

[17] I do not use an exact address match. Instead, I standardize the address iteratively, cleaning the street prefix and suffix.

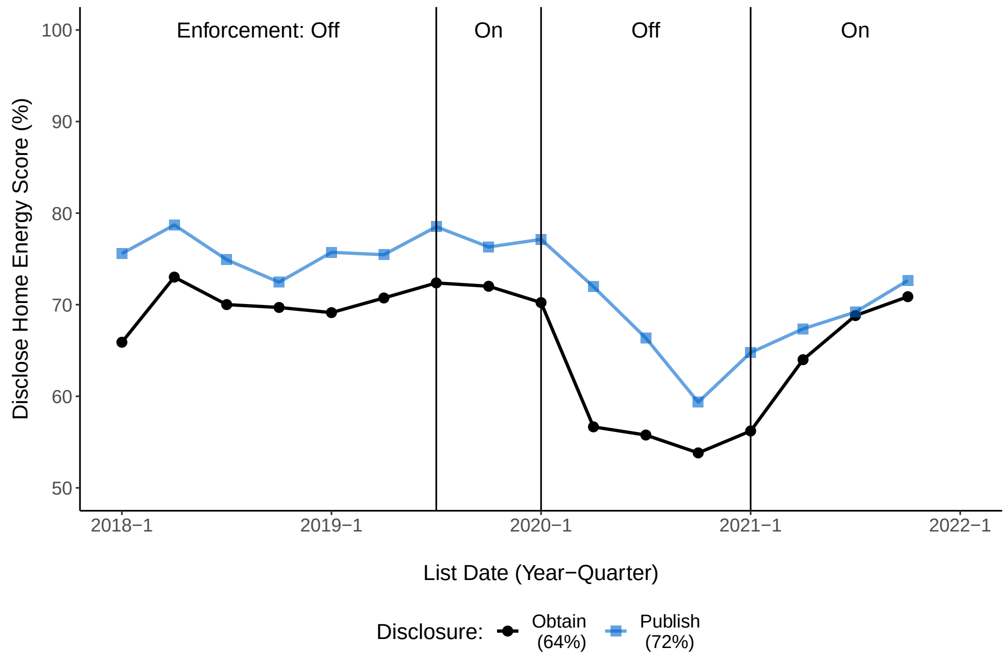
[18] The following are reasons why an assessment may not have matched successfully: there are discrepancies in the address field across the two data sets; there are multiple assessments for a single home; the assessment occurred after the close date; the home was sold by owner; and the home has yet to be transacted.

[19] Note that there are 25,048 housing transactions with an assessment. This is the result of repeat sales in which the same home has been transacted multiple times.

[20] The compliance rate observed in Portland is comparable to other mandatory residential energy disclosure policies. For example, the ECAD ordinance in Austin maintained a compliance rate of 62 percent over the first 2.5 years of the city ordinance (c.f. http://www.austintexas.gov/edims/document.cfm?id=192556). And, following the energy performance certificate mandate in the European Union, Germany maintained a compliance rate of about 60 percent (see Frondel et al., 2019).

[21] Here, the quarter of the sample is determined by the list date.

Figure 3: Compliance Rate



Notes: The figure plots the compliance rate throughout the duration of the program. *Obtain* represents obtaining an assessment and *Publish* represents publishing the assessment in real estate listings conditional on having obtained an assessment. The figure also documents the periods of enforcement.

to draw multiple hypotheses, which I test in the data.

3 Energy Efficiency and Sales Price

Before constructing the two-stage decision model, it is necessary to establish some facts about the empirical setting. As seen below, the seller's payoff depends, in part, on the price for energy efficiency. In this section, I explore the relationship between energy efficiency and sales price. To do so, I use a standard hedonic price model. While these estimates are not causal, they provide suggestive evidence that energy efficiency is correlated with price. In other words, buyers are willing to pay for energy efficiency when purchasing a home. Furthermore, buyers are willing to pay more for energy efficiency when the assessment is published in real estate listings.

Table 2: Estimates - Sales Price

	ln(Price)			
	(1)	(2)	(3)	(4)
Panel A				
Score	0.0082***	0.0052**	0.0050***	0.0051***
	(0.0006)	(0.0009)	(0.0005)	(0.0005)
Panel B				
Score	0.0067***	0.0036***	0.0031***	0.0041***
	(0.0011)	(0.0012)	(0.0009)	(0.0011)
Publish	-0.0141**	-0.0050	-0.0059	-0.0079
	(0.0060)	(0.0061)	(0.0052)	(0.0062)
Score × Publish	0.0021*	0.0020*	0.0023**	0.0013
	(0.0012)	(0.0098)	(0.0010)	(0.0012)
Controls	✓	✓	✓	✓
Fixed Effect: Quarter		✓		
Fixed Effect: Zip Code		✓		
Fixed Effect: Quarter × Zip Code			✓	✓
Fixed Effect: Realtor				✓
Observations	24,535	24,535	24,535	24,535

*p<0.1; **p<0.05; ***p<0.01

Notes: The table reports the estimates from the hedonic-price models. *Score* represents the home energy score. *Publish* is an indicator for publishing the assessment in real estate listings. Robust standard errors are reported in parentheses, clustered by zip code.

3.1 *Buyers are willing to pay for energy efficiency*

As previously mentioned, I measure energy efficiency by the home energy score. Since I only observe the score when a seller obtains an assessment, I drop the transactions for homes that do not have an assessment prior to the close date. Thus, I consider the subset of transactions with an assessment. I then estimate the following hedonic price model:

$$y_{irtz} = \beta_1 Score_i + \gamma X_i + \alpha_{tz} + \alpha_r + \varepsilon_{itrz} \tag{1}$$

where y_{irtz} is *ln(Price)* for home i sold by realtor r in quarter of sample t and zip code z. The home energy score is represented by $Score_i$. I control for the housing attributes X_i. To control for temporal and spatial variation, I include quarter of sample by zip code fixed effects α_{tz}. I also control for variation by realtor with realtor fixed effects α_r.

The estimates are presented in panel (a) of table 2. While column (4) is the preferred specification, as it has the most inclusive set of controls and fixed effects, the estimates are stable for other sets of fixed effects. The estimate for the score is 0.0051. Hence, a per unit increase in the score is associated with a 0.51% ($2,988) increase in price.[22] Since I have access to the other energy metrics in the assessment, I am able to estimate an equivalent change in energy cost savings. To do this, I regress energy costs on the score.[23] I then back out the present discounted value of energy cost savings over a 30-year mortgage.[24] For a per unit increase in the score, it yields energy cost savings of $2,719 . While these estimates are not causal, they suggest that buyers are willing to pay for the score and thereby energy efficiency. Moreover, the price for the score is roughly equivalent to the corresponding energy cost savings.

3.2 *Buyers are willing to pay more for energy efficiency when the assessment is published in real estate listings*

In the previous section, I estimate the price for the home energy score without consideration of whether the assessment is published in real estate listings or not. This implicitly assumes that buyers are willing to pay the same amount for the score when the assessment is or is not published. This, however, is unlikely to be the case. First, the score is available a wider audience of buyers when the assessment is published in real estate listings. Thus, the score is more likely to enter into the buyer's purchasing decision when the assessment is published. Second, there may be transaction or search costs associated with accessing the assessment when it is not published. Now, I examine whether buyers are willing to pay more for the score when the assessment is published. To do so, I estimate a similar hedonic price model,

[22] Note that the average sales price is $585,801 for the set of homes with an assessment.

[23] A per unit increase in the score is equivalent to energy costs savings of about $145.

[24] I use a discount rate equal to the average 30-year mortgage fixed rate during my sample period (3.63 percent).

now interacting $Score_i$ with $Publish_i$, which is an indicator for publishing the assessment:

$$y_{irtz} = \beta_1 Score_i + \beta_2 Publish_i + \beta_3 Score_i \times Publish_i + \gamma X_i + \alpha_{tz} + \alpha_r + \varepsilon_{irtz} \tag{2}$$

Note that β_1 measures the price for the score when the assessment is not published. Meanwhile, β_3 measures the additional premium for the score when the assessment is published. Thus, $\beta_1 + \beta_3$ measures the price for the score when the assessment is published. Lastly, β_2 measures the gap in price at the intercept.[25]

The estimates are presented in panel (b) of table 2. First, consider the specification in column (3), which does not include the realtor fixed effect. Here, the estimate for the score is 0.0031. Hence, a per unit increase in the score is associated with a 0.31% ($1,816) increase in price when the assessment is not published. Meanwhile, the estimate for the interaction term is 0.0023, statistically significant at the 5% level. This suggests that there is an additional premium for the score ($1,347) when the assessment is published. Thus, a per unit increase in the score is associated with a 0.54% ($3,163) increase in price when the assessment is published. Although the estimate for publishing the assessment is not statistically significant, the negative sign suggests that the intercept of publishing is less than not publishing. Because of this, the seller receives a penalty when publishing the assessment at low scores. Second, consider the specification in column (4), which includes the realtor fixed effect. Here, a per unit increase in the score is associated with a 0.41% ($2,402) increase in price when the assessment is not published. Whereas, a per unit increase in the score is associated with a 0.54% ($3,163) increase in price when then assessment is published. Now, however, the estimate for the interaction term (0.0013) is not statistically significant. As these estimates control for within realtor variation, the results suggest that the decision to publish the assessment has little to no effect on price for a given realtor. This may be the case, for example, if some realtors consistently publish or do not publish the assessment. Together, these results suggest that buyers are willing to pay more for the score, and thereby

[25]Note that a score is between 1 and 10, so the intercept is never reached.

energy efficiency, when the assessment is published, though it is driven by differences across realtors at the market level. These results also suggest that there may be a penalty for publishing the assessment at low scores. This relationship is reflected in the payoff structure in the following two-stage decision model.

4 Two-Stage Decison Model

It has long been hypothesized that voluntary and mandatory disclosure methods can be used to correct for the asymmetric information problem in which a seller holds private information about a good (see Grossman, 1981 and Milgrom, 1981). If sellers are able to credibly disclose the quality of their good at a low cost, then sellers of high-quality goods have an incentive to disclose the quality of their good, distinguishing themselves from other low-quality goods in the market. In doing so, the seller obtains a price equal to the observed quality of their good, which is greater than the expected quality of their good. As the expected quality of the remaining goods decreases, sellers of the next highest quality good similarly have an incentive to disclose. When there are no disclosure costs, this process continues until all but the sellers of the lowest quality good disclose. The extent to which this "unraveling effect" occurs in practice remains dependent on several conditions, including the presence of disclosure costs (see Dranove and Jin, 2010). In the remainder of this section, I examine this unraveling effect, looking at issues of non-compliance. To do so, I construct a two-stage decision model where a seller decides whether to obtain and publish an assessment.

The model is evaluated in terms of the seller's payoff from decision j:

$$j = \begin{cases} n & \text{if the seller does not obtain an assessment} \\ o & \text{if the seller obtains } \textbf{\textit{but does not}} \text{ publish an assessment} \\ p & \text{if the seller obtains } \textbf{\textit{and}} \text{ publishes an assessment} \end{cases}$$

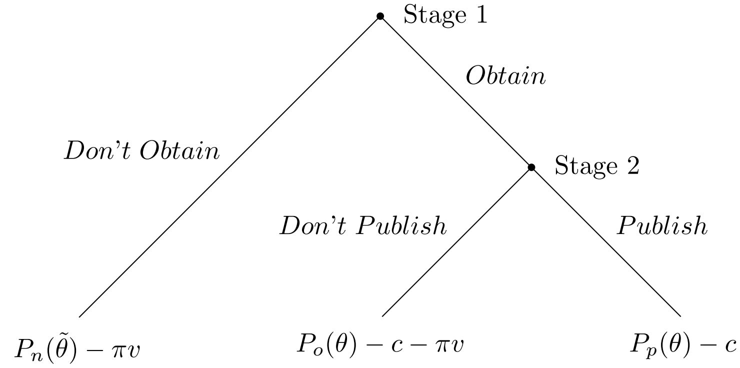
The payoff includes the price for energy efficiency that the seller receives when selling a home. Let θ_i be the "true" level of energy efficiency for home i. This is observed by the buyer when the seller obtains an assessment. Thus, the price for energy efficiency is $P_{ij}(\theta_i, X_i)$ when the seller obtains an assessment. If the seller does not obtain an assessment, the true level of energy efficiency is not known by the buyer. Instead, the buyer has a "perceived" level of energy efficiency, which is based on observable housing characteristics (e.g., appliances, cooling/heating equipment, windows, etc.). Let $\tilde{\theta}$ be this perceived level of energy efficiency. Thus, the price for energy efficiency is $P_{in}(\tilde{\theta}, X_i)$ when the seller does not obtain an assessment. For simplicity, I write the prices as $P_n(\tilde{\theta})$ and $P_j(\theta)$ for $j = o, p$. The payoff also includes the cost of the assessment as well as the expected cost of non-compliance. If a seller obtains an assessment, they face an assessment cost c. If, on the other hand, a seller does not obtain an assessment, they face a fine for non-compliance v. The probability of being caught in violation of the program (i.e., not publishing an assessment) is π. Practically, this can be measured by the degree of enforcement. Taken together, the expected cost of non-compliance is πv.

Figure 4 illustrates the seller's decision tree for this setting. In stage 1, a seller decides whether to obtain an assessment (*Obtain*) or not (*Don't Obtain*). If a seller does not obtain an assessment, they face the expected cost of non-compliance. Thus, their payoff is

$$P_n(\tilde{\theta}) - \pi v$$

If a seller obtains an assessment, they continue to stage 2 where, upon reviewing the results of the assessment, they decide whether to publish the assessment in real estate listings (*Publish*) or not (*Don't Publish*). In both cases, a seller faces the cost of the assessment. If a seller does not publish the assessment, they also face the expected cost of non-compliance.

Figure 4: Decision Tree



Notes: The figure illustrates the seller's decision tree. In stage 1, the seller decides whether to obtain an assessment. In stage 2, the seller decides whether to publish the assessment in real estate listings.

Thus, if a seller does not publish the assessment, their payoff is

$$P_o(\theta) - c - \pi v$$

Meanwhile, if a seller publishes the assessment, their payoff is

$$P_p(\theta) - c$$

4.1 *Stage 2: Publish Assessment*

The equilibrium solution is solved by backwards induction. Beginning with stage 2, a seller will publish the assessment if their payoff from publishing is greater than their payoff from not publishing. Thus,

$$\begin{aligned} &P_p(\theta) - c \geq P_o(\theta) - c - \pi v \implies \\ &\underbrace{P_p(\theta) - P_o(\theta) + \pi v}_{\text{LHS}} \geq 0 \end{aligned} \tag{3}$$

The left hand side of the equation can be separated into two terms. First is the gap in prices $P_p(\theta) - P_o(\theta)$, which captures the additional premium a seller receives from publishing the assessment. This gap, however, is not guaranteed to be positive. This may occur, for example, if the market penalizes less efficient homes with a low (or even negative) price. In this case, a seller with a less efficient home has an incentive to withhold their assessment from real estate listings so that it does not harm their sales price. The second term is the expected cost of non-compliance. As the left hand side represents the net benefit of publishing, this term can be interpreted as the avoided cost of non-compliance. Assuming an interior solution, there exists a θ^* such that $P_p(\theta^*) = P_o(\theta^*) - \pi v$.[26] This solution is unique, as the marginal benefit of publishing the assessment is greater than the marginal benefit of not publishing (i.e., $\frac{\partial P_p}{\partial \theta} > \frac{\partial P_o}{\partial \theta}$). With this interior solution, a seller will publish the assessment if $\theta \geq \theta^*$, as the net benefit of publishing is greater than not publishing. The converse is true if $\theta < \theta^*$.

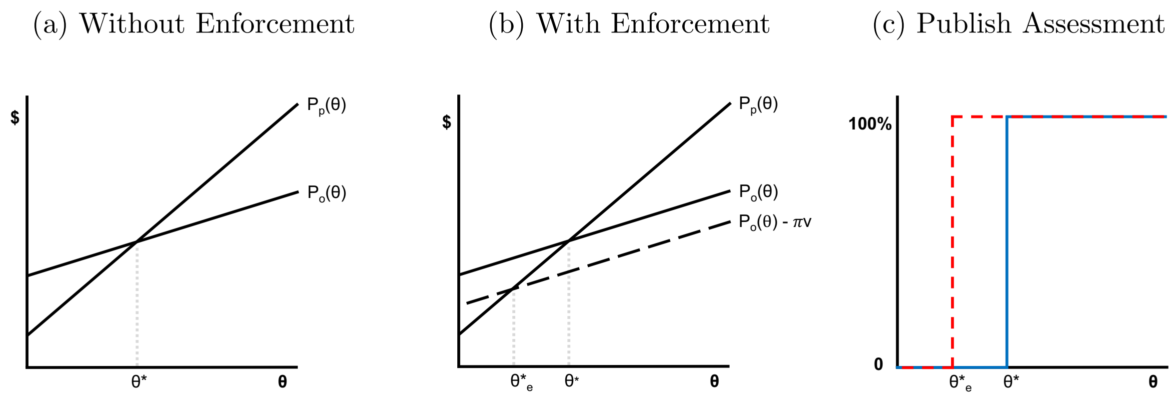
Next, I examine how the seller's decision to publish the assessment changes with the expected cost of non-compliance. To do so, I totally differentiate equation (3) with respect to the expected cost of non-compliance (πv). I then calculate the following:

$$\begin{aligned}\frac{\partial \theta^*}{\partial \pi v} &= \frac{-1}{\frac{\partial P_p(\theta^*)}{\partial \theta^*} - \frac{\partial P_o(\theta^*)}{\partial \theta^*}} \\ &< 0\end{aligned}$$

As long as buyers are willing to pay more for energy efficiency when the assessment is published in real estate listings (i.e., $\frac{\partial P_p}{\partial \theta} > \frac{\partial P_o}{\partial \theta}$), then this comparative static is negative. This relationship is observed in the data. As previously discussed, this occurs because the score is available to a wider audience of buyers when the assessment is published. Note that θ^* is the threshold value that determines the set of θ for which the seller will publish the assessment. If θ^* decreases, as observed here, then the the probability that the seller publishes the assessment increases. Thus, the probability that the seller publishes the assessment increases when the expected cost of non-compliance increases. I display this result graphically

[26] Note that there may be a corner solution if $P_p(\theta^*) \gtrless P_o(\theta^*) - \pi v$.

Figure 5: Interior Solution



Notes: The figure illustrates the interior solution for publishing the assessment. Panel (a) is the case without enforcement; whereas, panel (b) is the case with enforcement. Panel (c) is the cumulative density function of publishing the assessment.

in figure 5. In panel (a), I consider the case where the expected cost of non-compliance is zero. This may occur, for example, if there is no enforcement. Here, the solution occurs at θ^*. In panel (b), I introduce the expected cost of non-compliance through an increase in enforcement. Since the expected cost of non-compliance is fixed for all θ, it shifts the payoff of not publishing the assessment downward, and the solution occurs at $\theta_e^* < \theta^*$. As illustrated in panel (c), this shifts the cumulative density function to the left, making the seller more likely to publish the assessment.

In a similar fashion, I can examine how the seller's decision to publish the assessment changes with the housing attributes. Now, I totally differentiate equation (3) with respect to the housing attributes X. I then calculate the following:

$$\begin{aligned} \frac{\partial \theta^*}{\partial X} &= \frac{-\frac{\partial P_p(\theta^*, X)}{\partial X} + \frac{\partial P_o(\theta^*, X)}{\partial X}}{\frac{\partial P_p(\theta^*, X)}{\partial \theta^*} - \frac{\partial P_o(\theta^*, X)}{\partial \theta^*}} \\ &\gtreqless 0 \end{aligned}$$

While the denominator is positive, the numerator may be positive or negative depending on the housing attribute. For example, consider the size of a home. Since the home energy score is not normalized by the size of the home, a larger home, all else equal, will have a lower score and be less efficient. Because the size of a home is negatively correlated with energy efficiency, the buyer faces a trade-off between size and efficiency when purchasing a home. If the seller does not publish the assessment, there is uncertainty about energy efficiency, and the buyer is unable to assess this trade-off with much accuracy. Meanwhile, if the seller publishes the assessment, there is no uncertainty, and the buyer can accurately assess this trade-off. In this case, when the assessment is published, the buyer should be willing to pay more for the size of a home (i.e., $\frac{\partial P_p(\theta,X)}{\partial X} > \frac{\partial P_o(\theta,X)}{\partial X}$), as the uncertainty has been removed. As a result, the numerator is negative and θ^* decreases. Thus, the probability that the seller publishes the assessment increases when the size of a home increases. A similar argument can be made for the age of a home. Generally, a buyer will pay less for a home when the age of the home increases. Part of this is attributable to the energy efficiency level of the home, as older homes tend to be less efficient. Again, there is uncertainty about energy efficiency when the seller does not publish the assessment. In this case, when the assessment is not published, the buyer should pay even less when the age of the home increases (i.e., $\frac{\partial P_p(\theta,X)}{\partial X} > \frac{\partial P_o(\theta,X)}{\partial X}$). Similarly, the numerator is negative and θ^* decreases. Thus, the probability that the seller publishes the assessment increases when the age of the home increases. In summary, the seller is more likely to publish the assessment when the size or age of a home increase.

4.2 *Stage 1: Obtain Assessment*

Returning to stage 1, let $f(\theta)$ and $F(\theta)$ be the probability density function and cumulative density function for θ, respectively. Since $F(\theta^*) = \mathbb{P}(\theta \leq \theta^*)$, then $F(\theta^*)$ is the probability that a seller does not publish the assessment. Likewise, $1 - F(\theta^*)$ is the probability that a seller publishes the assessment. If a seller obtains an assessment in stage 1, their payoff is the expected payoff from stage 2.[27] Thus, the payoff from obtaining an assessment is,

$$\begin{aligned} &F(\theta^*)\Big[P_o\Big(\mathbb{E}(\theta|\theta \leq \theta^*)\Big) - c - \pi v\Big] + (1 - F(\theta^*))\Big[P_p\Big(\mathbb{E}(\theta|\theta > \theta^*)\Big) - c\Big] \implies \\ &F(\theta^*)\Big[P_o\Big(\mathbb{E}(\theta|\theta \leq \theta^*)\Big) - \pi v\Big] + (1 - F(\theta^*))\Big[P_p\Big(\mathbb{E}(\theta|\theta > \theta^*)\Big)\Big] - c \end{aligned} \tag{4}$$

For simplicity, let $\bar{\theta}_o = \mathbb{E}(\theta|\theta \leq \theta^*)$ and $\bar{\theta}_p = \mathbb{E}(\theta|\theta > \theta^*)$. Thus, $\bar{\theta}_o$ is the expected level of energy efficiency conditional on not publishing the assessment. A similar interpretation exists for $\bar{\theta}_p$. Now, a seller will obtain an assessment as long as the expected payoff of obtaining is greater than the payoff of not obtaining. That is,

$$\begin{aligned} &F(\theta^*)\Big[P_o(\bar{\theta}_o) - \pi v\Big] + (1 - F(\theta^*))\Big[P_p(\bar{\theta}_p)\Big] - c \geq P_n(\tilde{\theta}) - \pi v \implies \\ &\underbrace{F(\theta^*)\Big[P_o(\bar{\theta}_o)\Big] + (1 - F(\theta^*))\Big[P_p(\bar{\theta}_p) + \pi v\Big] - c - P_n(\tilde{\theta})}_{\text{LHS}} \geq 0 \end{aligned} \tag{5}$$

Note that a seller does not face the expected cost of non-compliance when they publish the assessment. Because of this, the expected cost of non-compliance does not affect the payoffs one-to-one, as the relative difference is $1 - F(\theta^*)$. Thus, $(1 - F(\theta^*))\,\pi v$ can be interpreted as the avoided cost of non-compliance, weighted by the probability of publishing the assessment.

Similar to before, I derive comparative statics from equation (5) to examine how the parameters impact a seller's decision to obtain an assessment:

[27]The expected price of energy efficiency from obtaining an assessment is

$$\int_{-\infty}^{\theta^*} P_o(\theta)f(\theta)d(\theta) + \int_{\theta^*}^{\infty} P_p(\theta)f(\theta)d(\theta) = F(\theta^*)\Big[\mathbb{E}\Big((P_o(\theta|\theta \leq \theta^*)\Big)\Big] + (1 - F(\theta^*))\Big[\mathbb{E}\Big(P_p(\theta|\theta > \theta^*)\Big)\Big]$$

Assuming that the price of energy efficiency is linear in θ, then the expected price becomes

$$\begin{aligned} &F(\theta^*)\Big[\mathbb{E}\Big(P_o(\theta|\theta \leq \theta^*)\Big)\Big] + (1 - F(\theta^*))\Big[\mathbb{E}\Big(P_p(\theta|\theta > \theta^*)\Big)\Big] \\ =\ &F(\theta^*)\Big[P_o\Big(\mathbb{E}(\theta|\theta \leq \theta^*)\Big)\Big] + (1 - F(\theta^*))\Big[P_p\Big(\mathbb{E}(\theta|\theta > \theta^*)\Big)\Big] \end{aligned}$$

1. Cost of assessment (c):

$$\frac{\partial LHS}{\partial c} = -1$$
$$< 0$$

2. Expected cost of non-compliance (πv):[28]

$$\begin{aligned}
\frac{\partial LHS}{\partial \pi v} = \quad & \underbrace{(1 - F(\theta^*))}_{\text{“Direct Effect”}} + \\
& \underbrace{\frac{\partial(1 - F(\theta^*))}{\partial \pi v}\Big[P_p(\bar{\theta}_p) - P_o(\bar{\theta}_o) + \pi v\Big]}_{\text{“Publish Effect”}} \quad + \\
& \underbrace{F(\theta^*)\frac{\partial P_o(\bar{\theta}_o)}{\partial \pi v} \quad + \quad (1 - F(\theta^*))\frac{\partial P_p(\bar{\theta}_p)}{\partial \pi v}}_{\text{“Price Effect”}} \\
= \quad & \underbrace{(+)}_{\text{“Direct Effect”}} \quad + \quad \underbrace{(+)}_{\text{“Publish Effect”}} \quad + \quad \underbrace{(-)}_{\text{“Price Effect”}} \\
\gtreqless \quad & 0
\end{aligned}$$

Since $\frac{\partial LHS}{\partial c} < 0$, then a seller is less likely to obtain an assessment if the cost of the assessment increases. Since $\frac{\partial LHS}{\partial \pi v} \gtreqless 0$, then the result is ambiguous if the expected cost of non-compliance increases. To better understand how the expected cost of non-compliance impacts the decision to obtain an assessment, I separate the effect into three parts. First is the “direct effect,” which measures the change in the avoided cost of non-compliance, weighted by the initial probability of publishing. By definition, the direct effect is positive. This effect is displayed graphically in panel (a) of appendix figure 4.[29] Second is the “publish effect,” which measures the change in the probability of publishing the

[28]For the derivation of this comparative static, please see the appendix.

[29]Note that in this graphical representation, I implicitly assume that energy efficiency follows a uniform distribution. The results are generalizable to other distributions.

assessment. This effect can be separated into two parts: the gap in the expected prices $\frac{\partial(1-F(\theta^*))}{\partial \pi v}\left[P_p(\bar{\theta}_p) - P_o(\bar{\theta}_o)\right]$ and the avoided cost of non-compliance $\frac{\partial(1-F(\theta^*))}{\partial \pi v}\left[\pi v\right]$. Since the gap in the expected prices and avoided cost of non-compliance are both positive, then the publish effect is positive. This effect is displayed in panel (b) of appendix figure 4. And, third is the "price effect," which measures changes in the expected prices, weighted by the initial probabilities. Note that the expected prices decrease as the expected cost of non-compliance increases. Because of this, the price effect is negative. This effect is displayed in panel (c) of appendix figure 4. As long as the sum of the direct effect and publish effect are greater than the price effect, then the aggregate effect is positive. In this case, a seller is more likely to obtain an assessment when the expected cost of non-compliance increases.

5 Empirical Setting and Results

With the conceptual framework from the two-stage decision model, I turn to the data to test the hypotheses. First, I examine whether sellers act strategically based on internal factors that are unique to a home. For example, I consider housing attributes and energy efficiency. Second, I consider external factors such as enforcement and realtors.

5.1 *Do sellers act strategically? It depends*

In this section, I focus on stage 2, where, conditional on obtaining an assessment, the seller decides to publish the assessment in real estate listings. As I observe the home energy score for all homes that obtain an assessment, I am able to elicit strategic behavior in this stage. I am unable to do the same in stage 1, since I do not observe the score for the homes that do not obtain an assessment.Here, I examine whether sellers act strategically, publishing the assessment based on internal factors.

First, I consider housing attributes. In the previous section, I derived comparative statics,

Table 3: Estimates - Publish Assessment

	Publish Assessment			
	(1)	(2)	(3)	(4)
Panel A				
Age	-0.000069	-0.000100	-0.000068	-0.000033
	(0.000068)	(0.000079)	(0.000069)	(0.000075)
Sqft	0.000008	0.000011**	0.000010*	0.000006
	(0.000006)	(0.000005)	(0.000006)	(0.000006)
Panel B				
Score	0.0097***	0.0089***	0.0092***	0.0059***
	(0.0011)	(0.0011)	(0.0014)	(0.0013)
Controls	✓	✓	✓	✓
Fixed Effect: Quarter		✓		
Fixed Effect: Zip Code		✓		
Fixed Effect: Quarter × Zip Code			✓	✓
Fixed Effect: Realtor				✓
Observations	24,535	24,535	24,535	24,535

*p<0.1; **p<0.05; ***p<0.01

Notes: The table reports the estimates from the linear probability models. *Score* represents the home energy score. Robust standard errors are reported in parentheses, clustered by zip code.

showing that the decision to publish the assessment depends on housing attributes. For example, a seller should be more likely to publish the assessment as the size and/or age of the home increases. To examine whether this is observed in practice, I estimate the following linear probability model:

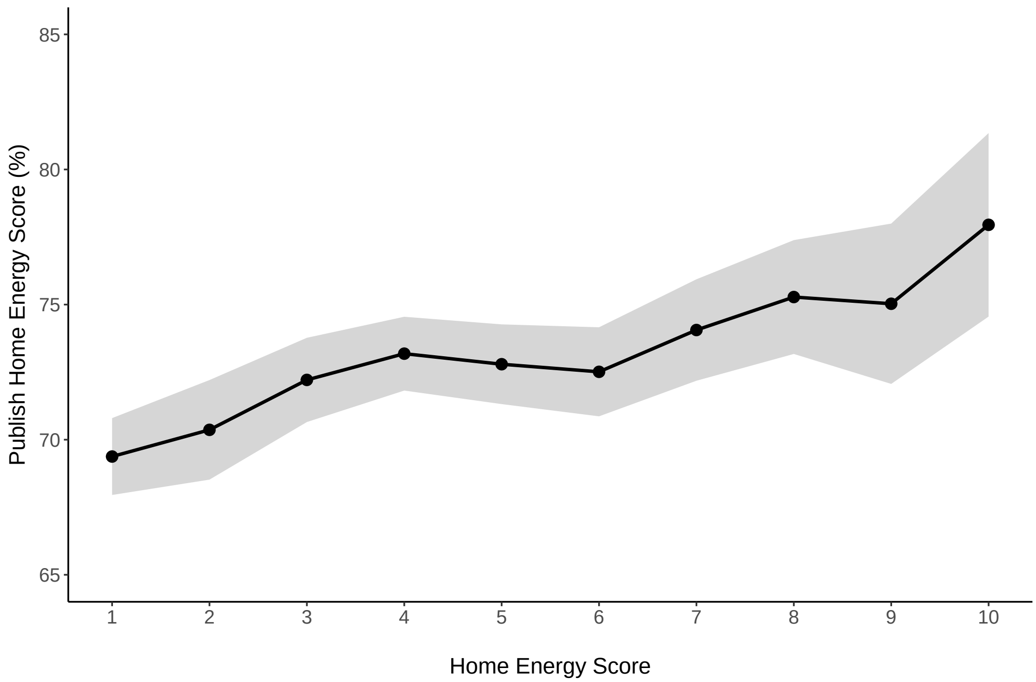
$$Publish_{irtz} = \gamma X_i + \alpha_{tz} + \alpha_r + \varepsilon_{itrz} \tag{6}$$

where $Publish_{irtz}$ is an indicator for publishing the assessment. Here, γ is the coefficient of interest, as it measures the effect of the housing attributes on the probability of publishing the assessment. Given the previous discussion, I focus on the size and age of a home.

The estimates are presented in panel (a) of table 3. The age of the home does not influence the seller's decision to publish the assessment, regardless of the specification. Without the realtor fixed effects, the size of a home (i.e., sqft) influences the seller's decision marginally. For example, a 1,000 sqft increase in the size of a home is associated with a 1 percentage point increase in the probability of publishing the assessment. These effects go away when introducing the realtor fixed effects. While the theory suggests that sellers have incentives to publish the assessment based on their housing attributes, sellers do not respond to these incentives in practice, as there is little to no selection on the housing attributes.

If there is not selection on the housing attributes, the question that remains is whether there is selection on other factors like energy efficiency? Here, I focus on home energy score, looking at whether sellers are more likely to publish the assessment as the score increases and a home becomes more energy efficient. Figure 6 plots the share of sellers that publish the assessment separated by the score. While there is not full compliance, sellers appear to act strategically, as they are more likely to publish the assessment as the score increases. This may occur, for example, if a seller decides to withhold their assessment from real estate listings for fear that a low score may adversely affect their sales price. This result is consistent with the theory of asymmetric information, as sellers with high quality goods have an incentive to disclose the quality of their goods. Surprisingly, however, there is not full compliance even with the most efficient homes, as about 80% of sellers publish the assessment with a score of 10. This may occur for a variety of reasons. First, there may be a coordination problem between a seller and their realtor when creating the real estate listing. Second, there may be transaction costs associated with publishing an assessment. This, however, is unlikely to be the case, as the realtor simply has to input the score to a pre-existing field in the listing. Third, the realtor may have little experience and thus they may not know about the program. Fourth, the realtor may not perceive the score to provide value to sellers in the form of a price premium. This may be a personal belief, for example, if the realtor never publishes the assessment, regardless of the score. It may also be a belief based on signaling. For example, if a home is perceived to be the most efficient home based on observable housing attributes, then the seller and/or realtor may choose to not publish the assessment as a form of countersignaling. Thus, by not publishing the assessment, buyers may perceive these homes to be of even higher quality. This list is not exhaustive, as there

Figure 6: Publish Assessment



Notes: The figure plots the share of sellers that publish the assessment, conditional on obtaining an assessment, by the score. The 95% confidence interval is displayed in gray.

may be other reasons for non-compliance.

Since the previous figure considers the unconditional means, I estimate a similar linear probability model, now including the score:

$$Publish_{irtz} = \beta_1 Score_i + \gamma X_i + \alpha_{tz} + \alpha_r + \varepsilon_{itrz} \tag{7}$$

The estimates are presented in panel (b) of table 3. Without the realtor fixed effects, a one unit increase in the score is associated with a 0.92 percentage point (1.3%) increase in the probability of publishing an assessment. With the realtor fixed effects, the magnitude decreases to 0.59 percentage points (0.8%). This may occur if some realtors consistently publish the assessment without consideration of the score. For example, if a realtor is risk adverse and wants to maintain an image of professionalism, then the realtor may choose to always publish the assessment. In this case, the realtor is unlikely to respond to changes in the score. These results suggest that the score influences the seller's decision to publish the assessment, though the effect decreases when considering variation within realtors. Given that the effect decreases with realtor fixed effects, it provides evidence that the decision to publish an assessment is not a single-agent decision, where the seller is making a sole decision. Rather, it is a dual-agent decision between the seller and the realtor. I explore this relationship in more detail later in the paper. Ultimately, these results suggest that the information (i.e., home energy score) is entering the market, influencing the decision to publish the assessment.

5.2 *Are there external factors that influence the seller's disclosure decision?*

Since there is not full compliance, my research setting provides a unique opportunity to examine external factors, unrelated to the housing attributes, that influence the seller's disclosure decision. In this paper, I consider two factors: enforcement and realtors.

5.2.1 *Enforcement*

Recall, from the theoretical model, that, under some conditions, a seller should be more likely to obtain and publish an assessment if the expected cost of non-compliance increases.[30] Note that enforcement is an element of the expected cost, as it influences the probability of being caught in violation of the program. So, if enforcement increases (decreases), then the expected cost of non-compliance increases (decreases) and the seller is more (less) likely to obtain and publish an assessment. Because the degree of enforcement varied throughout the duration of the program, I am able to test this hypothesis in the data.

Now, reconsider figure 3, which documents the compliance rate and periods of enforcement. To increase public perception of the program, the City of Portland did not issue fines for non-compliance for the first year and a half of the program. In this case, enforcement was essentially "turned off." This, however, was not communicated to the

[30]If the sum of the direct effect and publish effect is greater than the price effect, then a seller is more likely to obtain and publish an assessment.

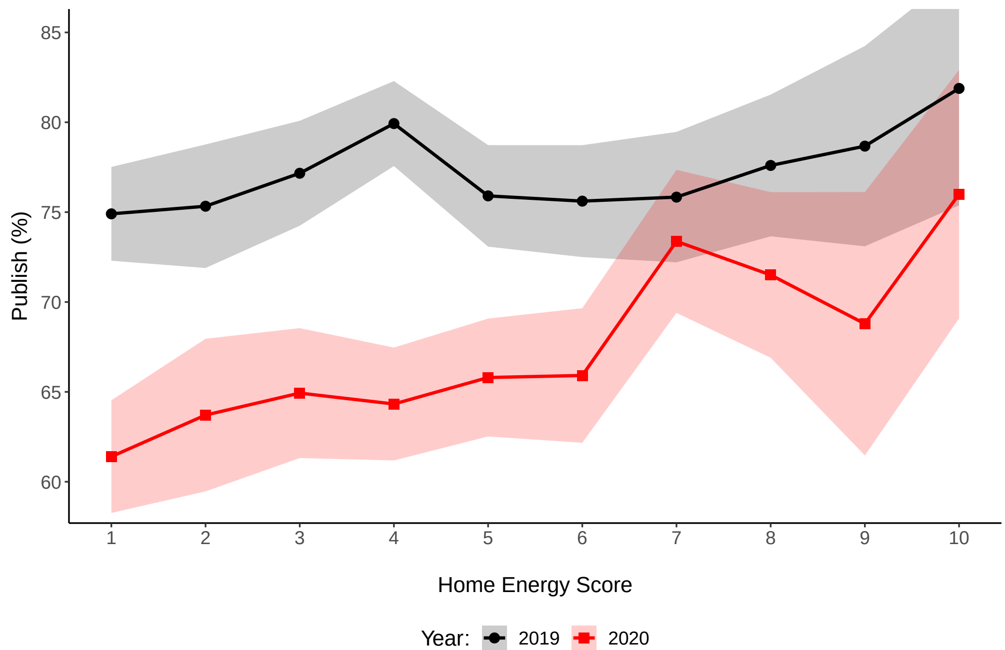
public. As a result, the threat of non-compliance was still present. This may partially explain why the compliance rate did not increase at the end of 2019 when the city announced that they would begin to issue fines, turning enforcement on.[31] With the COVID-19 pandemic, the city announced that they would reduce enforcement efforts, no longer issuing fines for non-compliance. This was later reversed in 2021.

The pandemic is particularly interesting to study. During the pandemic sellers are less likely to obtain an assessment. While this follows from the theory, it is difficult to separate whether this is an "enforcement effect" or a "pandemic effect" or some combination of the two. For example, the pandemic effect reflects changes in the perception of safety, as some sellers may be unwilling to invite an assessor into their home during this time period. Because of this, I focus on the decision to publish the assessment, conditional on having obtained an assessment. Relative to before the pandemic, these sellers are now less likely to publish the assessment. As there were no changes in the program over this time period, this possibly suggests that sellers publish the assessment more strategically without enforcement, withholding low scores from real estate listings. I am able to test this directly in the data.

Figure 7 plots the share of sellers that publish the assessment separated by the score and year of the program. Similar to before, this figure plots the unconditional means. Here, I compare the compliance rate in 2019 with enforcement to the compliance rate in 2020 without enforcement. With enforcement, there is little to no strategic behavior, as the share of sellers that publish the assessment is similar across the scores. This, however, is not the case without enforcement. Here, sellers act strategically as they are less likely to publish the assessment at low scores. For some scores, the gap between these periods of enforcement is as large as 15 percentage points. This may be the case if sellers perceive that there is a penalty for low scores. These sellers have an incentive to withhold their assessment from real estate listings as long as buyers do not penalize homes that do not publish the assessment, assuming that these homes are the least efficient. By not publishing the assessment, these

[31] c.f. https://www.pdxhes.com/blog/2019/9/20/sellers-start-receiving-fines-this-month-for-missing-home-energy-score

Figure 7: Publish Assessment by Enforcement



Notes: The figure plots the share of sellers that publish the assessment, conditional on obtaining an assessment, by the score and year of the program. The 95% confidence intervals are displayed in gray and red for 2019 and 2020, respectively.

sellers are able to mask their home as an average home, receiving a higher price for energy efficiency. Meanwhile, at high scores, sellers are about as equally as likely to publish the assessment as they were prior to the pandemic with enforcement. This may be the case if sellers perceive that there is a premium for energy efficiency.

To examine the role of enforcement between 2019 and 2020 more carefully, I estimate the following linear probability model, interacting the score with enforcement:

$$\begin{aligned} Publish_{irz} =& \beta_1 Score_i + \beta_2 Without\ Enforcement_i + \\ & \beta_3 Score \times Without\ Enforcement_i + \gamma X_i + \alpha_z + \alpha_r + \varepsilon_{irz} \end{aligned} \tag{8}$$

where $Without\ Enforcement_i$ is the indicator for the period without enforcement during 2020. While β_1 measures the effect of the score on publishing the assessment during 2019 with enforcement, β_3 measures the additional effect during 2020 without enforcement. Thus,

Table 4: Estimates - Publish Assessment by Enforcement

	Publish Assessment		
	(1)	(2)	(3)
Score	0.0042**	0.0034*	0.0003
	(0.0019)	(0.0020)	(0.0034)
Without Enforcement	-0.1584***	-0.1582***	-0.1543***
	(0.0172)	(0.0173)	(0.0211)
Score × Without Enforcement	0.0108***	0.0107***	0.0099***
	(0.0029)	(0.0029)	(0.0035)
Controls	✓	✓	✓
Fixed Effect: Zip Code		✓	✓
Fixed Effect: Realtor			✓
Observations	11,814	11,814	11,814

*p<0.1; **p<0.05; ***p<0.01

Notes: The table reports the estimates from the linear probability model. *Score* represents the home energy score. *Without Enforcement* is an indicator for the period without enforcement. Robust standard errors are reported in parentheses, clustered by zip code.

β_2 measures the gap in the probability of publishing the assessment at the intercept.

The estimates are presented in table 4. As suggested in the previous figure, sellers do not act strategically with enforcement, as there is a null effect. Thus, the score does not influence the seller's decision to publish the assessment. In contrast, sellers act strategically without enforcement, as a one unit increase in the score is associated with a 1 percentage point (1.4%) increase in the probability of publishing the assessment relative to the period with enforcement. At low scores this gap is large, as the difference is 14.4 percentage points at a score of 1.[32] Together, these results suggest that sellers act strategically without enforcement, responding to the information that is revealed through the assessment. In particular, sellers are more likely to publish the assessment as the score increases. Consistent with the initial hypothesis, sellers, on the whole, are less likely to publish the assessment when enforcement decreases. In other words, sellers respond to changes in enforcement when they are announced publicly.

[32] The estimate for without enforcement measures the gap (15.4 percentage points) at 0. Thus the gap is 14.4 percentage points ($|-15.4+1|$).

5.2.2 *Realtors*

As eluded to earlier, the decision to publish the assessment is linked to the seller's realtor, as it is the realtor that inputs the score into the real estate listing. The decision to obtain an assessment may also be linked to the realtor, especially if the realtor is risk adverse and does not want the seller to be caught in violation of the program. In this section, I explore the role of the realtor in more detail.

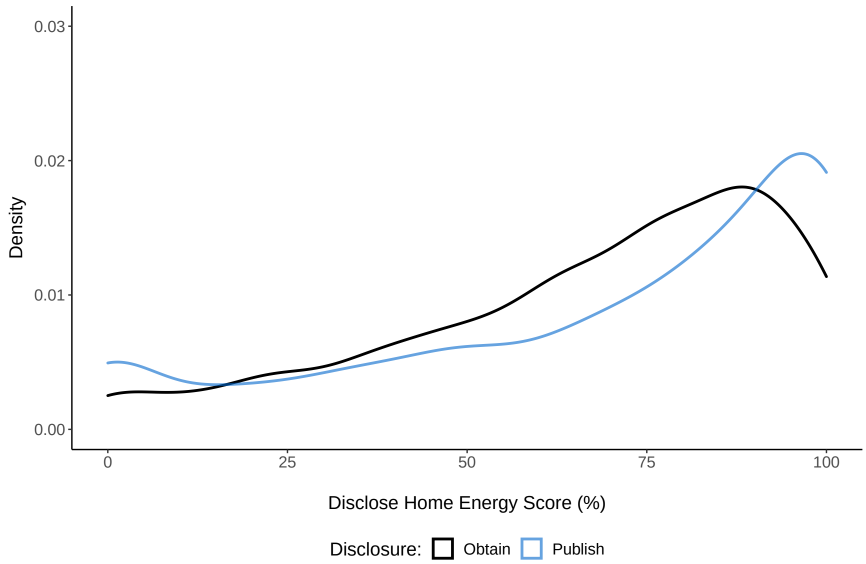
Panel (a) of figure 8 is a density plot of the compliance rate across realtors. Here, I restrict the set of realtors by the number of transactions. In particular, I consider the top quartile of realtors, that is, realtors with eight or more transactions. While the mass of realtors is skewed left, there is quite a bit of variation. There are even never-compliers. Given the variation in compliance, it is likely the case that realtors hold individual beliefs about enforcement and the probability of being caught in violation. Alternatively, they may hold individual beliefs about the value of disclosure.

Next, I examine the role of experience. I use the number of transactions as a proxy for experience. In panel (b) of figure 8, I plot the average compliance rate across realtors for a given number of transactions. I bin transactions by increments of 10, capping the number of transactions at 50.[33] For both stages of disclosure, the compliance rate initially increases with the number of transactions. This may reflect a "learning-by-doing" process, as experienced realtors are likely to be more aware of the program. In terms of obtaining an assessment, the compliance rate remains relatively unchanged after 10 transactions. Meanwhile, in terms of publishing the assessment, the compliance rate continues to increase with the number of transactions. At this point, realtors should be aware of the program. Thus, it is likely not the case that the increase in the compliance rate is the result of a learning-by-doing process. Instead, it may be a story of reputation. For example, if a realtor is well-established in the market, they may want to uphold an image of professionalism. If this is the case, then experienced realtors may be more likely to remain in compliance of the program, publishing

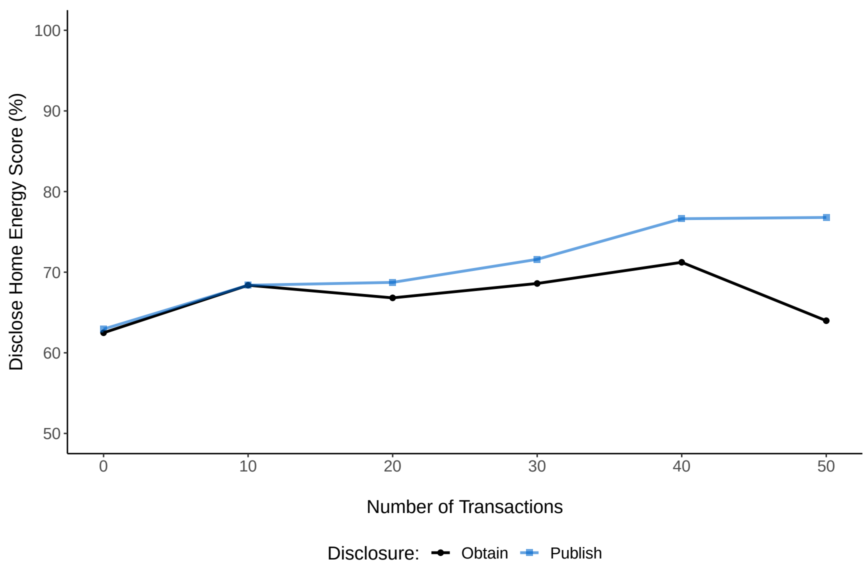
[33] I use a floor function. As a result, the label "0" includes realtors with 1-9 transactions.

Figure 8: Realtors

(a) Density Plot of Compliance



(b) Compliance by Experience



Notes: Panel (a) is the density plot of compliance for realtors within the top quartile of transactions (8^+). Panel (b) plots the average compliance rate among realtors for designated bins of transactions. The 0 bin includes realtors with 1-9 transactions. The 10 bin includes realtors with 10-19 transactions and so on... The 50 bin includes all realtors with 50 or more transactions.

the assessment. Alternatively, experienced realtors may have greater access to resources. For example, these realtors may have a team of realtors or other personnel that work with them. In this case, more time may be allocated to the listing, resulting in fewer input errors. Regardless of the mechanism, the results suggest that experienced realtors are more likely to publish the assessment.

6 Conclusion

When purchasing a home, buyers know little, ex-ante, about energy efficiency. One common method to address this problem of asymmetric information is voluntary and mandatory disclosure. While these disclosure policies are great in theory, causing the market to unravel, this unraveling rarely occurs in practice, as these policies suffer from issues of non-compliance. In this paper, I study a mandatory disclosure policy in Portland that requires sellers to publish an energy assessment in real estate listings. To examine compliance, I develop a two-stage decision model, evaluating the seller's decision to obtain and publish an assessment. From this model, I draw hypotheses, which I test empirically using data on the assessments and housing transactions. These hypotheses allow me to better understand the causes of non-compliance.

I focus on the second stage of this model, that is, the decision to publish the assessment, conditional on obtaining an assessment. In doing so, I am able to examine whether sellers engage in strategic behavior, basing their decision on the results of the assessment. Consistent with the theory of asymmetric information, I show that sellers act strategically, as they are more likely to publish the assessment if their home is efficient. This behavior was exacerbated during the COVID-19 pandemic when the city announced that they would reduce enforcement activity, suspending fines for non-compliance. Using the pandemic as a natural experiment, I show that, relative to before the pandemic, sellers act more strategically, as they are less likely to publish the assessment if their home is inefficient. This provides evidence that sellers alter their behavior in response to changes in enforcement. In addition, I consider the role of the realtor, finding heterogeneity across realtors. This suggests that there may be heterogeneity in the cost of compliance and/or perceived fine for non-compliance.

While I focus on the seller's decision to publish the assessment, more research is needed to understand their decision to obtain an assessment. I seek to address this in future work by predicting energy efficiency for the homes that do not obtain an assessment via a machine learning process. With these predictions, I can then examine if sellers decide to obtain an assessment strategically based on theory of asymmetric information. In addition, I will construct a structural model, estimating choice probabilities for obtaining and publishing an assessment. With this model, I will simulate how patterns of compliance respond to changes in the model's parameters (e.g., cost of assessment, fine for non-compliance, and enforcement). Ultimately, these results can help guide policy makers create more effective policies in the future.

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Appendix: Tables and Figures

Table 1: Summary Statistics: Housing Attributes by Home Energy Score

	Home Energy Score									
Characteristic	1	2	3	4	5	6	7	8	9	10
Sales Price	670,027	607,227	587,946	575,788	552,582	556,717	538,547	557,238	577,137	575,040
	(364,932)	(296,812)	(249,296)	(260,924)	(213,287)	(210,841)	(190,110)	(209,243)	(216,306)	(173,835)
Year of Construction	1939	1943	1945	1946	1948	1952	1957	1967	1974	1976
	(26)	(26)	(28)	(29)	(55)	(50)	(83)	(80)	(41)	(93)
Bedrooms	3.54	3.31	3.29	3.16	3.10	3.06	3.08	3.08	3.15	3.05
	(0.98)	(0.85)	(0.88)	(0.87)	(0.85)	(0.87)	(0.85)	(0.83)	(0.86)	(0.88)
Full Baths	1.98	1.83	1.83	1.79	1.77	1.81	1.82	1.91	1.96	1.95
	(0.90)	(0.80)	(0.78)	(0.75)	(0.71)	(0.73)	(0.69)	(0.71)	(0.67)	(0.68)
Total Sqft	2,579	2,259	2,168	2,053	1,954	1,902	1,826	1,824	1,879	1,810
	(1,199)	(990)	(885)	(856)	(774)	(752)	(695)	(697)	(713)	(663)
Levels	2.32	2.15	2.13	2.05	1.99	2.00	1.98	2.00	2.03	2.07
	(0.87)	(0.84)	(0.83)	(0.81)	(0.78)	(0.71)	(0.69)	(0.68)	(0.66)	(0.66)
Garages	1.22	1.19	1.22	1.20	1.19	1.15	1.13	1.11	1.06	0.87
	(0.93)	(0.85)	(0.86)	(0.85)	(0.83)	(0.79)	(0.77)	(0.71)	(0.69)	(0.65)
Acres	0.20	0.19	0.17	0.16	0.16	0.15	0.13	0.13	0.12	0.13
	(0.34)	(0.39)	(0.19)	(0.13)	(0.15)	(0.17)	(0.11)	(0.11)	(0.11)	(0.37)
Property Condition										
New	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.08	0.15	0.25
Fixer	0.07	0.05	0.04	0.02	0.02	0.02	0.01	0.01	0.01	0.00
Remodel	0.21	0.22	0.24	0.25	0.24	0.26	0.26	0.23	0.20	0.18
Restored	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.01	0.02	0.02
Other	0.69	0.70	0.70	0.70	0.70	0.69	0.67	0.66	0.62	0.56
Cooling System										
Central Air	0.38	0.39	0.43	0.42	0.42	0.42	0.39	0.39	0.34	0.26
Heat Pump	0.04	0.03	0.03	0.04	0.05	0.05	0.07	0.09	0.09	0.16
Wall / Window Unit	0.04	0.04	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.04
Other	0.02	0.03	0.03	0.03	0.03	0.04	0.05	0.10	0.13	0.19
None	0.14	0.14	0.13	0.13	0.13	0.11	0.11	0.11	0.10	0.07
Missing	0.39	0.37	0.34	0.36	0.34	0.34	0.34	0.29	0.31	0.29
Heating System										
Forced Air	0.82	0.85	0.91	0.91	0.93	0.92	0.90	0.86	0.85	0.74
Baseboard	0.04	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00
Heat Pump	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03
Wall Furnace	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00
Other	0.12	0.09	0.06	0.06	0.05	0.06	0.07	0.13	0.13	0.22
Fuel Type										
Gas	0.64	0.69	0.75	0.75	0.78	0.78	0.79	0.74	0.74	0.65
Electric	0.17	0.13	0.09	0.09	0.08	0.08	0.10	0.12	0.12	0.13
Electric and Gas	0.11	0.11	0.10	0.11	0.10	0.11	0.10	0.11	0.09	0.14
Other	0.09	0.08	0.07	0.05	0.04	0.03	0.02	0.03	0.04	0.08
Observations	4,036	2,362	3,174	4,046	3,499	2,823	2,097	1,614	821	576
(%)	(16)	(9)	(13)	(16)	(14)	(11)	(8)	(6)	(3)	(2)

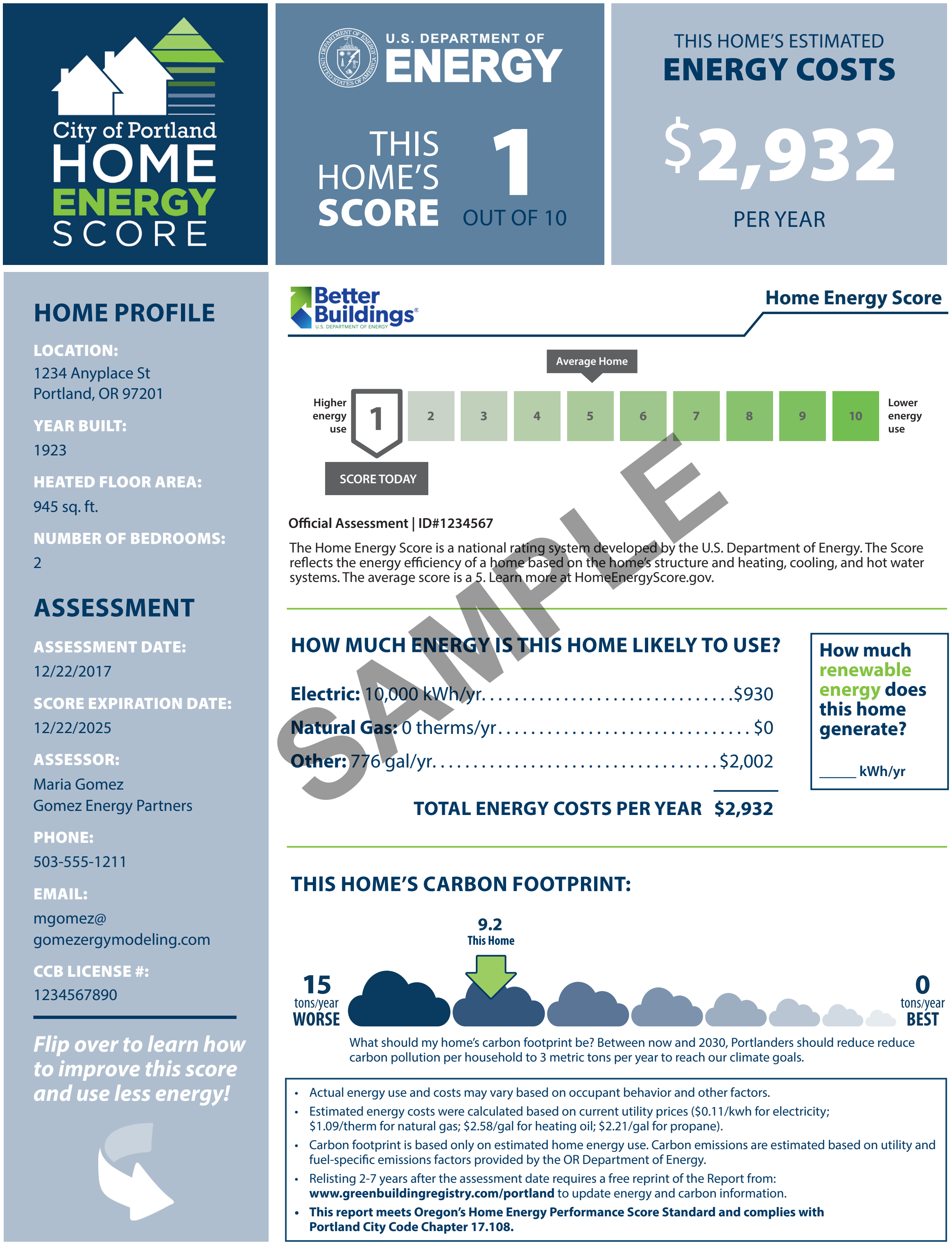
Notes: The table reports the mean (standard deviation in parentheses) of housing attributes for homes transacted in Portland with a home energy score assessment from 2018 to 2021, separated by the home energy score, a discrete metric (1-10), indicating the energy efficiency level of a home. A more efficient home receives a higher score.

Table 2: Summary Statistics: Housing Attributes by Disclosure Status

	Disclose Home Energy Score					
	Obtain			Publish		
Attribute	Yes	No	p-value	Yes	No	p-value
Home Energy Score	4.38	—	—	4.44	4.21	<0.01
	(2.42)	—		(2.42)	(2.39)	
Sales Price	585,801	636,372	<0.01	586,366	584,317	0.59
	(264,112)	(337,164)		(259,822)	(275,077)	
Year of Construction	1949	1969	<0.01	1949	1950	0.12
	(49)	(87)		(44)	(62)	
Bedrooms	3.22	3.53	<0.01	3.21	3.24	0.01
	(0.90)	(0.98)		(0.89)	(0.91)	
Full Baths	1.85	2.12	<0.01	1.85	1.86	0.23
	(0.77)	(0.83)		(0.77)	(0.76)	
Total Sqft	2,096	2,303	<0.01	2,102	2,079	0.08
	(922)	(1,040)		(925)	(913)	
Levels	2.09	1.96	<0.01	2.11	2.04	<0.01
	(0.79)	(0.71)		(0.80)	(0.79)	
Garages	1.17	1.62	<0.01	1.16	1.22	<0.01
	(0.83)	(0.92)		(0.82)	(0.86)	
Acres	0.16	0.29	<0.01	0.16	0.17	0.04
	(0.23)	(1.26)		(0.23)	(0.21)	
Property Condition						
New	0.02	0.12	<0.01	0.02	0.03	<0.01
Fixer	0.03	0.05	<0.01	0.03	0.04	<0.01
Remodel	0.24	0.18	<0.01	0.24	0.23	0.63
Restored	0.03	0.01	<0.01	0.03	0.03	0.01
Other	0.68	0.64	<0.01	0.69	0.67	0.01
Cooling System						
Central Air	0.40	0.48	<0.01	0.40	0.39	0.06
Heat Pump	0.05	0.05	0.25	0.05	0.04	<0.01
Wall / Window Unit	0.03	0.02	<0.01	0.03	0.04	0.01
Other	0.04	0.08	<0.01	0.04	0.05	0.08
None	0.12	0.08	<0.01	0.12	0.13	0.39
Missing	0.35	0.29	<0.01	0.35	0.35	0.28
Heating System						
Forced Air	0.88	0.89	<0.01	0.89	0.88	0.06
Baseboard	0.02	0.02	0.24	0.02	0.02	0.05
Heat Pump	0.01	0.01	0.98	0.01	0.01	0.57
Wall Furnace	0.01	0.01	0.73	0.01	0.01	0.69
Other	0.08	0.07	<0.01	0.08	0.08	0.37
Fuel Type						
Gas	0.73	0.74	0.49	0.74	0.71	<0.01
Electric	0.11	0.11	0.50	0.11	0.12	0.021
Electric and Gas	0.11	0.11	0.10	0.10	0.11	<0.01
Other	0.05	0.05	0.006	0.05	0.06	0.28
Observations	25,048	14,391		18,142	6,906	
(%)	(64)	(36)		(72)	(28)	

Notes: The table reports the mean (standard deviation in parentheses) of housing attributes for homes transacted in Portland from 2018 to 2021, separated by disclosure status.

Figure 1: Home Energy Score Assessment



City of Portland HOME ENERGY SCORE

U.S. DEPARTMENT OF ENERGY

THIS HOME'S SCORE 1 OUT OF 10

THIS HOME'S ESTIMATED ENERGY COSTS

$2,932 PER YEAR

HOME PROFILE

LOCATION:
1234 Anyplace St
Portland, OR 97201

YEAR BUILT:
1923

HEATED FLOOR AREA:
945 sq. ft.

NUMBER OF BEDROOMS:
2

ASSESSMENT

ASSESSMENT DATE:
12/22/2017

SCORE EXPIRATION DATE:
12/22/2025

ASSESSOR:
Maria Gomez
Gomez Energy Partners

PHONE:
503-555-1211

EMAIL:
mgomez@
gomezergymodeling.com

CCB LICENSE #:
1234567890

Flip over to learn how to improve this score and use less energy!

Better Buildings U.S. DEPARTMENT OF ENERGY

Home Energy Score

Average Home

Higher energy use | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Lower energy use

SCORE TODAY

SAMPLE

Official Assessment | ID#1234567

The Home Energy Score is a national rating system developed by the U.S. Department of Energy. The Score reflects the energy efficiency of a home based on the home's structure and heating, cooling, and hot water systems. The average score is a 5. Learn more at HomeEnergyScore.gov.

HOW MUCH ENERGY IS THIS HOME LIKELY TO USE?

Electric: 10,000 kWh/yr. $930
Natural Gas: 0 therms/yr. $0
Other: 776 gal/yr. $2,002

TOTAL ENERGY COSTS PER YEAR $2,932

How much renewable energy does this home generate?

_____ kWh/yr

THIS HOME'S CARBON FOOTPRINT:

9.2 This Home

15 tons/year WORSE

0 tons/year BEST

What should my home's carbon footprint be? Between now and 2030, Portlanders should reduce reduce carbon pollution per household to 3 metric tons per year to reach our climate goals.

- Actual energy use and costs may vary based on occupant behavior and other factors.
- Estimated energy costs were calculated based on current utility prices ($0.11/kwh for electricity; $1.09/therm for natural gas; $2.58/gal for heating oil; $2.21/gal for propane).
- Carbon footprint is based only on estimated home energy use. Carbon emissions are estimated based on utility and fuel-specific emissions factors provided by the OR Department of Energy.
- Relisting 2-7 years after the assessment date requires a free reprint of the Report from: **www.greenbuildingregistry.com/portland** to update energy and carbon information.
- **This report meets Oregon's Home Energy Performance Score Standard and complies with Portland City Code Chapter 17.108.**

Score today:	Score with improvements:*	Estimated **energy savings** with improvements:	Estimated **carbon reduction** with improvements:
1	**9**	**$1,672** PER YEAR	**57%** PER YEAR

TACKLE ENERGY WASTE TODAY!

Enjoy the rewards of a comfortable, energy efficient home that saves you money.

- [x] Get your home energy assessment. Done!
- [ ] Choose energy improvements from the list of recommendations below.

  Need help deciding what to do first? Non-profit Enhabit offers free 15-minute phone consults with expert home advisors. Call 855-870-0049.
- [ ] Select a contractor (or two, for comparison) and obtain bids.

  Checkout **www.energytrust.org/findacontractor** or call toll free **1-866-368-7878**.
- [ ] Explore financing options at **www.enhabit.org** or **www.energytrust.org**.

* PRACTICAL ENERGY IMPROVEMENTS | COMPLETE NOW OR LATER

To achieve the "score with improvements," all recommended improvements listed below must be completed. Improvements all have a simple payback of ten years or less and may be eligible for mortgage financing. For a more detailed explanation of costs and payback, please get a bid from a contractor.

FEATURE	TODAY'S CONDITION	RECOMMENDED IMPROVEMENTS
Attic insulation	Ceiling insulated to R-0	Insulate to R-38 or R-49 if code requires it
Attic insulation	Ceiling insulated to R-19	Insulate to R-38 or R-49 if code requires it
Duct insulation	Un-insulated	Insulate to R-8
Duct sealing	Un-sealed	Reduce leakage to a maximum of 10% of total airlfow
Envelope/Air Sealing	Not professionally air sealed	Professionally air seal
Heating Equipment	Oil furnace 60% AFUE	Upgrade to ENERGY STAR
Heating Equipment	Natural Gas/Propane Furnace	Upgrade to ENERGY STAR
Wall insulation	Insulated to R-0	Fully insulate wall cavities
Water Heater	Standard electric tank	Upgrade to ENERGY STAR, minimum 2.76 EF (Energy Factor)
Windows	Multiple types	Upgrade to ENERGY STAR
Air Conditioner	None	
Basement wall insulation	None	
Floor insulation	Insulated to R-0	
Foundation wall insulation	None	
Skylights	None	
Cathedral ceiling	None	
Solar PV	None	Visit www.energytrust.org/solar to learn more

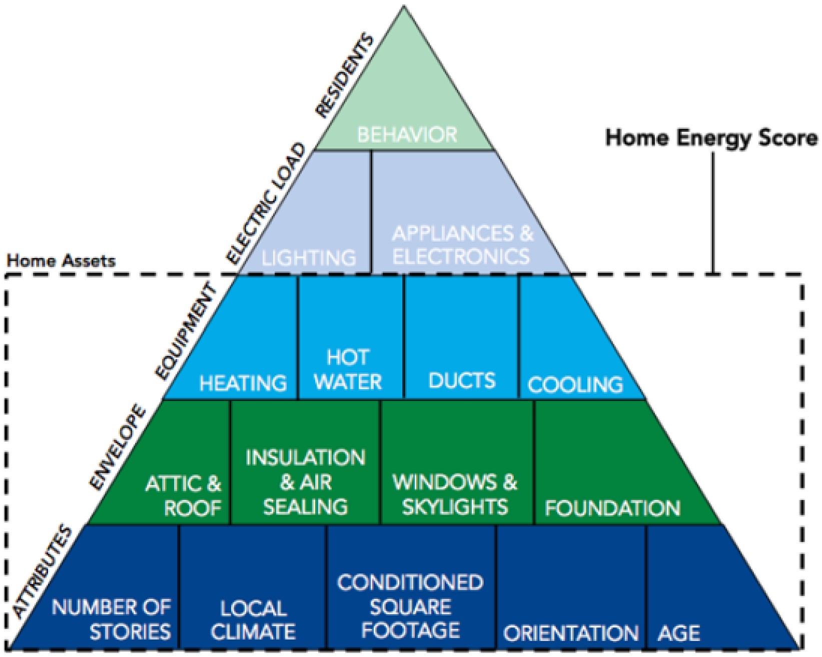
YOU CAN DO IT YOURSELF!

Looking for low-cost ways to cut energy waste, boost your comfort and lower your energy bills? Visit the resources below to learn about easy changes you can make today:

www.energytrust.org/tips and **www.communityenergyproject.org/services**

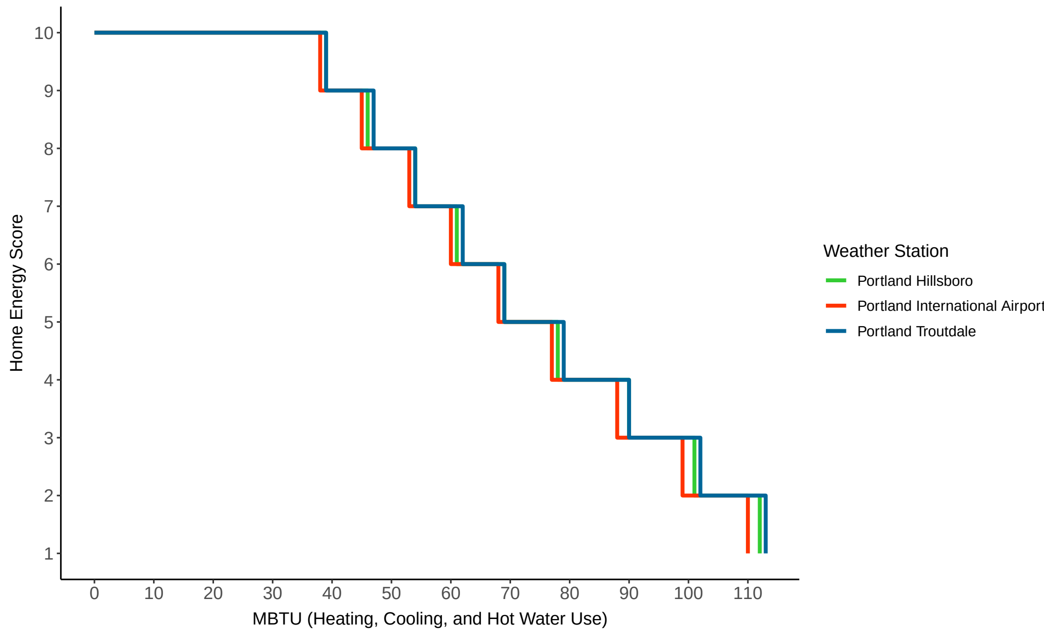
Notes: The figure presents a sample report from the home energy score assessment.

Figure 2: Home Energy Score Assets



Notes: The figure presents the home assets associated with the home energy score (see US Department of Energy, 2017). About 50 home assets go into the calculation of the score.

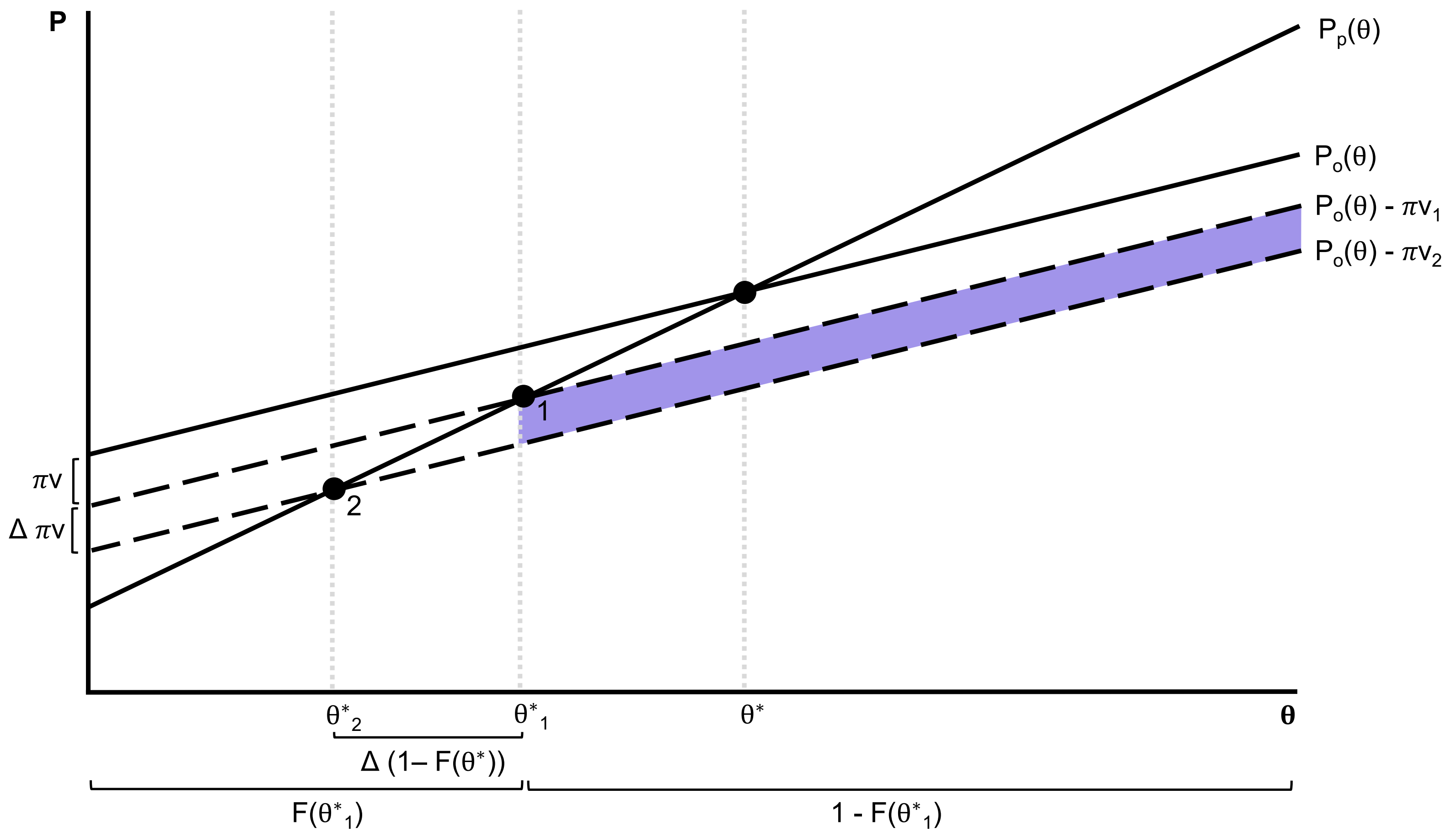
Figure 3: Home Energy Score Thresholds



Notes: The figure plots the mapping of the home energy score from expected annual energy consumption for heating, cooling, and hot water use (MBTU). The thresholds vary by weather station, accounting for regional climatic conditions. The majority of homes with a home energy score assessment (86 percent) are located within the Portland International Airport weather station.

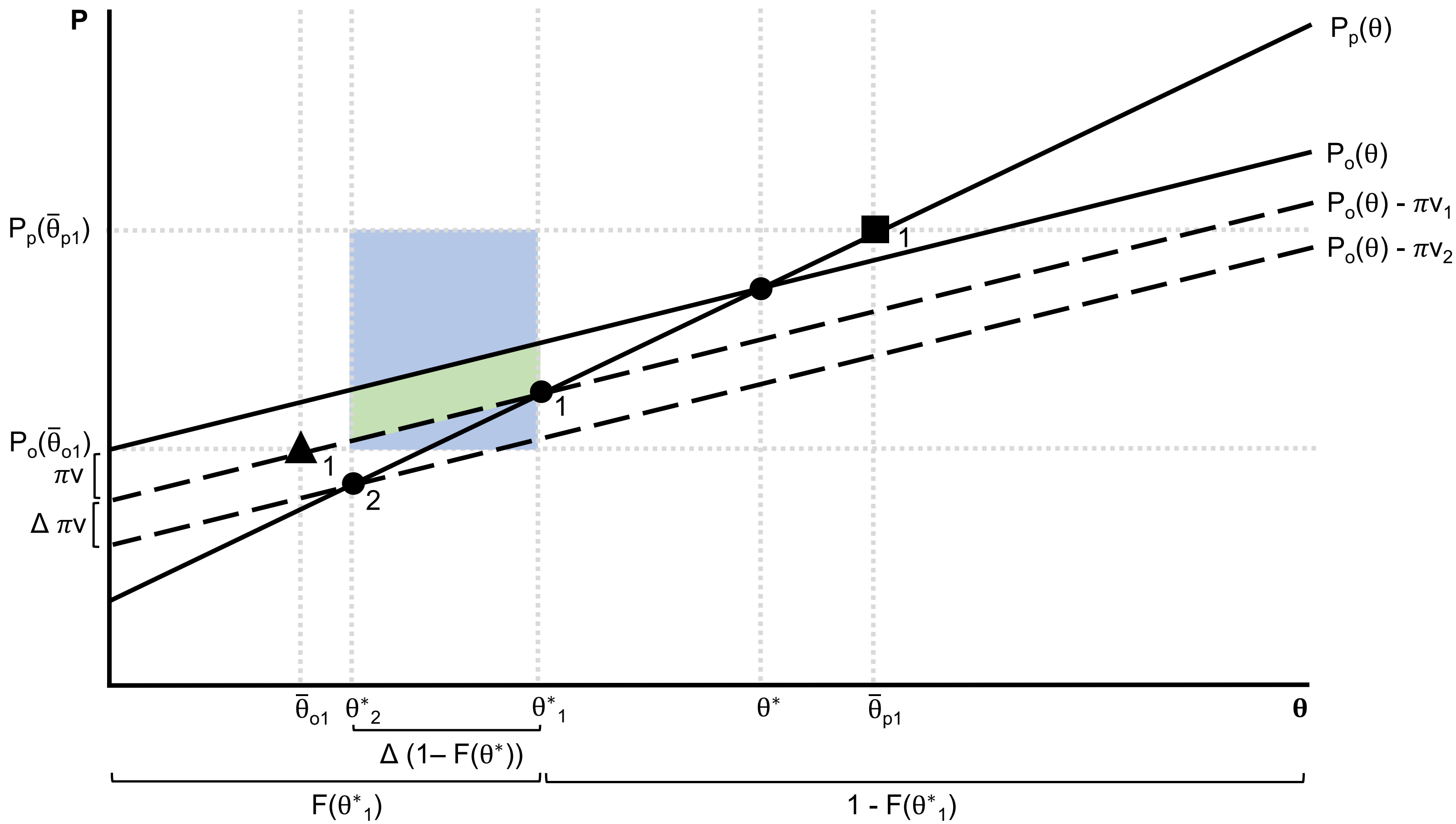
Figure 4: Effects from a Change in the Expected Cost of Non-Compliance

(a) Direct Effect



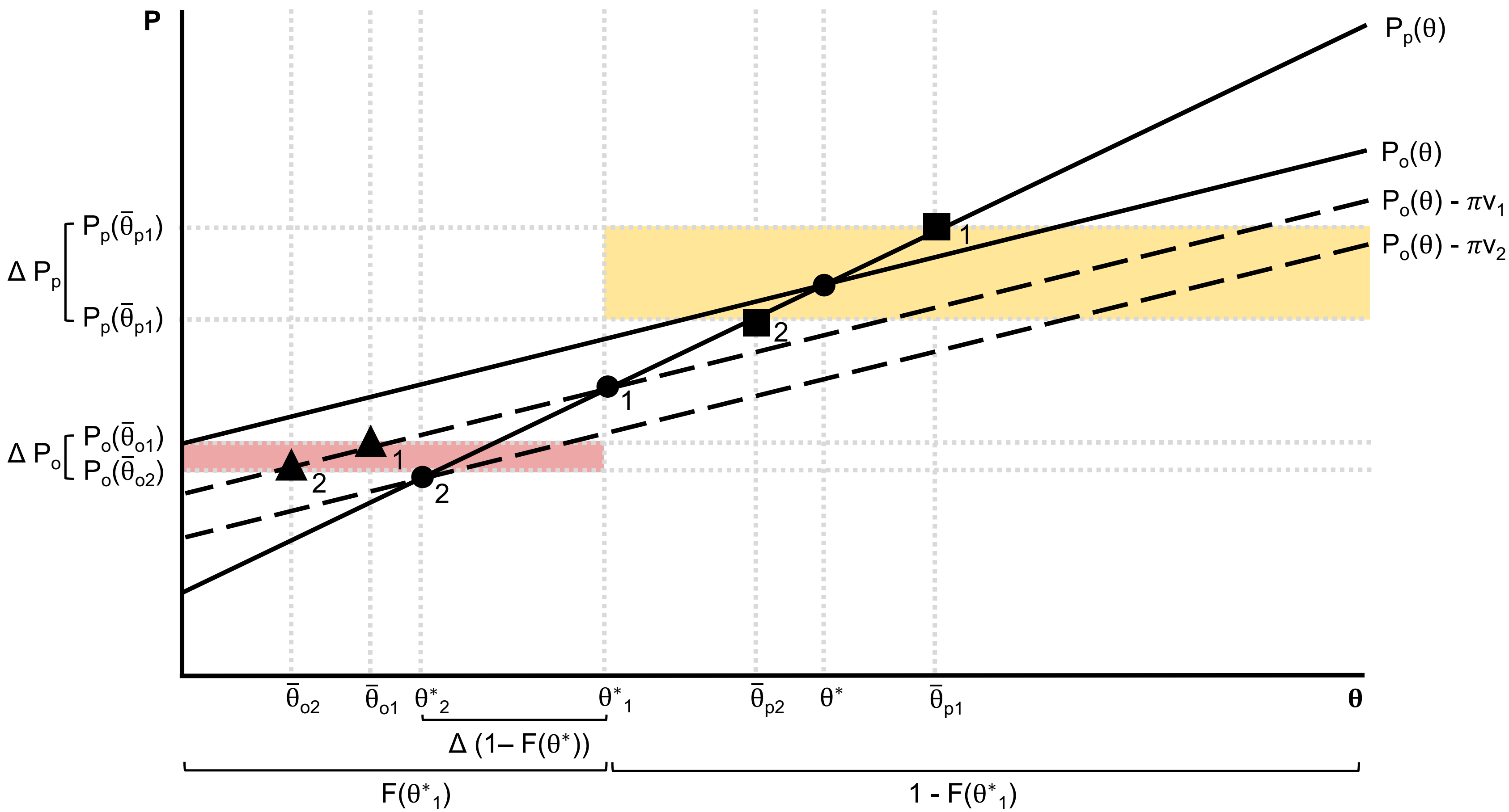
Notes: The figure illustrates the direct effect. The purple shaded area measures the change in avoided cost of non-compliance, weighted by the initial probability of publishing the assessment. This area is positive

(b) Publish Effect



Notes: The figure illustrates the publish effect. The green shaded area measures the change in the probability of publishing the assessment in terms of avoided costs. Meanwhile, the blue shaded area measures the change in the probability of publishing the assessment in terms of the price gap in expected prices. Both of these areas are positive.

(c) Price Effect



Notes: The figure illustrates the price effect. The red and yellow shaded areas measure the change in expected prices, weighted by the initial probabilities. Both of these shaded areas are negative.

Appendix: Theory

In this section, I derive the comparative static for the expected cost of non-compliance in stage 1 where a seller decides whether to obtain an assessment. The following information is used to determine the sign of the the comparative static:

1. $\dfrac{\partial \theta^*}{\partial \pi v} < 0$ (This result is derived in stage 2)
2. $\dfrac{\partial (1 - F(\theta^*))}{\partial \theta^*} < 0$ (By definition of the CDF)
3. $\dfrac{\partial P_o(\bar{\theta}_o)}{\partial \bar{\theta}_o} > 0$ and $\dfrac{\partial P_p(\bar{\theta}_p)}{\partial \bar{\theta}_p} > 0$ (Since $P_o(\theta)$ and $P_p(\theta)$ are increasing functions)
4. $\dfrac{\partial \bar{\theta}_o}{\partial \theta^*} > 0$ and $\dfrac{\partial \bar{\theta}_p}{\partial \theta^*} > 0$ (By definition of the conditional expectation)

Comparative static for the expected cost of non-compliance (πv):

$$
\begin{aligned}
\frac{\partial LHS}{\partial \pi v} = \quad & F(\theta^*)\frac{\partial P_o(\bar\theta_o)}{\partial \bar\theta_o}\frac{\partial \bar\theta_o}{\partial \theta^*}\frac{\partial \theta^*}{\partial \pi v} + P_o(\bar\theta_o)\frac{\partial F(\theta^*)}{\partial \theta^*}\frac{\partial \theta^*}{\partial \pi v} \quad + \\
& (1-F(\theta^*))\frac{\partial P_p(\bar\theta_p)}{\partial \bar\theta_p}\frac{\partial \bar\theta_p}{\partial \theta^*}\frac{\partial \theta^*}{\partial \pi v} + P_p(\bar\theta_p)\frac{\partial(1-F(\theta^*))}{\partial \theta^*}\frac{\partial \theta^*}{\partial \pi v} \quad + \\
& (1-F(\theta^*))\frac{\pi v}{\partial \pi v} + \pi v\frac{\partial(1-F(\theta^*))}{\partial \theta^*}\frac{\partial \theta^*}{\partial \pi v} \\
= \quad & \underbrace{(1-F(\theta^*))}_{\text{“Direct Effect”}} + \\
& \underbrace{\frac{\partial(1-F(\theta^*))}{\partial \theta^*}\frac{\partial \theta^*}{\partial \pi v}\Big[P_p(\bar\theta_p) - P_o(\bar\theta_o) + \pi v\Big]}_{\text{“Publish Effect”}} \quad + \\
& \underbrace{F(\theta^*)\Big[\frac{\partial P_o(\bar\theta_o)}{\partial \bar\theta_o}\frac{\partial \bar\theta_o}{\partial \theta^*}\frac{\partial \theta^*}{\partial \pi v}\Big] \quad + \quad (1-F(\theta^*))\Big[\frac{\partial P_p(\bar\theta_p)}{\partial \bar\theta_p}\frac{\partial \bar\theta_p}{\partial \theta^*}\frac{\partial \theta^*}{\partial \pi v}\Big]}_{\text{“Price Effect”}} \\
= \quad & \underbrace{(+)}_{\text{“Direct Effect”}} \quad + \\
& \underbrace{(-)(-)\Big[(+) - (+) + (+)\Big]}_{\text{“Publish Effect”}} \quad + \\
& \underbrace{(+)\Big[(+)(+)(-)\Big] + (+)\Big[(+)(+)(-)\Big]}_{\text{“Price Effect”}}
\end{aligned}
$$

$$\text{Since } P_p(\bar\theta_p) > P_o(\bar\theta_o) \text{ then } P_p(\bar\theta_p) - P_o(\bar\theta_o) > 0$$

$$
\begin{aligned}
= \quad & \underbrace{(+)}_{\text{“Direct Effect”}} \quad + \quad \underbrace{(+)}_{\text{“Publish Effect”}} \quad + \quad \underbrace{(-)}_{\text{“Price Effect”}} \\
\gtreqless \quad & 0
\end{aligned}
$$