Work Session WS

Milwaukie City Council

CITY OF MILWAUKIE

COUNCIL WORK SESSION

City Hall Council Chambers
10722 SE Main Street
www.milwaukieoregon.gov

AGENDA

JANUARY 7, 2020

Note: times are estimates and are provided to help those attending meetings know when an agenda item will be discussed. Times are subject to change based on Council discussion.

Page #

1. **Banking Services Request for Proposals (RFP) – Discussion** (4:00 p.m.) — **4**
   Staff: Keith McClung, Assistant Finance Director, and
   Kelli Tucker, Accounting and Contracts Specialist

2. **Home Energy Score (HES) – Discussion (continued)** (4:30 p.m.) — **7**
   Staff: Peter Passarelli, Public Works Director, and
   Natalie Rogers, Climate Action and Sustainability Coordinator

3. **HereTogether Strategic Framework – Report** (5:00 p.m.)
   Presenter: Cole Merkel, HereTogether Oregon

4. **Adjourn** (5:30 p.m.)

Americans with Disabilities Act (ADA) Notice

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Executive Sessions

The City Council may meet in Executive Session pursuant to ORS 192.660(2); all discussions are confidential and may not be disclosed; news media representatives may attend but may not disclose any information discussed. Executive Sessions may not be held for the purpose of taking final actions or making final decisions and are closed to the public.

Meeting Information

Times listed for each Agenda Item are approximate; actual times for each item may vary. Council may not take formal action in Study or Work Sessions. Please silence mobile devices during the meeting.

CITY OF MILWAUKIE

Memorandum

To: City Council
From: Planning Director Denny Egner
CC: City Manager Ann Ober & Community Development Director Leila Aman
Date: Thursday, January 2, 2020
Re: Community Development and Engineering Department Projects - City Council Update for January 7, 2020 Council meeting

Community Development/Housing/Economic Development	**Building**
▪ CET Oversight Group ▪ City Hall ▪ Current City Hall ▪ Pond House	▪ No update - November and December 2019 in review to come
Planning ▪ Comprehensive Plan ▪ Land Use/Development Review: • City Council • Planning Commission ▪ Design and Landmarks Committee	**Engineering** ▪ CIP Projects

COMMUNITY DEVELOPMENT/ECONOMIC DEVELOPMENT/HOUSING

CET Oversight Group

- The group is scheduled to meet on January 13th. Council will receive an update on the group's recommended criteria at the work session on January 21st.

City Hall

- On December 17th, the Council gave the City manager the authority to finalize the purchase and sale agreement for 10501 SE Main Street.

Current City Hall

- Staff will return to Council on January 7th, 2020 to discuss committee structure for repurposing the existing City Hall.

Pond House

- Staff has issued Request for Bids for the purchase of the Pond House. Bid deadline is Friday, January 31, 2020 at 12:30 p.m. More information about the Pond House and instructions on how to submit a bid to purchase the property visit Milwaukie Bid Management System, http://bids.milwaukieoregon.gov/.

PLANNING

Comprehensive Plan Update

- The format and layout of the draft Comprehensive Plan document was reviewed by the Planning Commission (December 10), Comprehensive Plan Advisory Committee (December 16), and City Council (December 17). Staff will incorporate comments and proposed edits into the public hearing version of the document.
- The first Planning Commission public hearing to review and make a recommendation to Council on the updated Comprehensive Plan policy document is scheduled January 14, 2020. Public comments are now being accepted and will be provided to the Commission for consideration at the hearing. City Council is tentatively scheduled to hold their first public hearing to consider the Commission's recommendation on March 3, 2020.

Land Use/Development Review

City Council

- On December 17, the City Council held a continued public hearing (AP-2019-003) on an appeal of the Planning Commission's decision to deny a proposed 12-unit natural resource cluster development west of SE 19th Ave in the Island Station neighborhood (master land use file #NR-2018-005 - Elk Rock Estates). The hearing was continued to February 4 to review an amended application for a total of 5 houses rather than 12.
- ZA-2019-002 – On December 17, the City Council adopted code amendments related to accessory dwelling units (ADUs) to comply with Oregon HB 2001. The code amendments remove the owner occupancy requirement and the requirement for an additional off-street parking space for ADUs.

Planning Commission

- VR-2019-013 – An application for a 4-story mixed-use building at 9391 SE 32nd Ave has been submitted. A Type III variance is required for a 4-story building in the Neighborhood Mixed Use zone. The application has been deemed incomplete.
- On December 17, the Planning Commission met with the City Council to discuss the planning work program for 2020. The Commission and Council agreed that the highest priority should be to update the zoning and subdivision ordinances to implement city housing policies and state law.

Type II Review

- DEV-2019-009 – The application for a 234-unit multifamily development on the site located at 37th Ave and Monroe St is currently under review by staff. Public comments on the project were accepted until noon on December 23.
- R-2019-005 – The proposal to create a new flag lot at 9311 SE 55th Ave was originally filed as a minor land partition (file MLP-2019-004) and later reclassified to a partition replat. The proposal has been approved, with a Notice of Decision issued on December 20, 2019.

Design and Landmarks Committee

- The next regular meeting of the DLC is Monday, January 6, 2020, when the group will continue its work on updating the Downtown Design Review code.
- The annual joint meeting with City Council is scheduled for Tuesday, January 21, 2020.

ENGINEERING

CIP Projects

Meek Stormwater:

- The portion of the project located south of Meek Street will be advertised for bid in January 2020.

McBrod Avenue

- Project will be advertised for bid in January 2020.

Linwood Avenue SAFE:

- The 60% design plans are complete. The second open house will be held Wednesday January 15 from 5 to 7 pm at Linwood Elementary School.

43rd Avenue SAFE:

- 30% open house scheduled for Wednesday January 29 from 5 to 7 pm at Lewelling Elementary School. Cross-section alternatives are in review.

22nd Avenue and River Road SAFE Project:

- A graphic showing the proposed 60% design plan is available on the project webpage for public review. JLA has created a survey to receive public comment that will be available until January 3, 2020 https://www.surveymonkey.com/r/SAFE22ndRiver.

Kronberg Park Multi-Use Walkway:

- All concrete is complete. Currently working on finishing the railing and explanation joints. Landscaping to start in early January. NCPRD is almost complete with the soft path, which includes a lookout site and connects to our walkway. Light poles have shipped and excepted to be installed in early January. Grand opening is scheduled for January 25, 2020 at 1 p.m.

CITY OF MILWAUKIE

WS 1.
1/7/2020
OCR USE ONLY

COUNCIL STAFF REPORT

To: Mayor and City Council
Ann Ober, City Manager

Date Written: Dec. 17, 2019

Reviewed: Bonnie Dennis, Finance Director
Kelli Tucker, Accounting & Contracts Specialist

From: Keith McClung, Assistant Finance Director

Subject: **Selection Criteria for Banking Services**

ACTION REQUESTED

Council is asked to discuss the upcoming formal solicitation for banking services and provide feedback regarding the selection criteria or scoring method.

HISTORY OF PRIOR ACTIONS AND DISCUSSIONS

May 2012: The city issued a request for proposals for banking services.

October 2012: An agreement was executed with Wells Fargo Bank, the most qualified institution to provide banking services.

May 2017: - Council adopted Resolution 52-2017 with three goals for the 2017-2018 biennium, which included Goal 2: Climate Change Action. Council directed the city manager to begin the process of addressing climate change in Milwaukie by creating a climate action plan and working towards reducing the city's carbon impact.

October 2018: Council adopted the Milwaukie Community Climate Action Plan (CAP) outlining the city's strategy and steps towards becoming a net zero energy community by 2040 and reducing greenhouse emissions and fossil fuel utilization within Milwaukie.

April 2019: Council adopted Resolution 26-2019 with three goals for the 2019-2020 biennium, which included Goal 2: Climate Change Mitigation and Resilience Action.

ANALYSIS

The city uses a wide variety of banking services for deposits, disbursements, and safekeeping of public funds. It is known that there are many financial institutions who directly participate in lending activities with oil, gas, and coal companies. As the city prepares to issue a formal solicitation for banking services, staff has considered Council's goals and the city's commitments through its CAP as part of the criteria for evaluating and selecting a financial institution to provide banking services.

Additionally, as a best practice for local governments, the Government Finance Officers Association (GFOA) recommends a periodic review of banking services by issuing a solicitation to evaluate and select a financial institution based on specific criteria. This recommendation aligns with the city's Public Contracting Rules (PCRs), which outlines procedures for a competitive procurement process that is fair and transparent.

Staff will issue a formal solicitation in January 2020 with the objective of selecting a financial institution that provides a full array of banking services and products. Proposals will be due in late February 2020 and a selection panel will evaluate and select the highest ranked proposal. Proposals will be evaluated and scored with the following suggested criteria and weight:

Criteria	Maximum Score
Responsive Proposal	Pass/Fail
Experience, References, and Financial Strength (*company history, public sector clients, credit ratings*)	20 points
Service Understanding and Approach (*key personnel, communication methods, customer support*)	30 points
Pricing (*earnings credit rates, fees, incentives)*	20 points
Corporate Responsibility (*fossil fuel questionnaire*)	30 points
Interview and Presentation	15 points
Total	**115 points**

As part of the proposal criteria, financial institutions will be asked to answer questions regarding the company's corporate responsibility in oil, gas, and coal lending activities. A weighted score will be given to each proposer based on their response and level of involvement. All criteria must be assigned a weight or value factor in order to establish its importance and provide a fair and transparent selection process. It is important to note that the selected financial institution may not be the highest scoring proposer in the corporate responsibility category, as the contract award is given to the highest overall score (based on all scoring criteria).

BUDGET IMPACTS

The annual budget for banking services is approximately $150,000. There is no change or impact to the budget.

WORKLOAD IMPACTS

No additional workload.

COORDINATION, CONCURRENCE, OR DISSENT

The finance department concurs with the recommendation as the solicitation criteria is consistent with Council's climate change action goals.

STAFF RECOMMENDATION

Staff recommends moving forward with the selection criteria and weight (as shown above) and inclusion of the attached Fossil Fuel Questionnaire in the solicitation for banking services.

ALTERNATIVES

Council may suggest alternative weight or value to the solicitation criteria, or other corporate responsibility criteria.

ATTACHMENTS

1. Draft Fossil Fuel Questionnaire

ATTACHMENT 1

This is a preliminary questionnaire. A substantially similar questionnaire will be added to the formal solicitation.

FOSSIL FUEL FINANCING AND GREENHOUSE GAS EMISSIONS QUESTIONNAIRE

Introduction

In 2017, City Council passed a resolution with three primary goals for the 2017-2018 biennium - one of these goals was climate change action. City Council directed the city manager to begin the process of addressing climate change in Milwaukie by creating a climate action plan and working towards reducing the city's carbon impact.

In October 2018, City Council adopted the Milwaukie Community Climate Action Plan, outlining our strategy and steps towards becoming a net-zero building energy community by 2040 and reducing greenhouse emissions and fossil fuel utilization within Milwaukie. By 2050, Milwaukie will be fully "carbon neutral," meaning the city will reduce or offset its carbon emissions entirely, including those from buildings, vehicles and production in the community.

This solicitation has been structured to make progress toward City Council's goals for climate action, while ensuring the city partners with financial institutions that can offer a wide range of banking services to meet the city's operational needs.

The purpose of this questionnaire is to assess the Proposer's involvement in fossil fuel financing, as well as company commitment to the city's Climate Action Plan goals through evaluation of corporate greenhouse gas emission inventories and reduction plans. As a part of the final stage of evaluation, this assessment will serve as a significant factor in selecting a financial institution for general banking and purchase card services. The Proposer with the highest overall score (based on all scoring criteria) will be awarded the contract.

Questions

1. Please describe your institution's involvement in oil, gas and coal lending activities, as well as project specific financing for the past three years by answering the following questions.
   a. If your institution is involved in lending directly to oil, gas and coal companies for exploration, production, refining and/or transportation, please indicate the amount of financing provided to oil, gas and/or coal sectors as a dollar amount and percent of total lending portfolio for the fiscal years 2016, 2017 and 2018. **(10 points)**
   b. Over the past three years, has your institution participated in financing of any specific fossil fuel projects in the pacific northwest region? **(10 points)**
      i. If yes, please list the projects financed and include the total dollar amount and percent of total lending portfolio provided to finance the projects mentioned above.
2. Does your institution perform corporate greenhouse gas emission inventories? If so, please provide for the fiscal years 2016, 2017 and 2018, and include any plans to reduce corporate greenhouse gas emissions. **(10 points)**

CITY OF MILWAUKIE

WS 2.
1/7/2020
OCR USE ONLY

COUNCIL STAFF REPORT

To: Mayor and City Council
Ann Ober, City Manager

Date Written: Dec. 16, 2019

Reviewed: Blanca Marston (as to form), Administrative Specialist

From: Natalie Rogers, Climate Action and Sustainability Coordinator, and
Peter Passarelli, Public Works Director

Subject: **Home Energy Score Program Continued Discussion (Part three)**

ACTION REQUESTED

Council is asked to review additional information from staff regarding regulated parties on a proposed residential energy performance rating and disclosure, or "Home Energy Score" (HES) program and provide guidance or concurrence on a potential program.

HISTORY OF PRIOR ACTIONS AND DISCUSSIONS

October 2, 2018: The Climate Action Plan (CAP) was unanimously adopted by Council.

July 10, 2019: City staff hosted a Milwaukie HES community forum to receive community feedback and answer questions with presentations from the city, Oregon Department of Energy (ODOE), City of Portland, and Earth Advantage.

July 16, 2019: Staff presented an overview of a potential program at the Council work session. Council provided staff initial feedback and questions to explore further.

August 13, 2019: Staff followed up on remaining questions at the Council study session. Council provided staff additional direction and questions.

October 15, 2019: Staff followed up on Council questions and Council provided staff additional direction.

ANALYSIS

In alignment with the CAP, Milwaukie staff presented a residential energy scoring program based on the City of Portland's Home Energy Score Program for potential adoption. Residential energy scoring programs using the US Department of Energy's (US DOE) HES methodology assess and inform homeowners and buyers on the energy efficiency of a residential building, with goals of educating homeowners on building energy efficiency, increasing transparency of the utility and carbon costs of homes, and encouraging the development or retrofitting of energy efficient buildings in the community to reduce community-wide carbon emissions. Recent studies assessing the effects of the City of Austin, Texas' mandatory residential energy scoring program (attached) have shown that their disclosure policy increases the capitalization of energy efficiency into housing transaction practices, and the policy successfully encourages investments in energy efficiency technologies by homeowners, both buyers and sellers. In addition, home buyers are not obtaining full information about a home's respective energy efficiency from other sources besides a disclosure policy, and government intervention addresses incomplete energy performance information in housing transactions. These studies further support that residential energy scoring programs are both a local climate action as well as a consumer protection effort.

Following direction from Council, staff have modified the Portland HES program framework to refine compliance processes, better inform residents, and scale a program to Milwaukie's staff and resource capacity. Staff have modified the draft HES code since originally presented to Council in July to reflect the program changes mentioned below and to change "may" language to "will."

Addition of Disclosure Statements to Scorecard
ODOE has supported Milwaukie's addition of extra disclosure statements to the HES scorecard. The proposed disclosure statements are:

"Trees and exterior building features may provide additional energy efficiency benefits to the building. Visit energy.gov to learn more."

"Additional energy efficient features may be present in the home and were not disclosed at time of Home Energy Score assessment."

Refinement of the disclosure statements may occur as staff work with ODOE to insert them into the scorecards. Scorecards for new buildings will not include the statement about undisclosed energy efficient features, as scorecard space is limited, and no additional improvements should be unknown at time of listing.

Removal of Foreclosure Exemption
Staff have moved forward with Council's guidance on removing foreclosures as an exemption as the foreclosed property is owned by a financial institution, and the original intention of limiting impact on financially distressed residents would not apply. The proposed code reflects this change.

Modification of Compliance Timeline
In previous discussions with Council, staff have received support in modifying the compliance timeline. Portland HES program performs notification of violations at 90 days, with recurring checks and potential fines at 180 days. Milwaukie's proposed HES program will have notification of violations at 30 days, with recurring checks and potential fines at 90 days.

HES Low-Income Assistance Supplemental Program
The city will work with Community Energy Project, a local non-profit specializing in energy efficiency and weatherization outreach, education, and services for low income communities to income qualify and perform assessments for low-income residents. After Council discussions highlighting the discrepancy in the number of residents qualifying for Milwaukie's utility assistance program and the estimated number of housing cost burdened residents stated in the Milwaukie Housing Affordability Strategy (MHAS), staff proposes an increase in the income qualification level for the HES low-income assistance to at or below the 80% median income for the Portland-Vancouver-Hillsboro OR-WA metropolitan statistical area. Income qualification will be performed by Community Energy Project through a self-attestation process, where Community Energy Project will screen residents over the phone before receiving written attestation to income level in person before performing the assessment. This process is performed by other regional agencies and reduces workload for staff and alleviating potential barriers for residents to qualify. Staff anticipate 8-10 low-income assessments will be performed per year based on the City of Portland's utilization. In addition to performing the HES

assessment, Community Energy Project can connect inquiring residents with additional internal and external resources or incentives to improve the energy efficiency of their homes.

Exemptions for sale circumstances, including pre-foreclosures and auction sales, will be processed by city staff internally with residents completing an application and submitting relevant documentation.

Implementation Timeline

If the Milwaukie HES program is adopted by Council in early Winter 2020, staff recommends a start date of October 1, 2020. This is after peak listing months for residential real estate and provides staff time to perform outreach and education in the community. Following program adoption, staff would coordinate internally to ensure secure and efficient pathways are established for exemption documentation and compliance. Staff would work with external partners, including ODOE, Earth Advantage, the Portland Metropolitan Association of Realtors (PMAR), and others to finalize scorecard development with Milwaukie's modifications, develop data processes to automize and link listing and HES services, promote state-level assessor training, provide learning opportunities to the real estate and assessor communities, and develop outreach and education materials for Milwaukie residents. In addition, staff are developing a draft letter for council review that highlights the restrictions for regulation of real estate licensees with the intention of introducing discussion in other regional communities.

BUDGET IMPACTS

Broadening qualifications for low-income assistance may increase utilization of the supplemental program by Milwaukie residents. Staff is proposing $2,500 a year in the draft biennium budget, and while staff predict that amount will meet the community's needs, more funds may be needed in the future if utilization is high.

WORKLOAD IMPACTS

Outsourcing income qualification to Community Energy Project will reduce staff workload impact. Post-adoption program outreach and implementation will require staff time and resources, primarily impacting the climate action and sustainability coordinator's workload.

COORDINATION, CONCURRENCE, OR DISSENT

Staff will continue to coordinate with ODOE, Earth Advantage, City of Portland, Community Energy Project, PMAR, industry assessors, and the city's code compliance team to finalize technology and compliance processes as well as perform post-adoption outreach and education.

STAFF RECOMMENDATION

Staff recommends Council approve the code changes as outlined above and provide staff guidance for any additional recommended program changes.

ALTERNATIVES

1. Council may suggest that staff continue to work with internal and external partners to modify the HES program process and code to fit the Milwaukie community.
2. Council may decline to move forward with an HES program at this time.

ATTACHMENTS

1. Proposed Milwaukie Residential Energy Performance Scoring Code
2. Effects of Mandatory Energy Efficiency Disclosure in Housing Markets (Myers et al. 2019)

3. How Does Mandatory Energy Efficiency Disclosure Affect Housing Prices? (Cassidy 2019)

Chapter 16.40 Residential Energy Performance Rating and Disclosure

16.40.010 Purpose.

The purpose of this chapter is to provide information to homebuyers about residential building energy performance. This information is designed to enable more knowledgeable decisions about the full costs of operating homes and to motivate investments in home improvements that lower utility bills, reduce carbon emissions, and increase comfort, safety, and health for home owners.

16.40.020 Definitions.

For purposes of this Chapter and any rules adopted under this chapter, the following terms have the following meanings.

"Accessory dwelling unit" means a second dwelling on a lot with a single-family detached dwelling. The accessory dwelling unit is incidental to, and smaller than, the primary dwelling on the lot. The accessory dwelling unit may be in a portion of the primary structure on the lot or contained in its own structure apart from the primary structure. The accessory dwelling unit includes its own independent living facilities including provisions for sleeping, cooking, and sanitation and is designed for residential occupancy by one or more people independent of the primary dwelling unit.

"Asset Rating" means a numerical value calculated by a home energy performance score system.

"Covered Building" means any residential structure containing a single dwelling unit or house, regardless of size, on its own lot, or any attached single dwelling unit, regardless of whether it is located on its own lot, where each unit extends from foundation to roof, such as a row house, attached house, common-wall house, duplex, or townhouse. Covered building does not include detached accessory dwelling units, manufactured dwellings, or single dwelling units used solely for commercial purposes.

"City Manager" means the City Manager or their authorized representative, designee, or agent.

"Energy" means electricity, natural gas, propane, steam, heating oil, wood, or other product sold for use in a building, or renewable onsite electricity generation, for purposes of providing heating, cooling, lighting, water heating, or for powering or fueling other end-uses in the building and related facilities.

"Homebuilder" means an individual or business entity building new construction single dwelling unit housing to be listed for sale.

"Home Energy Assessor" means a person who is certified as a home energy assessor by the Oregon Construction Contractors Board to determine home energy performance scores for residential dwelling units.

"Home Energy Performance Report" means the report prepared by a home energy assessor in compliance with Oregon Administrative Rules adopted by Oregon Department of Energy for Oregon Home Energy Score Standard. The Report must include the following information:

1. The home energy performance score and an explanation of the score;
2. An estimate of the total annual energy used in the home in retail units of energy by fuel type;

3. An estimate of the total annual energy generated by onsite solar electric, wind electric, hydroelectric, and solar water heating systems in retail units of energy, by type of fuel displaced by the generation;
4. An estimate of the total monthly or annual cost of energy purchased for use in the covered building in dollars, by fuel type, based on the current average annual retail residential energy price of the utility serving the covered building at the time of the report and the average annual energy prices of nonregulated fuels, by fuel type, as provided by the Oregon Department of Energy;
5. The current average annual utility retail residential energy price in dollars, by fuel type, and the average annual energy prices of nonregulated fuels, by fuel type, provided by the Oregon Department of Energy;
6. At least one comparison home energy performance score that provides context for the range of potential scores. Examples of comparison homes include, but are not limited to, a similar home with Oregon's average energy consumption, the same home built to Oregon energy code, or the same home with certain energy efficiency upgrades;
7. The name of the entity that assigned the home energy performance score and that entity's Oregon Construction Contractors Board license number if such a license is required by law;
8. The date the building energy assessment was performed;
9. For reports that meet all requirements of Oregon Administrative Rules adopted by Oregon Department of Energy for Oregon's Home Energy Performance Score Standard, the statement "This report meets Oregon's Home Energy Performance Score standard" must be included on home energy performance reports; and
10. Any additional "Home Energy Performance Report" or "Home Energy Performance Score" requirements as adopted by the Oregon Department of Energy

"Home Energy Performance Score" means an asset rating that is based on physical inspection of the home or design documents used for the home's construction.

"Home Energy Performance Score System" means a system that incorporates building energy assessment software to generate a home energy performance score and home energy performance report. Examples of home energy performance score systems include, but may not be limited to, the U.S. Department of Energy Home Energy Score or the Home Energy Rating System (HERS).

"House" means a single-family detached dwelling.

"Listed publicly for sale" means listing the covered building for sale by printed advertisement, internet posting, Regional Multiple Listing Service (RMLS) listing, or publicly displayed sign.

"Manufactured dwelling" means a residential trailer, mobile home, or manufactured home meeting ORS 446.003(25) and designed to be used as a year-round residential dwelling. The manufactured dwelling is a structure that is constructed for movement on the public highways, that has sleeping, cooking, and plumbing facilities and that is being used for residential purposes.

"Manufactured home" means a single-family residential structure, as defined in ORS 446.003(25)(a)(C), which includes a Department of Housing and Urban Development (HUD) label certifying that the structure is constructed in accordance with the Manufactured Housing Construction and Safety Standards of 1974 (42 USC Section 5401 et seq.) as amended on August 22, 1981.

"Mobile home" means a manufactured dwelling that was constructed between January 1, 1962, and June 15, 1976, and met the construction requirements of Oregon mobile home law in effect at the time of construction.

"Real estate listings" means any public real estate listing of homes for sale in the city of Milwaukie, by a property owner, representative of a property owner, or by a licensed real estate agent. Real estate listings include any printed advertisement, internet posting, or publicly displayed sign, including but not limited to Regional Multiple Listing Service, Craigslist, Nextdoor and other social media platforms, Redfin, Zillow, Trulia and other third-party listing services. Real estate listings are required to include the Home Energy Performance Score and the Home Energy Performance Report.

"Residential trailer" means a manufactured dwelling that was constructed prior to January 1, 1962.

"Sale" means the conveyance of title to real property as a result of the execution of a real property sales contract. Sale does not include transfer of title pursuant to inheritance, involuntary transfer of title resulting from default on an obligation secured by real property, change of title pursuant to marriage or divorce, condemnation, or any other involuntary change of title affected by operation of law.

"Seller" means any of the following: Any individual or entity possessing title to a property that includes a covered building, the association of unit owners responsible for overall management in the case of a condominium, or other representative body of the jointly-owned building with authority to make decisions about building assessments and alterations

"Single-family detached dwelling" means a structure, or manufactured home, containing one dwelling unit with no structural connection to adjacent units.

16.40.030 Authority of City Manager.

A. The City Manager is authorized to administer and enforce this chapter's provisions.

B. The City Manager is authorized to adopt procedures and forms to implement this chapter's provisions.

16.40.040 Energy Performance Rating and Disclosure for Covered Buildings.

Prior to publicly listing any covered building for sale, the seller of a covered building, or the seller's designated representative, must:

A. Obtain a home energy performance report of such building from a state licensed home energy assessor, and;

B. Provide a copy of the home energy performance report:

1. To all licensed real estate agents working on the seller's behalf; and

2. To prospective buyers who visit the home while it is listed publicly for sale; and

C. Maintain a copy of the home energy performance report available for review by City Manager upon request for quality assurance and evaluation of policy compliance.

D. Include the Home Energy Performance Score in all real estate listings, including the Home Energy Performance Report if attachments are accepted by the listing service.

116.40.050 Exemptions and Waivers.

A. The City Manager will exempt a seller from the requirements of this chapter if the seller submits documentation that the covered building will be sold through of any of the following:

1. A trustee's sale;

2 A deed-in-lieu of foreclosure sale; or

3. Any pre-foreclosure sale in which seller has reached an agreement with the mortgage holder to sell the property for an amount less than the amount owed on the mortgage.

B. The City Manager may exempt a seller from the requirements of this chapter after confirming that compliance would cause undue hardship for the seller under the following circumstances:

1. The covered building qualifies for sale at public auction or acquisition by a public agency due to arrears for property taxes;

2. A court appointed receiver is in control of the covered building due to financial distress;

3. The senior mortgage on the covered building is subject to a notice of default;

4. The covered building has been approved for participation in Oregon Property Tax Deferral for Disabled and Senior Citizens, or equivalent program as determined by the City Manager; or

5. The responsible party is otherwise unable to meet the obligations of this chapter as determined by the City Manager.

C. To the extent that city funds are available, the City Manager may exempt a seller from the assessment fee when the seller participates in the Milwaukie Home Energy Score Low-Income Assistance program by demonstrating household income that is at or below 80 percent of median household income for the Portland-Vancouver-Hillsboro, OR-WA Metropolitan Statistical Area;

16.40.060 Enforcement and Penalties.

A. It is a violation of this chapter for any person to fail to comply with the requirements of this section or to misrepresent any material fact in a document required to be prepared or disclosed by this chapter.

B. Any building owner or person who does not comply with the provisions of this chapter will be subject to the following:

1. Upon the first violation, the City Manager may issue a written warning notice to the entity or person, describing the violation and steps required to comply.

2. If the violation is not remedied within 30 days after issue of written warning notice, the City Manager may assess a civil penalty of up to $500. For every subsequent 90-day period during which the violation continues, the City Manager may assess additional civil penalties of up to $500.

C. The City may use the provisions of Milwaukie Municipal Code Chapter 1.08 to enforce this chapter.

ATTACHMENT 2

E2e Working Paper 044

Effects of Mandatory Energy Efficiency Disclosure in Housing Markets

Erica Myers, Steven Puller, and Jeremy West

October 2019

This paper is part of the E2e Project Working Paper Series.

E2e is a joint initiative of the Energy Institute at Haas at the University of California, Berkeley, the Center for Energy and Environmental Policy Research (CEEPR) at the Massachusetts Institute of Technology, and the Energy Policy Institute at Chicago, University of Chicago. E2e is supported by a generous grant from The Alfred P. Sloan Foundation.

Effects of Mandatory Energy Efficiency Disclosure in Housing Markets

Erica Myers[a,d]* Steven L. Puller[b,d,e] Jeremy West[c,d]

[a]University of Illinois at Urbana-Champaign
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[d]The E2e Project
[e]NBER

October 2019

Abstract

Mandatory disclosure policies are increasingly prevalent despite sparse evidence that they improve market outcomes. We study the effects of requiring home sellers to provide buyers with certified audits of residential energy efficiency. Using similar nearby homes as a comparison group, we find this requirement increases price capitalization of energy efficiency and encourages energy-saving residential investments. We present additional evidence characterizing the market failure as symmetrically incomplete information, which is ameliorated by government intervention. More generally, we formalize and provide empirical support for seller ignorance as a motivation for disclosure policies in markets with bilaterally incomplete information about quality.

JEL: Q48, K32, R31, D83

Keywords: disclosure policy evaluation, energy efficiency, real estate markets

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1 Introduction

Government-mandated information disclosure is increasingly used as a policy intended to improve the ability of consumers to make optimal decisions in the face of imperfect information about product quality. Policymakers view disclosure requirements as a lower-cost and less-intrusive means of improving market efficiency compared to alternative forms of regulation. As a result, such requirements are a significant policy component in many economic sectors including health care, education, and finance, among others (Hastings and Weinstein, 2008; Bollinger et al., 2011; Seira et al., 2017).[1] In theory, mandatory disclosure should improve the quality of goods and services by correcting for information-related market failures. In practice, the literature finds minimal evidence supporting the efficacy of disclosure programs at improving market outcomes (see Winston, 2008; Loewenstein et al., 2014; Ho et al., 2019). Reconciling the theoretical guidance with the empirical evidence necessitates an improved characterization of *which* information frictions are effectively corrected by disclosure mandates, so that policies can be better-targeted to address market failures.

This paper focuses on one setting where mandated disclosure may play a crucial role: investment in energy efficiency in housing markets. Prominent analyses such as McKinsey & Company (2009) point to substantial unexploited investment opportunities that would pay for themselves through energy savings within a short period, encouraging global climate mitigation plans to depend on energy efficiency to deliver more than forty percent of targeted emissions reductions (International Energy Agency, 2015). Towards this end, numerous jurisdictions have enacted mandatory residential energy efficiency audit and disclosure requirements in recent years, including many European countries, at least ten states in the U.S., and dozens of municipalities.[2]

The success of these programs in combating climate change ultimately depends on their ability to exploit cost-effective opportunities to improve energy efficiency, which in turn depends on the underlying market failure. If the "Energy Efficiency Gap" in residential investments is primarily attributable to behavioral or information-driven market frictions, then

[1]Several United States policies with mandatory disclosure requirements include the (1) Patient Protection and Affordable Care Act, (2) No Children Left Behind initiative, (3) Credit Card Accountability Responsibility and Disclosure Act, (4) Dodd-Frank Wall Street Reform, and (5) Consumer Protection Act.

[2]For example, the Oregonian (January, 5, 2018) states that Portland's policy "...is intended to give buyers a better idea of maintenance costs in the long run." Programs in Massachusetts and Austin, Texas are also motivated by a desire to increase residential energy efficiency investments. The Boston Globe (April 23, 2018) wrote that Massachusetts' program "could spur consumers to replace their windows or seal their doors, for example, reducing energy consumption." And, Austin Energy's website states that, "ECAD promotes energy efficiency by identifying potential energy savings in homes, businesses and multifamily properties."

mandatory audit and disclosure policies are poised to yield substantial benefits (Gillingham et al., 2009; Allcott and Greenstone, 2012; Gerarden et al., 2017). In contrast, if the perceived under-investment is simply because realized savings from energy efficiency programs often fall short of engineering projections, then disclosure policies will be largely ineffective at improving quality (c.f. Davis et al., 2014; Levinson, 2016; Allcott and Greenstone, 2017; Fowlie et al., 2018; Davis et al., 2019).

Our study examines the Energy Conservation Audit and Disclosure (ECAD) ordinance in Austin, Texas. As with similar disclosure policies, this law stipulates that home sellers must provide a standardized report of a certified technical audit of their properties' energy efficiency to prospective buyers. Our empirical setting and administrative data enable us to make two unique contributions. First, we identify a market failure that contributes to under-provision of information and under-investment in energy efficiency, such that an audit and disclosure program may be welfare-enhancing. We show that it appears to be a symmetric lack of information, i.e. ignorance about product quality on the part of both buyers *and* sellers, that is a barrier to voluntary disclosure of residential energy efficiency in housing transactions. Second, our study is one of the first to our knowledge to find credibly-identified evidence of product quality improvements resulting from *any* disclosure policy.

We identify the effects of this disclosure program by comparing homes sold in Austin to similar homes located just outside of the city limits but sold on the same real estate market and serviced by the same energy utility. We provide supporting evidence for this counterfactual; these homes are similar in their relevant attributes and we demonstrate that the jurisdictions exhibit parallel pre-policy trends for our outcomes of interest. For years spanning the policy's implementation and for areas both inside of and adjacent to Austin city limits, we use property-level data on housing transaction prices and characteristics, monthly electricity billing data, energy efficiency program participation, and technical information contained in the ECAD audit reports.

First, we estimate the effects of the ECAD disclosure program on the capitalization of energy efficiency into home prices and on homeowners' decisions to invest in energy efficiency. We use a panel fixed effects model including property fixed effects and a rich set of controls for local housing market shocks that might be correlated both with homes' energy efficiency and with the regression outcomes. We show that the policy significantly increases the capitalization of energy efficiency into housing transaction prices. This suggests that home purchasers are not obtaining full information about homes' respective energy efficiency from other sources in the absence of a disclosure policy. Next, we show that the policy successfully encourages investments in energy efficiency technologies by homeowners. Of note, we find that the policy increases investments made by both sellers and by home buyers.

We then explore the economic mechanism(s) underlying the effects we estimate for the disclosure policy. One interesting feature of our setting is that while the ECAD program is officially mandatory for all encompassed property sales, in practice few resources are dedicated to enforcement and compliance is incomplete (about 60 percent of targeted homes comply).[3] Therefore, we can leverage property owners' decisions of whether to comply with the program to explore pre-existing market failures that ECAD helps to correct. Voluntary disclosure theory would predict an "unraveling" effect from the highest quality sellers to the lowest (Grossman, 1981; Milgrom, 1981).[4] However, contrary to the theoretical prediction that the highest-quality sellers should be those most likely to disclose, we show that ECAD disclosure propensity varies little across the energy efficiency distribution of homes sold inside of Austin post-policy. That is, we find little evidence of an unraveling effect in this market, despite significant financial stakes associated with quality disclosure via policy compliance.

We examine several plausible explanations for the weak relationship between home sellers' relative energy efficiency and their likelihood of disclosure. First, we note that this pattern is not driven simply by seller ignorance about ECAD requirements. All sales in our sample are brokered through realtors, who are well-informed of the policy and whose financial incentives complement those of their home-selling clients. Moreover, the relationship is also not attributable to some realtors consistently complying while others consistently do not; instead, we find that the disclosure propensity across realtors follows a bell-shaped distribution. We additionally show that compliance is not attributable to buyers asking for the audit information, which could drive the flat relationship if the requests come from prospective home buyers uniformly-distributed across energy efficiency space. The timing of disclosure is generally within a few days of the real estate listing agreement – before a property is marketed – and is uncorrelated with the sale closing date.

This leaves two plausible explanations for the weak relationship between homes' relative quality and sellers' propensities to disclose: sellers might be ignorant about their own prop-

[3] In this sense, the ECAD program can be thought of as a disclosure encouragement policy: the government standardization of audits lowers the cost of disclosure and the threat of a fine for non-compliance increases the net benefits to sellers of disclosing.

[4] Because buyers may infer that undisclosed product quality implies poor quality, strategic sellers with the highest-quality products will always volunteer their private information so long as their disclosure costs are sufficiently low. This in turn creates an incentive for sellers with the next best quality products to disclose, and so on, until the benefits of disclosure for the next seller are equal to the costs, and all but the lowest-quality product sellers will voluntarily disclose quality information to the market.

erties' *relative* energy efficiency, and/or there might be substantial variation across sellers in effective compliance costs (including psychic and other nonmonetary disclosure costs). To distinguish between these candidate mechanisms, we construct a behavioral model of the seller's policy compliance decision. We then connect the model to our empirical findings using a computational simulation, in which we evaluate the decision to perform an ECAD audit given our capitalization estimates and a range of simulated distributions of effective disclosure costs. This exercise reveals that the flat empirical relationship between benefit from disclosure and likelihood of disclosure can be rationalized with the model only if there is either extremely large heterogeneity in disclosure costs or, much more plausibly, if a significant share of homeowners are uninformed about the (relative) energy efficiency of their homes. Thus, homeowners' ignorance about their own homes' respective quality appears to be a significant factor for why market-improving information disclosure does not occur in the absence of public policy.

Our study has several important policy implications and contributes to multiple strands of the literature. First, we provide some of the only empirical evidence of quality-improving effects of a mandatory disclosure policy. Second, we demonstrate evidence consistent with a specific market failure of symmetrically incomplete information – i.e. uninformed buyers *and* uninformed sellers – which likely explains why government intervention improves market outcomes in our context. In doing so, our study is also the first to our knowledge to test two of the "often strong assumptions" for the disclosure unraveling prediction: that sellers have complete information about their own product quality and that the distribution of available quality is public information (Dranove and Jin, 2010). In addition to real estate, as we study, there are likely other peer-to-peer markets where these strong assumptions do not hold and a disclosure mandate would improve market quality.

Our findings additionally speak to the Energy Efficiency Gap. Most prior work on the topic focuses on explanations of uninformed consumers or on optimistic engineering estimates of energy savings (Brounen and Kok, 2011; Busse et al., 2013; Allcott and Wozny, 2014; Myers, 2015; Sallee et al., 2016; Allcott and Greenstone, 2017; Fowlie et al., 2018; Grigolon et al., 2018; Allcott and Knittel, 2019; Myers, 2019). A smaller branch of this literature considers the role of nonmonetary costs, such as the hassle burden associated with investing in energy-saving technologies and building materials, and the implications for self-selection into program participation (Fowlie et al., 2015; Allcott and Greenstone, 2017). Prior research on the supply side explores whether the energy savings from more efficient technologies are fully capitalized into property values (Aydin et al., 2017; Frondel et al., 2017; Walls et al., 2017; Cassidy, 2018; Myers, 2019). To our knowledge, ours is the first study to consider that sellers' ignorance of their own properties' quality might also be a significant barrier to improving the energy efficiency of durable goods such as homes. Furthermore, because homeowners elsewhere may be as uninformed about residential energy efficiency as those in Austin, our study supports that mandatory disclosure programs are likely to lead to improvements in other markets as well.

2 Empirical setting

In order to estimate the effect of energy efficiency information disclosure on home prices and cost-saving investments, we leverage a natural policy experiment in the housing market provided by the City of Austin, Texas through the city's Energy Conservation Audit and Disclosure (ECAD) ordinance. Austin's ECAD ordinance came into effect on June 1, 2009. The policy mandates that qualifying residential properties obtain an official energy efficiency audit and that home sellers disclose this information to prospective buyers as part of the regular seller's disclosure notice. A home is subject to the disclosure requirement if all of the following conditions apply: (1) the home is within Austin city limits, (2) the home is aged ten years or older, (3) the home's electricity is serviced by Austin Energy (which services essentially all Austin homes), and (4) the home is sold. While audit reports must be disclosed for all qualifying home sales, an audit report itself remains valid for ten years following the date of the audit.[5] Originally, the energy audit must be provided to potential buyers before the point of sale. An amendment effective as of May 2011 pushed the disclosure timing more specifically to at least 3 days before the close of the option period, during which the prospective buyer may legally cancel their contract to purchase the home penalty-free.

These energy efficiency audits must be conducted by certified professional technicians who have received special training from Austin Energy and are approved contractors for the program.[6] A typical audit takes about an hour and costs the home seller around \$100-\$300 in direct cost. After completing the audit, the engineering professional provides a standardized report to both the seller and to Austin Energy, who publicly publishes each report.

An example ECAD audit report is included in Appendix A. The first page of the form

[5]Sellers are also exempted from obtaining a new audit report if the property has undergone major energy efficiency improvements through Austin Energy's Home Performance with ENERGY STAR (HPWES) program within the last 10 years, a mechanism that appears to be used minimally for compliance.

[6]These engineering professionals are certified either by the Residential Energy Services Network (RESNET) or the Building Performance Institute (BPI). For summary details of the ECAD process, c.f. https://austinenergy.com/ae/energy-efficiency/ecad-ordinance/energy-professionals/energy-professionals.

summarizes any cost-saving actions recommended in each of four categories: (1) windows and shading, (2) attic insulation, (3) air infiltration and duct sealing, and (4) heating and cooling system efficiency (HVAC). The remaining four pages of the form provide detailed information on specific measurements performed, such as the condition and estimated R-value of the attic insulation, the percentage of air leakage from the duct system, and the age, efficiency, and overall condition of the heating and cooling system, etc. Importantly, the ECAD Energy Professional is required to send the audit results to Austin Energy within 30 days following the inspection. Therefore, it is not possible for a home seller to obtain an audit and subsequently withhold that information from realtors and potential buyers.

As per the ECAD ordinance, Austin Energy maintains a record of the audits that are performed. However, it is not in its mission nor budget to track or enforce compliance. In a strictly statutory sense, noncompliance with the mandate can result in pecuniary penalties ranging from $500-$2000. However, because housing transactions are not directly monitored for compliance, penalties for noncompliance have almost never been incurred: to date, there has been only a single instance of an ECAD noncompliance penalty action being filed with Austin Municipal Courts.[7] As shown below, around 40 percent of homes in our sample are sold without complying with the program.

Austin Energy's service territory extends beyond the boundaries of Austin city limits. Therefore, while only homes inside of Austin are required to comply with ECAD, all of the homes within the territory receive the same utility promotional materials for its rebate and pricing programs. For the purposes of our analysis, we treat the establishment of the ECAD ordinance as an exogenous disclosure encouragement. The cost of disclosure is reduced for all households in the service territory by standardizing the audit format and even more so for Austin City homeowners by introducing the threat of a fine for non-compliance. We leverage the resulting change in the relative propensity to disclose between homes inside and homes just outside of Austin city limits to estimate the effects of the information on capitalization of and investment in energy efficiency. Further, imperfect compliance with the program provides us an opportunity to examine sellers' disclosure decisions in order to shed light on the economic mechanisms preventing voluntary disclosure unraveling in the absence of government intervention.

[7]Personal communication with Tim Kisner, ECAD project manager, Austin Energy.

3 Data

We combine data from several administrative sources for our analysis. First, to determine the physical location and characteristics of all single-family residences within the territory serviced by Austin Energy, we purchased the tax appraisal records and GIS shapefiles for all parcels in Travis and Williamson counties. From these appraisal records, we extracted the geographic location, construction year, square footage, and other details about each home. We use the shapefiles to assign each premise to either inside or outside of Austin city limits.

Next, we obtained residential property sales transaction details through the Austin Board of Realtors' (ABOR) Multiple Listing Service database (MLS). In most states, housing transactions are collected by county clerk offices and are public record; however, Texas is among a handful of non-disclosure states that do not provide the financing and sales price details for property transactions when a deed is transferred from one party to another. The data available through the MLS roughly correspond to all transactions conducted through a licensed realtor, which represents around 89 percent of sales.[8] We pulled the universe of transaction information for single-family homes sold in Travis and Williamson counties during 1997-2014. For our analysis, we use MLS data on the timing and closing price of each property sale.

Austin Energy provided us with property-level data on the universe of ECAD energy efficiency audit reports, participation in any utility-sponsored energy efficiency program, and monthly electricity billing records for all single-family residences during 2006-2014.[9] The ECAD audit reports include the date of the audit and the property address, along with the audit findings. For energy efficiency program participation, we focus on the utility's four largest residential programs: the Appliance Efficiency Program, Home Performance with ENERGY STAR Program (HPWES), Power Partner Thermostat Program, and Weatherization Assistance Program. We use information on the timing of participation and the total dollar amounts of rebates paid to property owners through these four programs. With few

[8] c.f. https://www.zillow.com/sellers-guide/for-sale-by-owner-vs-real-estate-agent/.

[9] The Appliance Efficiency Program provides customers with rebates for installing energy efficient equipment; about 95 percent of program participation is for air conditioning and heat pumps, with a small fraction of rebates awarded for pool pumps and water heaters. Home Performance with Energy Star focuses on improving the overall efficiency of a home, offering rebates for the following upgrades done through a participating contractor: new air conditioner or heat pump, HVAC tune up and efficiency improvement, attic insulation overhaul, duct and envelope sealing, covers for attic pull down stairs, solar shading for windows, and smart thermostats. The Power Partner Thermostat Program provides subsidies for purchasing smart thermostats from an approved list. The Weatherization Assistance Program helps low-to-moderate income customers to improve their homes' weatherization via new attic insulation, sealing duct work, weather stripping on doors, and similar upgrades. Combined, the AEP and HPWES programs account for more than 97 percent of energy efficiency program rebates.

exceptions, eligible utility customers may participate in each program at most only once per account. And, finally, the monthly billing data include the kWh of electricity consumed at the address between the start and end date for each bill.

3.1 Defining the energy efficiency proxy measure

Our empirical study focuses on the energy efficiency of homes sold. Ideally, we would directly observe an engineering measurement quantifying the efficiency for each home, but such data do not exist for the homes in our sample. For properties that obtained an ECAD audit, we do observe some engineering measures of energy efficiency, but many of the audit components are qualitative (non-quantitative), and the report does not provide any summary metric of the overall efficiency for the property (see Appendix A for a sample report). Moreover, ECAD audit measurements are only available for properties that obtained an audit – i.e. homes that were sold post-2009, particularly so within the city limits of Austin – whereas our identification strategies require a comprehensive measure of every in-sample property's energy efficiency.

Leveraging pre-policy energy consumption data and characteristics of the homes, we form an ordinal proxy measure of energy efficiency as follows. First, we use linear interpolation to recenter the monthly energy billing data for each property to correspond to calendar months rather than billing cycles.[10] Using these recentered values and dividing by each property's square footage, we determine the average monthly electricity consumption per square foot for each property during the full available pre-policy period spanning from January 2006 through May 2009. Finally, we rank these kWh/SqFt values within-vintage (but pooling jurisdictions) and scale the ordinal set to range from zero to one.

This proxy measure of energy efficiency has several advantages. In addition to being available for all in-sample homes, it serves as a single value that concisely summarizes the relative expected energy use at each property. Furthermore, because we define the measure within-vintage and accounting for home size, our proxy should primarily capture the less obvious components of energy efficiency that would comprise the information shock provided by an ECAD audit. That is, a home buyer can readily anticipate that a "newer" home is likely more energy efficient than an "older" home, but predicting differences in energy efficiency between two homes of the same vintage will be much more subtle. Finally, as our proxy

[10] For example, for a household that consumed 900 kWh during the billing cycle of May 16 through June 15 and 1000 kWh during the billing cycle of June 16 through July 15, we assign a consumption value of 950 kWh during June.

is ordinal rather than cardinal, it should be less sensitive to statistical outliers in energy consumption.

In Appendix A, we provide empirical support for our energy efficiency proxy. Using the sample of ECAD audited properties, Appendix Table A1 shows that various qualitative and quantitative measurements from the engineering inspections are significantly correlated with our proxy term. For instance, a ten percent improvement in our proxy is associated with: a one percentage point (two percent of the mean) increase in the probability that the home has double-pane or low-emissivity windows; a 0.22 degrees Fahrenheit square feet hours per Btu (one percent of the mean) increase in the R-value thermal resistance of the attic insulation; and a 0.16 percentage point (0.84 percent of the mean) reduction in air duct leakage. Thus, especially when considering that these correlations are not independent, while our ordinal proxy does not perfectly characterize residential energy efficiency, it seems very well-suited to serve as a tractable measure.

3.2 Sample compilation and summary statistics

We combine the data from our various sources using the unique tax appraisal id (parcel number) for each property.[11] In compiling our sample for analysis, we make several restrictions. Most substantially, we restrict our sample to properties that were constructed no later than 1998, as the ECAD policy enacted in 2009 applies only to homes aged ten years or older. In addition, we drop less than half of one percent of properties for which we are unable to determine the jurisdictional geography and/or energy efficiency. Our final sample consists of 131,028 single-family homes served by Austin Energy that were at least 10 years old at the start of the ECAD program, i.e. constructed in 1998 or earlier. Of these properties, 83.5 percent are within the Austin city limits, as depicted in a map in Appendix Figure A1. We observe 65,454 (50 percent) of these homes sold on the MLS at some point during 1997-2014, generating a total of 105,978 sales transactions.

Table 1 presents summary statistics for selected attributes of the homes in our empirical sample. The "full sample" in Column (1) includes all homes in the sample, regardless of whether or not the home was ever sold during our sample period. Columns (2) and (3) include, respectively, only the subset of these homes that are inside or outside the Austin city limits and were sold at least once during 1997-2014. Overall, homes in the sample are

[11] Technically, we rely on two identifier fields: the tax appraisal real "property id" and the "geographic id" or parcel number. For single-family homes, both values are unique to each particular parcel of land. The Austin Energy data are tracked by property id whereas the MLS data are tracked via the geographic id. We use the Travis and Williamson county tax appraisal roll files, which contain both identifiers, as a cross-walk.

sold on average 0.8 times each, and 0.22 times post-policy. The average vintage is 1973 and average size is 1839 square feet. By construction, the average energy efficiency quantile is 0.5, with corresponding average monthly electricity use of 1178 kWh (0.67 kWh per square foot). For homes that were sold at least once between 1997-2014, average sale prices are $228 thousand inside Austin and $315 thousand outside the city limits. "Pre-sale EE rebates ($)," which include the total dollar value of rebates paid to the property's owners by Austin Energy within two years prior to the property sale for participation in energy efficiency programs, average $29.6 and $27.6, respectively inside and outside of Austin; note, however, that 96 percent of these values are zero dollars.

Comparing Columns (2) to (3), the most stark differences are that homes sold just outside of the city limits are systematically newer and larger; correspondingly, they also tend to use more energy and command higher sales prices. Of interest, there is not much difference across jurisdictions in the energy use per square foot, which could arguably be more closely-related to a difference in the composition of occupants. And, there is not substantial difference in the homes' energy efficiency by jurisdiction. In most of the regression estimations to follow, we control for vintage-by-year or jurisdiction-by-year fixed effects – and often also for property fixed effects – in order to account for systematic differences across jurisdictions in the composition of properties. Overall, the descriptive statistics in Table 1, combined with the empirical identification exercises to follow, provide compelling support for the identification strategy outlined above in Section 2.

4 Empirical strategy and results

4.1 Capitalization effects of disclosure

Our first empirical question is whether ECAD increases the capitalization of homes' energy efficiency into sale prices. Because we use a proxy for homes' relative energy efficiency (discussed in Section 3.1), we do not view our estimates as fully capturing the capitalization of energy efficiency; rather, we examine whether our proxy – and by extension homes' true energy efficiency – becomes *more* capitalized into sale prices as a result of ECAD. To estimate the effects of the ECAD policy, we use a difference-in-differences identification strategy comparing outcomes of homes sold inside Austin versus outside of the city limits, before versus after the ECAD ordinance took effect only for homes within the Austin city limits. If our hypothesis is correct, then we should see the price spread between less- and more-efficient homes increase by more inside Austin than for the counterfactual.[12]

Appendix Figure A1 shows a map of the greater Austin area of our empirical sample, with our treatment and control group homes indicated by color in Panel (b). Not only are the counterfactual homes nearby to the treated homes, the properties are all sold on the same regional Realtor Multiple Listing Service and they are serviced by the same electric utility (Austin Energy). Further, the probability of selling a home in either jurisdiction is remarkably similar during the sample period. In Appendix Figure A2 we display the fraction of homes in each jurisdiction (i.e. inside or outside of Austin city limits) sold in each year in our sample. Importantly, there is no visible discontinuous change in the probability a home is sold inside of Austin relative to nearby outside of Austin areas, either just before or just after the change in policy regimes. This pattern, which is further supported by regression analyses in Appendix Table A2, indicates that homeowners do not appear to adjust the timing of sale or decision to sell in anticipation of or as a result of the introduction of the energy efficiency disclosure requirement.

To illustrate our "first stage" for compliance with the the policy, Figure 1 displays the fraction of sales in each jurisdiction with an ECAD audit for each year in our sample. Once the program begins in 2009 (depicted by the vertical line), roughly 60 percent of sales inside of Austin and 15 percent of sales outside of Austin obtain ECAD audits. The presence of audits for homes sold in the Outside Austin area could be due to treatment spillovers or curiosity on the part of homeowners.[13] However, the figure displays a substantial spread in energy efficiency disclosure across jurisdictions post-2009, a pattern that is further supported by regression analyses in Appendix Table A3.

Given this support for our identification strategy, our capitalization estimation asks whether the correlation between the energy efficiency proxy and the housing price is stronger when energy efficiency information is disclosed than when it is not. Figure 2 provides a graphical representation of the energy efficiency capitalization for each jurisdiction over time. We plot the year-specific correlation by jurisdiction between the homes' sale prices and the homes' energy efficiency proxy, controlling for property fixed effects as well as jurisdiction-by-year fixed effects. The omitted base year is 1997. Importantly, the residual correlation

[12]Conceivably, one might use a regression discontinuity design at the ten-year-old home age treatment cutoff. The first draw-back to using such an approach is relevance: homes constructed close to ten years prior to the policy, i.e. in the late 1990s and early 2000s, do not have nearly as much heterogeneity in energy efficiency as is present in older homes. More importantly, there is inadequate statistical power to conduct meaningful RDD tests around the 10-year-old cutoff.

[13]As these homes were all sold by professional realtors, who were well-informed of the specifics of the ECAD mandate, it is quite unlikely that seller confusion is responsible for audits outside of Austin.

between home price and energy efficiency appears to be on parallel trends in the two jurisdictions prior to the introduction of the ECAD program. However, following the policy change in 2009, the two lines discontinuously separate and show a relatively much more positive correlation between energy efficiency and sale price for homes inside of Austin compared to those outside of Austin. This visual evidence suggests that homes that are more energy efficient receive larger price premiums post policy inside of Austin compared to counterfactual.

In order to more formally estimate the energy efficiency capitalization effects of disclosure, our preferred specification is as follows:

$$\begin{aligned} ln(P_{ivjt}) = \; & \beta_1 EEProxy_i \times Post_t \; + \\ & \beta_2 EEProxy_i \times Austin_j \times Post_t + \mu_i + \tau_{vt} + \zeta_{jt} + \varepsilon_{ivjt} \end{aligned} \tag{1}$$

Our outcome variable is the log of the sales price for house i of vintage (year-built) v in jurisdiction j in month t. The energy efficiency proxy is denoted by $EEProxy_i$ and takes on a continuous value between zero and one, where one indicates the highest efficiency. The jurisdiction is indicated by $Austin_j$ and takes on a value of one for homes within Austin city limits (and zero otherwise), and $Post_t$ is an indicator for the months after the introduction of ECAD (post June 2009). House fixed effects are denoted by μ_i, τ_{vt} indicate vintage-by-month fixed effects, ζ_{jt} indicate jurisdiction-by-month fixed effects, and ε_{ivjt} is an idiosyncratic error term.

The house fixed effects control for the time-invariant qualities of a house that affect its price. Since the composition of the ages of the homes are different inside versus outside of Austin, we include vintage-by-month fixed effects to control for any differences in sales prices between the jurisdictions that are driven by differential trends in preferences for particular vintages of homes. Likewise, we include jurisdiction-by-month fixed effects to account for differential trends in preferences for homes inside or outside of the city that are not related to energy efficiency. Given these fixed effects, the identification of the coefficients in our model comes from comparing the slope of the energy efficiency proxy with respect to house price for same-age homes sold in the same month, controlling for any differential price trends in one jurisdiction relative to the other and for each homes' time invariant qualities. Our coefficient of interest is β_2, which is an estimate of the difference-in-differences of that price-efficiency slope for homes sold inside Austin versus outside of the city limits, before versus after the ECAD ordinance took effect.

Table 2 more formally evaluates this capitalization of energy efficiency, displaying regression estimates for how the natural log of properties' sale prices relates to interactions between energy efficiency, jurisdiction, and time period. The specification for Column (1) includes the full sample of sales, with jurisdiction and vintage-by-monthly fixed effects. For Column (2), we estimate a model that includes property fixed effects rather than jurisdiction fixed effects, which limits the sample to include only homes sold more than once between 1997 and 2014. The advantage of this sub-sampling is that property fixed effects account for substantially more potential heterogeneity across homes, controlling for any property-specific factors which might be correlated with both their energy efficiency and sale prices. In Column (3), we include property fixed effects and jurisdiction-by-monthly fixed effects rather than vintage-by-monthly fixed effects. Finally, Column (4) displays the results from our preferred and most saturated specification including property fixed effects and both vintage-by-monthly and jurisdiction-by-monthly fixed effects.

The first row in the table displays the estimates for the coefficient on the interaction between the energy efficiency proxy and the post-policy period (post-June 2009). This quantifies any change post- versus pre-policy for the residual correlation between energy efficiency and sale prices for homes *overall*. For the full sample of sales, the point estimate is positive and significant at the 10 percent level. However, once we include property fixed effects to control for any changes in the composition of homes' time invariant qualities (Columns (2-4)), the effect is no longer statistically nor economically distinguishable from zero.

The second row in the table displays estimates for our coefficient of interest: the triple interaction between the energy efficiency proxy, an indicator for being inside Austin city limits, and an indicator for post policy. Across specifications, the point estimates are positive and significant. This indicates that comparatively more efficient homes receive a deferentially higher price premium as a result of the ECAD policy applicable inside of Austin but not outside of Austin. The point estimate in Column (2) of .096 log-points is only half the magnitude of that in Column (1) of .186, suggesting that asymmetric changes in the composition of homes sold over time may be driving some of the relative differences in housing prices between the two jurisdictions over time. However, once we control for house fixed effects, as done in Figure 2, the pre-trends for the two jurisdictions are parallel and the point estimates then remain qualitatively and quantitatively consistent across specifications in Columns (2-4).

To provide some perspective for the quantitative magnitudes of the results shown in Table 2, consider the point estimate of 0.08 log-points in our preferred specification in Column (4). At the average inside Austin home sale price of $228,000 (Table 1), this treatment effect corresponds to about a $19,000 price difference in reduced-form between the lowest and highest quality home, or $190 for each percentage point improvement in our ordinal energy efficiency proxy. If we are willing to fully attribute the price difference only to the audits themselves and rescale by the 45 percentage point relative difference in audit disclosure, then the average treatment effect of disclosure is about $422 per percentage point increase in energy efficiency. We view this as a strong exclusion restriction, however, considering that the policy might also have more generally influenced the attention that home buyers pay to energy efficiency. More generally, we remain agnostic on the specific causal mechanisms by which ECAD influences the price capitalization of energy efficiency, which are likely a combination of increased salience and reduced computational costs of evaluating these features of homes, in addition to the added information provided to the market.[14]

In the underlying data for the summary statistics in Table 1, each percentage point improvement in homes' energy efficiency is associated with about an 11.26 kWh reduction in average monthly electricity use. Using the reduced-form capitalization estimate, at Austin Energy's average post-2009 electricity tariff of $0.10/kWh, a back-of-the-envelope calculation indicates an expected pay-back period of about 14 years.[15] For a homeowner operating with a 30-year outlook, this corresponds to about a six percent annual discount rate. For reference, 30-year mortgages had fixed rates of around four to five percent during this time period. Thus, our back-of-the-envelope calculation supports that the capitalization estimates in Table 2 are quite reasonable in quantitative magnitude.

4.2 Effects on investment in energy efficiency

We next explore how the ECAD disclosure program impacts home sellers' and buyers' investments in energy efficiency technologies and building materials. More specifically, we estimate how the ordinance affects the total dollar value of program rebates paid to property owners by Austin Energy for participation in any of the four energy efficiency rebate programs offered by the utility. Note that each dollar of rebates corresponds to substantially more out-of-pocket total dollars of energy efficiency capital investment on the part of the homeowner.[16]

[14]Our findings here are also consonant with Cassidy's (2018) evidence that less-salient energy efficiency features of homes tend to see the strongest capitalization when disclosed.

[15]That is, home buyers on average are willing to spend $190 more in purchase price in order to save an expected $1.126 each month, which balances after 14.06 years. We assume no change in tariffs for this back-of-the-envelope calculation. The findings of Ito (2014) support using the average tariff rate.

[16]The four programs are discussed in Section 3. Austin Energy's rebate payment schedule is here: https://savings.austinenergy.com/rebates/residential/offerings/home-improvements/hpwes-rebate.

We start by using our difference-in-differences framework to assess how the disclosure policy affects total program rebate dollars paid to (soon to be) home sellers. This evaluation tests whether the availability of credible energy efficiency disclosure provided through the ECAD ordinance induces sellers to invest in higher product quality prior to listing their home for sale. As our outcome variable, we use the total dollar value of rebates paid per property for any program participation within the two years prior to sale. Post-2009 overall, ninety-four percent of these values are zero within our sample.[17]

Figure 3 plots the annual inside Austin coefficients from regressing these rebate dollars on vintage-by-year fixed effects and annual jurisdiction indicators. The series starts with 2006 as these are the first home sales for which we observe program participation. The 2009 policy change year serves as the omitted base-year. Of importance to the identification strategy, the overall trends appear very similar across jurisdictions prior to the ECAD policy. Following 2009, there is a visible jump up in the investment dollars inside Austin compared to counterfactual, which persists throughout the rest of the time series in Figure 3.[18] As indicated by the confidence intervals for each plotted coefficient, each of these year-specific estimates is noisy. Table 3 shows a more formal evaluation.

In Column (1) of Table 3, we estimate the post-pre difference between the coefficients shown in Figure 3. The econometric specification regresses the total two-years pre-sale dollar value of rebates paid to each seller (inclusive of zeros) on an interaction for the sale occurring inside Austin and post-June 2009, controlling for jurisdiction and vintage-by-monthly fixed effects. The difference-in-differences coefficient of interest is an economically and statistically significant \$13.15 average effect of the policy on total energy efficiency investment rebate dollars. As the post-policy mean for this outcome variable is \$42.39, this reduced-form treatment effect is a 31 percent increase in average energy investment rebates paid to home sellers. In the second column, we focus more specifically on rebate dollars paid to the seller for participation in HPWES, the efficiency program that is explicitly highlighted on the first page of the ECAD report (see Appendix A) and therefore the types of investments that are most closely tied to ECAD report values. Here, we find an effect on HPWES-specific investment by home sellers that is larger in both point estimate (\$16.47) and relative to subgroup mean (61 percent). This evidence of investment by home sellers indicates that at

[17] Primarily for this reason, we focus on the average value of rebates, inclusive of zeros, rather than the share of sellers that participate. From a more practical standpoint, our approach is also able to leverage both extensive and intensive margins of program participation, which improves statistical precision.

[18] Although the policy change occurred in mid-2009, it is reasonable to expect a short lag before seeing effects on this outcome, as homeowners are unlikely to undergo additional major renovations in their current homes immediately following the policy change.

least *some* sellers are aware both of their homes' respective energy efficiency and that this quality is more likely to be capitalized into home prices when it may be credibly disclosed.

In the final two columns of Table 3, we evaluate the effects of the ECAD ordinance on energy efficiency program rebates paid for participation in the two-years post-sale, i.e. paid to home *buyers*. Column (3) shows the estimates for all program rebates. Although the point estimate is positive, it is statistically insignificant; moreover, it is smaller in both magnitude and proportionately compared to that for total pre-sale rebate dollars. In Column (4), however, which focuses only on rebates paid to home buyers for HPWES participation, we find a large and statistically significant effect of $21.25 (31 percent of the mean). Together, these latter two findings indicate that: (1) the ECAD ordinance induced investment in energy efficiency improvements highlighted on the ECAD audit report, and (2) these investments might in part be substitutions away from other program participation (e.g. appliance replacement).[19]

5 Market failures and value of mandatory disclosure

5.1 Relationship between energy efficiency and disclosure

Our finding that audits increase the internalization of energy efficiency into house prices creates a broader puzzle about the role of a government disclosure policy. Under some circumstances, policymakers need not mandate disclosure in order for quality information to be incorporated into market outcomes. For example, if sellers know quality but buyers do not, and if disclosure is sufficiently low cost, then sellers with the highest quality products have an incentive to *voluntarily* disclose quality to induce buyers to purchase from them. Given this incentive, the sellers with the next highest quality product also have incentives to disclose for similar reasons. This dynamic leads to an "unraveling" where all but the lowest quality seller discloses, which eliminates incomplete information in the market. Even given some disclosure costs, such incentives to voluntarily disclosure still predict a sharp relationship between quality and the decision to disclose (Grossman, 1981; Milgrom, 1981).

However, these dynamics of voluntary disclosure are inconsistent with two robust empirical features that we observe in our setting. First, the voluntary disclosure dynamics imply

[19] Given this evidence of increased investments, it is tempting to explore how the ordinance affects energy consumption. Two data limitations preclude such an exercise. First, the margin of investment is relatively small, so the analysis is under-powered statistically. Second, we cannot observe *which* households are buying which homes, and the policy might have facilitated increased sorting of households across homes.

that making audits mandatory should not increase price internalization. More precisely, given that an audit infrastructure was in place both inside and outside of Austin, there should not exist a greater annual relative energy efficiency capitalization in Austin versus outside of Austin after 2009. However our results in Section 4 indicate otherwise.

Second, the voluntary disclosure dynamics would imply a sharp relationship between the energy efficiency of homes and the disclosure decision. However, we find only a very weak relationship. Figure 4 plots the share of in-sample homes sold inside Austin post-June 2009 that complied with the ECAD policy by obtaining and disclosing an energy efficiency audit, across the homes' energy efficiency quantiles. Each point depicts a local average compliance rate for the respective energy efficiency decile. The line shows the linear fit to the underlying microdata. Strikingly, the slope between energy efficiency and disclosure propensity is fairly flat. The first decile does have the lowest average disclosure rate at 55.4 percent; however, the most efficient decile's average disclosure rate is only 3.5 percentage points higher at 58.9 percent. More broadly, sellers of properties with below-median energy efficiency obtain an audit in 59 percent of sales, while above-median efficiency homes are audited in 62.4 percent of sales.

In this section, we construct an alternative model of disclosure that predicts these two empirical regularities. We offer evidence supporting that the mechanism by which mandatory disclosure increases capitalization is that both buyers *and sellers* have incomplete information about quality. Specifically, some sellers do not know the energy efficiency of their own homes, and a mandatory disclosure policy encourages that information to be revealed and incorporated into market prices. This bilateral incomplete information stands in stark contrast to much of the literature on the role of disclosure, which assumes that sellers know product quality (Dranove and Jin, 2010). This mechanism suggests a rethinking about the normative implications of mandating disclosure in some market settings, as we discuss below.

Our model below shows that when some sellers are uninformed about the relative energy efficiency of their homes, the relationship between energy efficiency and disclosure can by weak. We note that there are several other *a priori* possible explanations for a flat relationship, but none appear to be plausible in this setting. The first is that our proxy for homes' energy efficiency is a poor or relatively meaningless one. It is difficult to argue that this is the case. For one, as shown and discussed in Section 3 and Appendix A, we validate that our proxy is highly correlated with actual audit measures of residential energy efficiency. In addition, our empirical results above demonstrate that this measure is significantly capitalized among treated homes post-policy relative to counterfactual.

A second possibility is that buyers are driving the compliance decision by asking sellers to provide the information as part of the closing process. If the requests come from home buyers who are uniformly distributed across efficiency space, it could drive the weak relationship we observe between compliance and energy efficiency. However, the timing of the audit is generally within a few days of the real estate listing agreement – before the property is marketed – and is uncorrelated with the closing date (see Appendix Figures A3 and A4). A related potential explanation is that the decision to disclose is driven by realtors. If some realtors consistently ask their clients to perform ECAD audits, while others consistently do not, this could result in the weak relationship between compliance and energy efficiency that we observe. In contrast, we find that the propensity to disclose across realtors instead follows a bell-shaped distribution as shown in Appendix Figure A5.

Another hypothetical explanation, in principle, is that many seller's are simply uninformed about the requirements of the ECAD program. However, this explanation has minimal support given that these are all properties sold via realtors, who are well informed about ECAD.[20] If sellers were well-informed about the efficiency quality of their properties, realtors would have a strong financial incentive to encourage their client sellers of more efficient homes to disclose. Therefore, if we take seriously that the compliance decision is most likely driven by the seller in consultation with a realtor who knows about the program, there are two plausible explanations for the empirical pattern of disclosure, which we model and evaluate just below: (1) sellers are not aware of the energy efficiency of their homes and (2) there is substantial heterogeneity in costs (including time, effort and psychological) of disclosure.

5.2 Model of ECAD compliance decision

We present a simple model of the seller's decision to comply with a mandatory disclosure policy. This model shows that when both the buyers and *some sellers* are uninformed about (relative) product quality, that compliance with a mandatory disclosure policy will be incomplete and only weakly related to quality.

Consider a single house that is being sold from a seller to a buyer. Beliefs about the energy efficiency of the house do not affect whether the house is sold, but do affect the negotiated transaction price. The house's true energy efficiency – which we refer to as quality – is characterized by $q \in [0, 1]$, with a larger q corresponding to a higher level of

[20] The Austin Board of Realtors regularly puts on events in coordination with Austin Energy to disseminate information about ECAD to local realtors, and our own discussions corroborate that they are well-informed.

energy efficiency.

In this incomplete information setting, denote seller beliefs about quality as q^s and buyer beliefs as q^b. First, consider the seller's beliefs. Let the seller be informed about the true quality with probability Φ, and we take this probability to be exogenous to the model. For example, the seller may be unaware of the number of inches of insulation in the attic or unaware of the relative energy efficiency of the home relative to other homes. An informed seller knows the true product quality ($q^s = q$) whereas an uninformed seller has beliefs about quality given by $q^s = \hat{q^s}$, which we specify below.[21]

Next, consider buyer beliefs. The buyer is uninformed about the true quality q unless the seller chooses to conduct an audit. If an audit is conducted, the results of the audit are automatically reported to the buyer (i.e. the seller cannot observe the audit results and keep that information private). We assume that the audit is unbiased and reports the true quality q.[22] Therefore, if no audit is conducted then the buyer's beliefs are given by $q^b = \hat{q^b}$, but if an audit occurs then buyer knows the true quality and $q^b = q$.

Beliefs about quality determine the buyer's and seller's respective beliefs about the dollar value of the home as given by $b(q^b)$ and $b(q^s)$. Nash Bargaining determines how beliefs about the pecuniary benefits of quality map to the price premium for the energy efficiency characteristics of the house. Therefore, the home's energy efficiency affects the negotiated transaction price of the house by the amount: $\frac{1}{2}[b(q^s) + b(q^b)]$.

The audit/disclosure decision is made by the seller. Let the net pecuniary costs of getting an audit versus not getting an audit be given by c. In other words, c is the dollar costs of paying for the audit process net of the expected penalty for not obtaining an audit prior to sale. (Voluntary disclosure corresponds to an expected penalty of zero). In our setting, the expected penalty appears to be very small given the degree of enforcement.

The benefits to the seller of undertaking an audit are driven by how much the disclosure changes the beliefs of the buyer. An informed seller will choose to disclose quality if $b(q) - c \geq \frac{1}{2}[b(q) + b(\hat{q^b})]$. That is, the seller chooses to disclose if and only if the expected benefit from disclosure is greater than the net of the direct disclosure cost and the expected Nash Bargaining opportunity cost. An uninformed seller faces a similar tradeoff but evaluates expected benefits on (perhaps incorrect) beliefs of the quality of the house. An uninformed seller discloses if $b(\hat{q^s}) - c \geq \frac{1}{2}[b(\hat{q^s}) + b(\hat{q^b})]$, where $\hat{q^s}$ may not necessarily be true quality q.

[21]For simplicity, we assume here that uninformed agents' beliefs are loaded at a single mass point, but one could also allow for non-degenerate distributions.

[22]See Dranove and Jin (2010) for a discussion of the literature investigating whether third-party certifiers necessarily have an incentive to report unbiased results.

Given this model, we illustrate how full unraveling can break down. Figure 5 presents several scenarios. In the illustration, we set the domain of $b(\cdot) \in [0, \bar{b}]$. For ease of exposition, these scenarios all assume that the buyer's belief in the absence of disclosure $\hat{q^b} = 0$. This assumption is equivalent to the seller operating as if the buyer's belief about an undisclosed product quality is that it is of the lowest possible quality, consistent with assumptions in classic models of voluntarily disclosing of asymmetric information (Dranove and Jin, 2010). Note that this assumption is not Bayesian in the sense that our model will predict something different – some high quality and some low quality homes will fail to get an audit. However, in this incomplete information environment, it is not clear that buyers follow a "fully strategic" model of belief formation.

Similarly, for exposition we assume in this illustration that an uninformed seller believes her house to be of median quality, i.e. $b(\hat{q}) = \bar{b}/2$. Of course, uninformed sellers and buyers might hold alternate beliefs, such as that unknown quality is positively correlated with true quality. The key insight of the model is to illustrate that incomplete information by both the buyer *and seller* yields a weak relationship between disclosure and quality.

In the first scenario, we illustrate that full unraveling can breakdown when disclosure is costly to the seller. In this benchmark scenario, all sellers are informed about the quality of their homes ($\Phi = 1$). Suppose that the seller faces a deterministic disclosure cost $c = \bar{b}/4$. Deterministically, the seller will disclose product quality if and only if $b(q) \geq \bar{b}/2$. This scenario is shown by the solid line in Figure 5. This signals to the market only that the energy efficiency value of an unaudited house lies in the range $b(q) \in [0, \bar{b}/2)$, but provides no more detailed information about product quality. In this scenario, the sellers of all houses of sufficiently high quality disclose quality to the buyer.

In the second scenario, all sellers are informed but there is heterogeneity in the cost of disclosure. Cost heterogeneity could reflect the fact that the time, effort, and psychological costs of disclosing and the perception of expected penalties of non-compliance may vary across sellers. In this illustration, the disclosure cost is drawn from a normal distribution around $\bar{b}/4$: $c \sim N(\bar{b}/4, \bar{b}/8)$. The relationship between quality and equilibrium disclosure is shown by the long-dashed line. The probability of disclosure is visibly smoother with respect to the seller's product quality q. Even the highest quality houses do not always have quality disclosed to the buyer, but higher quality homes are much more likely to have quality disclosed. In particular, a seller with benefit of less than $\bar{b}/2$ will still disclose quality if the cost draw is sufficiently small, and vice versa. Note that the relationship between disclosure probability and disclosure benefit is relatively steep when the seller is informed with certainty, despite our imposition here of sizable variation in disclosure cost.

Next we allow for the major innovation of this exercise – sellers can be uninformed about the quality of their own homes. We continue to model disclosure costs as heterogeneous as in the scenario above, but we reduce the probability Φ that the seller is informed. In the short-dashed line, the probability the seller is informed $\Phi = 0.50$ and independent of the true quality q. And in the dotted line, the probability is $\Phi = 0.10$. In general, when the seller is uninformed, the relationship between true quality and disclosure is substantially flattened.

Collectively, the theoretical scenarios illustrated in Figure 5 show two insights. The first is that, given either a dispersion in disclosure costs and/or the possibility for seller ignorance about product quality, the classic theoretical unraveling result breaks down. The second insight is that for unraveling to be minimal requires either that there be a large dispersion in disclosure costs or that there be a substantial likelihood that the seller is uninformed (or both).

5.3 Computational simulation

Next we conduct a simulation exercise that connects our reduced-form empirical findings to the theoretical model presented in Section 5.2. Our computational exercise simulates draws of audit costs for each post-policy inside Austin home seller and uses these simulated cost values – along with data on homes' true energy efficiency and sellers' actual disclosure decisions – to determine the maximum plausible share of home sellers that could be informed under various cost distributions without violating the specification of the model.

Our starting point for the simulation is the solution to the seller's disclosure problem in the model in Section 5.2. Recall, an informed seller will choose to disclose quality if $b(q) - c \geq \frac{1}{2}[b(q) + b(\hat{q}^b)]$ while an uninformed seller discloses if $b(\hat{q}^s) - c \geq \frac{1}{2}[b(\hat{q}^s) + b(\hat{q}^b)]$, where $\hat{q}^s$ may not necessarily be the true quality q. Let $i \in \{0, 1\}$ denote whether the seller is informed, with $i \sim \text{Bernoulli}(\Phi)$ and Φ taken as exogenous to the model. Then, the seller's decision to disclose $d \in \{0, 1\}$ can be summarized as a function of the seller's information status:

$$d = \begin{cases} 1 & \text{if} \quad i \cdot b(q) + (1-i) \cdot b(\hat{q}^s) \geq 2c + b(\hat{q}^b) \\ 0 & \text{if} \quad i \cdot b(q) + (1-i) \cdot b(\hat{q}^s) < 2c + b(\hat{q}^b) \end{cases} \tag{2}$$

That is, the seller chooses to disclose quality if and only if the seller's (expected) benefit from disclosure is greater than the seller's combined disclosure cost and expected Nash bargaining opportunity cost. When making the disclosure decision, the seller may or may not be informed, $i \in \{0, 1\}$, about the value of the home's quality. We observe disclosure decisions d in the data, we can use the reduced-form results shown above to provide a sale price benefit $b(q)$ for each property, and we can simulate values for $2c + b(\hat{q^b})$, which we hereafter refer to as effective disclosure cost. However, we do not observe whether or not a seller is informed, nor do we observe sellers' beliefs about their homes' quality, $\hat{q^s}$. By rearranging the above solution, we can define:

$$i \equiv \begin{cases} 0 & \text{if} \quad d = 0 \quad \text{and} \quad b(q) \geq 2c + b(\hat{q^b}) \\ 0 & \text{if} \quad d = 1 \quad \text{and} \quad b(q) < 2c + b(\hat{q^b}) \\ 1 & \text{if} \quad d = 1 \quad \text{and} \quad b(q) \geq 2c + b(\hat{q^b}) \\ 1 & \text{if} \quad d = 0 \quad \text{and} \quad b(q) < 2c + b(\hat{q^b}) \end{cases} \tag{3}$$

The first two scenarios in Equation (3) are mechanically true per the model, whereas the latter two only indicate that the seller is *plausibly* informed. Note that with this framing, we do not need to assume nor simulate any values for uninformed sellers' beliefs $b(\hat{q^s})$. We simulate values of the effective disclosure cost $2c + b(\hat{q^b})$ and conduct the computational simulation exercise as follows.

First, we linearly re-scale the gross price benefits to range $b(q) \in [0, 1]$ by using the energy efficiency proxy term directly as the gross benefit value. The advantage to this re-scaling is that it preserves the quantitative implications of the model without being sensitive to the specific values estimated for price capitalization above (i.e. it doesn't matter whether we use the reduced-form intent-to-treat or the ATE to quantify price benefit). Next, we assume that effective disclosure costs are normally distributed and determine the requisite average cost that would generate the empirically-observed (61 percent) share of sellers who disclose quality, using the model and assuming that all sellers are informed. This value is 0.44. That is, in the scenario that all sellers are informed about their homes' relative energy efficiency and with price capitalization re-scaled to be in $[0, 1]$, the only sellers to disclose will be those who would realize re-scaled gross price benefit of greater than 0.44.[23] We hold average effective disclosure cost fixed across all simulations and vary the standard deviation of simulated effective disclosure costs, such that $2c + b(\hat{q^b}) \sim N(0.44, \sigma)$. Within each simulation loop, we specify a value of σ and simulate a cost vector. Rather than randomly assigning cost values to sales, we sort the cost vector such that the maximum plausible share

[23]Note that the reason for the average effective disclosure cost value of 0.44, rather than 0.39, is that the distribution of energy efficiency for these sold homes slightly deviates from the overall sample distribution.

of sellers could be informed per Equation (3).[24]

Thus, for specified values of σ and observed vectors of values of $d \in \{0, 1\}$ and $b(q) \in [0, 1]$, the steps of each simulation loop are:

1. Draw a vector of gross effective disclosure cost values from $2c + b(\hat{q^b}) \sim N(0.44, \sigma)$.
2. Sort the cost vector such that the maximum possible share of sellers could plausibly be informed without violating the rationality of the model per Equation (3).
3. Store the aggregate value for this maximum possible fraction of informed sellers.

Simulation results are shown in Figure 6 and Table 4 for values of σ ranging from 0.0 to 0.3 in increments of 0.01. To reduce the influence of simulation variation, we repeat steps 1-3 for 1000 repetitions of each specified value for σ. The figure plots the median values from the repetitions for each σ in the solid line in the graph; the first and ninety-ninth percentile values for each simulated standard deviation value are shown in the dashed grey lines. Table 4 shows the first, median, and ninety-ninth percentile values for the share of plausibly-informed sellers from 1000 repetitions at selected σ values.

In the first row of Table 4, effective disclosure costs are set to be constant (at 0.44) across sellers. With no heterogeneity in audit costs, Equation (3) can be rationalized only with at most 54.18 percent of sellers being informed about their homes' relative energy efficiency. As the simulated spread in effective disclosure costs increases (moving down the first column of Table 4 or across the horizontal axis of Figure 6), the corresponding share of plausibly-informed sellers also increases. This is consistent with the illustration in Figure 5 of the theoretical model described in Section 5.2.

More quantitatively, the simulation shows that for all sellers to be plausibly-informed requires a standard deviation in simulated effective disclosure costs of at least 0.27, i.e. $2c + b(\hat{q^b}) \sim N(0.44, 0.27)$. At face value, this spread in costs might not seem very large economically. As noted in Section 2, the direct out-of-pocket cost of an ECAD audit is around \$100-\$300. However, because of the re-scaling in the simulation, the direct ECAD report cost is not the average value of $2c + b(\hat{q^b})$. For exposition, let average $b(\hat{q^b}) = 0$, average $c = \$200$, and use the ATE estimated in Section 4 to quantify $b(q) = 42200q$ for energy efficiency $q \in [0, 1]$. Recognizing that this benefit measure is a relative one, we can recenter (but do

[24]More precisely, we sort the vector of cost draws such that the largest cost value is assigned to the seller with the largest gross benefit among the subset of sellers who did not disclose. We assign the second largest cost value to the seller with the second largest gross benefit among sellers who did not disclose, and so on. After all nondisclosing sellers have been assigned a cost value, we assign the next largest available cost value to the seller with the largest gross benefit who *did* disclose, repeating the above process.

not re-scale) the distribution such that average gross effective disclosure costs $2c = \$400$ and $b(q) = \$42200q - \$18168$. This implies that $2c + b(\hat{q^b}) \sim N(\$400, \$11394)$.

In principle, one could argue that a very large spread in disclosure costs is possible if there are substantial nonmonetary costs involved with the disclosure process. For instance, there might be privacy considerations or hassle costs that are not captured in a technician's \$200 fee. This explanation is challenging to support for ECAD audits. These homes are all sold by a realtor and sales involve open houses, visits by buyers, other seller and buyer inspections, and often contractor work (e.g. touch-up painting). The short visit by an energy efficiency technician is unlikely to induce such sizable nonmonetary costs as would be required to support such a large spread in disclosure costs as $N(\$400, \$11394)$ – or even $N(\$400, \$2110)$, which corresponds to $\sigma = 0.05$ in the simulation.

Instead, it is much more plausible that the simulation exercise indicates that a significant share of homeowners are uninformed about the energy efficiency of their homes, at least in a relative sense. As highlighted in the theoretical scenarios in Figure 5, if few sellers are informed, then a large spread in disclosure costs is not required to support a relatively flat disclosure slope, as seen in our empirical Figure 4.

5.4 Discussion

These findings suggest a new dimension to the voluntary disclosure literature. In contrast to the stark theoretical prediction of complete voluntary disclosure through unraveling, the empirical literature finds that "there are many markets in which voluntary disclosure is incomplete" such that "unraveling often does not occur in practice" (Dranove and Jin, 2010). Explanations for this lack of unraveling have largely focused on the size of the disclosure costs (e.g. Jovanovic, 1982; Lewis, 2011), the role of consumers (e.g. Milgrom and Roberts, 1986; Fishman and Hagerty, 2003; Li and Shi, 2017), and the influence of competition (e.g. Board, 2009; Guo and Zhao, 2009). We provide suggestive evidence for another explanation for a lack of unraveling in information disclosure markets: sellers might also not be fully informed about their own products' relative quality.

For quality disclosure models, Dranove and Jin's (2010) review article notes (p. 943) that two of the "often strong assumptions" for the unraveling prediction are that sellers have complete information about their own product quality and that the distribution of available quality is public information. Ours is the first study to our knowledge, however, to provide empirical support for this plausible explanation for a lack of unraveling of quality disclosure in markets with private information. Market failures driven by sellers' ignorance about the relative quality of their own goods or services most closely applies to disclosure in markets that are peer-to-peer, including sales of previously-owned assets such as residential real estate (as we study) and used automobiles, but also digital marketplaces such as eBay and airbnb (e.g. Lewis, 2011; Klein et al., 2016; Ma et al., 2017). However, a growing literature shows that even firms and other organizations often appear to be ignorant of many of their own qualities (e.g. Brehm and Hamilton, 1996; Anderson and Newell, 2004; Bloom et al., 2013). Thus, the general insight from our findings that mandating standardized testing and disclosure can increase economic welfare would apply to other circumstances with symmetrically incomplete information about quality, even for goods and services provided by large organizations such as manufacturing plants, hospitals, and schools, to note but a few example settings from the literature on disclosure (Bui and Mayer, 2003; Dranove et al., 2003; Andrabi et al., 2017).

6 Conclusions

In this paper, we analyze the Energy Conservation Audit and Disclosure program in Austin, Texas. We show that encouraging home sellers to provide potential buyers with certified energy audits increases price capitalization of energy efficiency and leads to quality-improving residential investments in energy-saving technologies. This is one of the few empirical settings wherein a government disclosure program is shown to have socially beneficial effects, particularly for product quality in the targeted market.

To understand why government intervention is effective in this context, we examine sellers' decisions to comply with ECAD. Despite substantially larger expected price premiums from disclosure for more efficient homes, we find that properties' relative energy efficiency only weakly predicts whether or not sellers choose to disclose this information. We rule out that this weak relationship is attributable to buyers or realtors dictating compliance by asking sellers to provide audits, rather than by home sellers making the decision.

Then, we examine two other plausible explanations for the flat relationship between homes' relative energy efficiency and sellers' propensities to disclose: either sellers are ignorant about their own homes' relative quality or there is substantial variation in effective ECAD compliance costs. Using a computational simulation, we find that, given our estimated capitalization effects, this flat relationship can be rationalized only by either extremely large heterogeneity in disclosure costs or, much more plausibly, by a significant share of homeowners being ignorant about the relative energy efficiency of their own homes.

Our findings have important policy implications. First, our work suggests that homeowners' ignorance about their own energy efficiency is a market failure that disclosure policies can help to ameliorate. Our capitalization findings indicate that home purchasers do understand and care about residential energy efficiency information when it is made available. Thus, mandatory disclosure may improve residential sorting and, as we find, increase overall quality by creating stronger incentives to invest in energy efficiency. Our findings also support that homeowners' ignorance about energy efficiency may be a contributor to the Energy Efficiency Gap in residential housing. Therefore, encouraging homeowners to get energy audits can increase participation in energy efficiency incentive programs.

More broadly, our study indicates that in markets with symmetrically incomplete information, mandating standardized testing and disclosure has potential to increase economic welfare by harnessing the positive externalities associated with information provision. Our framework is most directly analogous to peer-to-peer markets, such as residential real estate, used automobiles or digital marketplaces such as eBay. However, in light of evidence that even large firms are often ignorant of their own qualities, the general insights from our study should apply even in markets supplied by incorporated organizations.

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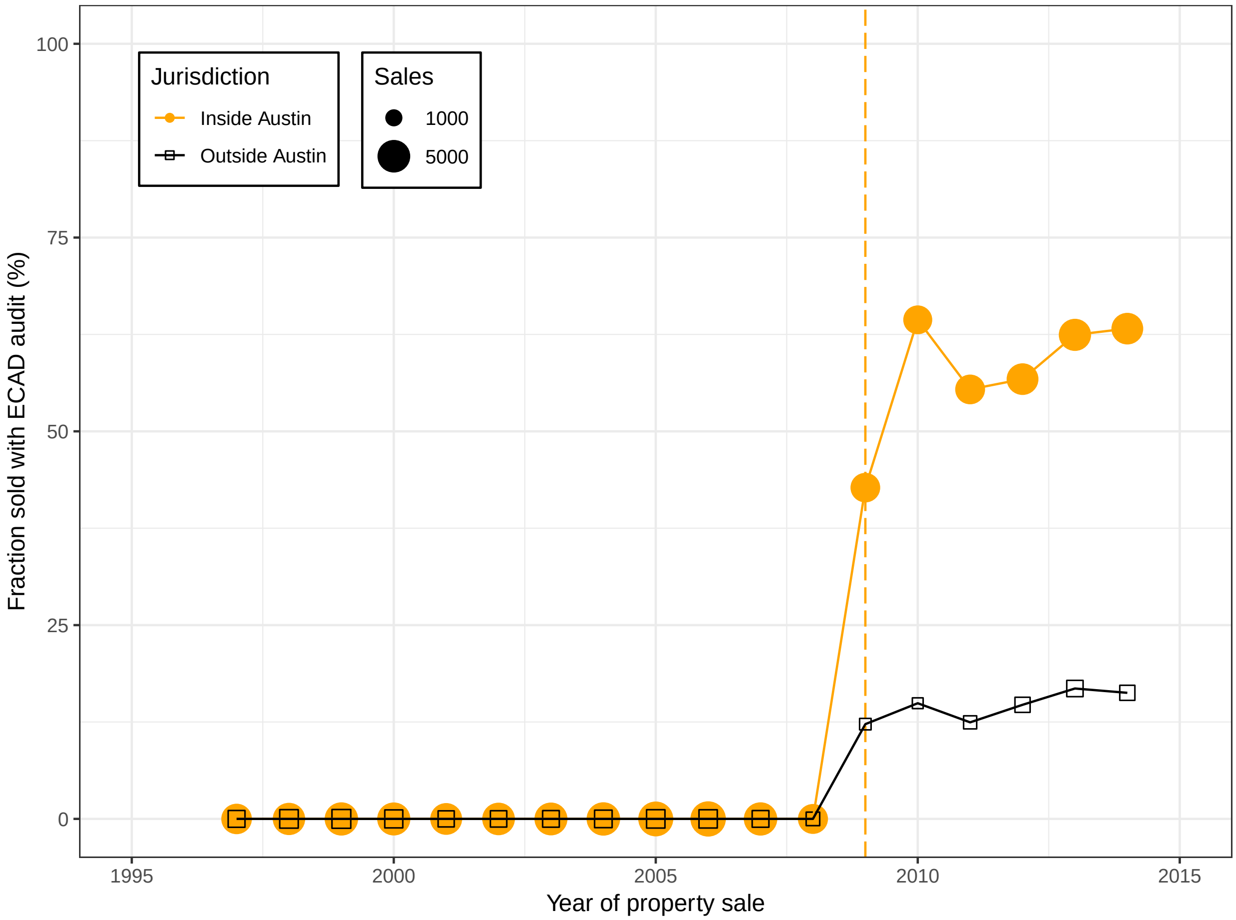
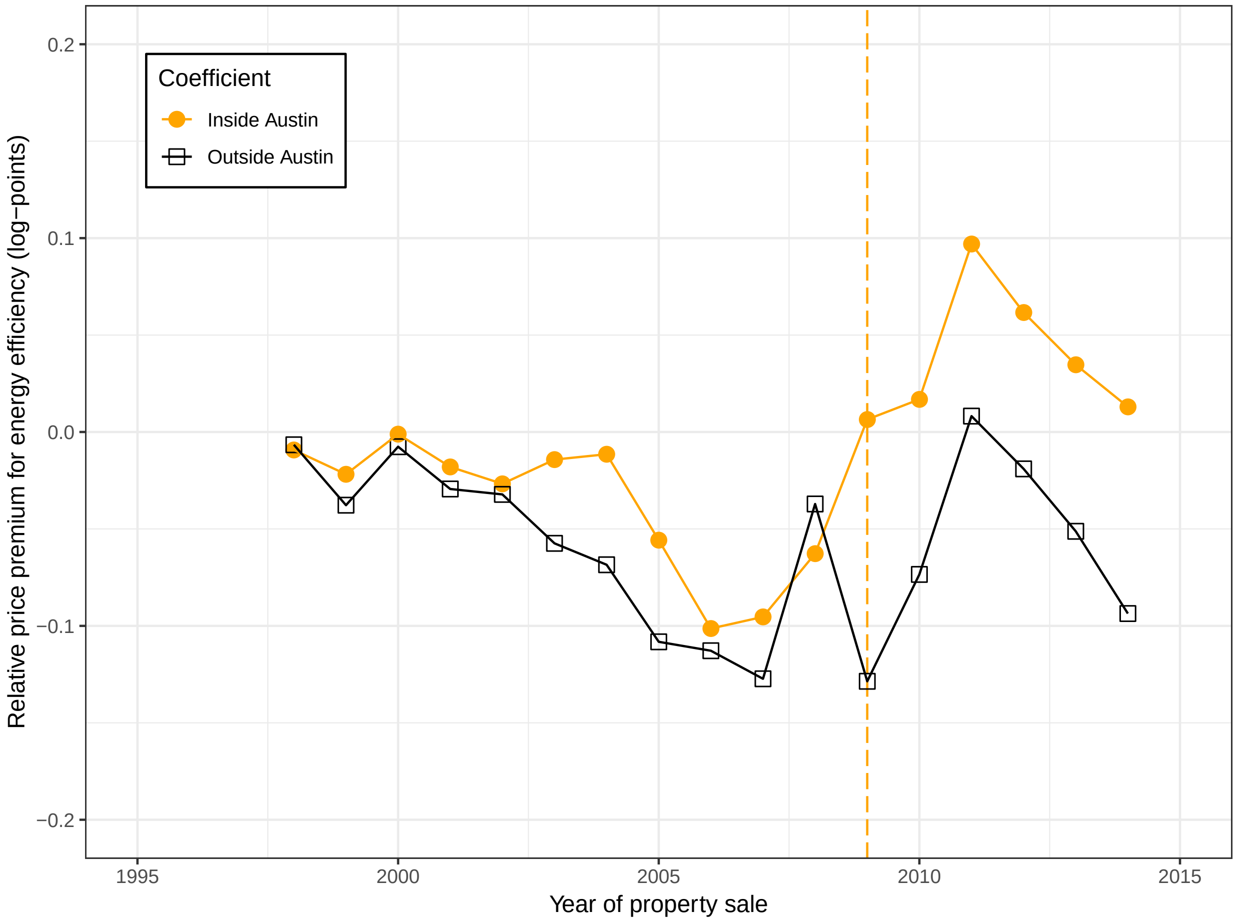
Figures and tables

Figure 1: Fraction of in-sample home sales each year that had conducted ECAD audit



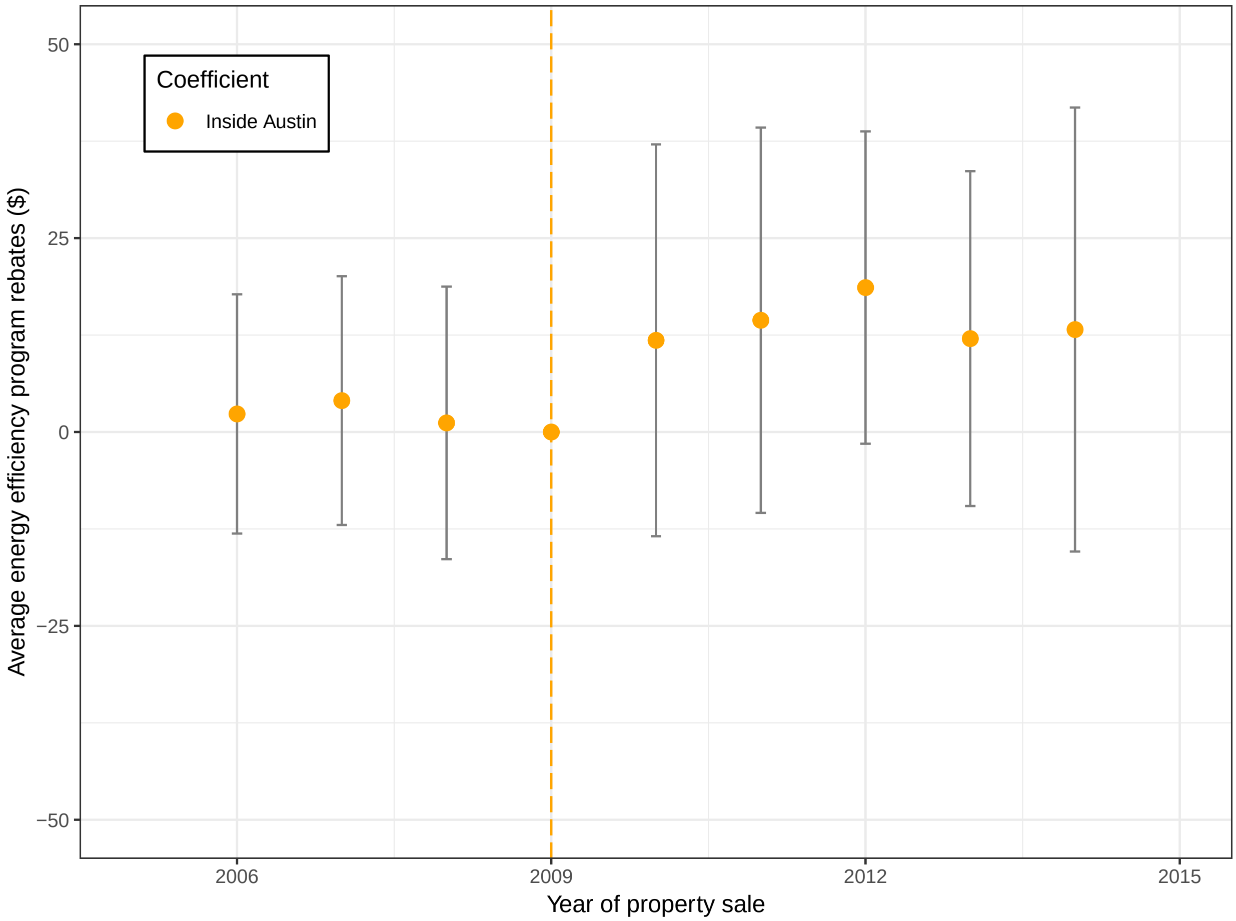
Notes: Figure 1 plots the annual fraction of in-sample home sales by jurisdiction – inside Austin versus outside of the Austin city limits – that had conducted an ECAD energy efficiency audit prior to the closing date of the sale. The dashed vertical line at 2009 indicates when the ECAD audit and disclosure policy went into effect for homes sold inside Austin only. The sample includes sales of single family residential properties constructed no later than 1998, for which all inside Austin sales were officially bound by the ECAD policy starting in June 2009.

Figure 2: Estimated annual relative energy efficiency capitalization by jurisdiction



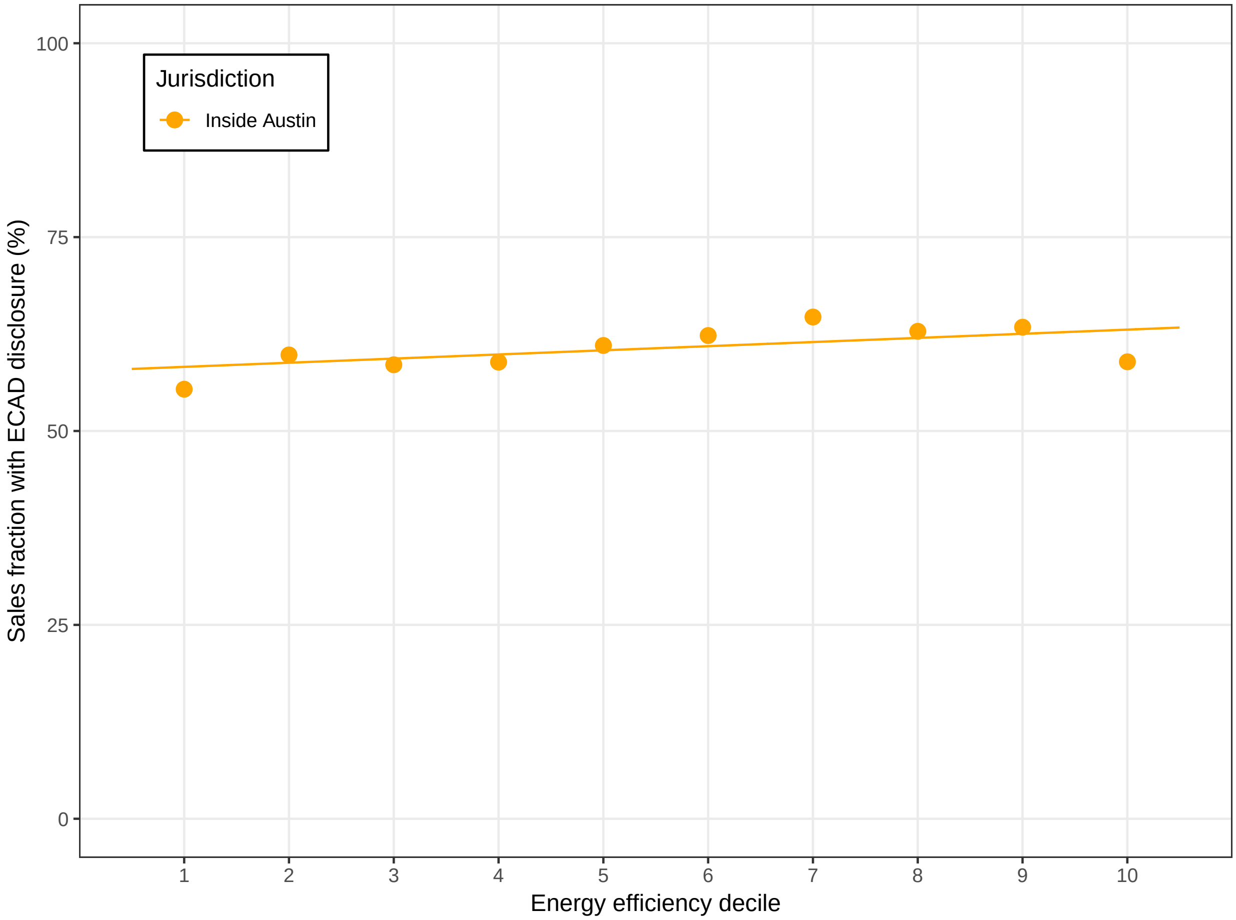
Notes: Figure 2 plots coefficients by jurisdiction – inside Austin versus outside of the Austin city limits – from regressing the natural log of homes' sale prices on the homes' energy efficiency, a term that ranges continuously from zero to one and indicates each home's fixed energy efficiency quantile. The underlying regression includes property fixed effects as well as jurisdiction-by-year fixed effects. The omitted base-year is 1997. The ECAD audit disclosure program for all sales inside Austin took effect in June 2009.

Figure 3: Inside Austin coefficients by year for pre-sale energy efficiency rebate dollars



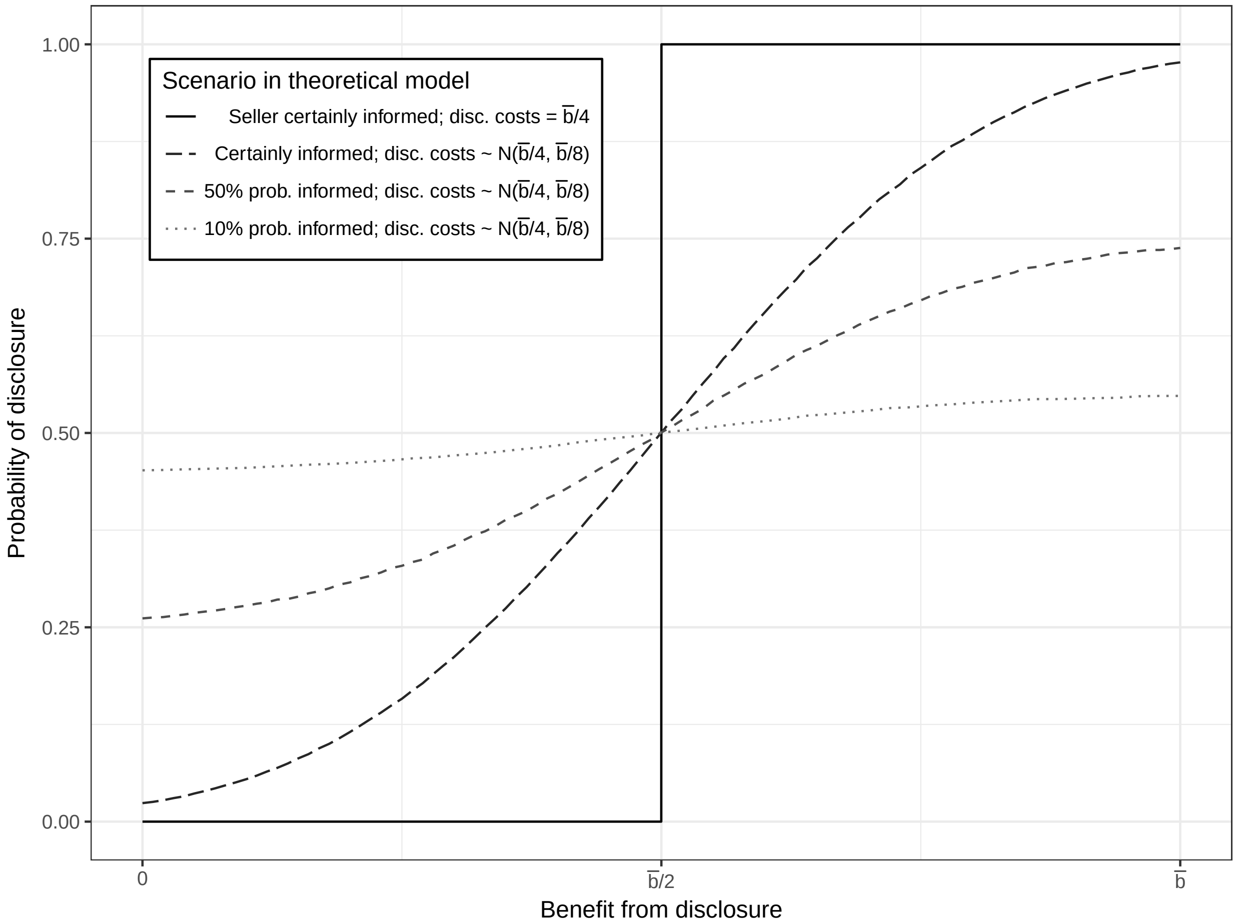
Notes: Figure 3 plots the annual inside Austin coefficients from regressing pre-sale energy efficiency rebate dollars on vintage-by-year fixed effects and annual jurisdiction indicators. The 2009 policy change year is the omitted base-year. The outcome variable is the total dollar value of rebates paid to the property's owners by Austin Energy within two years prior to the property sale for participation in any of the four energy efficiency rebate programs offered by the utility; 96 percent of these values are zero dollars.

Figure 4: ECAD audit disclosure propensity by energy efficiency of home sold



Notes: Figure 4 plots the share of in-sample homes sold inside Austin post-June 2009 that complied with the ECAD policy by obtaining and disclosing an energy efficiency audit, across the homes' energy efficiency quantiles. Each point depicts a local average compliance rate for the respective energy efficiency decile. The line shows the linear fit to the underlying microdata.

Figure 5: Illustration of various scenarios in theoretical model



Notes: Figure 5 depicts four scenarios in illustration of the theoretical model described in Section 5.2. The solid line illustrates the classic unraveling scenario, in which an informed seller will certainly disclose the quality of the product if and only if the expected benefit from disclosure is greater than the constant disclosure cost (inclusive of opportunity cost). The long-dashed line extends this scenario so that the seller's audit cost may vary, which visibly flattens the relationship between the magnitude of disclosure benefit and propensity for disclosure. The short-dashed line allows that the seller might be uniformed, with 50 percent probability, of the expected magnitude of the benefit from disclosure. Finally, the dotted line shows the case in which the seller is informed with only 10 percent probability.

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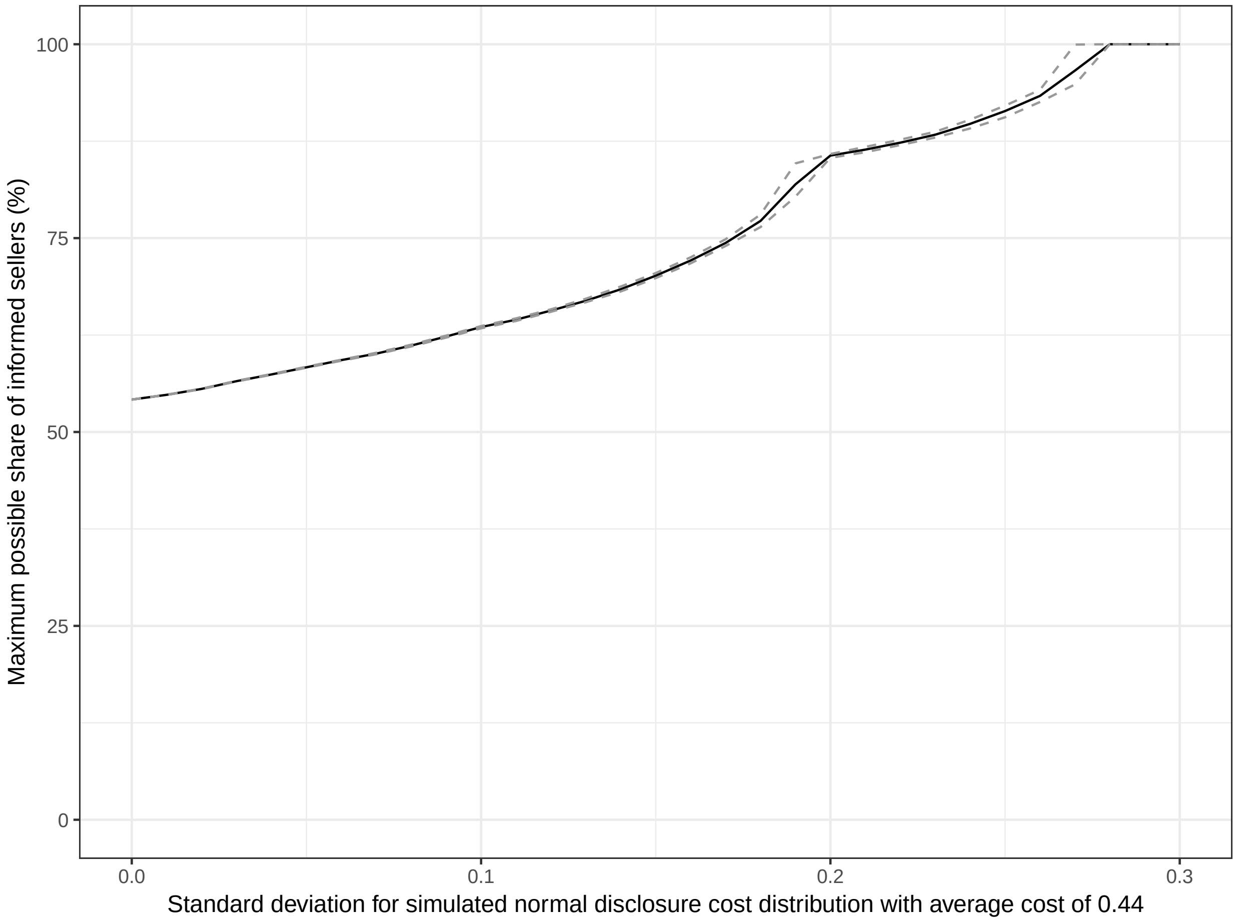
Figure 6: Simulation results for plausible share of informed sellers by audit cost spread



Notes: Figure 6 plots results from simulations of the model for the maximum share of plausibly-informed sellers at various given spreads in audit compliance costs. To generalize our simulation results, rather than pinning them to specific quantitative values for estimated capitalization, we linearly re-scale the gross disclosure benefits to range from zero to one by using the energy efficiency proxy directly to characterize disclosure benefit. We set the mean disclosure cost fixed at a value such that the empirically-observed aggregate 60.86 percent of sellers would obtain an audit in the scenario that all sellers are informed and audit costs are constant across sellers. This average cost value is 0.44. We simulate values in increments of 0.01 between 0.0 and 0.3 for the standard deviation around this average cost, running 1000 repetitions of each standard deviation value. The median values from these repetitions are shown in the solid line in the graph; the 1st and 99th percentile values for each simulated standard deviation value are shown in the dashed grey lines. Within each simulation loop, we sort benefits and costs such that maximum possible share of sellers could plausibly be informed.

Table 1: Summary statistics and covariate comparisons of homes

	Full sample	Properties sold	
		Inside Austin	Outside Austin
Attribute	(1)	(2)	(3)
Within Austin city limits	0.835	1.000	0.000
# Times sold: 1997-2014	0.809	1.606	1.681
	(1.001)	(0.827)	(0.856)
# Times sold: post-June 2009	0.222	0.447	0.433
	(0.469)	(0.586)	(0.573)
Year built (vintage)	1973	1972	1987
	(17.52)	(17.33)	(9.45)
Square feet	1839	1780	2421
	(931.1)	(759.7)	(1143.4)
Energy efficiency	0.500	0.534	0.448
	(0.289)	(0.275)	(0.286)
Monthly electricity use (kWh)	1178	1085	1650
(2006-2014 only)	(710.0)	(580.1)	(1023.2)
Monthly kWh/SqFt	0.673	0.636	0.693
(2006-2014 only)	(0.293)	(0.249)	(0.270)
Sale price ($)		228,003	315,452
		(185,280)	(311,946)
Pre-sale EE rebates ($)		29.64	27.64
(2006-2014 only)		(187.8)	(176.2)
Properties	131,028	53,752	11,702

Notes: Table 1 presents means and standard deviations (in parentheses) for selected attributes of single family residential properties in the greater Austin area during 1997-2014. The "full sample" in Column (1) includes all homes constructed no later than 1998, regardless of whether or not the home was ever sold during our sample period. Columns (2) and (3) include, respectively, only the subset of these homes that are inside (outside) the city limits and were sold at least once during 1997-2014. The "Energy efficiency" term is a value ranging continuously from zero to one that indicates each home's fixed energy efficiency quantile. "Pre-sale EE rebates ($)" include the total dollar value of rebates paid to the property's owners by Austin Energy within two years prior to the property sale for participation in the utility's four energy efficiency programs. 96 percent of these values are zero dollars.

Table 2: Estimated price capitalization of energy efficiency due to ECAD policy

	Dependent variable: Natural log of sale price			
	(1)	(2)	(3)	(4)
Energy efficiency X I{Post June-2009}	0.046^{*} (0.025)	-0.008 (0.014)	0.006 (0.019)	0.004 (0.020)
Energy efficiency X I{Inside Austin} X I{Post June-2009}	0.186^{***} (0.023)	0.096^{***} (0.012)	0.073^{***} (0.022)	0.080^{***} (0.024)
Sales sample	All	Repeat	Repeat	Repeat
Spatial fixed effects	Jurisdiction	Property	Property	Property
Time fixed effects	Vint-monthly	Vint-monthly	Juris-monthly	V-M and J-M
Number of homes	65,454	28,628	28,628	28,628
Observations	105,978	69,152	69,152	69,152

*p<0.1; **p<0.05; ***p<0.01 Each column presents estimates for the capitalization of energy efficiency into home sale prices. The "Energy efficiency" term is a value ranging continuously from zero to one that indicates each home's fixed energy efficiency quantile. The ECAD audit disclosure program for all sales inside Austin took effect in June 2009. Figure 2 shows annual coefficients for energy efficiency capitalization for each jurisdiction. Standard errors in parentheses are clustered by property.

Table 3: Energy efficiency program rebates: Difference in differences estimates

	Dependent variable: Total energy efficiency rebate dollars			
	Within 2-years pre-sale		Within 2-years post-sale	
	All programs	HPWES	All programs	HPWES
	(1)	(2)	(3)	(4)
I{Inside Austin} X I{Post June-2009}	13.149*** (4.395)	16.470*** (3.881)	11.144 (7.601)	21.246*** (6.894)
Post June-2009 mean	42.39	26.82	94.49	68.39
Spatial fixed effects	Jurisdiction	Jurisdiction	Jurisdiction	Jurisdiction
Time fixed effects	Vint-monthly	Vint-monthly	Vint-monthly	Vint-monthly
Number of homes	65,454	65,454	65,454	65,454
Observations	105,978	105,978	105,978	105,978

*p<0.1; **p<0.05; ***p<0.01 Each column presents a difference in differences estimate for the total energy efficiency program rebate dollars paid to the property owner for participation in the indicated energy efficiency program(s) during the indicated time period. Columns (1) and (2) evaluate rebates paid for improvements made within the two year prior to the sale. Columns (3) and (4) evaluate rebates paid for improvements made within the two year following the sale. Figure 3 shows the coefficients by year corresponding to Column (1). Standard errors in parentheses are clustered by property.

Table 4: Maximum plausible share of informed sellers by simulated audit cost spread

Simulated audit costs	Share of plausibly informed sellers (%)		
Standard deviation	1st percentile	median	99th percentile
0	54.18	54.18	54.18
0.050	58.28	58.34	58.42
0.100	63.37	63.53	63.66
0.150	69.84	70.16	70.49
0.200	85.36	85.65	85.85
0.250	90.58	91.39	92.08
0.270	94.81	96.60	99.95
0.300	100.00	100.00	100.00

Table 4 presents results from simulations of the model for the maximum share of plausibly-informed sellers at various given spreads in audit compliance costs. To generalize our simulation results, rather than pinning them to specific quantitative values for estimated capitalization, we linearly re-scale the gross disclosure benefits to range from zero to one by using the energy efficiency proxy directly to characterize disclosure benefit. We set the mean disclosure cost fixed at a value such that the empirically-observed aggregate 60.86 percent of sellers would obtain an audit in the scenario that all sellers are informed and audit costs are constant across sellers. This average cost value is 0.44. We simulate values in increments of 0.01 between 0.0 and 0.3 for the standard deviation around this average cost, running 1000 repetitions of each standard deviation value. The table shows the median values from these repetitions, along with the 1st and 99th percentile values for each simulated standard deviation value. Within each simulation loop, we sort benefits and costs such that maximum possible share of sellers could plausibly be informed. The 1st, median, and 99th percentile values from these repetitions are shown more generally across a broader set of simulated values in Figure 6.

A Appendix tables and figures

Table A1: Correlations between our energy efficiency proxy and ECAD audit measurements

	Dependent variable: Various components of ECAD audit reports				
	Double-pane windows	Programmable thermostat	Electric heating	Attic R-value	Duct leak percentage
	(1)	(2)	(3)	(4)	(5)
EE proxy	0.100***	0.068***	−0.144***	2.197***	−1.631***
	(0.016)	(0.016)	(0.009)	(0.289)	(0.413)
Mean	0.504	0.454	0.082	21.83	19.38
Std. Dev.	0.500	0.498	0.274	9.028	11.64
Observations	13,318	13,146	13,139	12,698	10,444

*p<0.1; **p<0.05; ***p<0.01 Each column presents linear estimates from regressing a measure from the actual ECAD audit report (in column titles) on our proxy for homes' energy efficiency. The sample used here is all homes from our analysis sample that conducted an ECAD energy efficiency audit. The "EE proxy" term is a value that ranges continuously from zero to one that indicates each home's fixed energy efficiency quantile, defined based on the pre-policy within-vintage electricity use per square foot for the home. "Double-pane windows" is a binary indicator for whether the home has double-pane and/or low-emissivity windows. "Programmable thermostat" is a binary indicator for whether the home has a programmable thermostat. "Electric heating" is a binary indicator for whether the home has electric heating (versus gas). "Attic R-value" is the measured R-value of insulation in the home's attic. "Duct leak percentage" is the measured percent air flow leakage from the home's air ducts. The differing number of observations across columns is due to heterogeneity in the completeness of official ECAD audit reports. For properties that conducted more than one audit, we use the first audit report for each property.

Table A2: Sales Probability: Difference in differences identification tests

	Dependent variable: Indicator for whether the home is sold within the year				
	Full sample			Homes with energy efficiency	
				Below-median	Above-median
	(1)	(2)	(3)	(4)	(5)
I{Inside Austin}	-0.0090^{***}	-0.0040^{***}	0.0020^{***}	0.0002	0.0022^{**}
	(0.0005)	(0.0009)	(0.0006)	(0.0007)	(0.0009)
I{Inside Austin} X I{Post 2009}	0.0062^{***}	0.0013	-0.0007	0.0009	-0.0016
	(0.0007)	(0.0011)	(0.0008)	(0.0010)	(0.0012)
Years included	1997-2014	2006-2014	1997-2014	1997-2014	1997-2014
Time fixed effects	Year	Year	Vintage-year	Vintage-year	Vintage-year
Sample mean	0.044	0.041	0.044	0.042	0.047
Number of homes	131,028	131,028	131,028	65,579	65,449
Observations	2,355,413	1,179,252	2,355,413	1,178,864	1,176,549

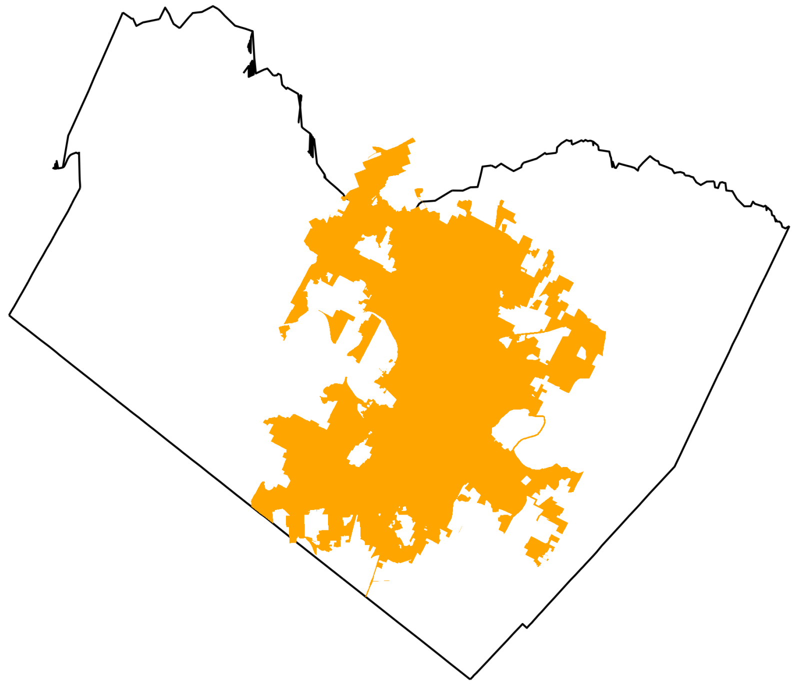
*p<0.1; **p<0.05; ***p<0.01 All columns present difference in differences estimates testing whether the probability that a home is sold varies asymmetrically between Inside Austin and Outside Austin pre- versus post-2009, when the ECAD audit and disclosure policy went into effect. The annual fraction of in-sample homes sold by jurisdiction is shown in Figure A2. Standard errors in parentheses are clustered by property.

Table A3: ECAD audit disclosure: Difference in differences estimates

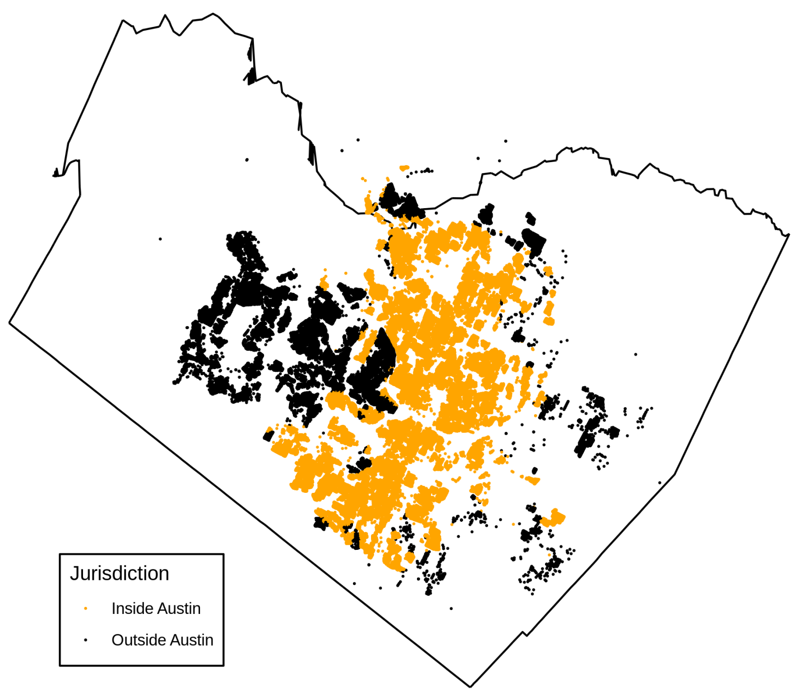
	Dependent variable: Indicator for ECAD audit			
	(1)	(2)	(3)	(4)
I{Inside Austin}	0.453^{***}	0.459^{***}	0.453^{***}	0.450^{***}
X I{Post June-2009}	(0.006)	(0.008)	(0.011)	(0.015)
Sales sample	All	All	Repeat	Repeat
Spatial fixed effects	Jurisdiction	Jurisdiction	Property	Property
Time fixed effects	Monthly	Vint-monthly	Monthly	Vint-monthly
Number of homes	65,454	65,454	28,628	28,628
Observations	105,978	105,978	69,152	69,152

*p<0.1; **p<0.05; ***p<0.01 Each column presents a difference in differences estimate for the probability that a home that is sold has conducted an ECAD audit. The ECAD audit disclosure program for all sales inside Austin took effect in June 2009. Columns (1) and (2) include all properties that were sold at least once during 1997-2014. Columns (3) and (4) include only properties that were sold more than once during 1997-2014. Figure 1 shows annual average ECAD audit rates by jurisdiction for this full sample. Standard errors in parentheses are clustered by property.

Figure A1: Map of the Austin, Texas study area



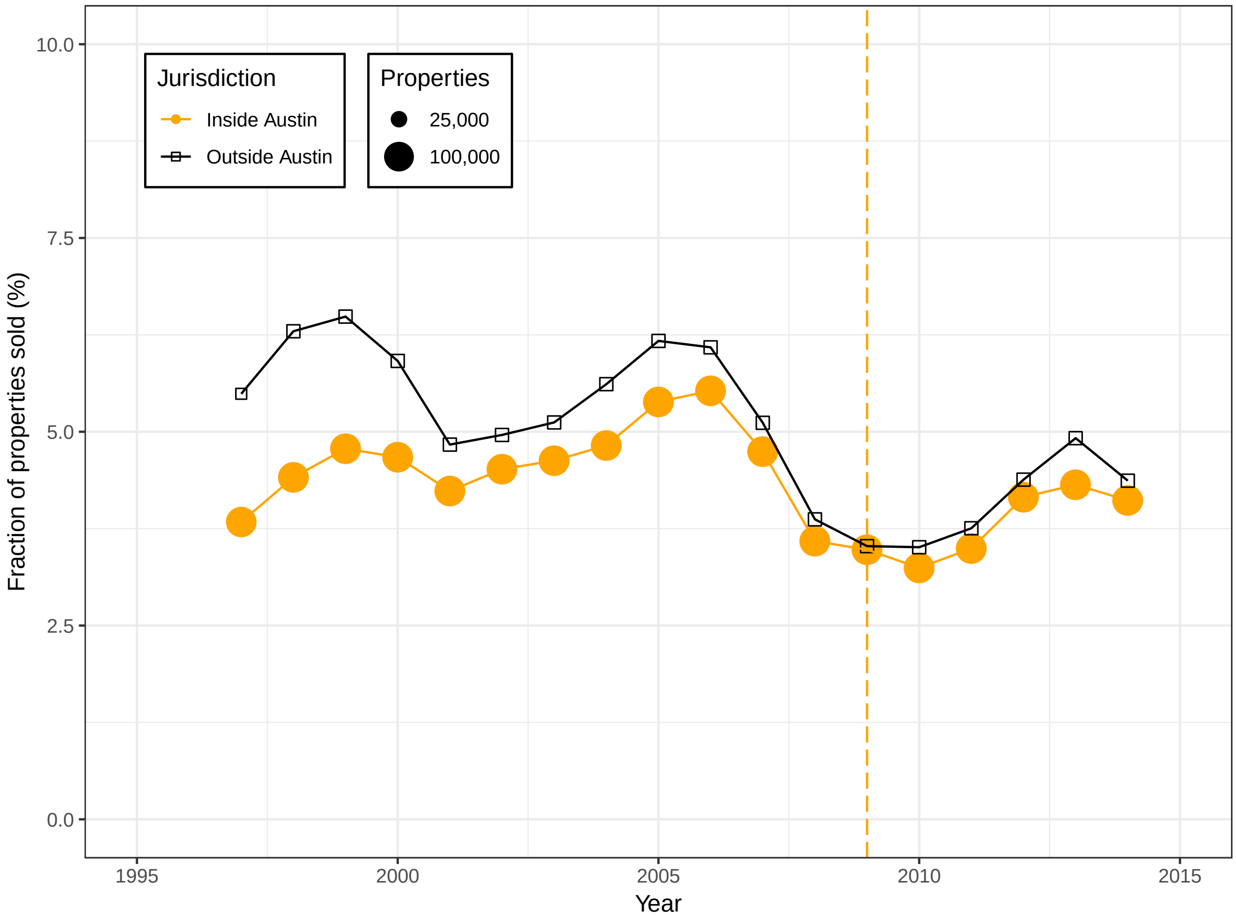
(a) Austin city limits (orange) and Travis county border (black)



(b) Properties included in empirical sample by jurisdictional designation

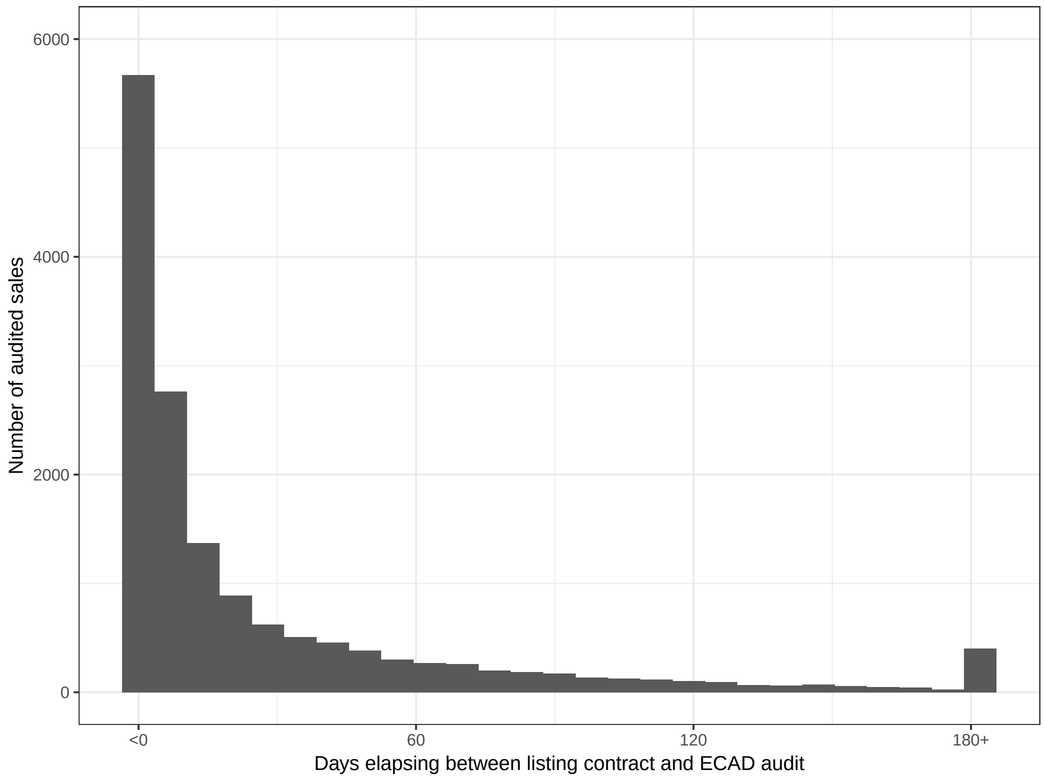
Notes: Appendix Figure A1 provides a map of our empirical study area. Panel (a) presents the jurisdictional coverage of Austin city limits, which excludes several "holes" as shown. Panel (b) plots points for each of the homes in our analysis sample, indicating by color each property's respective jurisdiction.

Figure A2: Fraction of in-sample homes sold each year inside Austin and outside city limits

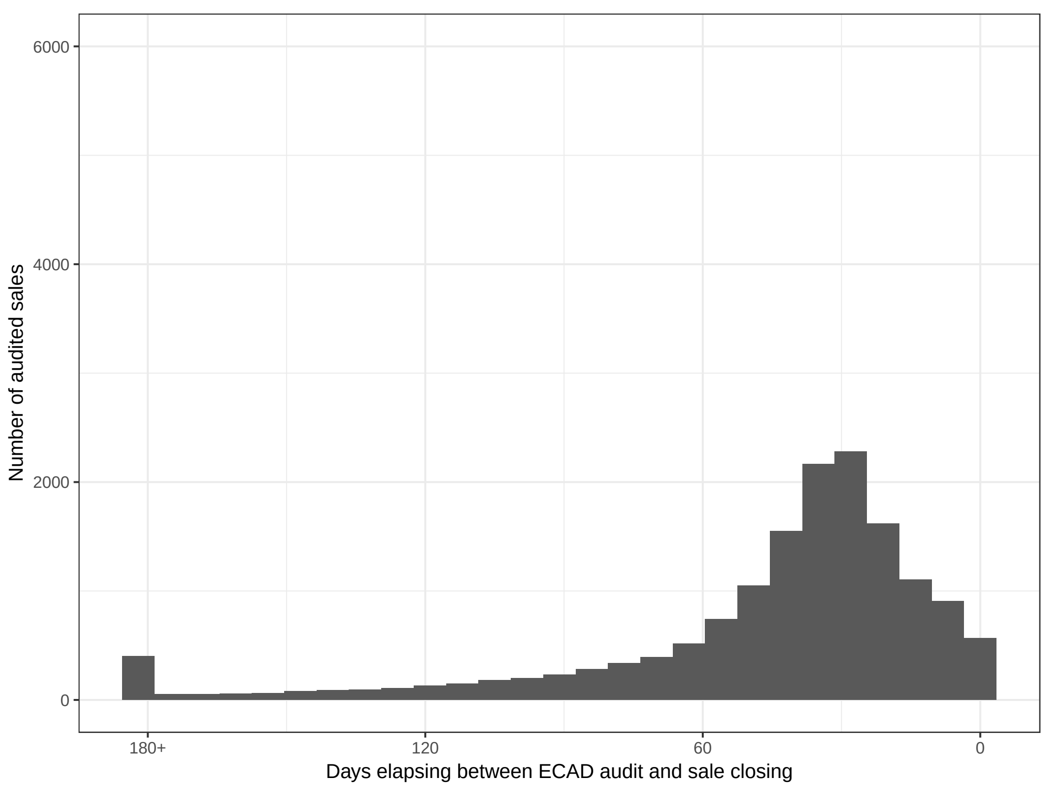


Notes: Figure A2 plots the annual fraction of in-sample homes sold by jurisdiction, inside Austin versus outside of the Austin city limits. The dashed vertical line at 2009 indicates when the ECAD residential energy efficiency audit and disclosure policy went into effect for homes aged 10 years or older sold inside Austin only. The sample includes single family residential properties constructed no later than 1998.

Figure A3: Timing of ECAD audits with respect to listing and sale contracts



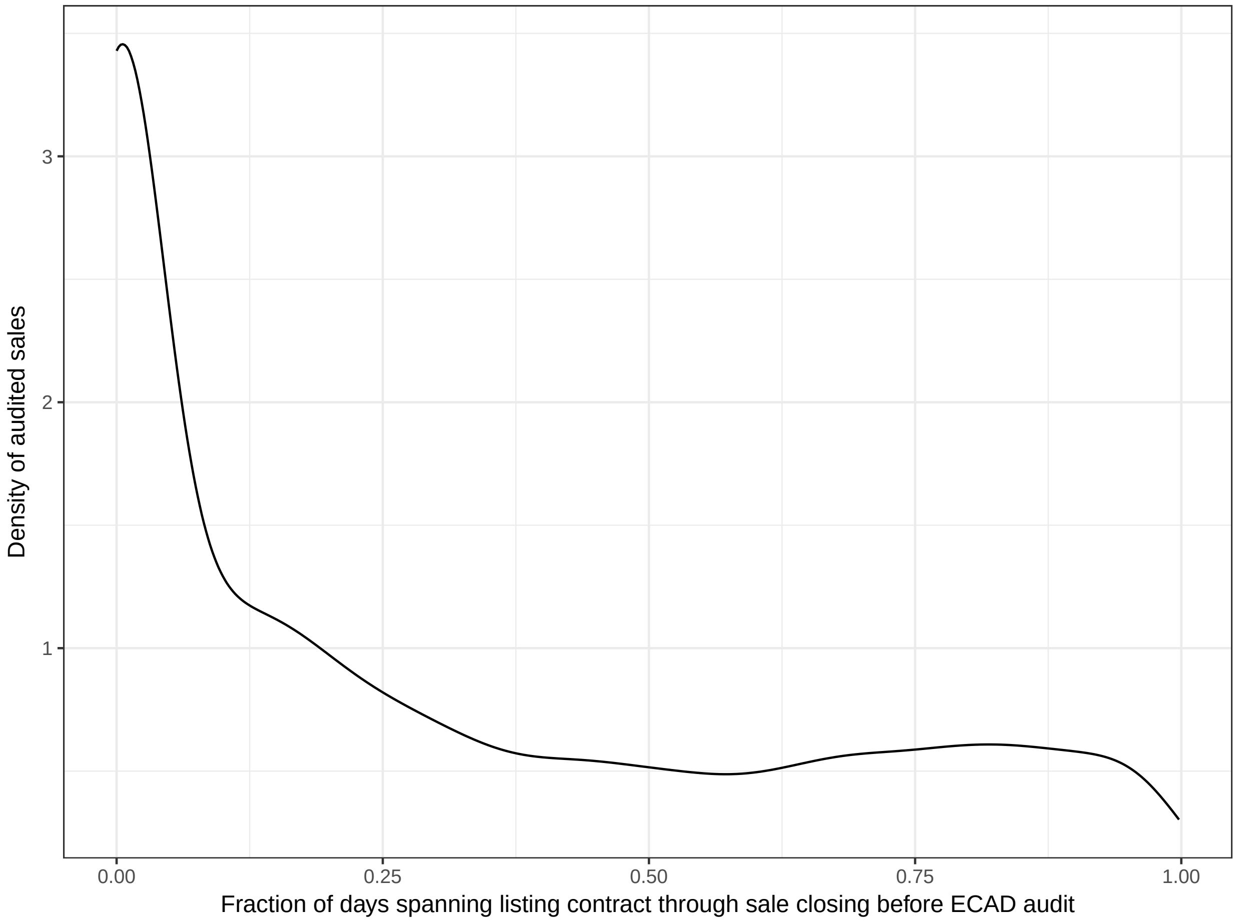
(a) Duration from listing contract to ECAD audit



(b) Duration from ECAD audit to sale closing

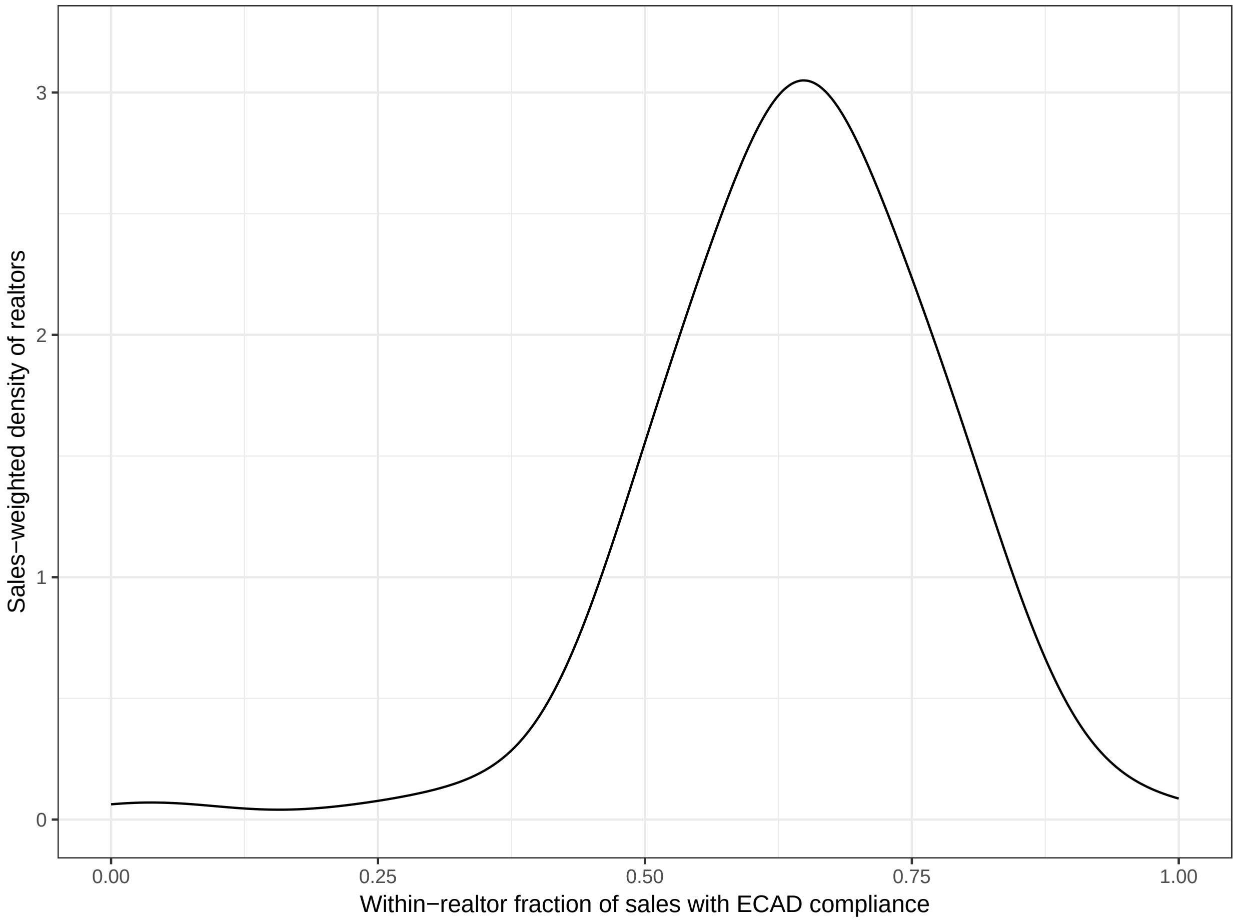
Notes: The date of the listing contract is when the seller formalizes an agreement with the seller's realtor to market the property, which typically occurs before any marketing activities. The date of the sale closing is the official closing date for the property sale transaction.

Figure A4: Timing of ECAD audits with respect to listing and sale contracts



Notes: Appendix Figure A4 shows the density of the fraction of days spanning between the listing contract and the ECAD audit with respect to the total number of days the property was marketed (spanning from the listing contract through the sale closing contract). For example, if a property was audited seven days after the listing contract was signed and was sold 28 days after the listing contract was signed, the value in the figure would be 0.25 for this sale. The date of the listing contract is when the seller formalizes an agreement with the seller's realtor to market the property, which typically occurs before any marketing activities. The date of the sale closing is the official closing date for the property sale transaction.

Figure A5: Density of ECAD compliance rates across realtors



Notes: Appendix Figure A5 shows the sales-weighted density of ECAD compliance for a random subset of realtors who handled home sales within-Austin after the ECAD policy was effective. To create this graph, we first took a one percent sample of post-ECAD sales within Austin City limits and matched each transaction to the seller's realtor using Zillow.com. Then, we determined the full set of properties sold inside Austin post-ECAD by each of these realtors, which we use to compute the compliance density depicted in the figure.

SINGLE FAMILY

ECAD Energy Audit Results

For Residence: Audit Date:

Thank you for complying with the City of Austin's ECAD Ordinance, which requires homeowners to provide these energy audit results to buyers.

SAVE THIS FORM! This ECAD audit is valid for 10 years after the audit date.

This audit helps you identify energy efficiency improvements that could lower your monthly energy costs and make your home more comfortable. Austin Energy's Home Performance with ENERGY STAR® program offers rebates and low-interest loans that make these improvements more affordable. Before you begin making any home energy efficiency improvements, be sure to get the latest program details from austinenergy.com or by calling 512-482-5346.

ENERGY AUDIT SUMMARY

	Action Recommended?	Potential Annual Savings*:
A. Windows and Shading		
B. Attic Insulation		
C. Air Infiltration and Duct Sealing		
D. Heating and Cooling System Efficiency (HVAC)		
	Total Annual Savings:	

HOME IMPROVEMENT RECOMMENDATIONS:

Austin Energy recommends the following actions based on the energy audit performed by

DISCLOSURES: Figures are based on an estimate from the average single-family house in Austin (1800 - 2000 sq. ft.) that has made improvements through an efficiency program by Austin Energy or Texas Gas Service. Weather, equipment installation and electric usage will all effect actual savings. There is no guarantee or warranty, either expressed or implied, as to the actual effectiveness, cost or utility savings, if you choose to implement these recommendations.

The Energy Conservation Audit and Disclosure is not required to be included in the sales contract nor the Seller's Disclosure form (Texas Real Estate Commission), but instead is a stand-alone requirement of the City of Austin.

In support of the City of Austin's
Energy Conservation Audit and Disclosure Ordinance
Austin City Code Chapter 6-7, June 2009
.

SINGLE FAMILY

Energy Audit Data

DATA SUMMARY

Submission Date:

PROPERTY

Austin Energy Electric Meter Number:
Owner Name:
Street Address:
City, State, Zip Code:

Tax Assessor's Property ID:
Year Built:
Estimated Square Footage:

AUDITOR

Auditor:
Company Name:

Phone Number:
Property Audit Date:

WINDOWS & SHADING

Type(s) of Window(s):
Type(s) of Existing Solar Shading:

ATTIC INSULATION

Attic Insulation Type:
Open Chases(s):

Average R-Value:

HEATING & COOLING AIR DUCT SYSTEM

HVAC SYSTEM:
Condenser: Manufacturing Date: Estimated EER:
Furnace/AH: Manufacturing Date: Estimated AFUE:
HVAC Duct Air Leakage: % Leakage:
Duct System Type(s)
Enrolled in the Austin Energy Power Partner Thermostat Program:

ADDITIONAL SYSTEM:
Condenser: Manufacturing Date: Estimated EER:
Furnace/AH: Manufacturing Date: Estimated AFUE:
HVAC Duct Air Leakage: % Leakage:
Duct System Type(s):
Enrolled in the Austin Energy Power Partner Thermostat Program:

AIR INFILTRATION/WEATHERIZATION

Exterior doors: weather-stripped?
Plumbing penetrations: sealed?

Attic access: weather-stripped?

ADDITIONAL AUDIT INFORMATION

Domestic Water Heater Type(s):
Type(s) of Toilet(s):

PROPERTY IDENTIFICATION — Outdoor Temperature F

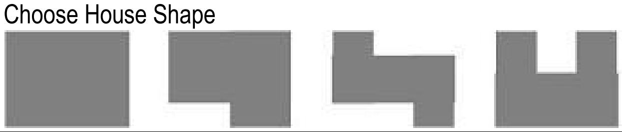
County | Property ID | Property Type | Building Count
Meter Number | Second Meter | Gas Type
Street # | Direction | Street Name | Suffix | Unit
City | State | Zip | Occupied By | Count of Occupants
Year Built | Foundation | Estimated Sq Footage | Average Duct Leakage
Levels | Bedrms | Baths | Fireplaces | Average Wall Height | Average Attic R-Value

WINDOWS & SHADING

Types of Windows | Single Pane | Double Pane | Low-e | Skylights | Other
Types of Shading | Solar Screens | Solar Film | Awnings | Skylights Cover | Other

Windows	S	SW	W	NW	N	NE	E	SE	Skylight
Needs Shade (sq ft)									

Choose House Shape



Bldg Front Orientation: NW | N | NE | W | E | SW | S | SE

APPLIANCES & WATER HEATER

APPLIANCES (Remaining in Home) | '92 or older | '93 or newer

- Refrigerators
- Freezers
- Clothes Washers
- Clothes Dryers
- Dish Washers
- Range/Stove/Ovens
- Inefficient Toilets (> 1.6 gal)
- Efficient Toilets (<= 1.6 gal)

Pool Pumps | Speed
Pool Pump Timers

Water Heaters
- WH1 | Fuel 1
- WH2 | Fuel 2

Water Heater Timers

MISC Lighting | Solar PV | Electric Vehicle Charger | Natural Gas Generator
Sprinklers | Year Installed | Rainwater Collector | Water Saving Devices

ATTIC INSULATION & AIR INFILTRATION

Roof Type | Roof Materials | Roof Color | Total Attic R-Value

Attic Insulation | Insulation Type | Secondary Insulation Type
Square Feet | Inches Deep | R-Value

Vaulted Ceiling Insulation | Insulation Type | Secondary Insulation Type
Square Feet | Inches Deep | R-Value

Cathedral Ceiling Insulation | Insulation Type
Square Feet | Inches Deep | R-Value

Attic/Knee Wall Insulation Status
- Radiant Barrier | Chases
- Plumbing Penetrations Sealed | Furnace & WH Closet Appropriately Sealed
- # Exterior Doors | # Doors Weather-stripped | Whole House Fan
- # Conditioned Stair Boxes/Hatches | # Insulated | # Weather-stripped

HEATING & COOLING (1)	Zone Description				Est. Sq. Ft. (Zone)	
COOLING Type				Thermostat		
Condenser Mfg Date		Est. EER	Est. Condenser BTUs			
Tonnage	From Mfg Spec	OR	Est. from Sq. Ft.		Sq. Ft. per Ton	
HEATING Type		Fuel Type	Location		Air Handler	
Furnace Mfg Date		Est. BTUs	Est. BTUs (other)		AFUE	
DUCT SYSTEM *(Check all that apply)*		NONE	Mylar Flex	Grey Flex	Duct Board	Sheet Metal
Duct Locations	Conditioned Space		Crawl Spaces	Furrdowns	Attic	
Duct Condition		R-Value				
	Return Air Sq. In.	Grille Type		Return Plenum Seal		
LEAKAGE	Target CFM			Current Est. CFM		
	Did Not Reach Pressure		Measured Pressure Test Leakage CFM		% Leakage	
	Supply Air Reading F		Return Air Reading F		Delta T	

HEATING & COOLING (2)	Zone Description				Est. Sq. Ft. (Zone)	
COOLING Type				Thermostat		
Condenser Mfg Date		Est. EER	Est. Condenser BTUs			
Tonnage	From Mfg Spec	OR	Est. from Sq. Ft.		Sq. Ft. per Ton	
HEATING Type		Fuel Type	Location		Air Handler	
Furnace Mfg Date		Est. BTUs	Est. BTUs (other)		AFUE	
DUCT SYSTEM *(Check all that apply)*		NONE	Mylar Flex	Grey Flex	Duct Board	Sheet Metal
Duct Locations	Conditioned Space		Crawl Spaces	Furrdowns	Attic	
Duct Condition		R-Value				
	Return Air Sq. In.	Grille Type		Return Plenum Seal		
LEAKAGE	Target CFM			Current Est. CFM		
	Did Not Reach Pressure		Measured Pressure Test Leakage CFM		% Leakage	
	Supply Air Reading F		Return Air Reading F		Delta T	

HEATING & COOLING (3)	Zone Description				Est. Sq. Ft. (Zone)	
COOLING Type				Thermostat		
Condenser Mfg Date		Est. EER	Est. Condenser BTUs			
Tonnage	From Mfg Spec	OR	Est. from Sq. Ft.		Sq. Ft. per Ton	
HEATING Type		Fuel Type	Location		Air Handler	
Furnace Mfg Date		Est. BTUs	Est. BTUs (other)		AFUE	
DUCT SYSTEM *(Check all that apply)*		NONE	Mylar Flex	Grey Flex	Duct Board	Sheet Metal
Duct Locations	Conditioned Space		Crawl Spaces	Furrdowns	Attic	
Duct Condition		R-Value				
	Return Air Sq. In.	Grille Type		Return Plenum Seal		
LEAKAGE	Target CFM			Current Est. CFM		
	Did Not Reach Pressure		Measured Pressure Test Leakage CFM		% Leakage	
	Supply Air Reading F		Return Air Reading F		Delta T	

HEATING & COOLING (4)	Zone Description			Est. Sq. Ft. (Zone)	
COOLING Type				Thermostat	
Condenser Mfg Date		Est. EER	Est. Condenser BTUs		
Tonnage	From Mfg Spec	OR	Est. from Sq. Ft.	Sq. Ft. per Ton	
HEATING Type		Fuel Type	Location	Air Handler	
Furnace Mfg Date		Est. BTUs	Est. BTUs (other)	AFUE	
DUCT SYSTEM *(Check all that apply)*	NONE	Mylar Flex	Grey Flex	Duct Board	Sheet Metal
Duct Locations	Conditioned Space	Crawl Spaces	Furrdowns	Attic	
Duct Condition		R-Value			
	Return Air Sq. In.	Grille Type	Return Plenum Seal		
LEAKAGE	Target CFM		Current Est. CFM		
	Did Not Reach Pressure	Measured Pressure Test Leakage CFM		% Leakage	
	Supply Air Reading F	Return Air Reading F		Delta T	
HEATING & COOLING (5)	**Zone Description**			**Est. Sq. Ft. (Zone)**	
COOLING Type				Thermostat	
Condenser Mfg Date		Est. EER	Est. Condenser BTUs		
Tonnage	From Mfg Spec	OR	Est. from Sq. Ft.	Sq. Ft. per Ton	
HEATING Type		Fuel Type	Location	Air Handler	
Furnace Mfg Date		Est. BTUs	Est. BTUs (other)	AFUE	
DUCT SYSTEM *(Check all that apply)*	NONE	Mylar Flex	Grey Flex	Duct Board	Sheet Metal
Duct Locations	Conditioned Space	Crawl Spaces	Furrdowns	Attic	
Duct Condition		R-Value			
	Return Air Sq. In.	Grille Type	Return Plenum Seal		
LEAKAGE	Target CFM		Current Est. CFM		
	Did Not Reach Pressure	Measured Pressure Test Leakage CFM		% Leakage	
	Supply Air Reading F	Return Air Reading F		Delta T	

NOTES & INSTRUCTIONS

How Does Mandatory Energy Efficiency Disclosure Affect Housing Prices?*

Alecia Cassidy†

July 13, 2019
(Latest version here)

Abstract

Since 2012, the United States has witnessed explosive growth in mandatory energy efficiency disclosure policies, which aim to address market failures in housing. I examine one such policy, comparing prices before and after the policy's introduction for homes with different levels of energy efficiency features. I find increased capitalization of energy efficiency features. Effects are larger for difficult-to-observe features, suggesting the results are driven by information and not changing preferences for energy efficiency over time. This highlights the potential for disclosure policies to promote long-run energy efficiency investment by increasing the returns homeowners expect on these investments when they sell.

*I would especially like to thank the Austin Board of Realtors for generously providing invaluable real estate data, without which my paper would not exist. I would like to thank SmartyStreets for generously providing access to top-notch address standardization and validation services. I would like to thank Traviss Cassidy, Jeffrey Smith, Mike Price, Thomas Lyon, Joel Slemrod, Catie Hausman, Michael Moore, Dakota Dennison, Ryan Kellogg, Robyn Meeks, Andrei Lubomudrov, David Miller, Mike McWilliams, Connor Cole, Ariel Binder, Michael Ricks, John Bound, Scott Horowitz, Anna Levitt, Bharathan Balaji, Eric Wilson, Stephen Salant, Shaun McRae, and Daniel Macumber. Austin-area realtors Zia Lowe, Jenny Deschard, Claire McAdams, and several realtors who would prefer to remain anonymous provided invaluable interviews. I would also like to thank Tim Kisner, Jessica Galloway, Andrew Tighe, Michael Scott Jarman, Jaime Gomez, and Debbie Plank at Austin Energy for help with data and institutional details. Participants at the University of Michigan Resource Economics Student Seminar and the University of Michigan Labor Lunch also provided insightful comments. This research was made possible by support from the Dow Sustainability Institute, which provided me with a PhD fellowship covering tuition, benefits, and a stipend; and the Michigan Institute for Teaching and Research in Economics, which provided research funding and travel support.

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1 Introduction

A large portion of energy demand comes from the buildings sector, which accounted for about 40 percent of energy use and 37 percent of carbon dioxide emissions in the United States in 2016 (U.S. Energy Information Administration, 2017b, 2016a,b). One promising policy tool for reducing energy demand is mandatory energy efficiency disclosure, which requires building owners to disclose energy efficiency-related characteristics or energy use to buyers or the public. These policies aim to increase energy efficiency by addressing sources of market failures associated with imperfect information, such as asymmetric information and salience, that could lead consumers to under-invest in efficient equipment relative to their private optimum. In the residential sector, energy efficiency disclosure policies might spur investment in efficient equipment by increasing information available to buyers, which in turn raises the premium a buyer is willing to pay for a home with energy-efficient features. By increasing energy efficiency investment, disclosure policies could also partially correct for externalities associated with residential energy use.

The popularity of energy disclosure policies has grown rapidly in recent years. Ten years ago, mandatory energy disclosure policies in the residential sector were virtually unheard of in the United States, but there has been an explosion of such policies in the past five years. Since 2012, ten states and over thirty major cities have passed legislation to implement mandatory energy efficiency disclosure policies in the residential sector.[1] However, little is known about whether disclosure policies have their intended effects on housing markets.

This paper asks whether mandatory energy disclosure policies increase the capitalization of energy efficiency into housing prices. To answer this question, I examine the introduction of the Energy Conservation Audit and Disclosure (ECAD) policy in Austin, Texas, which mandated that homeowners get an energy efficiency audit before selling their home, starting in June 2009. The energy efficiency audit provided statistics like the percent duct leakage of the home, the duct R-value, the attic R-value, the Energy Efficiency Rating (EER) of the Heating, Ventilation, and Air Conditioning (HVAC) system, and whether the water heater used natural gas or electricity.[2]

I evaluate the policy's capitalization effects by comparing prices before and after the policy for homes with different levels of energy efficiency features. My design is equivalent to a treatment intensity difference-in-differences, where the treatment intensity variable is the level of energy efficiency for various energy efficiency features. Using energy efficiency as my source of cross-sectional variation allows me to consistently estimate the change in capitalization

[1] The states are Alaska, California, Hawaii, Kansas, Maine, Massachusetts, New Jersey, New York, Oregon, and South Dakota. Legislation is under way in Vermont and Missouri. The cities include New York, Washington D.C., Seattle, Atlanta, and Los Angeles. Many more cities are considering such policies. See Palmer and Walls (2017) and Coleman (2011) for reviews of disclosure ordinances in buildings.

[2] Percent duct leakage measures how much air is escaping from the ducts. R-values measure the thickness of insulation. An HVAC system's Energy Efficiency Ratio (EER) is defined as the ratio of a heating or cooling system's output in British Thermal Units per hour to its power draw in watts.

even though it is impossible to know the static capitalization of energy efficiency into prices. I use only two observations per home, from a sale just before and just after the audit policy went into effect, to ensure that the change in capitalization I find is not driven by changes in the composition of sales from before to after the policy.

I find that ECAD increases capitalization of energy efficiency features into home prices, suggesting that consumers adjust their willingness to pay for a home based on available information. I explore the change in capitalization of four energy efficiency features. The evidence for additional capitalization varies by feature and is strongest for duct leakage, which is the feature that was the most difficult to observe in the absence of the policy, and weakest for the EER, which was easiest to observe in the absence of the policy. This result survives a battery of robustness checks. For each of the four energy efficiency features, additional capitalization looks to be substantial (on the same order of magnitude as the present discounted value of savings associated with a unit increase in the feature).

One challenge to answering the question of whether an information policy increased capitalization of energy efficiency is that there could be changes in capitalization not due to the policy. For example, awareness of the benefits of energy efficiency could be increasing over time. Consumers could increasingly request energy bills when buying a home. General concern for the environment could increase over time. Macroeconomic factors like the recession could lead consumers to value savings from energy efficiency more, or lead them to be liquidity constrained when buying a home. Energy costs could change. If capitalization of energy efficiency as a whole is increasing over time due to other factors, that could artificially inflate estimates of policy impacts.

To rule out these unobserved confounders, I undertake a thorough categorization of twelve measures of energy efficiency on the audit form according to the expected change in information about the audit variables due to the policy. I divide the features into groups using criteria such as whether the feature can be visually determined during a walk-through, whether it is reported on home inspections in Austin, whether the feature is a field in the Multiple Listing Service (MLS) system, and whether the front page of the audit form called attention to the feature. For each criterion, I construct an index that summarizes the variation in the group of features. I find more evidence of additional capitalization due to the policy for the index that summarizes the variation in the features on which information was harder to come by before the policy, and I find more evidence of additional capitalization for measures that were featured on the front page of the audit form. The takeaway is that the capitalization effect from just before to just after the policy for energy efficiency measures that were already observable in Austin, TX is much lower than for energy efficiency features that were not. Additionally, the features made more salient by the policy experience more increase in capitalization than others. This serves as a unique falsification test for my baseline estimates. My technique could be applicable for analysis of other information policies that contain multidimensional information.

Additionally, I form a supplemental sample of sales of homes in my main sample that occurred prior to my main sample. This supplemental sample is used to test for pretrends that could drive my results; I find little evidence that pretrends in capitalization of energy efficiency features drive my results.

My findings have prescriptive implications for the design of energy disclosure policies. Policymakers could lower compliance costs and maximize impact by first exploring what information consumers already have access to through other means, and then only requiring disclosure of the features that they do not have access to. This is important given the popularity of the Home Energy Score (HES) among policymakers. Cities like Portland have recently enacted energy disclosure policies that require the seller to show a Home Energy Score (HES) to buyers. Readily observable factors such as the home size, number of bedrooms, fuel type of appliances, EER, HVAC size, and year built play an important role in determining the HES. This is by design: the HES is designed to have high predictive power of energy bills, and these factors matter more than others for those bills. The effect of HES disclosure policies might be weakened because consumers already take these observable factors into account. In fact, the measure for which I find the most evidence of a change in capitalization due to ECAD, duct leakage, is often estimated for the HES based on more observable features of the home (like the system age).

Little research exists on energy efficiency disclosure policies in the housing market. The closest studies to this paper are the working papers by Aydin, Brounen, and Kok (2018) and Frondel, Gerster, and Vance (2018). Both papers examine the impact of mandatory disclosure on capitalization of a single energy efficiency index into housing prices. In contrast, I study the capitalization of individual energy efficiency features. This is important because it helps me to rule out confounds that could threaten my identification strategy, and makes my study more informative for policymakers.

Aydin et al. (2018) examine the impact of mandatory disclosure of energy performance certificates in the Netherlands on capitalization of energy efficiency into housing prices. They use data from after the policy was implemented and employ a regression discontinuity design to test for discontinuous changes in price at energy efficiency letter grade cutoffs. They find no evidence of a discontinuous change in price at the letter grade cutoffs. One reason why there might be no effect in their setting is that the policy publicized the energy efficiency index that underlies the letter grade system. My finding contrasts with theirs: I find that a mandatory disclosure policy increased capitalization of energy efficiency.

Frondel et al. (2018) examine the effect of introducing mandatory disclosure in the context of voluntary disclosure, focusing on differential effects of voluntary and mandatory disclosure on the homes that disclose versus homes that do not and pinpointing the effect of information asymmetry. They find that voluntary disclosure of home energy use is more likely for more energy efficient homes, and mandatory disclosure of home energy use causes a decline in home prices for homes that might not have disclosed voluntarily. My paper differs from theirs in that homes in my sample were all required to comply by law, and the audits were not offered on a voluntary basis before the year that the mandatory policy took effect. A unique advantage of my context over theirs is that it allow me to study multiple energy efficiency features to rule out confounders such as changes in preferences for energy efficiency over time.

This paper contributes to the rich literature on how consumers respond to energy efficiency information in general (Faruqui, Sergici, and Sharif, 2010; Jessoe and Rapson, 2014; Gans, Alberini, and Longo, 2013; Davis and Metcalf, 2016; Newell and Siikamaki, 2014; Allcott and Sweeney, 2016). Recent work has looked at the effect of energy efficiency audits or disclosure of energy efficiency information in buildings, but has focused on energy use or investment in durables, rather than housing prices, as an outcome (Palmer and Walls, 2015; Alberini and Towe, 2015; Allcott and Greenstone, 2017; Considine and Sapci, 2016; Allcott and Greenstone, 2017; Delmas, Fischlein, and Asensio, 2013; Gillingham and Tsvetanov, 2018; Holladay, LaRiviere, Novgorodsky, and Price, 2016).

A large literature explores the energy efficiency gap in the housing market. The "energy efficiency gap" is a phenomenon characterized by failure of consumers to make energy efficiency investments that would seemingly save them money.[3] This literature has estimated both the capitalization of fuel bills into housing prices and the capitalization of features and ratings. Early papers by Dinan and Miranowski (1989) and Nevin and Watson (1998) find full capitalization of fuel bills into housing prices. In this same vein, more recent work by Myers (2018) examines how prices of homes with natural gas and electric Heating, Ventilation, and Air Conditioning (HVAC) systems respond to changes in the relative prices of natural gas and electricity and finds no evidence of undervaluation.[4] The conclusions drawn in Myers (2018) apply more to the context of relatively salient and easily observed aspects of energy efficiency than to the context of the less salient and less observable features that I study in this paper, such as duct leakage. A burgeoning literature[5] finds that consumers and firms are willing to pay a premium for green labels such as Energy Star, LEED, Austin Energy Green Buildings, and high performance ratings. These papers are sometimes cited as finding that energy efficiency is not undervalued, when in reality the labeling systems might arise precisely because of information asymmetries which could lead to undervaluation in general. Unfortunately, little work has been done to analyze policies that could remedy undervaluation, which is a gap in the literature that my paper helps fill.

This paper is also related to the hedonics literature that focuses on impacts of information on

[3]See Jaffe and Stavins (1994); Blumstein and Taylor (2013); Gerarden, Newell, and Stavins (2015a,b); Greene (2011); Gillingham and Palmer (2014).

[4]Myers interprets her findings as showing no evidence of inattention; her results also show there is no evidence of undervaluation.

[5]See Amado (2007), Walls, Gerarden, Palmer, and Bak (2017), Aydin, Brounen, and Kok (2015), Bruegge, Carrión-Flores, and Pope (2016), Eichholtz, Kok, and Quigley (2013), Eichholtz, Kok, and Quigley (2010), Brounen and Kok (2011), Dressler and Cornago (2017), Bond and Devine (2016), Zheng, Wua, Kahn, and Deng (2012), Deng, Li, and Quigley (2012), Fuerst, McAllister, Nanda, and Wyatt (2015), Stanley, Lyons, and Lyons (2016), Hyland, Lyons, and Lyons (2013) and Kahn and Kok (2014).

housing prices. This literature has explored housing price impacts from information on airport noise, toxic releases and toxicity, water quality of nearby watersheds, flood risk and insurance, and more (Pope, 2008a; Sanders, 2014; Hibiki and Managi, 2011; Meeks, Moore, and Plough, 2016; McCoy and Walsh, 2018; Pope, 2008b). In many hedonic analyses, the goal is to obtain an estimate of consumers' willingness-to-pay for an amenity by looking at how the capitalization coefficient on the amenity changed when the amount of, quality of, or information about an amenity changed. Strong assumptions are necessary to equate capitalization coefficients with willingness-to-pay (Kuminoff and Pope, 2014). I do not attempt to calculate consumer willingness-to-pay for energy efficiency; rather, changes in capitalization due to the disclosure policy are my parameters of interest. This is because capitalization, not willingness-to-pay, determines what premium homeowners will receive for energy efficiency related investments when they sell their homes; these private incentives to invest are of primary policy importance in my context.

Section 2 describes the setting in which the policy took place. Section 3 describes the data I use. Section 4 introduces a simple theoretical framework. Section 5 introduces the empirical specification. Section 6 presents and discusses the empirical results. Section 7 undertakes robustness checks. Section 8 discusses potential mechanisms behind the empirical results. Section 9 concludes.

2 Institutional Background

In 2009, the City of Austin enacted the Energy Conservation Audit and Disclosure (ECAD) ordinance, which required the results of an energy audit to be disclosed before any single-family home or multi-family building of four units or less was sold if the building was over 10 years old.[6] I will use the ECAD ordinance as a source of policy variation to learn about energy efficiency and information in the housing market.

The ECAD ordinance started in June of 2009 for single-family homes, at which time audit results had to be presented to buyers before the sale. The rules became more strict in May of 2011, at which point the results had to be presented to the buyer at least three days before the end of the option period. Condominiums were exempt from the ordinance until May of 2011, at which point they were required to comply in the same way as single-family homes.

Consumers could go to Austin Energy's website to find information about ECAD. The website maintains a list of all qualified ECAD auditors. Austin Energy's website refers to auditors as "energy professionals." ECAD auditors are typically also Home Energy Rating System (HERS) or Building Performance Institute (BPI) certified raters, and are sometimes also associated with companies that provide energy efficiency retrofits. Auditors must receive special training from Austin Energy. They are unlikely to also be general home inspectors.[7]

[6]This only applies to buildings within the Austin city limits, which account for roughly 50% of Austin Energy customers.

[7]Reference: Conversations with Tim Kisner and Jessica Galloway of Austin Energy.

Audits typically cost about $200–300 for a single-family home with one air conditioning system.[8] Advertising by auditors focuses on audit price, consulting on what rebates the consumer could get, and price quotes for upgrades and retrofits.

I only study homes that had an audit. Sellers could claim exemption from the audit requirement by showing that they made eligible repairs or upgrades to the energy efficiency of their homes in the last ten years or if the sale was to a family member, was an auction or foreclosure, or was due to divorce or inheritance. Noncompliance with ECAD is a class C misdemeanor, punishable with fines that range from $500 up to $2000. In a 2014 *Austin Monitor* article, Vice President of Customer Energy Solutions Deborah Kimberly explained that "the city does not actively issue citations, but anyone can file a complaint with the City of Austin Municipal Courts for review and action," and noted that she has not heard of complaints being filed.[9] Despite a lack of formal enforcement, real estate agents were aware of ECAD and informed their clients.[10] One could imagine that if a buyer's real estate agent was unable to obtain the ECAD audit form from the seller's agent, the buyer might see this as a red flag. Austin Energy calculates percent compliance with ECAD to be 76 percent in 2009 and then 70, 49, 50, and 52 percent in subsequent years,[11] but these compliance statistics are likely to be underestimated, especially in later years. Austin Energy's procedure to calculate compliance in the years 2009–2013 was to divide the total number of audits that occurred in a given year by the total number of deeds recorded by the county that were associated with addresses in Austin Energy's service area that did not participate in a retrofit, rebate, or weatherization program. The number of audits that were performed in a year is an underestimate of the number of homes that sold that were audited in all years after 2009, as the audits are valid for 10 years. Thus, homes that sold more than once with the same audit would be counted as not complying. Furthermore, the total number of deeds recorded by the county that were associated with addresses in Austin Energy's service area that did not participate in a retrofit, rebate, or weatherization program is a vast overestimate of the total number of homes that had to comply with ECAD, because non-arm's length sales and deed changes due to divorce or inheritance are not required to comply with ECAD. Section 5 explains why I only study homes that complied with the policy and got an audit.

3 Data

My housing price data comes from the Austin Board of Realtors (ABOR) and is pulled directly from their Multiple Listing Service database. This means that it is the same data that buyers see when they visit real estate websites like realtor.com, Redfin, and realtors' websites, and it

[8] See Austin Energy (2017a).

[9] See Whitson (2014).

[10] Interviews with realtors, summarized in Section A.4 in the appendix, suggest most realtors complied with ECAD.

[11] See http://www.austintexas.gov/edims/document.cfm?id=238880 and http://www.austintexas.gov/edims/document.cfm?id=192556

is the data that realtors can access. It is by far the most accurate and comprehensive data that exists on the Austin Housing market. Texas is a nondisclosure state, which means that buyers and sellers have no obligation to report the sale price of a home being transacted to the county or any other governmental body.[12] The Board of Realtors requires realtors to keep very careful record of transaction prices, as there is no other record of these prices.[13]

My energy audit data comes from "Austin's Open Data Portal," a website managed by the City of Austin.[14] The data is publicly available and contains all of the ECAD audits for the years 2009–2013, but only a subset of the fields on the audit form. I use the "residential" data, which consists of data on single family homes or multi-family homes that have fewer than five units. All of the homes in my sample were audited through the ECAD program.

I use the SmartyStreets address standardizer and verifier to match the homes in my sample to those in the audit database and to the city permit database.[15] I limit the sample to homes that have at least one repeat sale over the time period 2000–2015 and that obtained an energy audit before at least one sale and after at least one sale. From this sample, I construct a primary sample that consists of one sale just before the audit and one sale just after the audit per home. I only use sales occurring between 2005 and 2015 for this sample.[16] I construct a secondary sample that contains sales before 2005, which I use to conduct robustness checks to ensure that my results are not driven by pre-existing trends in capitalization of the audit measures.[17] See Section A.1 in the appendix for more details on data cleaning.

Table 1 presents summary statistics for prices, sale years, audit measures, and house characteristics. On average, 5 years elapse between sales and the price grows on average by approximately $18,500. The highest price increase is around $1,355,400. The mean year built is 1975.

The four main audit variables I focus on in this paper are attic R-value, duct R-value, EER, and negative percent duct leakage. Attic R-value measures the resistance to heat transfer of the

[12]Looking through county records, one can see such sale prices as "$10," "Love and affection," and "My boat," calling into question the data quality of data sources based only off of county records, such as CoreLogic, in the Texan context. CoreLogic is the data source most commonly used by economists studying housing markets.

[13]The Boards of Realtors does not share their housing price data with local county governments or public appraisers in Texas.

[14]See City of Austin (2017). Other studies have used ECAD audit data to explore various facets of energy use. Rhodes, Stephens, and Webber (2011) use data from Austin Energy audits to identify the most common air-conditioning system design and installation issues and evaluate how incorrectly installed equipment might affect power demand. Rhodes, Gorman, Upshaw, and Webber (2015) use audit data to compare predictions of engineering models to actual residential use and find that the engineering model performs reasonably well but consumer behavior is an important missing variable. ECAD data is also used less directly to answer other energy-related questions, such as how energy use might respond to a smart grid or an integrated thermal energy and rainwater storage system (Upshaw, Rhodes, and Webber, 2013; Rhodes, Upshaw, Harris, Meehan, Walling, Navrátil, Beck, Nagasawa, Fares, Cole, Kumar, Duncan, Holcomb, Edgar, Kwasinski, and Webber, 2014).

[15]A previous version of this paper did not use SmartyStreets, and suffered from a lower match rate between datasets. More accurate matching has allowed me to expand my sample size.

[16]Single-family homes had to be audited in 2009 and condos in 2011. Thus, this imposes a four-year window around the audit deadlines.

[17]A previous version of this paper used all pairs of sales in the primary estimation. This was changed to allow for pre-trend testing.

insulation in the attic. Duct R-value measures the resistance to heat transfer of the insulation surrounding the ducts. An HVAC system's Energy Efficiency Ratio (EER) is defined as the ratio of a heating or cooling system's output in British Thermal Units per hour to its power draw in watts. Percent duct leakage measures how much air is escaping from the ducts. These four variables are chosen because they take many values, and I exploit the rich variation in them in my estimation strategy. The publicly available audit data for the years 2009–2013 only contain six continuous measures of energy efficiency.[18] The baseline specification omits two of the six, HVAC system size and HVAC system age. System size is not used in the baseline specification because it is not a pure measure of energy efficiency. Oversized systems are inefficient, but size on its own is more related to comfort than energy efficiency. System age is similar: it is related to comfort as well as energy efficiency. It captures how well the system works and whether it breaks down often, and is therefore not a pure measure of energy efficiency.

Although I conduct my main estimation using the four audit variables described above, I also show results with a larger set of audit variables to construct a set of falsification tests. See Table A.1 in the appendix for a summary of all the audit variables I use in this paper. I code my variables so that a higher level of an audit variable represents a higher level of energy efficiency, so that the signs of my effects are all theoretically in the same direction. This means that I use the negative of duct leakage and system age.[19]

The empirical framework relies on a locally linear relationship between price and energy efficiency. Section A.3 in the appendix presents descriptive evidence in support of the linearity assumption for each of the four main audit variables, and also shows that the gradient of each residualized audit measure is steeper after the policy than before for attic R-value, Negative Duct Leakage, and Duct R-value, but not for EER.

4 Theoretical Framework

4.1 Static Capitalization of Energy Efficiency

I now present a theoretical framework to motivate my regression specification. Assume that the equilibrium housing price is a linearly separable function of other characteristics of a home and the home's energy bill. The capitalization coefficient for the energy bill, Γ, is defined as:

$$P(X, B) = g(X) + \Gamma B \tag{1}$$

where $B > 0$ is the expected total discounted future energy bill, X is a vector of all other home characteristics, and $\Gamma < 0$. An energy-efficiency gap is present when $\Gamma > -1$.

Assume that consumers use a fixed discount rate of r and only care about the next S years

[18] While not technically continuous, these variables are not binary like the rest of the energy-efficiency related audit variables.

[19] For one measure, whether the ducts were metal or not, the impact on energy efficiency is ambiguous. See more in Section A.1 for why I chose to assign metal ducts=1 and other duct types=0, implying that metal ducts are more efficient than other duct types.

when they buy a home. Let $b_t(m)$ denote the per-period part of the energy bill, where m is a vector of K characteristics of the home that determine energy efficiency, some of which are audit measures. Assume for expositional simplicity that energy prices are constant over time and that the consumer does not substitute between various sources of fuel for any reason, so that the per-period bill is not indexed by year:[20]

$$b_t(m) = b(m) \; \forall \; t \in \{1, \ldots, S\}$$

The present discounted value of the energy bill, B, can be expressed as:

$$B = \sum_{s=0}^{S-1} \left(\frac{1}{1+r} \right)^s b(m) = \left(\frac{(1+r)^S - 1}{r(1+r)^{S-1}} \right) b(m) \tag{2}$$

Suppose the per-period bill can be broken into additively separable components for each measure:

$$b(m) = b^0 + \sum_{k=1}^{K} b^k m^k \tag{3}$$

Assume the measures m^k are constructed such that a higher level of each measure m^k saves money, i.e. $b^k < 0$. The price can be expressed as a function of the bill components.

$$P(X, m) = g(X) + \sum_{k=1}^{K} \gamma^k m^k \tag{4}$$

where I have assumed that the slope of price with respect to the energy efficiency measures is linear. As discussed in Section A.3 in the appendix, the price functions appear approximately linear for most of the support of my data. Combining (1), (2), and (3), we get that the coefficient γ^k on bill component m^k in (4) should equal:

$$\gamma^k = \Gamma \left(\frac{(1+r)^S - 1}{r(1+r)^{S-1}} \right) b^k$$

4.2 Effect of Information on Capitalization

If information were complete, consumers were fully attentive to their energy bill, and there were no market frictions, we would have that $\Gamma = 1$ and the capitalization coefficients on each component of the bill would equal:

$$\gamma^k = \left(\frac{(1+r)^S - 1}{r(1+r)^{S-1}} \right) b^k$$

[20] See Section 7.1 for a discussion of how violations of these assumptions might impact my empirics.

If there is an energy efficiency gap, then:

$$\gamma^k < \left(\frac{(1+r)^S - 1}{r(1+r)^{S-1}}\right) b^k$$

Under no information about characteristic k (neither buyer nor seller knows k), the price cannot reflect the level of characteristic k, and so:

$$\gamma^k = 0$$

Now define two periods, $t \in \{0, 1\}$, and index γ^k by t, so that γ_t^k is the capitalization coefficient for measure m^k in time t. Between periods 0 and 1, information is revealed by a disclosure policy. This information is revealed to both buyers and sellers. Presumably, the seller had more information in the absence of the policy. Therefore, the policy levels the playing field between buyer and seller in terms of information about the home. The policy also draws a buyer's attention to the information provided. In my empirical specification, I will use the energy efficiency level of a home as a source of variation to analyze the effects of the policy. I posit that higher-efficiency homes will experience more price change from the policy than lower-efficiency homes.

Assume that the energy efficiency gap cannot be negative. Then $\gamma_t^k \in \left[0, \left(\frac{(1+r)^S-1}{r(1+r)^{S-1}}\right) b^k\right] \forall k, t$, and so an upper bound for the difference in capitalization coefficients for measure m^k is $\left(\frac{(1+r)^S-1}{r(1+r)^{S-1}}\right) b^k$. The condition that $\gamma_1^k - \gamma_0^k = \left(\frac{(1+r)^S-1}{r(1+r)^{S-1}}\right) b^k$ will hold if and only if $\gamma_0^k = 0$ and $\gamma_1^k = \left(\frac{(1+r)^S-1}{r(1+r)^{S-1}}\right) b^k$. I call this the "none-to-full capitalization" scenario. Figure 1a gives a graphical interpretation. The slope of price with respect to m^k is positive under full information and no market failures, and 0 under no information. The none-to-full capitalization case can provide a useful benchmark for the magnitude of the effects of the policy.[21]

In reality, consumers probably have partial information in the absence of an audit and the audit does not fully inform them about the energy costs they face because much of the information on the audit form is hard to interpret. Furthermore, market failures like myopia could depress capitalization, even when consumers are fully informed. Figure 1b illustrates the effect of an audit under this more realistic scenario. The change in the slope of the price curve represents the change in capitalization of feature m^k due to the audit.

Thus far, I have discussed the model as if I could recover the true hedonic willingness-to-pay parameter. It is important to note that even though this context does not fulfill the stringent requirements necessary for recovering consumer willingness-to-pay for energy efficiency in the housing market, a finding that $\gamma_1^k > \gamma_0^k$ indicates that the premium to energy efficiency has increased in the housing market, which could induce more investment by homeowners who know they might sell their home at some point. Furthermore, I cannot identify whether there

[21]Correlated features complicate interpretation of coefficients relative to none-to-full capitalization. We revisit this idea in Section 4.4.

is an energy efficiency gap: I compare changes in capitalization, and so the absolute magnitude of γ^k cannot be recovered in my model. What I *can* determine is whether capitalization has changed.

4.3 Differential Capitalization and Confounding Effects

I will use differential changes in information across features to rule out the possibility that increases in capitalization are being driven by non-policy effects. We can think of the capitalization coefficients γ_t^k on each audit characteristic as a function of the information available to consumers at time t. Denote this information for measure k by π_t^k. Assume capitalization at any point in time is a function of information about the feature and other factors:

$$\gamma_t^k \equiv \gamma^k(\pi_t^k, Y_t)$$

Y_t is a vector of all factors that are specific to time t, such as preferences for energy efficiency at time t, the interest rate, the bargaining power of buyers and sellers at time t, the marginal utility of income at time t, the overall cost of a marginal kilowatt or kilowatt-equivalent at time t, the overall demand for housing at time t, and the liquidity constraints facing buyers at time t.

Suppose I find that $\gamma_1^k - \gamma_0^k > 0$ for a particular feature m^k. I would like to conclude that the policy, which changes π_t^k, caused the change in γ^k. But, an alternative explanation is reasonable: a change in Y could also give us the result that $\gamma_1^k - \gamma_0^k > 0$.

Denote the change in γ^k between period 0 and 1 by $\Delta\gamma^k$:

$$\Delta\gamma^k = \gamma^k(\pi_1^k, Y_1) - \gamma^k(\pi_0^k, Y_0)$$

A first-order approximation to the change in capitalization is:

$$\Delta\gamma^k \cong \overbrace{\gamma_\pi^k(\pi_0^k, Y_0)\Delta\pi^k}^{\text{Policy}} + \overbrace{\gamma_Y^k(\pi_0^k, Y_0)'\Delta Y}^{\text{Non-Policy}} \tag{5}$$

In (5), $\Delta\pi^k = \pi_1^k - \pi_0^k$, $\Delta Y = Y_1 - Y_0$ is a vector of changes in each individual y_t, and $\gamma_Y^k(\pi_0^k, Y_0)$ is a vector of partial derivatives of γ with respect to each element of Y:

$$\gamma_Y^k(\pi_0^k, Y_0) = \left(\frac{\partial\gamma^k(\pi_0^k, Y_0)}{\partial Y^1}, \frac{\partial\gamma^k(\pi_0^k, Y_0)}{\partial Y^2}, \frac{\partial\gamma^k(\pi_0^k, Y_0)}{\partial Y^3}, \ldots\right)'$$

The policy effect is $\gamma_\pi^k(\pi_0^k, Y_0)\Delta\pi^k$ and the non-policy effect (that could be confounding estimates of the change in capitalization) is $\gamma_Y^k(\pi_0^k, Y_0)'\Delta Y$. Intuitively, the policy effect is higher if more information is revealed about the feature. The non-policy effect is higher when capitalization of the feature depends more strongly on Y or when the change in Y is larger.

This yields our first prediction: if the change in information due to the policy, $\Delta\pi^k$, is strictly positive, then we should observe a positive capitalization effect, so long as the non-policy effects are not large enough to completely overwhelm the effect of increased information.

Consider comparing capitalization effects from two features, j and h:

$$\Delta\gamma^j - \Delta\gamma^h \approxeq \gamma^j_\pi(\pi^j_0, Y_0)\Delta\pi^j - \gamma^h_\pi(\pi^h_0, Y_0)\Delta\pi^h + \gamma^j_Y(\pi^j_0, Y_0)'\Delta Y - \gamma^h_Y(\pi^h_0, Y_0)'\Delta Y \tag{6}$$

Combining the last two terms:

$$\Delta\gamma^j - \Delta\gamma^h \approxeq \gamma^j_\pi(\pi^j_0, Y_0)\Delta\pi^j - \gamma^h_\pi(\pi^h_0, Y_0)\Delta\pi^h + \left(\gamma^j_Y(\pi^j_0, Y_0) - \gamma^h_Y(\pi^h_0, Y_0)\right)'\Delta Y \tag{7}$$

Notice that $\Delta\gamma^j - \Delta\gamma^h$ is increasing in $\Delta\pi^j$ and decreasing in $\Delta\pi^h$, and so if we compare two features where $\Delta\pi^j > \Delta\pi^h$, we should see a higher capitalization of one than the other, all else equal. This yields our second prediction: a feature that experiences a larger change in information due to the policy should have a higher change in capitalization than features that experienced a smaller change in information due to the policy. An example of a feature for which information did not change is whether the furnace is gas or electric, because consumers could easily acquire this information before the audit policy as it is typically in the listing and it is required to be documented in an inspection. Seeing the information again on an audit form should not change the price consumers are willing to pay for the home.

Under what conditions will we be able to observe that the capitalization coefficient is higher for j than h and conclude that indeed, the true policy effect is higher for j than h? To answer this question, rearrange (7) so that the difference in policy effects is on one side of the equation:

$$\gamma^j_\pi(\pi^j_0, Y_0)\Delta\pi^j - \gamma^h_\pi(\pi^h_0, Y_0)\Delta\pi^h \approxeq \Delta\gamma^j - \Delta\gamma^h + \left(\gamma^j_Y(\pi^j_0, Y_0) - \gamma_Y(\pi^h_0, Y_0)\right)'\Delta Y \tag{8}$$

Roughly speaking, if ΔY is small, dependence of capitalization of energy efficiency features on Y is small, or the difference between the dependence of capitalization of energy efficiency features on Y is similar for the two features, then observing that the capitalization effect is higher for j than for h (observing $\Delta\gamma^j - \Delta\gamma^h > 0$) will tell us that $\gamma^j_\pi(\pi^j_0, Y_0)\Delta\pi^j - \gamma^h_\pi(\pi^h_0, Y_0)\Delta\pi^h > 0$ and hence that the true policy effect is larger for feature j than for feature h. More precisely, it needs to be the case that the difference in nonpolicy effects is not larger than the difference in capitalization effects for us to draw this conclusion. Even weaker conditions can be derived for showing that $\gamma^j_\pi(\pi^j_0, Y_0)\Delta\pi^j > 0$, or that the policy effect is positive for feature j.

Two special cases merit attention. First, if the nonpolicy effects are the same for both features, they cancel each other out and we the difference in changes in capitalization exactly characterizes the difference in the policy effects of the two features. Second, if we are willing to assume that the policy did not change information at all for feature h, i.e., that $\Delta\pi^h = 0$, then $\Delta\gamma^h$ reflects only the non-policy effects. If we are willing to assume that the nonpolicy effects are the same in this case, then $\Delta\gamma^j - \Delta\gamma^h$ gives the true change in capitalization for feature j. To the extent that the change in information is nonzero but smaller for h than j, the difference $\Delta\gamma^j - \Delta\gamma^h$ gives a lower bound on the true increase in capitalization due to the policy for feature j.

Note that if I were to use the true energy bill (or any single energy efficiency index) for this exercise, in an attempt to analyze $\Gamma_1 - \Gamma_0$ from (1), if I found that $\Gamma_1 - \Gamma_0 > 0$, I would not be able to conclude that the policy was the driving factor behind the change in Γ. Ruling out confounding factors requires one to break the energy bill into its components, which experienced differential information changes due to the policy.

4.4 Correlated Energy Efficiency Features

Now, consider the case of correlated features. If features are correlated, information about one feature reveals information about another feature even in the absence of information changing for the other feature.

Suppose first that the two features are positively correlated. Following a positive change in information about both features, there is an indirect effect of learning about each feature on the other's capitalization coefficient. Thus, if we analyze the change in capitalization of feature j in isolation, we will find that it also reflects information about feature h. If this effect is strong enough, the estimated $\Delta\gamma^j$ could even exceed the true γ^j, leading to a capitalization coefficient change that *could surpass the none-to-full capitalization savings*. This can be ameliorated by controlling for m^h in my regressions, however, not all energy efficiency features are observed, and so not all features that j might be correlated with can be controlled for. For this reason, I de-emphasize comparison with the none-to-full capitalization savings in Section 6. Nevertheless, a finding that $\Delta\gamma^j > 0$ does indicate that capitalization has increased, which means that investment incentives for feature j have increased for feature j, and thus the policy has achieved its goal.

Now, consider what happens if information changes about only one feature. If the two features are positively correlated, then following a direct change in information about feature j and no direct change in information about feature h (so that $\Delta\pi_j > 0$ and $\Delta\pi_h = 0$), information increases for both of the features, where one change is direct and the other is indirect. If we were to solely analyze feature h, we would find that $\Delta\gamma^h > 0$ despite the fact that information did not change for feature h. In this case, $\Delta\gamma^j - \Delta\gamma^h$ will be lower than it would be if the features were uncorrelated, and we should have that $\Delta\gamma^j > \Delta\gamma^j - \Delta\gamma^h$. In this case, we should find that both $\Delta\gamma^j > 0$ and $\Delta\gamma^h > 0$. In this case, because consumers can learn about measure h from direct information about measure j, $\Delta\gamma^j$ *could again surpass the none-to-full capitalization savings.*[22]

If the two features are negatively correlated, then following a direct change in information

[22]It is worthwhile to note that studies employing a difference-in-differences design that analyze whether energy efficiency is undervalued might be picking up positively correlated features and thus overestimating valuation of energy efficiency, even if they show that there is no change in information about other features occurring during the study period.

about feature j and no direct change in information about feature h (so that $\Delta\gamma_j > 0$ and $\Delta\gamma_h = 0$), information again increases for both of them, but a direct change in information about feature j can lead to both higher capitalization of feature j and lower capitalization of feature h. This results in $\Delta\gamma^j - \Delta\gamma^h$ being higher than it would be if the features were uncorrelated, and we have that $\Delta\gamma^j - \Delta\gamma^h > \Delta\gamma^j$. A finding that $\Delta\gamma_j > 0$ still indicates that capitalization of feature j has increased.

In sum, with either positively or negatively correlated features, we should still find that both $\Delta\gamma_j > 0$ and $\Delta\gamma^j - \Delta\gamma^h > 0$ if j is the feature for which information changed the most. Under positive correlation, $\Delta\gamma_h > 0$ and under negative correlation, $\Delta\gamma_h < 0$. In words, for both positively and negatively correlated features, a situation where we observe a positive capitalization change for the feature for which information changed more and a higher capitalization change for the feature for which information changed more compared to that of the feature for which information changed less, provides evidence that the policy impacted capitalization. However, caution is warranted when interpreting the magnitude of the observed capitalization effect for the features that experienced the most information change when the features are correlated, as correlation can cause it to surpass the none-to-full capitalization savings.[23]

5 Empirical Specification

The baseline specification captures how the capitalization of audit measures into the housing price changes with the policy. I use the audit measures as "intensity of treatment" variables to model the change in housing prices associated with the policy. My sample consists of exactly two sales per home, between which the home was required to comply and the home was audited. I regress the change in price of the house on audit measures, sale-year fixed effects, and controls. The baseline specification is:

$$\Delta P_{ist} = \beta' M_i + \theta' X_i + \tau_{yt} + \tau_{ys} + \epsilon_{ist} \tag{9}$$

In (9), ΔP_{ist} is the change in price from sale s, which occurs both before the audit and before the home was required to be audited, to sale t, which occurs after both the audit and the requirement to be audited. M_i is a vector of K audit measures m_i^k that do not change over time. The vector β contains the parameters of interest, β^k, each of which is a change in capitalization for a particular audit feature m_i^k. The effect of m_i^k is assumed to be linear in the housing price, so that the change in capitalization is well-defined. I provide supporting evidence for the linearity assumption in Section A.3 in the appendix. X_i is a vector of N controls x_i^n, that do not change over time (they are determined prior to the first sale in the sample). The inclusion

[23] Generalizing to the case where we compare a group of difficult-to-observe audit features to a group of easy to observe audit features, there can be correlation across groups and between groups. Broadly speaking, across-group correlation will tend to have the same effects detailed above for the case of two features that differ in their observability in terms of conclusions that can be drawn.

of X_i in this differenced equation allows for the effect of the control variables on the price to change over time. For example, the capitalization of square footage or whether the house has a pool could change from before to after the policy, and might confound our estimates if there is correlation between pools and audit measures. One important group of control variables is the year-built-group dummies. This is a vector of year built groups that determines the date the home had to comply by. Including these in the vector of controls allows the price dynamics to vary by treatment cohort. τ_{yt} and τ_{ys} are sale-year fixed effects for the year of each of the two sales. See Section A.2 in the appendix for a detailed derivation of (9) from an intensity of treatment difference in differences design.

Each β^k is represented by $\Delta\gamma^k$ in the theoretical model. Theory predicts that the sign of each β^k should be non-negative because I have defined my measures so that for each of them, an increase in the measure increases energy efficiency. A positive and economically significant estimate for β^k indicates that the ECAD policy increased capitalization for energy-efficiency related feature m^k. I expect little effect for features that were already easily observed before the policy compared to features that were more difficult to observe before the policy. I use this logic to construct falsification tests to rule out the possibility that changes in capitalization of energy efficiency over time that are not due to the policy drive my results.

Because energy efficiency of audit features is typically positively correlated across features, the β^k cannot be interpreted as ceteris paribus effects of increasing energy efficiency by one unit of each audit variable, as they reflect the influence of excluded audit variables they are correlated with, even when we control for the other observed audit features in the regression. Thus, each β^k can be thought of as an index reflecting information about multiple energy efficiency features, with more weight on feature m^k. The absolute magnitudes of the change in capitalization due to the policy are thus not particularly informative. Thus, I focus on differential capitalization of the features by comparing their effects.

I only study the homes that were audited due to the policy. Within the set of sales of homes that were audited, I further restrict my sample. I do not include audited homes that only have one sale, because I need repeat sales to difference out unobserved housing characteristics. I use data from just before and just after the audit requirement (2005–2015). This imposes a four-year window around each of the audit deadlines for homes ten years and older, because single-family homes had to comply in 2009 and condos had to comply in 2011. By using a relatively narrow time band around the compliance deadline, I mitigate concerns over satisfying the time constant gradient assumption discussed in Kuminoff and Pope (2014).[24] Furthermore, the composition of homes sold could change from before to after the audit policy was implemented, because the policy could induce certain homes to strategically sell before or after the audit; the use of just two sales per home, one of which occurred before and one of which occurred after both the audit and the audit requirement, ensures that composition effects do not bias

[24] This choice was also made so that I could construct a sample of sales that occurred prior to my main sample that I use to test for pre-trends. The MLS data starts in 2000.

my estimates.

The cross-sectional source of variation I am using is the level of energy efficiency. As such, my estimates are differential impacts of the audit policy treatment by energy efficiency level, *only for the homes that were treated.* This is important because it differentiates my specification from that of Frondel et al. (2018), who use variation in whether a home disclosed to identify a treatment effect of a policy.

In my context, it is not feasible to use variation in whether a home disclosed to measure the overall effect of the audit policy. First, I do not observe m^k for those homes. Second, I do not observe exemptions from the ECAD policy. Therefore, I cannot tell whether a particular house was exempt (and thus might have retrofitted or made some upgrade just before sale) or simply did not comply with the policy if they were sold after the audit deadline but did not get the audit. Each of these reasons why a home was not audited could bias results in opposite directions, so my results would not even represent a bound on the treatment effect of the audit policy. This prevents me from including homes that were sold after the compliance deadline but did not receive an audit. Similarly, I cannot include homes that were less than 10 years old for all sales but never audited. I do not know whether they would have eventually been the type of home to pursue the audit, the type of home to pursue exemption, or the type of home to break the law. Therefore, there is no way of knowing whether the price changes for these unaudited homes would be comparable to those for the homes that were audited, were they not audited.

There are pros and cons to my approach. Suppose it were feasible to observe m^k for homes that did not obtain an audit. Then, I could also use variation in whether a home was audited. But, endogeneity due to self-selection into audits could introduce bias into the estimates. To be concrete, suppose for a moment that I were to implement a modified difference-in-differences estimator that included as regressors a dummy variable for whether the home had been audited before the sale, an interaction between this dummy variable and each m^k, and each m^k itself. Endogenous selection into the audit would contaminate *all* of the estimates, leading to bias in the estimate of the change in capitalization for the audited homes.

My specification cannot suffer from the aforementioned endogeneity bias. However, the downside of only using homes that were audited is that my effects may not necessarily capture what the effect would be for the homes that did not get the audit had they obtained the audit. If the effects for the homes in my sample are representative of what they would be for all homes in Austin (i.e. there is no selection into complying with the law), then my estimation technique and the hypothetical technique above would both measure the exact same effect of the policy on changes in capitalization.

How strong might the selection effects be? I cannot formally test this, because I lack information on exemption and energy efficiency in unaudited homes. One way to obtain suggestive evidence on the strength of the selection effects is to look at homes that had a sale after their compliance deadline and then an audit after that sale. Among repeat sales that satisfy the requirements to be included in my sample, very few homes sold after their compliance deadline but before an audit (131 homes out of 4,070 that matched to the audit database).[25] See Table A.7 in the appendix for a comparison between my sample and these 131 homes. I do not find that there are significant differences between the two samples on most variables, and there does not appear to be a pattern in terms of the differences in my audit variables between the two samples. In sum, I do not find evidence that these 131 homes are different in terms of audit features than the homes in my sample. If these 131 homes are representative of other noncompliers, then perhaps self-selection into the audit is not substantial.

6 Empirical Results for Baseline Audit Measures

In my baseline estimation, I regress the change in price on the four main audit measures, clustering at the home level. Table 2 shows the results. In the first four columns of the table, I show the coefficients from the regressions of the price difference on each of the four measures separately. I find that one additional unit of Attic R-value increases the change in price by $421. This represents the difference in expected sales price due to the policy when the energy efficiency is increased from the energy efficiency of the average house with a typical R-value to the energy efficiency of the average house with one additional unit of R-value. The interpretations are similar for the coefficients from columns 2 through 4, with values of $338, $1,953 and $1,296 for negative percent leakage, duct R-value, and EER, respectively. As expected, all coefficients are positive, indicating increased capitalization of energy efficiency. The coefficients are statistically significant for attic R-value, negative percent duct leakage, and duct R-value, and are most significant for negative percent duct leakage.

As explained above, coefficient estimates in the first four columns of Table 2 cannot be interpreted as ceteris paribus effects of increasing energy efficiency by one unit of each audit variable. The audit variables are correlated with one another, so each point estimate reflects the influence of both the included variable and the excluded audit variables.[26] To disentangle the effects of the four main variables, I include all of the main audit measures in column 5. Each coefficient now represents the partial effect of energy efficiency on the price difference, holding the other three features fixed. The coefficients are still positive. The magnitudes of the individual coefficients decrease for attic R-value, duct R-value, and EER, but increase for negative percent duct leakage. This means that the capitalization changes are probably biased upwards in the single-variable regressions of attic R-value, duct R-value, and EER because those three audit measures are positively correlated with negative percent duct leakage and that the change in information about duct leakage might be driving increased capitalization of energy efficiency. The standard errors are larger in column 5 because of cross-correlation between

[25] I do not observe exemptions from the law, so this is an upper bound on the number of late compliers in my repeat sales sample, because some of the 131 homes could be exempt at their first sale after the audit was required, but not exempt at the sale after that.

[26] See Table A.2 in the appendix for correlations between the measures, which vary from approximately 0.05 to 0.25.

audit features; a high degree of collinearity makes it less likely that we will find statistically significant effects for each audit measure. The four main variables are jointly significant with a p-value of 0.001,[27] which indicates that the policy led to an increase in capitalization of at least one of the four energy efficiency features. Taken as a whole, I conclude that strong effects on duct leakage might be (at least partially) driving the increased capitalization of energy efficiency that I find in columns 1, 3, and 4.

The four audit variables are in different units, so to ease comparison of the magnitudes of capitalization changes between them, I also reproduce the baseline results after standardizing the audit variables. The results are shown in column 6. Negative percent duct leakage has a higher capitalization change than any other audit variable, over twice that of Duct R-value and EER, indicating that the policy may have had a stronger effect on capitalization of duct leakage than on the other three audit variables. However, the test statistics at the bottom of the table indicate that we cannot reject the null hypothesis that the coefficient on negative percent duct leakage is equal to the others; nor can we reject the null hypothesis that the coefficients on the four audit variables are each equal to one another. Not being able to reject the null hypothesis for the aforementioned set of tests is to be expected given that there is multicollinearity.

The results in Table 2 make intuitive sense because the duct leakage was most difficult to observe in the absence of the policy. Buyers would have to hire an energy auditor to conduct a duct blower test, which was not done in the home inspection. Features like EER, on the other hand, were comparatively easier to learn about. Many HVAC systems have stickers on them that reveal their EER. Therefore, the policy would likely change the information available about duct leakage more than the information available about EER. The theoretical framework thus predicts that the capitalization change should be higher for duct leakage than EER. In Section 7.2, I investigate the predictions of the theoretical framework in a more systematic fashion as a falsification test of my findings of increased capitalization due to ECAD.

As explained in Section 5, because of correlation between the audit measures, the magnitudes of the individual coefficients should not be interpreted to reflect changes in capitalization for individual audit variables, but rather changes in capitalization associated with a weighted efficiency index with the strongest weight on that individual audit feature. Nevertheless, to get a benchmark for evaluating the magnitude of the estimates shown in Table 2, it is instructive to think about the coefficients that should be expected on each of these four main measures if the audit resulted in none-to-full capitalization *and ignoring correlation between these four variables and other audit variables.* If before the policy, capitalization was partial and if the policy did not fully inform consumers, then my estimates should be less than the none-to-full capitalization savings. Thus, the none-to-full capitalization savings can serve as a benchmark for the magnitudes of the coefficients, under no correlation. To enable comparison of my estimates to the none-to-full capitalization savings, the first two rows of Table 3 display my estimates and the 95% confidence interval from the fifth column of Table 2 and the third

[27] Refer to the bottom of the table.

row presents the expected present discounted value of savings from a one-unit increase in each main audit measure. For attic R-value, negative percent duct leakage, and EER, I use engineering estimates of savings from Austin, TX. I am unaware of a reliable estimate of the savings from increasing duct R-value for Austin, TX, so I chose to use one from Albuquerque, NM. I use a discount rate of 7% and the expected lifetime of each retrofit from Rhodes (2014). [28]

For all four measures considered in Table 3, I find that the expected savings are within my point estimate confidence intervals. Note, however, that these confidence intervals are large. The two numbers are most similar for duct leakage. My estimate is larger in magnitude than the none-to-full capitalization savings for all four audit measures. This could be due to the fact that there are additional audit measures correlated with these whose capitalization due to the policy is also reflected in my estimated coefficients, as detailed in the theoretical framework (Section 4.4).[29]

7 Robustness Checks

I divide my robustness checks into three subsections. In the first subsection, I undertake general robustness checks. In the second subsection, I use the predictions of my theoretical framework to construct falsification tests based on information and observability. These serve to rule out potential confounders that might affect capitalization of energy efficiency during my study period. In the third subsection, I use a supplemental sample of sales (of the homes in my sample) to explore potential pre-trends.

7.1 General Robustness Checks

I now discuss general potential concerns. One concern is that energy efficiency might be endogenous because homeowners can improve it before sale. Conversations with realtors indicated that they did not think that sellers routinely made energy-efficiency related upgrades

[28]See Table A.5 in the appendix for other assumptions used. I also show the results using various discount rates and the infinite lifetime in Table A.4 in the appendix. It is unclear what discount rate should be used to calculate expected savings. One might argue that the mortgage interest rate is the most appropriate, but it is common enough to purchase a home when still in debt from other sources to warrant a higher discount rate than the mortgage interest rate, because other sources of debt often carry much higher interest rates (e.g. student loan and credit card debt).

[29]Some readers might also be interested in the how the costs of the retrofits compare to the changes in capitalization for each measure. I gathered approximate cost data from the National Residential Efficiency Measures Database, which is a dataset composed by the National Renewable Energy Laboratory. The database contains cost estimates for retrofitting equipment.[30] See Table A.6 in the appendix for cost information. The fourth row of Table 3 contains the cost of the minimum upgrade job that is defined in the NREM cost database. The fifth row contains that cost divided by the number of units upgraded in the minimum job. The job level costs fall within the 95% confidence intervals for attic R-value and duct R-value, but not for negative percent duct leakage and EER. The per unit costs fall within the 95% confidence intervals for attic R-value, duct R-value, and EER, but not for negative percent leakage. The costs are lower than the lower bound of the confidence interval of my estimate in the case of negative percent duct leakage, and higher in the case of EER. The exact relationship we should expect between costs of retrofit and my estimates is unclear, and it is unclear whether the reader should be comparing the cost at the unit or job level to my estimates, as making an improvement of only one unit at the unit cost is generally infeasible. The costs at both the unit and job level are smaller for attic R-value, negative percent duct leakage, and duct R-value, but larger for EER. Surprisingly, the costs of retrofit sometimes differ substantially from the present discounted value of savings.

immediately before sale.[31] This might be because homeowners could be exempt from the policy if they made an improvement through an Austin Energy retrofit or rebate program. This means that few homes were audited after having made energy-efficiency related improvements. That said, even improvements of other aspects of a home could be problematic if the change in other attributes of the home differ for homes of different energy efficiencies. For example, if the high energy efficiency homes increase their investment in sidewalks after the introduction of the policy more so than the low energy efficiency homes, then the difference-in-difference estimates would partially reflect this differential change in sidewalk upgrades. Table A.8 in the appendix displays the results of the baseline regression after controlling for an indicator for whether the household completed any permitted work.[32] Duct R-value is no longer statistically significant when it is the only regressor. The coefficient on negative percent duct leakage is smaller in column 2 than in column 2 of the baseline. However, when we put the audit variables together in the same regression in column 5, the coefficient on negative percent duct leakage becomes larger and more significant. The coefficient on negative percent duct leakage has the highest magnitude in column 6 just like in the baseline. The coefficient on EER shows a negative sign, with a large confidence interval. Taken as a whole, this robustness check provides suggestive evidence that the policy had a stronger effect on the capitalization of duct leakage compared to its effect on capitalization of other features, and perhaps had no effect at all on EER.

One might worry that there were changes in valuation of other features of homes over time that are correlated with audit measures that coincided with the introduction of ECAD. Therefore, Table A.9 in the appendix presents the main results, controlling for square footage, bedrooms, bathrooms, and pool. Columns 1-5 show results that are substantively similar to the baseline for the audit variables. Column 6 shows the results of a regression with no audit variables. The magnitudes of the coefficients on square footage, bedrooms, bathrooms, and pool are all about the same in column 6 as they are in columns 1-5, indicating that it is unlikely that changes in valuation of these could be driving my findings. Bedrooms, bathrooms, and pool are often significant, but the sign pattern that we obtain for them probably reflects their correlation with each other rather than suggesting that they are confounders in my baseline results. There is no intuitive reason why the sign should be negative for bathrooms, positive for bedrooms, positive for square footage, and negative for whether the home has a pool. The seventh column shows the results with standardized audit variables. Again, duct leakage has the highest magnitude. The results tell the same story as the baseline.

ECAD's effects on my main audit variables could vary over time due to market conditions. Realtors I spoke with seemed to believe that energy efficiency was more likely to impact housing prices during "cold" markets than "hot" markets. They said that when several buyers

[31] See interview summary in appendix.

[32] I match all permits from the City of Austin website to my homes data for this regression. My indicator is whether there was any permitted work between the two sales. Not all homes match to the permit data, which is why the sample size is smaller in this specification. See section A.1 in the appendix for details.

are in a bidding war, it is unlikely that ECAD would matter at all. This consumer behavior may be irrational. Nonetheless, it is worth testing whether the audit policy had different capitalization effects during hot and cold markets. The answer could be useful to policymakers deciding when to introduce a new audit policy. To test this hypothesis, I interact each of the four main audit measures with various indicators for market "hotness": total number of sales, average price, median price, months of inventory, total listings, and volume of sales in dollars. The results from the modified specification are shown in Table A.10 in the appendix. A large number of sales might mean that the market is "hot" in the sense that homes are easy to sell. A higher-than-usual average or median price might indicate that housing is particularly in demand in the short run. Months of inventory is defined as the number of months it would take for the current housing supply to be exhausted if no new homes came on the market and if sales continued at the current monthly rate. A lower than median months of inventory indicates a scarcity of listings. A large number of listings could indicate that sale volume is high, or that there is excess supply in the short run. A large volume of sales in dollars could mean that homes are relatively easy to sell. All of these measures are based on all listings/sales in a month in the Austin area; my sample is a small fraction of these. All of my "hotness" variables refer to market conditions at the time of sale 2 and all are standardized to have a mean of 0 and a standard deviation of 1. Overall, I do not see a consistent pattern that would indicate that "hotness" plays a role in the capitalization of audit features into home prices. Few of the interaction coefficients from the six "hotness" regressions are statistically significant. There is limited evidence that "hotness" might mediate the capitalization of attic R-value, but no evidence for any of the other variables. The coefficients on negative percent duct leakage are very stable across the six specifications, indicating that hotness probably does not play a role in capitalization of negative percent duct leakage.

I also produce results for my baseline specification using alternative dependent variables. In Table A.11 in the appendix, I show the results when the change in list price is used as a dependent variable. I use the last available list price before a sale in my data.[33] The results are substantively similar. I also show the results for the change in Time on Market (TOM) in Table A.12 in the appendix. If buyers value energy efficiency but sellers do not realize that buyers value energy efficiency, energy efficient homes could sell more quickly than other homes, which would produce a decrease in TOM for more energy efficient homes. There appears to be little effect on TOM (though three out of four coefficients have the expected sign), with the largest coefficient being a reduction of 2.28 days (for EER). This is not a consequential reduction in TOM. In Table A.13, I show the results of my baseline specification for the change in the difference between the list and sale price. We would expect these coefficients to be negative if the seller did not expect for the energy efficiency features to be capitalized or was

[33] I do this out of pragmatism. The "first" list price associated with a sale is ill-defined because realtors often "game the system" by allowing listings to expire and then re-listing the home, hence re-setting the time on market for the home.

unaware of the energy efficiency features of their home. The coefficients on the audit features are all negative except for in the equation where duct leakage is included on its own, where it is extremely small. The coefficients are not statistically significant. I conclude that capitalization in list prices follows that in sales prices closely, there is little evidence for effects on TOM, and there is no evidence that the policy changed the difference between capitalization of sale price and list price for these features.

Recall that the policy was enacted in 2009 and only applied to homes ten years old or older. Buyers and sellers might have been confused about the official age of the home for the purposes of the policy. Was it when the utilities were connected, when ground was broken, or some other time? One might be concerned that this confusion created a situation where sellers who were less likely to benefit from the policy interpret the policy as not applying to them. Furthermore, the effects could be different for homes that had to comply after the policy was first implemented. For this reason, I show the results from excluding all homes built after 1999 in Table A.14 in the appendix, and the results are comparable to those in the baseline.

Another concern is that homes that are resold within a short period of time are "flipped" and that substantial improvements have been made to them. Consequently, I check whether the results change when I omit homes resold within 365 days from the baseline regression; the results are shown in Table A.15 in the appendix, and do not differ substantially from the baseline results.

I now discuss how my estimates could be affected by changing electricity and natural gas prices over time. In an ideal thought experiment, I would randomize efficiencies to houses and then sell them all at one time. In my case, however, the home is sold and then consumers receive information that allows them to update their beliefs about energy costs. I will assume throughout this discussion that consumers believe that electricity and natural gas prices in the future are roughly equal to prices today.[34] Under this assumption, in markets where energy is less expensive, the audit should matter less. This means that if energy is becoming cheaper over time, the second sale should have an attenuated capitalization coefficient when compared with the capitalization coefficient for the first sale, and so if I wanted to measure the change in capitalization at the midpoint in time between the two sales, I would be underestimating the response.

Fuel substitution would exacerbate the degree to which my parameters underestimate the true response to the policy that would occur had I run the ideal thought experiment. This is because natural gas has become less expensive between the two sales and so people would expect to spend even less on fuel costs over the lifetime of the home in the second sale than they would at the midpoint in time between the two sales if they can substitute natural gas consumption for electricity consumption. Table 1 shows that the average price of electricity faced by households in my sample at sale 1 was 4.12 cents/kWh and at sale 2 was 3.92 cents/kWh, and for natural gas that price was 18.28 dollars/1000 cubic feet and

[34]See Anderson, Kellogg, and Sallee (2013) for more about this assumption.

15.34 dollars/1000 cubic feet, respectively.[35] This change in the price of natural gas relative to electricity might entice households in my sample to switch to natural gas. To give the reader a sense for the prevalence of fuel switching, I consider the 1,149 households in my sample which reported either a natural gas or an electric HVAC in the listing for both sales, but did not report having both a natural gas and an electric HVAC. Unfortunately, for most of my sample, one or both of the MLS listings do not specify the heater fuel type. This information was available on inspection reports, though. Of these 1,149 households, 924 stayed natural gas, 156 stayed electric, 25 switched from natural gas to electric, and 44 switched from electric to natural gas. As long as the households reporting their heater type for both sales are representative of the whole sample, fuel switching is unlikely to substantially affect my estimates, because only about 6% of households switched between fuels. I produce additional results using only those homes we know did not switch between fuels in Table A.16 in the appendix. The sample sizes are much smaller than my main sample, but I still find that negative percent duct leakage is statistically significant with a magnitude that is comparable to my baseline. For attic R-value, the standard errors are larger than in the baseline, but the magnitude of the coefficients is similar to the baseline, especially in the regression where the audit variables are included together. The coefficients on Duct R-value are negative. The coefficient on EER is positive but has very large standard errors. It is unclear what conclusions can be drawn because the samples are all less than one-third of what they are in the baseline specification.

In an additional set of robustness checks, I vary the spatial level at which I cluster the standard errors. Zip-code level price shocks could mean that the standard errors are underestimated in my baseline specification. I present the results from clustering on zip code in Table A.17 in the appendix. The standard errors are larger in general, but still significant for negative percent duct leakage. Noting that perhaps 39 zip code clusters is too few, I re-run my results clustering on elementary school in Table A.18 in the appendix. There are 113-116 elementary school clusters, depending on the specification, and elementary school is missing for a handful of observations. The significance pattern tells the same story as in the baseline specification. I additionally produce results using Conley standard errors in Tables A.19 and A.20 in the appendix to account for possible spatial correlation. The Conley standard errors are sometimes higher and sometimes lower than White standard errors, depending on the distance cutoff used. The distance cutoff is the point beyond which we impose that the correlation between two points is zero.[38] The standard errors are similar enough to the White standard errors that the substantive conclusions about the pattern of significance of the coefficients does not change.

I also check robustness to different fixed effects structures. In Tables A.21 and A.22 in the

[35] Electricity prices are for the City of Austin and from Austin Energy's website.[36] Average residential natural gas price paid per unit for Austin was not available, so the natural gas price for the state of Texas is substituted from EIA's website.[37]

[38] Conley standard errors are calculated using code on Timothy Conley's website: https://economics.uwo.ca/people/faculty/conley.html.

appendix, I include zip code fixed effects to capture zip code specific price trends, in addition to the sale year and year built group fixed effects. The results are similar to those in my baseline specification. A previous version of this paper used year built group by sale year pair fixed effects, which I show in Table A.23 of the appendix in this version of the paper. This is a much finer set of fixed effects than in my baseline specification. It allows for arbitrary price trends that could differ over time by year built group. These fixed effects require estimation of many more parameters than in our baseline specification, resulting in much higher R-squared in all regressions. The estimates of capitalization changes for our audit measures have smaller standard errors with this finer set of fixed effects. The attic R-value has a larger coefficient in column 1 than in column 1 of the baseline specification, and the coefficient on duct leakage is smaller in column 2 than in column 2 of the baseline. In column 5, we include all four main audit variables, and find that there is a statistically significant coefficient for all three of attic R-value, negative percent duct leakage, and duct R-value, but not for EER. When we compare the standardized coefficients in column 6, negative percent duct leakage is again more significant than the rest, indicating that the policy indeed had a stronger effect on the capitalization of duct leakage compared to its effect on capitalization of other features. I also show the results from my baseline using a full set of year built fixed effects instead of the year built group fixed effects in Table A.24 in the appendix; results are substantively similar to the baseline.

One might be concerned that outliers in sale price are driving the results. Because of this concern, A.25 in the appendix presents the baseline results excluding observations where the first sale is below the 5th percentile of first sales or above the 95th percentile of first sales. This drops roughly 10% of the sample and so we might expect the point estimates to be less precise.[39] The point estimates are roughly the same, but the coefficient on duct leakage drops when other measures are included, which is not as expected. The other two coefficients that are significant in the baseline results, Attic R-value and Duct R-value, drop as well going from columns 1-4 to column 5. There is a general loss in statistical significance when including all the variables together in column 5. Column 6 indicates that the capitalization coefficient on attic R-value is higher than that on negative percent duct leakage, but there is an overall lack of precision that makes it harder to draw conclusions. It is unclear whether this is because the baseline results are driven by outliers or because the robustness check excludes 10% of the sample and therefore results in less precise estimates. Moreover, as discussed in Section 3, my transaction price data are very reliable, and so these outlier prices should not be viewed as measurement error in the price variable. Therefore, it is not entirely clear that this robustness check is necessary.[40]

For completeness, I also show the results of my model when price is specified in logarithms

[39]It drops more observations in some than others, because I calculate the 5th and 95th percentile before running the regressions.

[40]Many papers that undertake robustness checks like these in the hedonics literature use public transaction data, for example data from CoreLogic, Inc., which often contains mis-recorded prices.

in Table A.26. Some readers might be interested in this because the hedonics literature often specifies the housing price in logarithms. I still find a very strong effect on the capitalization of duct leakage. I caution the reader to think carefully about whether this is a misspecification in light of the functional form discussion in Section A.3 in the appendix.

7.2 Falsification Tests Using Information and Observability

One remaining concern with my baseline regressions that needs to be ruled out is that there are potential confounders that could drive the results. There could be changes in preferences for energy efficiency over time. Trends in the national or local business cycle, such as the financial crisis, could affect prices of homes of high and low energy efficiency differently. Austin-specific policies and conditions, such as changes in property taxes, could differentially affect certain segments of the market, and thus differentially impact high and low energy efficiency homes. If these potential confounders were responsible for my baseline results, their effects should be apparent for *all* energy efficiency features. On the other hand, if the policy is driving the baseline results, then the capitalization effect should be larger for features for which information changed the most.

Accordingly, I want to know which measures should have a substantial change in the probability of consumers being informed due to ECAD. My framework suggests that the policy should not change capitalization as much (or at all) for features that the consumer would know about in absence of the policy. Also, if the policy drew consumers' attention to certain audit characteristics more so than others (thus providing more information for some features than others), then I should expect more of a change in capitalization for those features.

I devise three criteria that determine observability before the audit policy: whether the information was available in the listing, whether it was required to be in home inspection reports, and whether it is observable via visual inspection. I divide my audit feature variables into groups based on these three criteria.[41] For these three criteria, I score a 1 if the audit variable meets the criteria and a 0 if not in Table 4. Sometimes information is partially available; in this case, I give the variable a score of 0.5 in Table 4. I cover examples of partially available criteria when I discuss each criterion below.

In Table 4, the first column describes the listing criterion. The audit information appearing in the listing means that the Multiple Listing Service has a field for the audit variable that realtors may use to describe the home. In most cases, MLS fields for audit variables are of the checkbox sort, rather than being required fields. For example, the "Programmable Thermostat" field is optional. I assume that at least part of the time, realtors aware of programmable thermostats will fill out that field in order to advertise a favorable feature of a home. Partial

[41] Four audit variables are not considered here. Toilet type was not used because it is not related to energy efficiency. Recommended additional R-value was not used because it is simply 38−R-value in most cases (the guide for auditors said it should be this, but is not always followed). Air handler type was not used because it is too highly correlated (0.92) with air handler location. Whether window shading was recommended or not was excluded because it might be endogenous: because it is a recommendation, auditors could conceivably be selected based on their recommendations.

information in the listing describes a situation where the Multiple Listing Service has a field that gives only some information about the value of an audit variable. For example, although EER is not an MLS field, listings can specify whether the HVAC is Energy Star or in specific EER ranges.[42,43]

In Table 4, the second column describes the inspection criterion. Full information required in inspection reports means that the TREC (Texas Real Estate Council) requires that home inspectors reveal the audit variable in their inspection reports.[44] Partial information required in inspection applies to variables that must be noted on the inspection report, but where the inspection report would only partially inform the consumer. For example, the inches of insulation for attic and duct R-value must be noted on an inspection report, but those measurements do not exactly pinpoint an R-value.

The third column in Table 4 describes the visual inspection criterion. Full information here entails a consumer being able to discover the value of the variable while touring the home, without any special equipment or industry knowledge. For example, a consumer can easily see whether the home has a programmable thermostat. However, in order to know the duct leakage, the consumer would have to hire an expert. Partial information would entail a situation where the feature is only sometimes observable via visual inspection. For example, the R-value is usually only stamped on certain types of ducts.

I also use a criterion that indicates whether a consumer's attention is called to an audit variable by the front page recommendations, which is in the fourth column of Table 4. There are four recommendations on the audit form, and they mention certain audit measures but not others. For example, one recommendation that could be made by the auditor is to increase the R-value of the attic. This criterion should reflect the salience of the audit measures. Note that I am not using the recommendations themselves, because as discussed above, they are subject to endogeneity concerns. The fact that these audit features are highlighted on the front page of the form means that consumers' attention might be directed to them, regardless of whether the recommendations were made for an individual home.

Cross-audit-characteristic correlation makes it difficult to tell whether features for which information changed the most experienced more change in capitalization due to ECAD. One way to test these criteria would be to use joint hypothesis tests for groups of variables that met and did not meet each criteria. The issue with implementing such joint hypothesis tests

[42]The ranges do not span the entire spectrum of possible EERs; rather, they are used to advertise the fact that an HVAC is relatively energy efficient. Furthermore, this is an optional field, so realtors have no obligation to check a box.

[43]I exclude fields from the Energy, Environment, and Sustainability (EES) attachment but not in the main listing fields because the attachment is rarely used and does not show up in listings on websites. The attachment was not implemented until 2011. It can only be accessed by realtors, and so it is unlikely that information contained in it would be readily available to buyers. I do not have access to data in the EES because it was not in a format that could be easily transferred to me by the MLS administrators. However, I do have data on whether an EES attachment existed for the sale. To construct my primary sample, I drop the 21 homes that had an EES attachment in their listing.

[44]See Green Tag Inspection Services (2014).

is that the likelihood of rejecting the null hypothesis depends on the number of variables being considered in the joint hypothesis test, which is undesirable. Because the variables are correlated, I use principal component analysis (PCA) to construct a single index that represents most of the variation in the group of variables. PCA is a data reduction technique that uses the leading eigenvectors from the eigen-decomposition of the correlation matrix of the variables to construct uncorrelated linear combinations of the (standardized) variables. I use the first principal component as an index to summarize the energy efficiency of each group of variables.[45]

I first consider each information criterion separately, because readers might differ in their opinions of which criteria are more credible. Table 6 presents the results from regressions for each of the three observability criteria, Listing, Home Inspection, and Visual Inspection. The independent variables are different for each regression and vary based on which criterion was used (which criterion was used is indicated in the second-to-last row of the table). Since there is sometimes partial information, I present two versions of each regression. In version I of each of the observability criteria, I count each score of 0.5 as a 0, and in version II, I count each score of 0.5 as a 1. The independent variable "More observable group" is the first principal component of the group of variables that satisfy the observability criterion indicated, and "Less observable group" is the first principal component of the group of variables that do not satisfy the observability criterion indicated.

We would expect that if the policy affected less observable variables more, we should see positive effects for the "Less observable group" and smaller, if not no, effects for the "More observable group." This is the pattern we observe: for all criteria, there is a positive coefficient for the less observable group. Five out of six coefficients for the the less observable group are statistically significant at the 10% level; one of the three is significant at the 5% level and the other two are statistically significant at the 1% level. The more observable group is statistically insignificant and smaller in magnitude in all cases, which accords with the predictions of our theoretical model. However, in some cases, we cannot reject the null that the coefficients on the less and more observable groups are equal, which is to be expected given the positive correlations between energy efficiency features.

Similarly, Table 7 presents the results for the first principal components of the groups of variables that are and are not featured on the front page of the audit form. The first principal component of the group that is on the front page has an estimated coefficient that is statistically significant at the 1% level, positive, and higher in magnitude than the first principal component of the group that is not on the front page, which is statistically insignificant. We reject the null hypothesis that the two coefficients are equal at the 5% level.

For each criterion, I repeat the regressions excluding the Tankless or Solar WH variable from the group of variables to include in the PCA. I do this because a field for whether the home had a tankless water heater appeared for the first time in the listing in 2009, but was

[45]PCA loadings can be found in Tables A.30 through A.33 in the appendix.

seldom used by realtors.[46] Therefore, this change in the listing fields is a potential confounder. These results can be found in Tables A.27 and A.28 in the appendix. The results are similar except for the In Listing II criterion, for which the less observable group's principal component is insignificant and the coefficients on the more observable group is higher, though neither of the coefficients are statistically significant. For the front page criterion, the results are similar to those where the PCA includes the Tankless or Solar WH.

Some readers may wish to see the regression results using an index summarizing the overall change in information expected from the policy. I add the observability criterion and subtract the front page variable to arrive at a simple rough ordering of the audit variables that takes multiple criteria into account, which is shown in the last column of Table 4. I construct three groups of four variables by excluding Tankless or Solar WH.[47] The information groups are summarized in Table 5.

I show the results using the first principal component from PCA of each group of variables in Table 8. In this specification, group 1 is the only group with a statistically significant first principal component. The magnitude of group 1's coefficient is also higher than that of the other two groups, as expected from our theoretical model. But we cannot reject the null hypothesis that the coefficients are significantly different for the pairs of groups. Table 8 suggests that the variables in information group 1 are probably most important to explaining the change in housing prices. Taken as a whole, these information criteria and information group regressions show that effects of the policy differ by the amount of information change due to the policy, suggesting that ECAD, and not confounders, is driving the results in my baseline specification.

Another test is to look at whether the change in capitalization coefficients follows the amount of information change from the policy for each audit measure. I run my baseline specification including all audit measures and plot the results in Figure 2. The variables are standardized before these regressions so that the magnitudes can be interpreted more easily relative to one another.[48] The audit characteristics displayed on the left-hand side of the figure are ranked in terms of change in information expected due to the policy. We should expect to see larger magnitudes at the top of the figure and smaller ones at the bottom of the figure, and indeed, the coefficients seem to follow this pattern, with a few exceptions. Figure A.1 in the appendix shows analogous results, including each audit variable separately. The figures are similar, though Figure A.1 shows smaller standard errors around most of the coefficients.

I also conduct joint hypothesis tests for groups of variables. Results are shown at the bottom of Figure 2. I test joint hypotheses that all of the coefficients in a given group equal

[46] To my knowledge, there were not concomitant changes for other variables in my analysis.

[47] While two groups would be more natural, it is not possible to split these variables into two equal groups without assigning variables with the same rank to both groups, which would be undesirable. Furthermore, if the groups did not contain and equal number of variables, the joint hypotheses from Table A.29 would not be comparable.

[48] Full results can be found in column 4 of Table A.29 in the appendix.

zero. The joint significance patterns for the three groups of variables are increasing in the change in information expected from the policy in both the regressions where the groups are treated separately and the regressions where the groups are considered together, implying that perhaps the lowest-information energy efficiency features were brought to the forefront by the audit. This constitutes supporting evidence that the audit had an effect and that results are not driven by changing preferences for energy efficiency over time.

One robustness check of the second information group is warranted because, as discussed in Table 4, it is unclear what effect we should expect for metal ducts. Metal ducts tend to be less well-sealed than other duct types and hence leak more air. They also tend to be less well-insulated than other types of ducts, but are not subject to the severe installation issues or airflow restrictions that other duct types are subject to, do not degrade as rapidly over time, and are not vulnerable to pests. If consumers know that metal ducts are usually not as well-sealed as other types of ducts but have advantages in terms of airflow, longevity, and pests, they could account for the relationship between duct type, leakage, and R-value in their home purchase decisions. In that case, we would expect them to pay a higher premium for metal ducts after the policy is enacted, conditional on a given value of R-value and duct leakage. If consumers simply use characteristics such as whether the home has metal ducts or not as heuristics for energy efficiency, then they might put less of a premium on metal ducts because they usually leak more air and are not as well-insulated. In the fifth column of Table A.29 in the appendix, I control for duct leakage and duct R-value to take account of the relationship between duct type, leakage, and R-value. I find that the coefficient on metal ducts is positive in all three specifications (columns 2, 4, and 5), but is more positive in the specifications where leakage and R-value are controlled for. I interpret this as weak evidence that consumers might become aware of the relationships between energy efficiency features due to the policy.

7.3 Falsification Tests Using Supplemental Pre-Sample Data

To construct an additional set of falsification tests, I combine my main sample with a supplemental sample of prior sale pairs from homes that are in my main sample. These are the sale pairs just prior to my main sample, and they occurred before the sales in my main sample, but after 2000. Unfortunately, I cannot conduct a true test of pre-trends because more than 1 sale prior to my main sample is rare. This is a problem faced by many housing market researchers: most houses are not sold every year.

Using only these pre-sample sales, I first reproduce my baseline specification, again regressing the change in price on the main audit measures, treating the pre-sample as if it were my main sample. Refer to Table 9 for the results. I find that for attic R-value and negative percent duct leakage, the coefficient signs are negative and not statistically significant. The signs are positive for duct R-value and EER, and only statistically significant for EER (although the coefficient on EER is not significant when controlling for the other main audit measures). This is reassuring, because my baseline results point to additional capitalization of attic R-value and negative percent duct leakage from the policy but less evidence for duct R-value, and no statistically significant evidence for EER. Finding evidence of a potential pretrend in EER combined with little evidence of additional capitalization due to the policy could mean that capitalization of EER was on an upward trend before the policy but was not significantly affected by the policy. Overall, I find no evidence of pretrends driving my baseline conclusions.

8 Mechanisms

There are two possible market failures that an energy efficiency audit policy might address, and each represents a potential channel through which my empirical results could obtain. First, the housing market might be characterized by imperfect information which is possibly asymmetric. Because consumers do not observe energy efficiency, they are unwilling to pay for it. It is likely that information would also be asymmetric: sellers, having lived in a home for a while, probably know more than buyers do about the energy efficiency of the home. Thus, prices might not fully reflect energy costs.[49]

Second, an energy efficiency audit policy could address salience effects. Salience is a broad term that refers to the phenomenon where when a person's attention is focused on one particular aspect of their environment, that aspect receives disproportionate weighting in the decisions at hand (Taylor and Thompson, 1982, p. 175). A multitude of models could justify behavior that is seen as reactions to "salience." For example, Sallee (2014), Bordalo, Gennaioli, and Shleifer (2013), Gabaix (2014), and Gabaix and Laibson (2006) present models where salience is driven by relative quality and price dispersion for attributes in the context of limited attention. Other papers focus on misperceived prices or costs (Chetty, Looney, and Kroft, 2009; Allcott and Sunstein, 2015; Allcott, 2013; Levy, Norton, and Smith, 2018) or optimization errors in general (Chetty, 2009) as the cause for salience effects.

My empirical strategy cannot distinguish between asymmetric information and salience. The first page of the audit, the Single Family Energy Audit Summary, has four categories for recommendations, on windows and shading, attic insulation, the heating and cooling air duct system, and air infiltration. If the policy changes the salience of features but there is no asymmetric information, then I should see stronger effects for features that are on the front page of the audit form. Unfortunately, these are also the features that are least observable before the audit, so I cannot tell whether salience or asymmetric information is driving my effects.

A further barrier to disentangling the two suspected mechanisms is that we do not know how salient the characteristics that were harder to observe before the policy were before the policy. It could be that easy-to-observe features like programmable thermostats and HVAC fuel were salient before the policy, but hard-to-observe features like duct leakage were not

[49] Furthermore, adverse selection may result: low energy-efficiency homes might "drive out" high energy-efficiency homes, because owners of high energy-efficiency homes would rather keep their homes than be under-compensated for their high energy efficiency (Akerlof, 1970). In order to mitigate concerns over adverse selection, my empirical design focuses on homes sold both before and after the audit.

salient before the policy and the policy increased their salience.

Interviews with realtors in the Austin area reveal that perhaps both mechanisms are at play, though salience effects may be stronger. See Section A.4 in the appendix for a summary of key points from interviews. Realtors seemed to think that only some customers cared about ECAD, with two realtors agreeing that "hippies and engineers" were the only customers that took an active interest in acquiring the ECAD form. Despite this, realtors representing buyers typically said that they asked for the form and sellers or sellers' realtors were willing to provide it to them well in advance of the sale. Then, they handed it to the buyer, whether the buyer asked for it or not. There are two points to note here. First, sellers might not be trying to hide ECAD results. Second, even if buyers are not initially interested in the form, they might be prompted to read it once their realtor hands it to them. If buyers are handed ECAD forms while they are still touring multiple homes, it might influence which home they choose, which should have an effect on prices of energy-efficient versus energy-inefficient home prices in equilibrium. Further, buyers might be more likely to ask for energy bills if they are primed to think about energy efficiency. Both of these points indicate a strong role for salience as a mechanism behind my results.

An important question is whether which market failure generated my results matters. If there is an increased premium to energy efficiency, then that incentivizes increased investment in energy efficiency in the long run. That is, the policy goal is achieved. But, welfare effects could depend on the underlying model used. For example, if inattention is the reason consumers do not fully factor energy efficiency into their purchase decisions initially, then it is important to know whether the inattention is rational or whether it arises from systematic mistakes.[50]

9 Conclusion

The growing popularity of mandatory energy efficiency disclosure policies raises the important question of how they impact capitalization of energy efficiency features into housing prices. I use data from a policy in Austin, TX that required sellers to reveal the results of an energy efficiency audit before selling their house. I find that the policy increased capitalization of energy efficiency features, and that the increase was higher for features that were harder-to-observe in the absence of the policy. To my knowledge, this paper presents the first empirical estimates of the effect of mandatory disclosure on capitalization of energy efficiency features into housing prices.

This paper contributes to the understanding of policy solutions for an energy efficiency gap and externalities in the housing market. My results suggest that disclosure policies might remedy an energy efficiency gap. These policies could remind buyers of the benefits of energy efficiency in housing and could help consumers to better evaluate the energy benefits of housing they plan to own or rent, aligning the incentives of buyers and sellers, and potentially

[50]For a more thorough discussion of welfare effects under inattention and assumptions about underlying models of inattention, see Sallee (2014).

promoting long-term energy efficiency investment. Disclosure policies are also important to study because energy use produces both global and local externalities, including CO_2, SO_2, and NO_x. Even in the absence of an energy efficiency gap, there might be a difference between the socially optimal level of energy efficiency investment and the actual, privately optimal, level of energy efficiency investment. Thus, it is important to consider whether disclosure policies can increase energy efficiency investment even if consumers currently invest at a privately optimal rate, if pollution externalities are not adequately priced.

My findings have implications for the design of energy disclosure policies. My finding that the audit policy increased capitalization much more for difficult-to-observe features means that policymakers might be able to shorten the list of features required on energy audit forms without diminishing the benefits of the program. Furthermore, some cities have recently enacted energy disclosure policies that require the seller to show a Home Energy Score (HES) to buyers (e.g. Portland, OR). Factors such as the home size, number of bedrooms, fuel type of appliances, EER, HVAC size, and year built play a sizable role in determining the HES. This is by design: the HES is designed to have high predictive power of energy bills, and these factors matter more than others for those bills. However, my results imply that the effect of HES disclosure policies might be attenuated because consumers already take readily observable factors into account. In fact, the measure for which I find the most evidence of a change in capitalization due to ECAD, duct leakage, is often estimated for the HES based on more observable features of the home (like the system age). This could further attenuate the effect of the policy on capitalization of energy efficiency into house prices.

From a welfare perspective, disclosure policies like the Energy Conservation And Disclosure (ECAD) Ordinance that increase energy efficiency information in the housing market potentially have two main benefits. First, they should stimulate long-run energy efficiency investment, because higher premiums to energy efficiency should encourage homeowners to upgrade (or at least remove disincentives to upgrade). Second, they improve allocative efficiency by ensuring that buyers who care most about energy efficiency are matched to energy efficient homes. There is scope for future work on both how sellers respond to increased premiums to energy efficiency and how allocative efficiency could be improved through enhanced information in the housing market. Fruitful directions for future study include modeling the investment response to such a policy in equilibrium, comparing the effects of energy cost disclosure with audit information disclosure, and evaluating mechanisms through which disclosure policies might work, such as salience and asymmetric information.

10 Tables

Table 1: Summary Statistics

	Mean	Std. Dev.	Min.	Max.	Obs.
Δ Price	1.85	7.18	−70.09	135.54	3939
Annualized Price Difference	0.45	2.25	−13.37	49.03	3939
1st Sale Price	30.85	20.75	3.35	312.15	3939
2nd Sale Price	32.70	21.56	3.80	329.28	3939
Year of Sale 1	2006.61	1.30	2005.00	2013.00	3939
Year of Sale 2	2011.56	1.48	2009.00	2015.00	3939
Gas WH	0.59	0.49	0.00	1.00	3939
Tankless or Solar WH	0.04	0.20	0.00	1.00	3939
Attic R-value	22.47	8.50	0.00	84.00	3549
Gas Furnace	0.61	0.49	0.00	1.00	3939
EER	10.18	1.77	3.00	15.00	3146
− % Duct Leakage	−19.17	11.09	−100.00	−0.10	3741
Return Sizing Adequate	0.83	0.37	0.00	1.00	3880
Duct R-value	5.54	1.47	0.00	15.00	3728
− System Age	−12.88	5.47	−30.00	0.00	3180
Metal Ducts	0.17	0.38	0.00	1.00	3847
HVAC Size (sqft/ton)	500.55	88.09	200.00	1000.00	3736
Programmable Thermostat	0.68	0.47	0.00	1.00	3939
AH in Closet	0.40	0.49	0.00	1.00	3771
Vertical AH	0.60	0.49	0.00	1.00	3808
Conditioned Sqft	1739.81	739.89	120.00	6875.00	3925
Sqft Total	1760.43	746.45	376.00	7310.00	3939
Bedrooms	3.09	0.80	1.00	6.00	3939
Bathrooms	2.27	0.80	1.00	8.00	3939
Year Built	1975.19	18.73	1875.00	2005.00	3939
Attic Sqft	1287.97	522.70	0.00	5403.00	3466
Price of Elec at Sale 1	4.12	0.39	3.48	4.63	3938
Price of Elec at Sale 2	3.92	0.28	3.35	4.32	3939
Price of Gas at Sale 1	18.28	3.73	8.45	27.72	3938
Price of Gas at Sale 2	15.34	4.01	8.45	22.51	3939

Notes: See Table A.1 in the appendix for audit variable definitions. Square footage variables (conditioned, total, and attic) are in 1000's. WH=water heater, EER=Energy Efficiency Ratio, AH=air handler. All prices are in $10,000 units, with the exception of electricity and gas prices. Electricity prices are in Cents/kWh, and gas prices are in dollars/1000 ft^3.

Table 2: Baseline Specification

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0421**				0.0311	0.2642
	(0.0166)				(0.0196)	(0.1668)
− % Duct Leakage		0.0338***			0.0365***	0.4046***
		(0.0092)			(0.0109)	(0.1209)
Duct R-value			0.1953**		0.0695	0.1019
			(0.0935)		(0.1255)	(0.1841)
EER				0.1296	0.1120	0.1985
				(0.0928)	(0.0999)	(0.1771)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.517
−% DL = DR p						0.147
−% DL = EER p						0.371
All = p						0.436
All > 0 p					0.001	0.001
R-squared	0.109	0.106	0.110	0.107	0.113	0.113
Home Clusters	3549	3741	3728	3146	2755	2755
Observations	3549	3741	3728	3146	2755	2755

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for audit variable definitions. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table 3: Expected Savings and Costs of Retrofit

Variable	Attic R-value	- % Duct Leakage	Duct R-value	EER
My estimate	$311	$365	$695	$1,120
95% CI	(-$81, $703)	($147, $583)	(-$1,815, $3,205)	(−$878, $3,118)
PDV Savings	$71	$209	$193	$959
Cost (job)	$189	$114	$532	$3,417
Cost (unit)	$47	$16	$67	$2,670

Notes: My estimate and the corresponding 95% confidence interval associated with it come from the baseline specification that includes all four main variables, which is shown in the fifth column of Table 2. See Tables A.4 through A.6 in the appendix for construction of PDV Savings and Costs. PDV Savings refers to the present discounted value of savings using a 7% discount rate and the expected lifetime of the appliance.

Table 4: Information Criteria and Information Groups

	Listing (L)	Home Inspection (H)	Visual Inspection (V)	Front Page (F)	L+H +V-F	Group
Percent Leakage	0	0	0	1	−1	1
Attic R-value	0.5	0.5	0	1	0	1
Duct R-value	0	0.5	0.5	1	0	1
System Age	0	0	0.5	0	0.5	1
Return Sizing Adequate	0	1	0	0	1	2
System Size	0	0.5	0.5	0	1	2
Metal Ducts	0	0	1	0	1	2
EER	0.5	0	0.5	0	1	2
Tankless or Solar WH	0	0	1	0	1	N/A
Prog Thermostat	1	0	1	0	2	3
AH in Closet	1	0.5	1	0	2.5	3
Gas WH	1	1	1	0	3	3
Gas Furnace	1	1	1	0	3	3

Notes: See Section A.6 in the appendix for details on how this table was constructed.

Table 5: Information Groups

1 (Most Change in Info)	2	3 (Least Change in Info)
− Percent Leakage	Return Sizing Adequate	Programmable Thermostat
Attic R-value	System Size	AH in Closet
Duct R-value	Metal Ducts	Gas WH
− System Age	EER	Gas Furnace

Notes: See Table 4 for more on how the groups are constructed from scores that represent whether the audit feature is observable according to the criteria. See Section A.6 for information on how the scores are constructed.

Table 6: Different Observability Criteria, PCA Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
More observable group	−0.0123	0.0227	0.0168	0.0874	−0.0007	0.0379
	(0.1265)	(0.1266)	(0.1288)	(0.1228)	(0.1248)	(0.1334)
Less observable group	0.2129*	0.0498	0.2651**	0.6979***	0.3662***	0.3297**
	(0.1264)	(0.1418)	(0.1311)	(0.1581)	(0.1306)	(0.1434)
Observability Criterion	In listing I	In listing II	In home inspection I	In home inspection II	In visual inspection I	In visual inspection II
More=less p	0.210	0.889	0.150	0.001	0.042	0.163
R-squared	0.108	0.107	0.109	0.118	0.111	0.109
Home Clusters	2150	2150	2150	2150	2150	2150
Observations	2150	2150	2150	2150	2150	2150

Notes: The dependent variable is the change in price. "More observable group" is the first principal component of the group of variables that can be observed via the means indicated in the column header. "Less observable group" is the first principal component of the group of variables that cannot be observed via the means indicated in the "Observability Criterion" row. I have grouped the "partially observable" variables (indicated by a score of 0.5 in Table 4) with the less observable (score of 0 in Table 4) variables in version I of each possible method of observation and with the more observable variables (score of 1 in Table 4) in version II. All prices are in \$10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. More = Less p refers to the p-value associated with the t-test that the coefficients on the more and less observable groups are equal to one another.

Table 7: Front Page, PCA Analysis

	(1)
Not on front page group	0.0085
	(0.1279)
On front page group	0.4096***
	(0.1426)
On FP= Not on FP p	0.040
R-squared	0.111
Home Clusters	2150
Observations	2150

Notes: The dependent variable is the change in price. "Not on front page" is the first principal component of the group of variables that are not mentioned on the front page of the audit form. "On front page" is the first principal component of the group of variables that are mentioned on the front page. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. On FP = Not on FP p refers to the p-value associated with the t-test that the coefficients on the front page group and the not on front page group are equal to one another.

Table 8: Change in Information Groups According to Overall Ranking, PCA Analysis

	(1)	(2)	(3)	(4)
Group 1 (Most)	0.3775***			0.3178**
	(0.1181)			(0.1381)
Group 2		0.1258		0.0713
		(0.1268)		(0.1418)
Group 3 (Least)			0.1328	0.0403
			(0.0812)	(0.1245)
Group 1=Group 2 p				0.252
Group 1=Group 3 p				0.147
Group 2=Group 3 p				0.863
R-squared	0.106	0.113	0.109	0.110
Home Clusters	2718	2971	3771	2150
Observations	2718	2971	3771	2150

Notes: The dependent variable is the change in price. See Table 5 for a list of audit features in each group. See Table 4 for how the groups are constructed from scores representing whether the audit feature is observable according to the criteria. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. Group 1 = Group 2 p refers to the p-value associated with the t-test that the coefficient on the index summarizing the group 1 variables equals the coefficient on the index summarizing the group 2 variables. Indices are constructed using PCA.

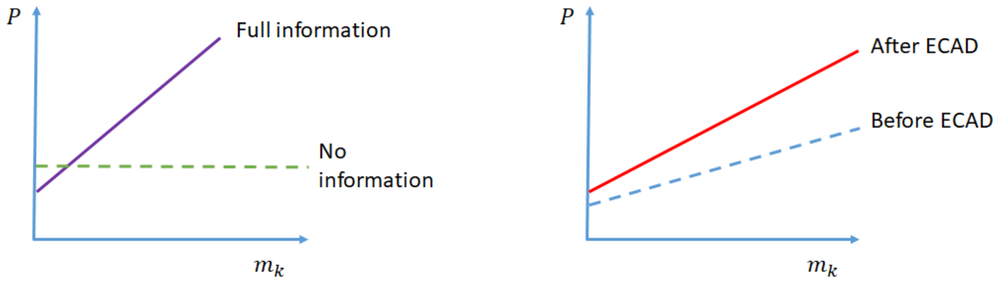
Table 9: Testing for Differential Pre-trends

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	−0.0044				−0.0090	−0.0764
	(0.0227)				(0.0257)	(0.2189)
− % Duct Leakage		−0.0009			−0.0022	−0.0240
		(0.0177)			(0.0241)	(0.2678)
Duct R-value			0.0859		0.0211	0.0310
			(0.1244)		(0.1518)	(0.2227)
EER				0.2530**	0.1471	0.2609
				(0.1042)	(0.1067)	(0.1892)
Standardized?	No	No	No	No	No	Yes
−% DL = AR *p*						0.885
−% DL = DR *p*						0.879
−% DL = EER *p*						0.391
All = *p*						0.656
All > 0 *p*					0.720	0.720
R-squared	0.088	0.110	0.110	0.113	0.092	0.092
Home Clusters	1517	1595	1599	1377	1207	1207
Observations	1517	1595	1599	1377	1207	1207

Notes: This table shows results from the falsification test to check for pre-trends in capitalization of the four main audit variables. The dependent variable is the change in price. See Table A.1 in the appendix for audit variable definitions. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0. Here, I only use the sale pairs from the supplementary sample. These are sale pairs that occurred just prior to the main sample, but are for homes from the main sample.

11 Figures

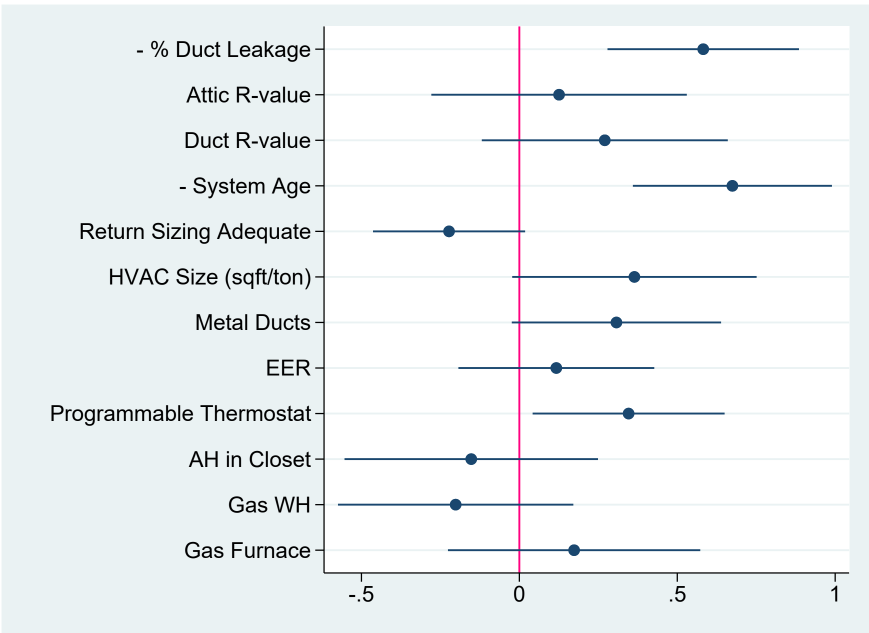
Figure 1: Effect of Policy under Assumptions of Conceptual Framework



(a) None-to-Full Capitalization (b) Partial Capitalization

Notes: This diagram illustrates the expected effects in the cases of none-to-full capitalization and partial capitalization, which are discussed in Section 4.

Figure 2: Capitalization Effects by Energy Efficiency Features



Notes: This diagram shows the coefficients from Table A.29 and their standard errors. Audit variables are standardized prior to regression.

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A Appendix (for Online Publication)

A.1 Data Cleaning

I first use SmartyStreets to standardize and verify the addresses in my MLS and audit datasets. The initial audit dataset contains 17,296 observations; 608 are not found by Smarty Streets. For three of the variables, I combine categories to create dummy variables. For air handler installation type, I combine upflow and downflow air handlers into one category because they are typically more energy efficient than horizontally installed air handlers. In the raw audit dataset, there were 92 downflow, 7600 horizontal, and 10,932 upflow air handlers. For the water heater tank type, there were three possible responses: tank, tankless, and solar. I combined solar with tankless because both are more energy efficient than tank systems. In my dataset, there are 40 solar water heaters, 16,073 tank water heaters, and 575 tankless water heaters. For the duct system type, I combine Mylar Flex, Grey Flex, and duct board into one category and leave sheet metal as its own group. This is because all three of Mylar Flex, Grey Flex, and duct board are likely less energy efficient when controlling for duct leakage and duct R-value. In my dataset, there are 3,466 observations that are duct board, 3,084 that are grey flex, 8,419 that are Mylar flex, and 3,679 that are sheet metal.

For some audit variables, a home could have two HVAC systems. In my dataset, 2,889 homes had two systems and 13,799 had just one system. I average the value of the two systems for the following variables if two systems exist: duct leakage, duct R-value, EER, system age, system size. I also average the variable indicating whether or not the return sizing was adequate for the two systems. For the following variables, I simply use the value given for the first (primary) system: whether the air handler is horizontal and whether the ducts are flex. After restricting to one audit per address, I have 16,688 observations.

The initial MLS dataset contains 781,127 observations, each of which has a listing and possibly a sale. This includes years I do not eventually use, homes that are not in Austin or are in Austin but not in the Austin Energy service area and thus not subject to ECAD, and homes that never had an audit. 22,781 observations have addresses that SmartyStreets cannot verify. 42,725 of the remaining observations match to the cleaned audit data on the delivery point barcode, which is used by USPS workers to deliver packages. Of these, 571 have zero sales (they are just listings) and 8,498 have just one sale; these will not be used in my estimation. I drop all 275,358 observations without a sale date. Two sales have a date but no price. I do not include sales that occurred after an audit but more than 60 days before the compliance deadline. Houses are often listed for more than 2 months, so getting an audit upon listing your home in anticipation of the policy going into effect is to be expected to the extent that people do not have full control over whether their home sells after or before they have to comply. This affects 102 observations. 474,977 have no sales after the audit (or no audit) and 9,807 have no sales before the compliance deadline, and those are dropped. 7,011 sale pairs are such that one occurred just before and one occurred just after the audit.

For my permits dataset, I start with 1,901,522 construction permits. I drop 638,712 nonresidential permits. Of the remaining permits, 48,401 have addresses that SmartyStreets cannot verify, and 100,846 have no date (neither a completed nor an issue date). 498,060 permits were completed before 2000, and were thus dropped. I reorganized the data to be at the address level, which translated to a total of 239,917 observations. I merged these into my MLS data, 6,127 of the 7,011 valid sale pairs (sale pairs are such that one occurred just before and one occurred just after the audit) match to the permit data (I keep the ones that do not match to permit data for the other regressions). I then further restrict the primary sample to those sale pairs where the first one occurred after 2005 and the second occurred before 2015; this is so that I can construct a second sample of supplementary data from sales that occurred prior to these and so that the sales in my primary sample are not temporally removed from the time of policy implementation.

This drops 2,933 sale pairs, leaving 4,078 sale pairs. I then drop 8 observations that had a nonmissing EES attachment (Energy, Environment, and Sustainability attachment) to their listing. This leaves 4,070 sale pairs in my primary sample. I then calculate some statistics on and then subsequently drop 131 sale pairs associated with late compliers (those homes had a sale after their theoretical compliance deadline); refer to the main text for more information. I use the exact same cleaning steps for my supplementary sample, which I use in one set of falsification tests, but ensure that all homes in my secondary sample also appear in my primary sample so that they are comparable. For list price, I use only homes that are also in my primary sample (hence, they are eventually sold). For both list price and time of market data, I do not use observations where the list date is after the sale date. This only affects one sale pair in my sample.

All prices are inflation adjusted to be equivalent to May 2019 prices using the CPI series "Consumer Price Index for All Urban Consumers" from U.S. Bureau of Labor Statistics (2017). List and Sale prices are in \$10,000 units.

A.2 Equivalence to DID

For purpose of illustration, consider the following "intensity of treatment" specification:

$$P_{it} = \alpha d_{it} + \sum_k \beta^k m_i^k d_{it} + \sum_k \delta^k m_i^k + \sum_n \theta^n x_i^n d_{it} + \sum_n \xi^n x_i^n + \tau_{yt} + \eta_i + \omega_{it} \tag{A.1}$$

In (A.1), P_{it} is the sale price of home i occurring on date t, M_i is a vector of K audit measures m_i^k, X_i is a vector of N controls x_n that do not change over time (they are determined prior to the first sale in the sample), d_{it} is a dummy that indicates whether the home was audited by time t (because of my sample selection, d_{it} is also an indicator for the home being required to be audited), τ_{yt} is a year fixed effect for the year of sale, and η_i is a house fixed effect. The second summation contains the β^ks which are our parameters of interest. The third summation allows for the effect of the control variables on the price to change over time. For example, the capitalization of square footage or whether the house has a pool could change from before to after the policy, and might confound our estimates if there is correlation between pools and audit measures. One important group of control variables is the year built group dummies. This is a vector of year builts that determines the date the home had to comply by. Including these in the vector of controls allows the price dynamics to vary by treatment cohort.

Because the house features M_i and X_i do not change over time in my sample, they are collinear with the fixed effects η_i, and so I can express (A.1) without the second and fourth summations:

$$P_{it} = \alpha d_{it} + \sum_k \beta^k m_i^k d_{it} + \sum_n \theta^n x_i^n d_{it} + \tau_{yt} + \eta_i + \omega_{it} \tag{A.2}$$

I can subtract the price at sale s from the price at sale $t > s$ to get:

$$P_{it} - P_{is} = \alpha(d_{it} - d_{is}) + \sum_k \beta^k m_i^k (d_{it} - d_{is}) + \sum_n \theta^n x_i^n (d_{it} - d_{is}) + \tau_{yt} - \tau_{ys} + \eta_i - \eta_i + \omega_{it} - \omega_{is} \tag{A.3}$$

Simplifying,

$$P_{it} - P_{is} = \alpha(d_{it} - d_{is}) + \sum_k \beta^k m_i^k (d_{it} - d_{is}) + \sum_n \theta^n x_i^n (d_{it} - d_{is}) + \tau_{yt} - \tau_{ys} + \omega_{it} - \omega_{is} \tag{A.4}$$

Denote the change in price $P_{it} - P_{is}$ by ΔP_{ist} and denote the difference in the error terms $\omega_{it} - \omega_{is}$ by ϵ_{ist}. We can rewrite (A.4) as:

$$\Delta P_{ist} = \alpha(d_{it} - d_{is}) + \sum_k \beta^k m_i^k (d_{it} - d_{is}) + \sum_n \theta^n x_i^n (d_{it} - d_{is}) + \tau_{yt} - \tau_{ys} + \epsilon_{ist} \tag{A.5}$$

Because I only observe m_i^k for the homes that were audited, and I restrict my main sample to two sales per home, one before the audit policy took effect and the home was audited and one after both of those events, $d_{it} - d_{is} = 1$, and (A.5) becomes:

$$\Delta P_{ist} = \alpha + \sum_k \beta^k m_i^k + \sum_n \theta^n x_i^n + \tau_{yt} - \tau_{ys} + \epsilon_{ist} \tag{A.6}$$

τ_{yt} and τ_{ys} are both dummies, so we can express them both as positive indicators (including τ_{yt} and τ_{yt} separately is slightly more flexible than subtracting them out as if they were one yearly effect):

$$\Delta P_{ist} = \alpha + \sum_k \beta^k m_i^k + \sum_n \theta^n x_i^n + \tau_{yt} + \tau_{ys} + \epsilon_{ist} \tag{A.7}$$

α will be collinear with one of the sets of year dummies, and so we can exclude it from the estimation equation:

$$\Delta P_{ist} = \sum_k \beta^k m_i^k + \sum_n \theta^n x_i^n + \tau_{yt} + \tau_{ys} + \epsilon_{ist} \quad \text{(A.8)}$$

In vector notation, this becomes:

$$\Delta P_{ist} = \beta' M_i + \theta' X_i + \tau_{yt} + \tau_{ys} + \epsilon_{ist} \quad \text{(A.9)}$$

A.3 Functional Form of the Price Curve

One important assumption from my conceptual framework is that price is linear in audit measures; it is important because the interpretation of my coefficients depends on it.[51] Furthermore, it is common in the literature on housing prices to use the logarithm of price rather than the level of price as the dependent variable, so I need to determine whether using the logarithm of price is appropriate in my setting.[52] I will first discuss the relationship we should expect between savings and the main audit measures. Then, I will examine whether a linear relationship holds in my data.

Holt Architects (2017) explains that for insulation (including duct and attic insulation), the energy savings associated with R-value is characterized by diminishing returns. Figure A.2, reproduced from Holt Architects (2017), shows the deterministic relationship between heat flow reduction and R-value graphically. Savings should track heat flow reduction fairly consistently. Attic R-value ranges from 2 through 60 in my sample, with a mean of 22.62, and Duct R-value ranges from 0 to 12, with a mean of 5.52 (see Table 1 for summary statistics). This means that most of the homes in my sample are probably in a range of attic R-value where savings are relatively flat, but many of the homes in my sample may be in the relatively curved segment of Figure A.2 for duct R-value, implying decreasing returns to duct R-value.

Witriol, Erinjeri, Allouche, Katz, and Nassar (2008) quantify the savings from reducing duct leakage. Figure A.3 plots Witriol et al.'s (2008) results and shows that the relationship is approximately linear. An HVAC system's Energy Efficiency Ratio (EER) is defined as the ratio of a heating or cooling system's output in British Thermal Units per hour to its power draw in Watts. This means that electricity use will be approximately inversely related to EER for a given cooling or heating capacity, implying that energy savings are increasing at a decreasing rate in EER.

It bears mentioning that even if energy savings are increasing at a decreasing rate in a given audit measure, it could be the case that consumers perceive the relationship between energy savings and the energy efficiency of the audit measures to be linear; there is evidence of this in the context of automobiles (Larrick and Soll, 2008).

With the exception of the Witriol et al. (2008) study on duct leakage, the above arguments

[51] A slope change is well-defined when the price is a linear function of each audit feature. My results would be subject to misspecification bias if linearity is not approximately true.

[52] Notice that specifying price in logs implies *increasing* returns to the audit measures.

on decreasing or linear returns in *energy cost savings* have relied on the fact that there are decreasing or linear returns in *energy savings*. However, some customers may face an increasing marginal cost of electricity or natural gas, which could impact how energy savings translate to energy cost savings. Austin Energy established a two-tiered rate structure for residential customers in 1994 and switched to a five-tiered structure in 2012.[53] All customers were switched as there was no provision for grandfathered rate structures. Both tiered structures have the characteristic that energy prices per kilowatt-hour increase in usage. If the tiers are salient to consumers and consumers consider major improvements that could impact which tier they fall on, then even if energy savings show linear returns, energy cost savings could yield decreasing returns.[54] However, Ito (2014) finds that consumers probably respond to average, rather than marginal, price, which would imply that if energy savings from improving audit measures exhibit linear returns, then consumers will perceive linear energy cost savings.

Because there could be nonlinearities in the relationship between monetary savings and three of the four main audit variables I study (Attic R-value, Duct R-value, and EER), the linearity assumption merits further investigation. I examine cross-sections of my data from before and after the policy to determine empirically whether linearity is reasonable. Figures A.4 through A.7 in the appendix present the sale price plotted against each measure, residualizing by the following variables: number of bedrooms, number of bathrooms, lot size area, square footage, bins for year built, home type (Condo, Single-Family, Duplex, etc.), year sold, and whether there was a pool on the property. Categories for square footage each represent 1000 square feet. Lot size area categories are in one-acre increments. I have included a locally weighted scatterplot smoothing (LOWESS) curve in each graph. This curve is the result of a locally weighted regression where each smoothed value is given by a weighted linear least squares regression. The weight function weights closer data points more heavily than more distant data points. I use a bandwidth of 0.8 to fit this curve and the standard tri-cube weight function.[55] This means that the LOWESS smoothing uses 80% of the data around a point to estimate the value of the curve at that point. These subsets of data are centered where possible and uncentered at the ends. Smaller subsets of data are used at the endpoints of the graph. When I use smaller bandwidths so that 20%, 40% and 60% of the data is used, the graphs look similar, though less smooth.

It is hard to tell from Figures A.4 through A.7 whether the fitted values are roughly linear and whether the slopes indeed change from "Before" to "After". Therefore, I have included graphs in Figure A.8 that each compare the "Before" and "After" LOWESS-smoothed curves for the plots in a single graph. These graphs exaggerate nonlinearities compared with the graphs

[53]Summer and non-summer rates differ. This is notwithstanding solar, community solar, and pilot programs (which include Time of Use and other elective schedules). See Jacobsen (2012), Austin Energy (2011), Austin Energy (2016a), and Austin Energy (2016b).

[54]Witriol et al.'s (2008) study uses REM/RATE software, which does take rate structure into account, so this argument would not apply to duct leakage.

[55]A bandwidth of 0.8 is the default in Stata when using LOWESS smoothing.

in Figures A.4 through A.7, but have the advantage of clarifying the difference in the fitted curves. The attic R-value and percent leakage are both roughly linear. The linearity of duct R-value is suspect. EER looks to be an in-between case. Note that around zero, though, all of the graphs look roughly linear. That means that the majority of homes are in a segment where the relationship between residualized price and residualized audit measures is approximately linear, which suggests that linearity might be a good approximation for the majority of homes. Additionally, Figure A.8 contains the 5th and 95th percentiles of the residuals for each variable for both before and after the policy, expressed as vertical lines. These percentiles are so close that it looks like they completely coincide in all four graphs. These show that linearity is plausible in the range of the four main variables faced by 90% of the observations in my sample.

In Figure A.9, I show the results of fitting a linear specification to the same residualized audit measures. In all cases, the slope of the line is steeper after the policy took effect and the signs of the slopes are all as expected. This is suggestive evidence that the policy increased capitalization of the audit features into the housing price.

A.4 Interviews with Realtors

Below, I briefly summarize the results of my interviews with realtors.

1. Nearly all realtors interviewed said that they complied with the policy. They said the ECAD results were generally handed over as soon as they were obtained, and in most cases well before 3 days before the end of the option period. Most of the time, an audit was already on file when negotiating with a buyer and so the audit would be provided to the buyer a few weeks in advance. When realtors represented buyers, they often obtained ECAD results in advance, even before any option period contract.

2. Realtors thought that the majority of buyers did not care about ECAD right now. This was evidenced by the fact that when they represented buyers, the buyers did not ask for the ECAD results. Realtors said that consumers might have cared in 2009, but would not care now because of the way that there are currently lots of potential buyers that want each house. Sellers always have some backup buyer in case a negotiation falls through. Therefore, realtors reasoned that it would be unlikely for the buyers to be able to negotiate over ECAD. See section A.10 for a specification in which I test the hypothesis that market "hotness" moderates the effect of disclosure on the change in housing price.

3. Two realtors agreed that "engineers and hippies" are, in their view, the only types of buyers who care about ECAD. I should expect to find a small average effect if some consumers care but others do not.

4. One realtor noted that ECAD had helped her to convey her listings more accurately through the MLS system. She explained that there is risk in advertising a home as having

energy efficient features, because there are repercussions when realtors present a feature as energy efficient when it is not. With the audit results in hand, she was more likely to fill in the MLS fields about energy efficient features and write about energy efficiency in the description, because somebody else had verified them and she would not be held accountable if the information proved to be incorrect.

5. The percent of buyers that asked for energy bills increased over time. Realtors cannot tell if this was due to ECAD or not.

A.5 Construction of Cost Estimates in Table A.6

The cost information in Table A.6 is from NREL's NREM cost database (U.S. Office of Energy Efficiency and Renewable Energy, 2018). I used the smallest upgrade possible, so the costs should be interpreted as maximal costs because of decreasing marginal costs.

For Attic R-value, I assumed that the attic had Cellulose and vented insulation. I chose the baseline amount level of R-21 because it was closest to the mean R-value of 22.63 among R-values given in the NREM costs. I used Attic Square footage to proxy for the ceiling square footage.

For Duct R-value, I assumed the percent leakage of 15% because that was closest to the 19.33% average in my sample. Though R-6 was closest to the Duct R-value in my sample, the cost of insulating from R-6 to R-8 was missing from the NREM cost database. So, I had to use the cost of insulating from no insulation to R-8. I used the duct surface assumption of 380 from Baylon and Murray (2016) because that is the duct surface of the prototype home with square footage most similar to the average in my sample.

For EER, I used the assumptions for a central AC. I converted from SEER to EER using the formula

$$SEER = (1.12 - \sqrt{1.2544 - 0.08 * EER})/0.04$$

from Power Calculation Website (2018) to convert the average EER in my sample of 10.17 to a SEER of 11.40. So, I used a SEER of 11 as the baseline and a SEER of 13 (minimal possible upgrade in NREM cost database) as the new value, converting these back to EER for display in the table.

For system size, I multiplied the inverse of the average system size in sqft/ton of 499.60 in my sample by the average conditioned square footage in my sample of 1,665.72 to get an average tonnage of the system of 3.33. Since one ton is able to cool 12,000 BTUs every hour, the average kBTUh is 3.33*12=39.96.

For duct leakage, the average in my sample was 19.33%, so that number was used to choose the baseline of 15% (the closest possible duct leakage in the NREM cost database). The R-value of 6 was chosen because it is closest to the average Duct R-value in my sample. The duct surface assumption is the same as for the duct R-value upgrade cost.

A.6 Determination of Observability Groups in Table 4

Attic R-value is assigned a value of 0.5 for the listing criterion because the type of insulation can be entered in the listing, but not the R-value. Attic R-value is assigned a value of 0.5 for the home inspection criterion because inches of insulation are required to be reported by the inspector, but not R-value.

Duct R-value is assigned a value of 0.5 for the home inspection criterion because inches of insulation are required to be reported by the inspector, but not R-value. Duct R-value is assigned a value of 0.5 for the visual inspection criterion because most of the time, the R-value is stamped on ductboard and flex duct insulation, but not labeled if metal.

System size is assigned a value of 0.5 for the visual inspection criterion because it is on the label attached to the equipment, if the label has not been removed. System size is assigned a value of 0.5 for the home inspection criterion because home inspectors are required to note deficiencies in performance, which would partially tell consumers about the size of the system.

EER is assigned a value of 0.5 for the visual inspection criterion because it is on the label attached to the equipment, if the label has not been removed. EER is assigned a value of 0.5 for the listing criterion because the listing only has fields for the EER being energy efficient, Energy Star, or in certain ranges.

Tankless or solar water heater is assigned a value of 0 for the listing criterion because the listing checkbox currently exists, but did not exist until 2012. Therefore, it was not observable through the listing until after the first sale.

Air handler in closet is assigned a value of 0.5 for the home inspection criterion because the inspector is required to note whether it is in an appropriate location.

A.7 Appendix Tables

Table A.1: Summary of Audit Variables

Term	About	Expected Effect on Energy Costs
Attic R-value	R-value is the capacity of an insulating material to resist heat flow. A higher R-value indicates better insulating power. Austin Energy uses a simple formula to calculate R-values. They multiply the thickness of the insulation (in inches) by a factor that depends on the type of insulation, because different materials perform differently. The factors are 2.2 for Fiberglass and Insulsafe, 3.5 for Cellulose, and 2.9 for Rockwool.	–
– % Duct leakage	Duct Leakage is measured by putting a calibrated fan in front of a return grille or access panel of the air handling unit, obstructing the other return grilles and supply registers with tape, and then using a pressure sensing device to measure the airflow at 25 Pascals. In the ECAD data, this is then normalized by the airflow rate of the system, which is estimated. I include negative duct leakage so that energy costs are lowered when the variable is increased.	–
Duct R-value	Duct R-value refers to the insulation around the ducts. This is analogous to the Attic R-value. For flex ducts and duct board, the R-value is usually stamped on the material by the manufacturer. Energy auditors are trained to visually inspect duct systems. If the ductwork does not have R-value available, inspectors can estimate the R-value by measuring the depth of the exterior insulation and multiplying by a factor for the material type.	–

Table A.1: Summary of Audit Variables, Continued

Term	About	Expected Effect on Energy Costs
EER	This is the ratio of a heating or cooling system's output, per hour, in British Thermal Units to the input in watts, used to measure the system's efficiency.	–
Gas Furnace	Gas is less expensive to operate.	–
Gas WH	This stands for gas water heater. Electric tank heaters operate more efficiently in an engineering sense than gas heaters because gas heaters lose heat through venting. However, because gas is less expensive, energy costs associated with operating a gas water heater are lower.	–
Metal Ducts	There are three types of ducts in my dataset: flex, duct board, and metal. Flex ducts are made of a flexible hose. This hose is often installed improperly. If it is kinked, it can restrict airflow, lowering system efficiency. Flex ducts can also be too long, and energy efficiency decreases with the distance the air has to travel. Furthermore, they can have poorly fastened and sealed connections. Duct board deteriorates more quickly than other types of ducts and is often subject to installation problems, like flex ducts. Duct board also cannot be cleaned and is likely to have problems with humidity and rodents. Duct board and flex ducts both generally leak less air than metal ducts do. Metal ducts are better than flex in terms of air flow, which improves the efficiency of the system. They hold up longer than both flex ducts and duct board, and are less likely to have installation issues. On the other hand, metal ducts are more likely to leak and are often poorly insulated. Thus, which type of ducts is most energy efficient is ambiguous (see Bailes (2012)). However, after conditioning on R-value of the ducts and leakage, metal ducts should be positively associated with energy efficiency. I code the variable assuming that metal ducts positively affect energy efficiency (and negatively affect energy use) versus other duct types. (See also: House Energy Website (2017))	?

Table A.1: Summary of Audit Variables, Continued 2

Term	About	Expected Effect on Energy Costs
Programmable Thermostat	This variable indicates whether or not the thermostat is programmable.	–
Return Sizing Adequate?	Return sizing is the total area of the return grilles/vents. The HVAC system operates most efficiently when the area is around 200 square inches/ton capacity of the HVAC unit. To measure the return sizing, one would simply take a ruler to the grilles and make area calculations. If a system has adequate return sizing, the flow for the HVAC supply and return is unrestricted, so heating or cooling would be delivered more quickly.	–
System Size (sqft/ton)	This is the inverse of the system's size in tons/sqft. One ton is able to cool 12,000 BTUs in an hour. A BTU, or British Thermal Unit, is the amount of energy needed to heat or cool one pound of water by 1 degree Farenheit. So an air conditioner with 1 ton of capacity can cool 12,000 pounds of water by one degree every hour. Square footage is considered because the conditioned area can tell us whether the system is oversized (too much capacity for the conditioned area) or not. Whenever an HVAC system switches on, there is a large amount of power drawn to start it up. It is optimal from an energy cost perspective to spread the initial power draw over a long period of time by running the system for a longer period of time to minimize switch-ons. However, a high capacity AC cooling a small space will cool the space too quickly and then shut off, and end up with more switch-ons. Thus, the higher the square footage per ton of capacity, the better for energy efficiency.	–
– System Age	This refers to the negative of the age of the HVAC system. An older system is less efficient for two reasons: first of all, it typically has a lower EER. Second of all, it is likely to suffer from leaks due to wear.	–
Vertical AH	This stands for vertical air handler. An air handler draws in cold air and expels heated air. A horizontal air handler draws in cool air from one side and expels heated air from the other. Horizontal air handlers are less efficient than up-flow or down-flow air handlers, which draw the cool air in at their base and expel heated air at their top.	–

Table A.1: Summary of Audit Variables, Continued 3

Term	About	Expected Effect on Energy Costs
Tankless or Solar WH	This stands for tankless or solar water heater. This refers to the tank type of the water heater. Tankless water heaters provide water only as it is needed. They save energy for the typical household because an entire tank of water is not being constantly reheated. Solar water heaters save electricity by using water warmed by the sun.	–

Notes: This table describes the audit measures.

Table A.2: Correlations Between Audit Measures, First Sale Price, and Price Change

	- % DL	AR	DR	MD	RSA	EER	-SA	TSWH	SZ	VAH	AHC	PT	GWH	GF	S1P	Δ P
- % DL	1.0000															
AR	0.2081	1.0000														
DR	0.1072	0.2541	1.0000													
MD	−0.0239	−0.1668	−0.3080	1.0000												
RSA	0.1366	0.1054	0.1778	−0.0643	1.0000											
EER	0.0494	0.0466	0.1267	0.0489	0.0516	1.0000										
-SA	−0.0658	−0.0734	0.0149	0.0451	−0.0355	0.2446	1.0000									
TSWH	0.0328	−0.0005	0.0355	0.0116	0.0220	0.0462	0.0895	1.0000								
SZ	−0.0049	0.1355	0.0161	−0.0017	0.0599	0.0305	−0.0157	−0.0376	1.0000							
VAH	−0.1812	−0.1299	−0.1947	0.1845	−0.1299	−0.0046	−0.0341	−0.0963	0.0935	1.0000						
AHC	0.1928	0.1251	0.1987	−0.1965	0.1265	0.0010	0.0175	0.0924	−0.0819	−0.9490	1.0000					
PT	0.0722	0.1277	0.0442	−0.0796	0.0530	0.0357	−0.0220	0.0256	0.0517	−0.1112	0.1234	1.0000				
GWH	0.0448	0.0416	0.1755	−0.0182	0.1114	0.0316	−0.0410	−0.1001	0.0265	0.0956	−0.0997	0.0460	1.0000			
GF	0.0071	0.0354	0.1236	0.0616	0.0680	0.0709	−0.0551	−0.0122	0.0128	0.3235	−0.3243	0.0420	0.6523	1.0000		
S1P	0.0454	0.0837	0.0547	0.0011	0.0804	0.0325	0.0423	0.0675	0.0646	−0.2990	0.3143	0.1262	−0.0628	−0.0894	1.0000	
Δ P	0.0558	0.0015	−0.0093	0.0359	−0.0188	0.0519	0.0859	0.1226	0.0385	0.0138	−0.0312	0.0284	−0.0372	−0.0038	−0.1254	1.0000

Notes: See abbreviations in Table A.3 on next page.

Table A.3: Abbreviations

Abbreviation	Variable
GWH	Gas Water Heater
TSWH	Tankless or Solar Water Heater
AR	Attic R-value
GF	Gas Furnace
EER	Energy Efficiency Ratio
− % DL	− % Duct Leakage
RSA	Return Sizing Adequate
DR	Duct R-value
− SA	− System Age
MD	Metal Ducts
SZ	Size (sqft/ton)
PT	Programmable Thermostat
VAH	Vertical AH
S1P	Sale 1 Price
Δ P	Δ Price

Notes: These are the abbreviations used in Table A.2.

Table A.4: Expected Savings Associated with None-to-Full Capitalization Due to ECAD

	Attic R-value	Duct Leakage	Duct R-value	EER
PDV Savings (Expected Lifetime), by Discount Rate:				
1%	$166.02	-$409.36	$377.95	$1,377.44
3%	$119.19	-$317.06	$292.73	$2,209.47
5%	$90.20	-$253.49	$234.05	$1,072.01
7%	$71.41	-$208.52	$192.53	$958.59
10%	$53.85	-$162.85	$150.36	$822.97
15%	$38.24	-$118.59	$109.49	$661.43
PDV Savings (Infinite Lifetime), by Discount Rate:				
1%	$505.63	-$1,586.19	$1,464.50	$9,934.59
3%	$171.88	-$539.20	$497.83	$3,377.10
5%	$105.13	-$329.80	$304.50	$2,065.61
7%	$76.52	-$240.06	$221.64	$1,503.54
10%	$55.07	-$172.75	$159.50	$1,081.98
15%	$38.38	-$120.40	$111.17	$754.11

Notes: This table shows the present discounted values of savings associated with a one-unit increase in each audit measure using a variety of interest rates. See Table A.5 for assumptions used in the savings calculations.

Table A.5: Assumptions for Expected Savings Associated with None-to-Full Capitalization Due to ECAD

	Attic R-value	Duct Leakage	Duct R-value
Savings Estimate from Retrofit	1.7	1.56 (This retrofit includes sealing thermal envelope.)	$58
Savings Unit	kwh/day	kwh/day	$/yr
Source: Savings Estimate	Rhodes (2014)	Rhodes (2014)	(Kinney, 2005, p.13), Albuquerque
Assumption About Baseline Average	23.3	14.3	4
Source: Assumption About Baseline	Rhodes (2014), p. 135	Rhodes (2014), p. 135	(Kinney, 2005, p.13), Albuquerque
Assumption About New Value	38	10	8
Source: Assumption About New Value	Not assumed. Stated in section describing retrofit: Rhodes (2014), p. 124	10% duct leakage is AE's recommendation (Rhodes, 2014), p. 18	(Kinney, 2005, p.13), Albuquerque
Description of Estimate	Electricity Savings Only	Electricity Savings Only	Electricity and Gas Savings
Calculation Method	Linear Interpolation	Linear Interpolation	Linear Interpolation
Expected Lifetime	40	30	30
Source for Expected Lifetime	Rhodes (2014), p. 123	Rhodes (2014), p. 123	Rhodes (2014), p. 123
Price of Fuel	$0.12	$0.12	N/A
Source for Price of Fuel	U.S. Energy Information Administration (2017a)	U.S. Energy Information Administration (2017a)	N/A

Notes: This table explains the assumptions used to calculate the present discounted value of savings in Tables A.4 and 3 .

Table A.5: Assumptions for Expected Savings Associated with None-to-Full Capitalization Due to ECAD, Continued

	EER
Savings Estimate from Retrofit	4.09
Savings Unit	kwh/day
Source: Savings Estimate	Rhodes (2014)
Assumption About Baseline Average	10.2
Source: Assumption About Baseline	Rhodes (2014), p. 135
Assumption About New Value	12
Source: Assumption About New Value	Rhodes (2014) said they were upgraded to be Energy Star. This means an EER of at least 12 (Energy Star Program, 2017).
Description of Estimate	Electricity Savings Only
Calculation Method	Linear Interpolation
Expected Lifetime	15
Source for Expected Lifetime	Rhodes (2014), p. 123
Price of Fuel	$0.12
Source for Price of Fuel	U.S. Energy Information Administration (2017a)

Notes: This table explains the assumptions used to calculate the present discounted value of savings in Tables A.4 and 3 .

Table A.6: Expected Costs Associated with Retrofit

	Attic R-value	**- % Duct Leakage**	**Duct R-value**	**EER**
Baseline	21	15	0	9.9
New	25	7.5	8	11.18
Average Cost	\$0.15 per sqft ceiling	\$0.3 per sqft duct surface	\$1.4 per sqft duct surface	\$64 per kBtuh+ 860
Cost Range	(0.098,0.2)	(0.15,0.44)	(0.95,1.9)	(44, 83) per kBtuh + (610,1100)
Assumption(s)	1257 sqft ceiling	R-6, 380 sqft duct surface	15% leakage, 380 sqft duct surface	39.96 kBtuh
Total Average Cost	188.55	114	532	3417.44
Total Range	(123.18, 251.4)	(57, 167.2)	(361, 722)	(2368.24,4416.68)
Per Unit, Interpolated Average Cost	47.1375	16.2857	66.5	2669.875
Per Unit, Interpolated Range	(30.79, 62.85)	(8.14, 23.89)	(45.125, 90.25)	(1850.19,3450.531)

Notes: This table explains the calculation of retrofit costs in Table 3. See Section A.5 for more details.

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Table A.7: Equality of Means for Homes Sold after Compliance Deadline without an Audit and My Sample

	Sample	Late Compliers	Diff	p-val	Obs Sample	Obs Late Compliers
Δ Price	1.851	0.440	1.4111	0.321	3939	131
Annualized Price Difference	0.450	0.559	-0.1091	0.805	3939	131
Price at Sale 1	30.847	27.702	3.1453*	0.092	3939	131
Price at Sale 2	32.698	28.142	4.5564*	0.084	3939	131
Year of Sale 1	2006.607	2006.458	0.1492	0.153	3939	131
Year of Sale 2	2011.560	2010.527	1.0331***	0.000	3939	131
Gas WH	0.592	0.611	-0.0191	0.661	3939	131
Tankless or Solar WH	0.042	0.092	-0.0492*	0.056	3939	131
Attic R-value	22.472	23.719	-1.2466	0.145	3549	115
Gas Furnace	0.606	0.641	-0.0352	0.412	3939	131
EER	10.180	10.106	0.0738	0.710	3146	113
− % Duct Leakage	-19.168	-20.485	1.3166	0.188	3741	129
Return Sizing Adequate	0.830	0.849	-0.0189	0.549	3880	129
Duct R-value	5.536	5.582	-0.0458	0.748	3728	121
− System Age	-12.880	-12.120	-0.7600	0.138	3180	108
Metal Ducts	0.170	0.104	0.0657**	0.021	3847	125
HVAC Size (sqft/ton)	500.546	496.248	4.2977	0.607	3736	122
Programmable Thermostat	0.677	0.622	0.0550	0.203	3939	131
AH in Closet	0.401	0.341	0.0594	0.176	3771	123
Vertical AH	0.602	0.677	-0.0755*	0.077	3808	127
Conditioned Sqft	1739.810	1731.108	8.7020	0.911	3925	130
Sqft Total	1760.429	1735.443	24.9863	0.753	3939	131
Bedrooms	3.085	3.015	0.0700	0.458	3939	131
Bathrooms	2.272	2.260	0.0124	0.885	3939	131
Year Built	1975.190	1976.137	-0.9478	0.558	3939	131
Attic Sqft	1287.971	1228.491	59.4803	0.265	3466	106
Price of Elec at Sale 1	4.118	4.113	0.0045	0.893	3938	131
Price of Elec at Sale 2	3.924	4.034	-0.1106***	0.000	3939	131
Price of Gas at Sale 1	18.278	18.401	-0.1237	0.716	3938	131
Price of Gas at Sale 2	15.344	14.992	0.3517	0.293	3939	131

Notes: This is a comparison of means of main variables between the late compliers, which are not in my sample, and the homes in my sample.

Table A.8: Baseline Specification, Controlling for Permitted Improvements and Repairs

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0373**				0.0302	0.2564
	(0.0174)				(0.0207)	(0.1761)
− % Duct Leakage		0.0250**			0.0331***	0.3668***
		(0.0100)			(0.0115)	(0.1271)
Duct R-value			0.1654		0.0857	0.1257
			(0.1032)		(0.1388)	(0.2037)
EER				−0.0156	−0.0047	−0.0083
				(0.1053)	(0.1128)	(0.1999)
Permit	3.1681***	3.3587***	3.3148***	3.4034***	3.0699***	3.0699***
	(0.3575)	(0.3550)	(0.3505)	(0.4022)	(0.4307)	(0.4307)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.628
−% DL = DR p						0.294
−% DL = EER p						0.138
All = p						0.340
All > 0 p					0.014	0.014
R-squared	0.148	0.152	0.155	0.152	0.149	0.149
Home Clusters	3172	3251	3250	2746	2465	2465
Observations	3172	3251	3250	2746	2465	2465

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for audit variable definitions. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.9: Baseline Specification, Controlling for Square Footage, Bedrooms, Bathrooms, and Pool

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Attic R-value	0.0357**				0.0255		0.2168
	(0.0169)				(0.0205)		(0.1742)
− % Duct Leakage		0.0253***			0.0323***		0.3578***
		(0.0093)			(0.0111)		(0.1231)
Duct R-value			0.1476*		0.0646		0.0948
			(0.0858)		(0.1220)		(0.1791)
EER				0.1025	0.0931		0.1650
				(0.0921)	(0.0992)		(0.1758)
Sqft Total	0.0007	0.0009	0.0007	0.0010	0.0005	0.0009	0.0005
	(0.0006)	(0.0006)	(0.0006)	(0.0007)	(0.0007)	(0.0006)	(0.0007)
Bedrooms	0.7053**	0.5878**	0.5791**	0.5917*	0.8735**	0.5858**	0.8735**
	(0.2819)	(0.2908)	(0.2917)	(0.3323)	(0.3432)	(0.2789)	(0.3432)
Bathrooms	−0.7955***	−0.5460**	−0.4502*	−0.6484**	−0.7539**	−0.5927**	−0.7539**
	(0.2666)	(0.2730)	(0.2650)	(0.3054)	(0.3118)	(0.2589)	(0.3118)
Pool	−0.3492	−0.6191	−0.5830	−0.5304	−0.0353	−0.7317*	−0.0353
	(0.5101)	(0.4691)	(0.4651)	(0.5330)	(0.6067)	(0.4380)	(0.6067)
Standardized?	No	No	No	No	No	No	Yes
−% DL = AR p							0.519
−% DL = DR p							0.208
−% DL = EER p							0.401
All = p							0.539
All > 0 p					0.007		0.007
R-squared	0.117	0.118	0.118	0.118	0.121	0.117	0.121
Home Clusters	3549	3741	3728	3146	2755	3939	2755
Observations	3549	3741	3728	3146	2755	3939	2755

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for audit variable definitions. All prices are in \$10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.10: Market Hotness, Standardized

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0326*	0.0248	−0.0183	−0.0115	0.0313	0.0358*
	(0.0193)	(0.0190)	(0.0216)	(0.0208)	(0.0199)	(0.0207)
− % Duct Leakage	0.0335***	0.0343***	0.0354***	0.0326***	0.0347***	0.0352***
	(0.0110)	(0.0106)	(0.0115)	(0.0109)	(0.0109)	(0.0112)
Duct R-value	0.0793	0.0813	0.0737	0.0629	0.0715	0.0738
	(0.1239)	(0.1258)	(0.1399)	(0.1373)	(0.1268)	(0.1306)
EER	0.1151	0.1134	0.0457	0.0446	0.1123	0.1106
	(0.0962)	(0.0871)	(0.1064)	(0.0988)	(0.0979)	(0.1018)
Attic R-value × Hotness	0.0659***	0.0935***	0.1681***	0.1814**	−0.0090	−0.0224
	(0.0234)	(0.0325)	(0.0614)	(0.0707)	(0.0198)	(0.0178)
− % Duct Leakage × Hotness	−0.0117	−0.0126	−0.0030	0.0061	−0.0021	−0.0026
	(0.0129)	(0.0166)	(0.0268)	(0.0298)	(0.0109)	(0.0102)
Duct R-value × Hotness	−0.0620	−0.0308	0.0141	0.0520	−0.0281	−0.0331
	(0.1701)	(0.2104)	(0.3060)	(0.3517)	(0.1005)	(0.0976)
EER × Hotness	−0.0023	−0.0030	0.1763	0.2303	−0.0365	−0.0488
	(0.1430)	(0.2037)	(0.3510)	(0.3781)	(0.0927)	(0.0967)
Hotness	−0.6022	−1.0928	−4.1762	−4.7176	1.5833	1.8336*
	(1.3036)	(1.9152)	(3.7110)	(4.2634)	(1.0384)	(1.0612)
Hotness Var	Sales, 1,000's	Volume, 10 Mil USD	Avg Price	Med Price	Tot Listings, 10,000's	Mos Inventory
R-squared	0.12	0.12	0.12	0.12	0.12	0.12
Home Clusters	2755	2755	2755	2755	2755	2755
Observations	2755	2755	2755	2755	2755	2755

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for audit variable definitions. In each regression, "Hotness" refers to the market hotness variable given at the bottom of the table, which is standardized and measured at the time of the sale that occurred after the audit. "Med Price" is the median price. "Tot Listings" is the total number of listings in the MLS system. "Mos Inventory" stands for months of inventory. All prices are in \$10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc.

Table A.11: Baseline Specification, List Price

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0408**				0.0301	0.2561
	(0.0165)				(0.0196)	(0.1671)
− % Duct Leakage		0.0345***			0.0352***	0.3906***
		(0.0088)			(0.0110)	(0.1217)
Duct R-value			0.0883		0.0429	0.0629
			(0.0977)		(0.1271)	(0.1865)
EER				0.0723	0.0589	0.1044
				(0.0945)	(0.1031)	(0.1828)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.533
−% DL = DR p						0.129
−% DL = EER p						0.226
All = p						0.336
All > 0 p					0.004	0.004
R-squared	0.098	0.095	0.096	0.095	0.101	0.101
Home Clusters	3548	3740	3727	3145	2754	2754
Observations	3548	3740	3727	3145	2754	2754

Notes: The dependent variable is the change in list price. See Table A.1 in the appendix for variable definitions. All prices are in \$10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999 , 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.12: Baseline Specification, Time on Market

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	−0.0665				−0.0825	−0.7018
	(0.1683)				(0.2001)	(1.7014)
− % Duct Leakage		−0.0387			−0.0328	−0.3635
		(0.1377)			(0.1648)	(1.8282)
Duct R-value			0.5469		0.7724	1.1333
			(1.0853)		(1.1828)	(1.7355)
EER				−2.2810***	−2.1432**	−3.7995**
				(0.8576)	(0.9037)	(1.6022)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.901
−% DL = DR p						0.565
−% DL = EER p						0.159
All = p						0.230
All > 0 p					0.209	0.209
R-squared	0.055	0.068	0.070	0.068	0.057	0.057
Home Clusters	3548	3740	3727	3145	2754	2754
Observations	3548	3740	3727	3145	2754	2754

Notes: The dependent variable is the change in time on market. See Table A.1 in the appendix for variable definitions. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999 , 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.13: Baseline Specification, List - Sale Price

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	−0.0013				−0.0009	−0.0079
	(0.0041)				(0.0047)	(0.0402)
− % Duct Leakage		0.0007			−0.0013	−0.0142
		(0.0045)			(0.0036)	(0.0401)
Duct R-value			−0.1070**		−0.0266	−0.0390
			(0.0479)		(0.0300)	(0.0440)
EER				−0.0574**	−0.0532**	−0.0943**
				(0.0238)	(0.0232)	(0.0411)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.916
−% DL = DR p						0.680
−% DL = EER p						0.184
All = p						0.413
All > 0 p					0.200	0.200
R-squared	0.027	0.019	0.021	0.019	0.028	0.028
Home Clusters	3548	3740	3727	3145	2754	2754
Observations	3548	3740	3727	3145	2754	2754

Notes: The dependent variable is the change in list-sale price. See Table A.1 in the appendix for variable definitions. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.14: Baseline, Excluding Homes Built After 1999

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0418**				0.0316	0.2687
	(0.0171)				(0.0203)	(0.1723)
− % Duct Leakage		0.0344***			0.0370***	0.4107***
		(0.0093)			(0.0111)	(0.1232)
Duct R-value			0.1869*		0.0656	0.0963
			(0.0955)		(0.1281)	(0.1879)
EER				0.1261	0.1155	0.2048
				(0.0960)	(0.1032)	(0.1830)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.527
−% DL = DR p						0.140
−% DL = EER p						0.386
All = p						0.431
All > 0 p					0.001	0.001
R-squared	0.106	0.100	0.103	0.101	0.112	0.112
Home Clusters	3347	3529	3516	2968	2594	2594
Observations	3347	3529	3516	2968	2594	2594

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for audit variable definitions. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.15: Baseline, Excluding Repeat Sales Within 1 Year

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0435***				0.0341*	0.2902*
	(0.0167)				(0.0199)	(0.1688)
− % Duct Leakage		0.0346***			0.0363***	0.4028***
		(0.0092)			(0.0109)	(0.1214)
Duct R-value			0.2010**		0.0637	0.0934
			(0.0951)		(0.1271)	(0.1865)
EER				0.1388	0.1171	0.2077
				(0.0932)	(0.1005)	(0.1781)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.606
−% DL = DR p						0.140
−% DL = EER p						0.400
All = p						0.436
All > 0 p					0.001	0.001
R-squared	0.109	0.106	0.109	0.107	0.113	0.113
Home Clusters	3526	3714	3702	3121	2735	2735
Observations	3526	3714	3702	3121	2735	2735

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for audit variable definitions. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.16: Baseline, Only Known Non-switchers with One Heater Fuel Type in Both Sales

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0265				0.0330	0.2803
	(0.0289)				(0.0332)	(0.2827)
− % Duct Leakage		0.0343**			0.0515***	0.5715***
		(0.0156)			(0.0192)	(0.2125)
Duct R-value			−0.2314		−0.3839**	−0.5633**
			(0.1513)		(0.1902)	(0.2791)
EER				0.0716	0.0855	0.1516
				(0.1238)	(0.1301)	(0.2306)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.388
−% DL = DR p						0.002
−% DL = EER p						0.196
All = p						0.018
All > 0 p					0.016	0.016
R-squared	0.103	0.108	0.106	0.098	0.106	0.106
Home Clusters	1002	1048	1044	863	782	782
Observations	1002	1048	1044	863	782	782

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for audit variable definitions. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.17: Baseline, Clustering on Zip Code

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0421				0.0311	0.2642
	(0.0282)				(0.0312)	(0.2649)
− % Duct Leakage		0.0338***			0.0365***	0.4046***
		(0.0116)			(0.0110)	(0.1220)
Duct R-value			0.1953		0.0695	0.1019
			(0.1307)		(0.1423)	(0.2088)
EER				0.1296	0.1120	0.1985
				(0.1123)	(0.1362)	(0.2414)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.544
−% DL = DR p						0.177
−% DL = EER p						0.370
All = p						0.053
All > 0 p					0.022	0.022
R-squared	0.109	0.106	0.110	0.107	0.113	0.113
Zip Clusters	39	39	39	39	39	39
Observations	3549	3741	3728	3146	2755	2755

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for variable definitions. All prices are in $10,000 units. Standard errors are clustered at the zip code level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.18: Baseline Specification, Clustering on Elementary School

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0419*				0.0310	0.2635
	(0.0238)				(0.0277)	(0.2359)
− % Duct Leakage		0.0338***			0.0365***	0.4053***
		(0.0098)			(0.0116)	(0.1286)
Duct R-value			0.1951*		0.0686	0.1007
			(0.1076)		(0.1328)	(0.1949)
EER				0.1297	0.1121	0.1988
				(0.1159)	(0.1368)	(0.2425)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.572
−% DL = DR p						0.125
−% DL = EER p						0.444
All = p						0.209
All > 0 p					0.037	0.037
R-squared	0.109	0.106	0.110	0.107	0.113	0.113
Elem School Clusters	115	116	116	115	113	113
Observations	3547	3739	3726	3145	2754	2754

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for variable definitions. All prices are in $10,000 units. Standard errors are clustered at the elementary school level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.19: Comparison of White and Conley Standard Errors, Single Var Regressions

			Conley SE with Cutoff (km):					
	Coefficient	White SE	0.000001	1	5	10	20	40
Attic R-value	0.0421	0.0166	0.0165	0.0179	0.0266	0.0299	0.0265	0.0189
− % Duct Leakage	0.0338	0.0092	0.0091	0.0090	0.0122	0.0147	0.0127	0.0090
Duct R-value	0.1947	0.0935	0.0934	0.0932	0.1244	0.1453	0.1259	0.0884
EER	0.1274	0.0928	0.0921	0.0933	0.1160	0.1065	0.0780	0.0569

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for variable definitions. All prices are in $10,000 units. Conley Standard errors are used with cutoff in km. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. Each standard error corresponds to Conley version of SE in columns 1-4 of Table 2.

Table A.20: Comparison of White and Conley Standard Errors, Multiple Audit Var Regression

			Conley SE with Cutoff (km):					
	Coefficient	White SE	0.000001	1	5	10	20	40
Attic R-value	0.0311	0.0196	0.0195	0.0205	0.0277	0.0259	0.0226	0.0162
− % Duct Leakage	0.0365	0.0109	0.0109	0.0105	0.0124	0.0153	0.0135	0.0091
Duct R-value	0.0695	0.1255	0.1249	0.1225	0.1337	0.1251	0.1074	0.0785
EER	0.1120	0.0999	0.0995	0.1026	0.1266	0.1177	0.0923	0.0685

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for variable definitions. All prices are in $10,000 units. Conley Standard errors are used with cutoff in km. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. Each standard error corresponds to Conley version of SE in column 5 of Table 2.

Table A.21: Baseline, with Zip Code FE

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0377**				0.0292	0.2479
	(0.0171)				(0.0207)	(0.1758)
− % Duct Leakage		0.0321***			0.0395***	0.4380***
		(0.0097)			(0.0116)	(0.1286)
Duct R-value			0.0446		−0.1079	−0.1584
			(0.0958)		(0.1298)	(0.1904)
EER				0.0520	0.0614	0.1088
				(0.0976)	(0.1040)	(0.1843)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.396
−% DL = DR p						0.008
−% DL = EER p						0.163
All = p						0.039
All > 0 p					0.004	0.004
R-squared	0.048	0.050	0.046	0.046	0.051	0.051
Zip Clusters	3549	3741	3728	3146	2755	2755
Observations	3549	3741	3728	3146	2755	2755

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for variable definitions. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include zip code fixed effects, sale year fixed effects, and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.22: Baseline, with Zip Code FE, Clustering on Zip Code

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0377				0.0292	0.2479
	(0.0276)				(0.0340)	(0.2895)
− % Duct Leakage		0.0321**			0.0395***	0.4380***
		(0.0119)			(0.0115)	(0.1272)
Duct R-value			0.0446		−0.1079	−0.1584
			(0.1132)		(0.1544)	(0.2265)
EER				0.0520	0.0614	0.1088
				(0.1238)	(0.1475)	(0.2615)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.453
−% DL = DR p						0.035
−% DL = EER p						0.171
All = p						0.003
All > 0 p					0.005	0.005
R-squared	0.048	0.050	0.046	0.046	0.051	0.051
Zip Clusters	39	39	39	39	39	39
Observations	3549	3741	3728	3146	2755	2755

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for variable definitions. All prices are in $10,000 units. Standard errors are clustered at the zip code level. Specifications include zip code fixed effects, sale year fixed effects, and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.23: Baseline Specification, Year Built Group by Sale Year Pair FE

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0571***				0.0370*	0.3148*
	(0.0178)				(0.0219)	(0.1858)
− % Duct Leakage		0.0295***			0.0401***	0.4443***
		(0.0099)			(0.0117)	(0.1302)
Duct R-value			0.2716***		0.1846*	0.2709*
			(0.0886)		(0.1097)	(0.1609)
EER				0.1024	0.0538	0.0953
				(0.0747)	(0.0729)	(0.1292)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.577
−% DL = DR p						0.382
−% DL = EER p						0.061
All = p						0.279
All > 0 p					0.001	0.001
R-squared	0.367	0.363	0.366	0.390	0.409	0.409
Home Clusters	3549	3741	3728	3146	2755	2755
Observations	3549	3741	3728	3146	2755	2755

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for audit variable definitions. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year pair by year built group fixed effects. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.24: Baseline, with Year Built FE (no year built group FE)

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0673***				0.0532**	0.4526**
	(0.0182)				(0.0219)	(0.1859)
− % Duct Leakage		0.0363***			0.0401***	0.4443***
		(0.0096)			(0.0111)	(0.1233)
Duct R-value			0.2653***		0.1206	0.1770
			(0.0896)		(0.1167)	(0.1712)
EER				0.0913	0.0652	0.1156
				(0.0842)	(0.0876)	(0.1553)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.970
−% DL = DR p						0.190
−% DL = EER p						0.111
All = p						0.240
All > 0 p					0.000	0.000
R-squared	0.188	0.184	0.187	0.182	0.194	0.194
Home Clusters	3549	3741	3728	3146	2755	2755
Observations	3549	3741	3728	3146	2755	2755

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for variable definitions. All prices are in \$10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and a full set of year built fixed effects. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.25: Baseline, Excluding Homes with First Sale Price Below 5th Percentile or Above 95th Percentile

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0508***				0.0409**	0.3474**
	(0.0147)				(0.0161)	(0.1367)
− % Duct Leakage		0.0317***			0.0259**	0.2873**
		(0.0087)			(0.0106)	(0.1173)
Duct R-value			0.1515**		0.0659	0.0967
			(0.0736)		(0.0917)	(0.1345)
EER				0.1005	0.1143	0.2027
				(0.0897)	(0.0935)	(0.1658)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.745
−% DL = DR p						0.252
−% DL = EER p						0.701
All = p						0.470
All > 0 p					0.002	0.002
R-squared	0.144	0.140	0.144	0.140	0.152	0.152
Home Clusters	3223	3377	3373	2838	2503	2503
Observations	3223	3377	3373	2838	2503	2503

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for audit variable definitions. All prices are in \$10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.26: Baseline, with Price in Logs

	(1)	(2)	(3)	(4)	(5)	(6)
Attic R-value	0.0001				−0.0000	−0.0003
	(0.0004)				(0.0004)	(0.0034)
− % Duct Leakage		0.0007**			0.0007**	0.0082**
		(0.0003)			(0.0003)	(0.0034)
Duct R-value			0.0035*		0.0012	0.0018
			(0.0021)		(0.0024)	(0.0036)
EER				0.0033*	0.0033*	0.0058*
				(0.0018)	(0.0019)	(0.0034)
Standardized?	No	No	No	No	No	Yes
−% DL = AR p						0.105
−% DL = DR p						0.196
−% DL = EER p						0.635
All = p						0.340
All > 0 p					0.041	0.041
R-squared	0.176	0.173	0.172	0.183	0.182	0.182
Home Clusters	3549	3741	3728	3146	2755	2755
Observations	3549	3741	3728	3146	2755	2755

Notes: The dependent variable is the change in the logarithm of price. See Table A.1 in the appendix for variable definitions. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. All = p refers to the p-value associated with the t-test that the coefficients on the four main audit variables are all equal to one another. All > 0 p refers to the p-value associated with the t-test that the coefficients on the four main variables are all > 0.

Table A.27: Different Observability Criteria, PCA Analysis (No TSWH)

	(1)	(2)	(3)	(4)	(5)	(6)
More observable group	0.0504	0.0867	0.0174	0.0839	0.0600	0.0954
	(0.1250)	(0.1251)	(0.1287)	(0.1230)	(0.1230)	(0.1333)
Less observable group	0.2081*	0.0443	0.2174*	0.5392***	0.3617***	0.3214**
	(0.1263)	(0.1416)	(0.1293)	(0.1493)	(0.1305)	(0.1435)
Observability Criterion	In listing I	In listing II	In home inspection I	In home inspection II	In visual inspection I	In visual inspection II
More=less p	0.374	0.825	0.242	0.012	0.090	0.280
R-squared	0.109	0.108	0.109	0.114	0.111	0.110
Home Clusters	2150	2150	2150	2150	2150	2150
Observations	2150	2150	2150	2150	2150	2150

Notes: The dependent variable is the change in price. "More observable group" is the first principal component of the group of variables that can be observed via the means indicated in the column header. "Less observable group" is the first principal component of the group of variables that cannot be observed via the means indicated in the "Observability Criterion" row. I have grouped the "partially observable" variables (indicated by a score of 0.5 in Table 4) with the less observable (score of 0 in Table 4) variables in version I of each possible method of observation and with the more observable variables (score of 1 in Table 4) in version II. All prices are in \$10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. More = Less p refers to the p-value associated with the t-test that the coefficients on the more and less observable groups are equal to one another.

Table A.28: On Front Page, PCA Analysis (No TSWH)

	(1)
On front page	0.4037***
	(0.1425)
Not on front page	0.0679
	(0.1267)
Not on FP=On FP *p*	0.083
R-squared	0.111
Home Clusters	2150
Observations	2150

Notes: The dependent variable is the change in price. "Not on front page" is the first principal component of the group of variables that are not mentioned on the front page of the audit form. "On front page" is the first principal component of the group of variables that are mentioned on the front page. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. On FP = Not on FP p refers to the p-value associated with the t-test that the coefficients on the front page group and the not on front page group are equal to one another.

Table A.29: Information Groups According to Overall Ranking, Joint Hypotheses

	(1)	(2)	(3)	(4)	(5)
− % Duct Leakage	0.4370***			0.5822***	
	(0.1205)			(0.1546)	
Attic R-value	0.2908*			0.1258	
	(0.1640)			(0.2063)	
Duct R-value	0.1267			0.2705	0.2086
	(0.1617)			(0.1986)	(0.1685)
− System Age	0.7275***			0.6746***	0.5579***
	(0.1380)			(0.1607)	(0.1424)
Return Sizing Adequate		−0.1714		−0.2226*	−0.1474
		(0.1136)		(0.1228)	(0.1178)
HVAC Size (sqft/ton)		0.3885**		0.3643*	0.4194**
		(0.1508)		(0.1973)	(0.1686)
Metal Ducts		0.1605		0.3074*	0.2297
		(0.1264)		(0.1690)	(0.1529)
EER		0.2648		0.1171	0.2587*
		(0.1630)		(0.1581)	(0.1507)
Programmable Thermostat			0.3342***	0.3460**	
			(0.1049)	(0.1550)	
AH in Closet			0.0012	−0.1523	
			(0.1430)	(0.2046)	
Gas WH			−0.0158	−0.2017	
			(0.1504)	(0.1900)	
Gas Furnace			0.1785	0.1734	
			(0.1620)	(0.2037)	
Standardized?	Yes	Yes	Yes	Yes	Yes
Group 1 joint p	0.000			0.000	
Group 2 joint p		0.003		0.011	0.002
Group 3 joint p			0.021	0.083	
All joint p				0.000	
R-squared	0.117	0.118	0.111		0.125
Home Clusters	2718	2971	3771	2150	2433
Observations	2718	2971	3771	2150	2433

Notes: The dependent variable is the change in price. See Table A.1 in the appendix for audit variable definitions. All prices are in $10,000 units. Standard errors are clustered at the residence level. Specifications include sale year fixed effects and year built group fixed effects, where the year built groups are < 1999, 1999, 2000, etc. Group 1 joint p refers to the p-value associated with the t-test that the coefficients on the variables in group 1 are all > 0. All joint p refers to the p-value associated with the t-test that the coefficients on all audit variables are all > 0.

Table A.30: Principal Components Analysis, Listing Criteria

Component:	1	2	3	4	5	6	7	8	9	10
In Listing I: More Observable Group										
Programmable Thermostat	0.062	0.681	−0.347	−0.642	−0.020					
Tankless or Solar WH	−0.110	0.393	0.905	−0.080	−0.088					
AH in Closet	−0.277	0.589	−0.207	0.703	0.201					
Gas WH	0.658	0.177	−0.036	0.292	−0.669					
Gas Furnace	0.688	0.069	0.127	0.048	0.709					
In Listing I: Less Observable Group										
− % Duct Leakage	0.359	−0.113	0.146	0.646	0.374	0.420	−0.321	−0.013		
Attic R-value	0.489	−0.104	0.187	−0.079	0.396	−0.223	0.685	−0.180		
Duct R-value	0.555	0.110	−0.246	−0.115	−0.092	−0.181	−0.137	0.739		
Metal Ducts	−0.423	0.051	0.497	0.403	0.044	−0.245	0.255	0.531		
Return Sizing Adequate	0.330	−0.034	0.280	0.248	−0.827	0.101	0.181	−0.156		
EER	0.156	0.667	0.233	0.094	0.062	−0.505	−0.342	−0.303		
− System Age	−0.042	0.710	−0.048	−0.079	0.040	0.595	0.342	0.111		
HVAC Size (sqft/ton)	0.102	−0.104	0.708	−0.569	0.065	0.249	−0.277	0.103		
In Listing II: More Observable Group										
Programmable Thermostat	0.052	0.545	−0.152	−0.202	−0.772	−0.200	−0.015			
Tankless or Solar WH	−0.111	0.179	0.881	−0.388	0.081	−0.120	−0.092			
AH in Closet	−0.293	0.510	−0.053	−0.052	0.164	0.758	0.216			
Gas WH	0.650	0.130	−0.020	−0.095	0.093	0.325	−0.661			
Gas Furnace	0.683	0.020	0.111	−0.105	0.041	0.039	0.712			
EER	0.097	0.259	0.355	0.886	−0.106	−0.023	−0.017			
Attic R-value	0.032	0.571	−0.245	−0.015	0.591	−0.513	−0.016			
In Listing II: Less Observable Group										
− % Duct Leakage	0.364	0.270	0.620	0.003	0.622	−0.151				
Duct R-value	0.641	−0.181	−0.142	0.012	0.023	0.732				
Metal Ducts	−0.539	0.307	0.368	0.316	−0.037	0.615				
Return Sizing Adequate	0.400	0.320	0.179	0.532	−0.609	−0.226				
− System Age	−0.077	−0.613	−0.013	0.722	0.294	−0.107				
HVAC Size (sqft/ton)	0.014	0.568	−0.654	0.310	0.392	−0.016				

Notes: This table shows the loadings for the PCA for each of the listing-related criteria. Each column is the nth principal component of the group of variables.

Table A.31: Principal Components Analysis, Home Inspection Criteria

Component:	1	2	3	4	5	6	7	8	9	10
In Home Inspection I: More Observable Group										
Return Sizing Adequate	0.182	0.983	0.015							
Gas Furnace	0.694	−0.140	0.706							
Gas WH	0.696	−0.118	−0.708							
In Home Inspection I: Less Observable Group										
− % Duct Leakage	0.355	−0.118	−0.005	0.429	0.544	0.236	0.161	−0.008	−0.546	−0.028
Attic R-value	0.433	−0.146	0.335	−0.002	0.078	0.264	−0.258	0.564	0.425	−0.194
Duct R-value	0.499	0.091	−0.012	−0.322	−0.075	0.127	−0.253	−0.221	−0.075	0.706
Metal Ducts	−0.419	0.058	0.188	0.485	0.309	0.080	−0.088	0.005	0.382	0.543
EER	0.125	0.620	0.316	0.001	0.244	−0.001	−0.224	−0.492	0.148	−0.355
− System Age	−0.019	0.696	0.045	−0.087	−0.001	−0.099	0.319	0.570	−0.199	0.174
HVAC Size (sqft/ton)	0.019	−0.157	0.731	−0.021	−0.298	0.132	0.536	−0.191	−0.061	0.079
Programmable Thermostat	0.250	−0.067	0.226	0.382	−0.188	−0.790	−0.232	0.061	−0.126	0.054
Tankless or Solar WH	0.080	0.230	−0.176	0.542	−0.642	0.417	−0.146	−0.035	−0.070	−0.056
AH in Closet	0.419	0.051	−0.367	0.173	0.032	−0.163	0.567	−0.157	0.532	0.014
In Home Inspection II: More Observable Group										
Return Sizing Adequate	0.212	0.340	−0.019	0.857	−0.323	−0.014	−0.023			
Gas Furnace	0.659	−0.179	−0.076	−0.062	0.030	0.077	0.719			
Gas WH	0.649	−0.060	−0.132	−0.064	0.239	0.238	−0.664			
Attic R-value	0.128	0.477	0.396	−0.408	−0.534	0.385	−0.012			
Duct R-value	0.220	0.555	−0.083	−0.240	0.130	−0.750	−0.018			
AH in Closet	−0.175	0.560	−0.264	0.042	0.567	0.472	0.201			
HVAC Size (sqft/ton)	0.071	−0.012	0.862	0.181	0.463	−0.061	0.026			
In Home Inspection II: Less Observable Group										
− % Duct Leakage	−0.096	0.612	0.037	0.411	−0.616	0.260				
Metal Ducts	0.133	−0.426	0.392	0.780	0.153	0.124				
EER	0.668	0.185	−0.184	0.200	−0.078	−0.663				
− System Age	0.694	−0.049	−0.161	−0.173	0.004	0.678				
Programmable Thermostat	−0.019	0.613	0.019	0.162	0.766	0.105				
Tankless or Solar WH	0.210	0.179	0.886	−0.356	−0.074	−0.082				

Notes: This table shows the loadings for the PCA for each of the home inspection-related criteria. Each column is the nth principal component of the group of variables.

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Table A.32: Principal Components Analysis, Visual Inspection Criteria

Component:	1	2	3	4	5	6	7	8	9	10
In Visual Inspection I: More Observable Group										
Metal Ducts	0.145	−0.574	0.389	0.367	0.602	−0.010				
Programmable Thermostat	0.039	0.501	0.272	0.797	−0.193	−0.017				
Tankless or Solar WH	−0.108	0.085	0.875	−0.401	−0.216	−0.087				
AH in Closet	−0.313	0.570	0.023	−0.173	0.713	0.197				
Gas WH	0.638	0.272	−0.033	−0.154	0.211	−0.670				
Gas Furnace	0.679	0.114	0.082	−0.122	−0.021	0.710				
In Visual Inspection I: Less Observable Group										
− % Duct Leakage	0.438	−0.141	−0.340	−0.279	0.720	0.085	0.264			
EER	0.229	0.648	0.121	−0.034	0.188	−0.655	−0.215			
− System Age	−0.038	0.715	0.042	−0.044	0.051	0.687	0.094			
Return Sizing Adequate	0.397	−0.060	0.039	0.863	0.157	0.155	−0.208			
Attic R-value	0.537	−0.129	0.112	−0.408	−0.255	0.236	−0.629			
Duct R-value	0.532	0.104	−0.184	0.033	−0.576	−0.101	0.574			
HVAC Size (sqft/ton)	0.160	−0.133	0.906	−0.078	0.150	0.031	0.327			
In Visual Inspection II: More Observable Group										
Metal Ducts	0.025	−0.529	0.209	0.179	0.198	0.236	0.481	0.250	0.504	−0.023
Programmable Thermostat	0.097	0.258	−0.078	0.596	0.114	0.658	−0.314	−0.102	0.083	−0.026
Tankless or Solar WH	−0.095	0.108	0.200	0.359	0.737	−0.497	−0.073	−0.055	−0.057	−0.091
AH in Closet	−0.229	0.518	−0.083	0.019	0.109	0.153	0.525	0.485	−0.262	0.241
Gas WH	0.644	0.071	−0.034	−0.089	0.082	0.034	0.092	0.297	−0.225	−0.645
Gas Furnace	0.666	−0.069	0.011	−0.049	0.172	−0.037	−0.047	0.021	−0.075	0.714
Duct R-value	0.194	0.574	−0.023	−0.129	−0.071	−0.199	0.084	−0.110	0.742	−0.041
HVAC Size (sqft/ton)	0.116	−0.045	−0.048	0.664	−0.554	−0.431	0.091	0.194	−0.030	0.041
− System Age	−0.070	0.093	0.683	−0.109	−0.128	0.030	−0.460	0.520	0.076	0.052
EER	0.114	0.156	0.658	0.060	−0.168	0.106	0.390	−0.529	−0.231	−0.034
In Visual Inspection II: Less Observable Group										
− % Duct Leakage	0.638	−0.293	−0.713							
Return Sizing Adequate	0.440	0.898	0.025							
Attic R-value	0.632	−0.329	0.701							

Notes: This table shows the loadings for the PCA for each of the visual inspection-related criteria. Each column is the nth principal component of the group of variables.

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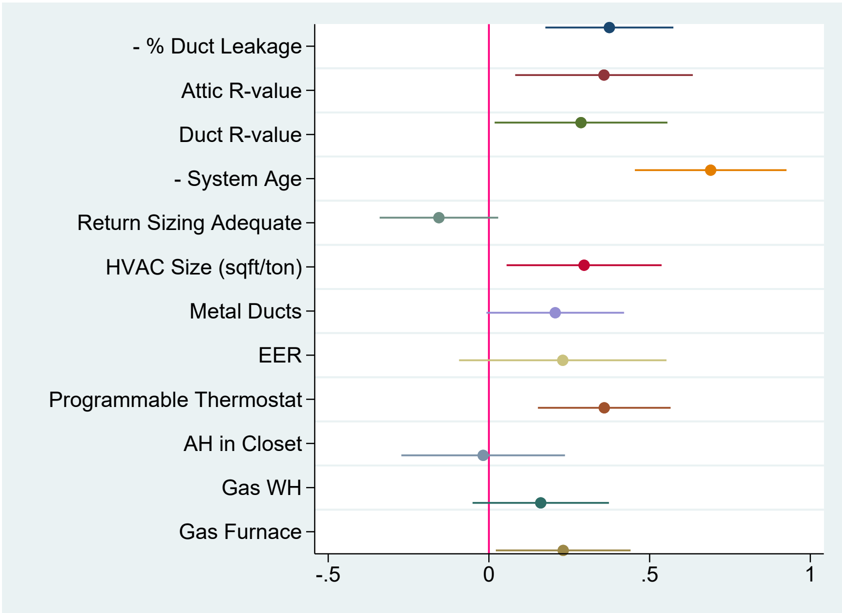
Table A.33: Principal Components Analysis, On Front Page Criterion

Component:	1	2	3	4	5	6	7	8	9	10
On Front Page										
− % Duct Leakage	0.534	0.779	0.330							
Attic R-value	0.625	−0.101	−0.774							
Duct R-value	0.570	−0.619	0.541							
Not On Front Page										
Metal Ducts	0.129	−0.470	0.133	0.324	0.268	−0.015	0.606	0.125	0.430	−0.006
Programmable Thermostat	0.070	0.445	−0.013	0.234	−0.044	0.703	0.414	−0.204	−0.180	−0.024
Tankless or Solar WH	−0.103	0.141	0.203	0.328	0.799	0.091	−0.402	0.026	−0.060	−0.096
AH in Closet	−0.298	0.561	−0.007	−0.161	0.028	−0.038	0.055	0.320	0.641	0.230
Gas WH	0.623	0.182	0.001	−0.212	0.017	0.028	−0.115	0.038	0.303	−0.653
Gas Furnace	0.663	0.028	0.020	−0.120	0.143	0.063	−0.120	0.002	0.007	0.711
HVAC Size (sqft/ton)	0.128	0.043	−0.048	0.768	−0.452	−0.039	−0.362	0.051	0.222	0.041
− System Age	−0.088	−0.034	0.692	−0.113	−0.142	0.024	−0.104	−0.623	0.277	0.053
EER	0.090	0.128	0.677	0.028	−0.177	−0.084	0.115	0.589	−0.342	−0.039
Return Sizing Adequate	0.135	0.439	−0.041	0.212	0.108	−0.694	0.337	−0.318	−0.183	−0.007

Notes: This table shows the loadings for the PCA for the group of audit characteristics that are on the front page and the group that are not. Each column is the nth principal component of the group of variables.

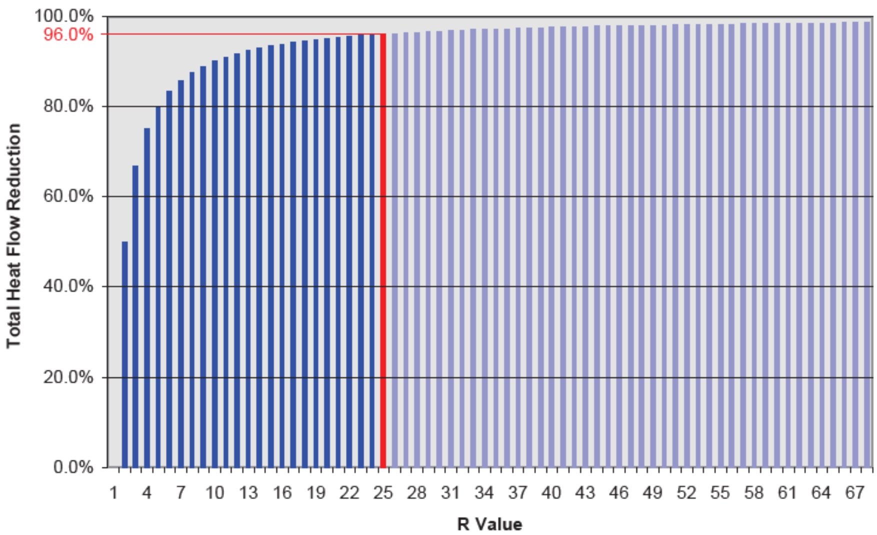
A.8 Appendix Figures

Figure A.1: Capitalization Effects by Energy Efficiency Features, Single Variable Regression Coefficients



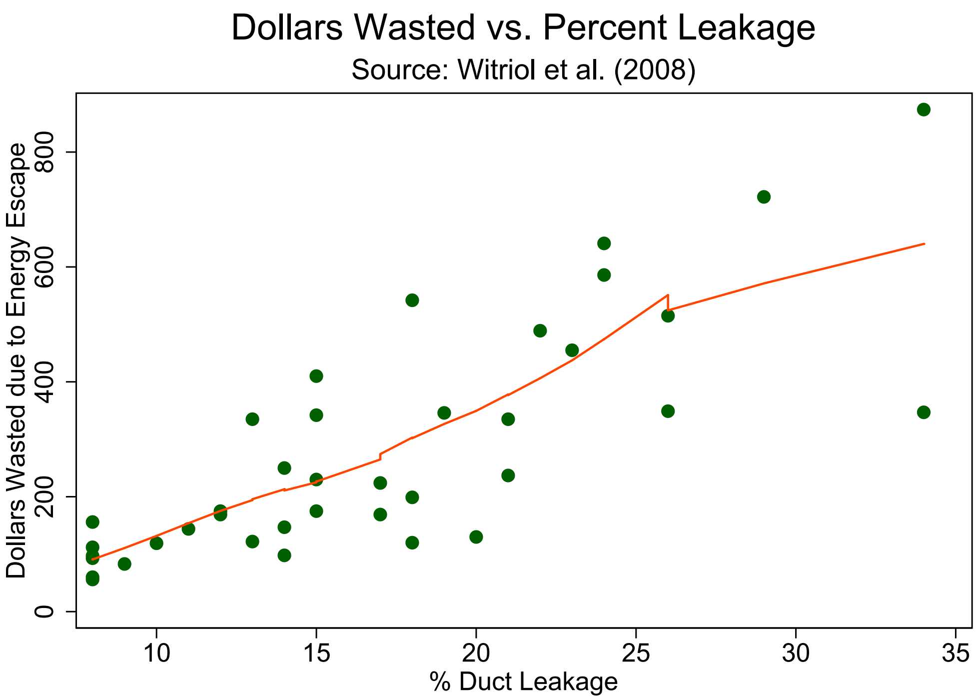
Notes: This diagram shows the coefficients from single audit variable regression versions of Table A.29 and their standard errors. Audit variables are standardized prior to regression.

Figure A.2: Total Heat Flow Reduction vs R-value, Holt Architects (2017)



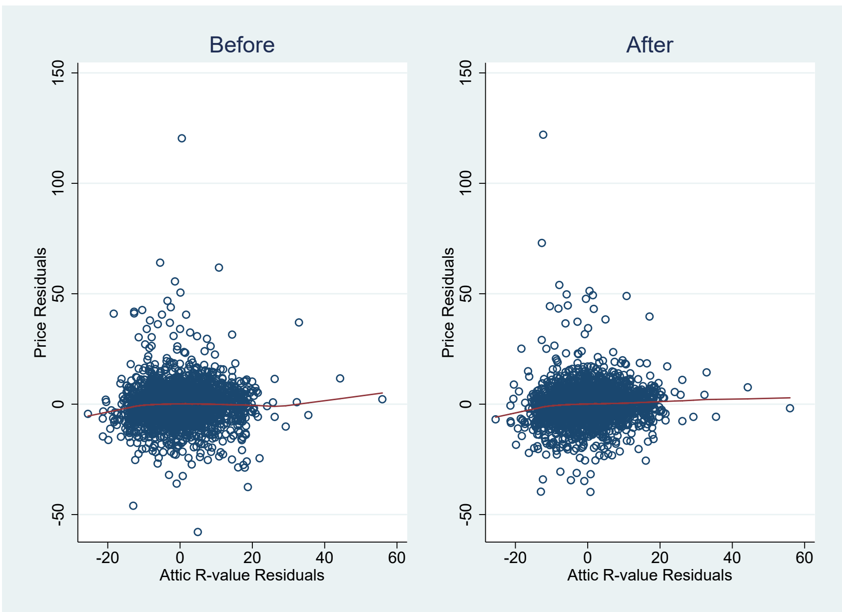
Notes: This diagram shows the relationship between total heat flow reduction and R-value, reproduced from Holt Architects (2017).

Figure A.3: Savings and Duct Leakage, Witriol et al. (2008)



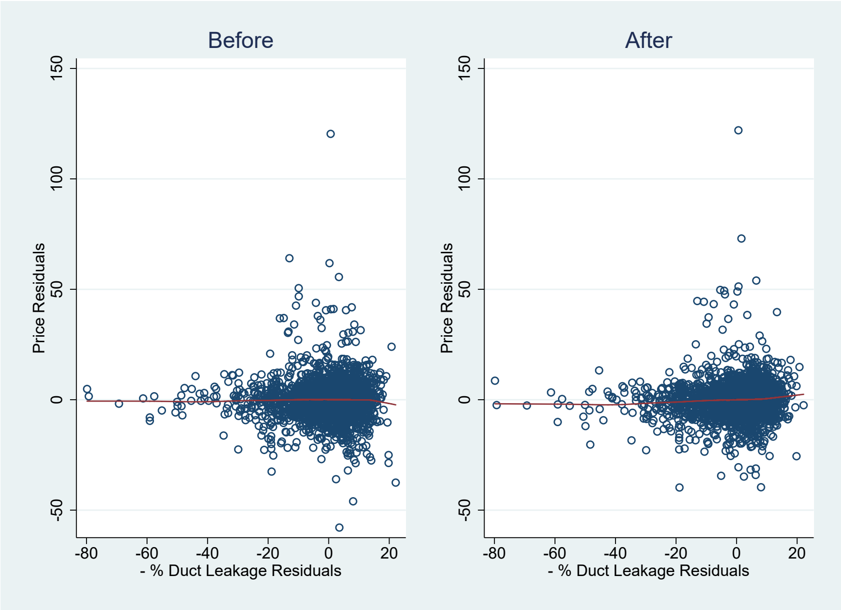
Notes: This diagram shows the relationship between dollars and duct leakage, reproduced from Witriol et al. (2008).

Figure A.4: Scatterplot of Residualized Price on Attic R-value, with LOWESS Smoothed Curve



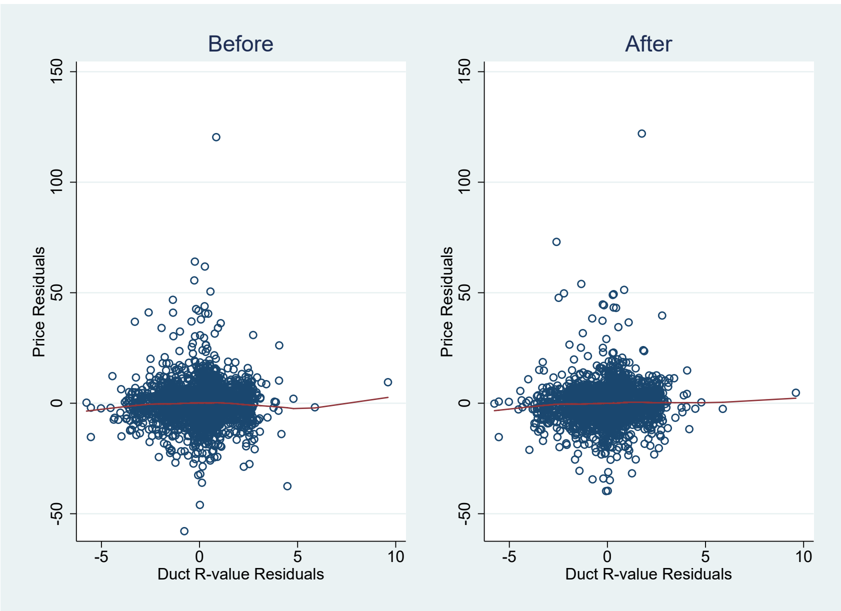
Notes: This diagram shows the residualized price plotted against the residualized Attic R-value for before and after the policy. The solid red lines correspond to LOWESS-smoothed curves that are displayed in a crisper manner in Figure A.8a.

Figure A.5: Scatterplot of Residualized Price on Negative Duct Leakage, with LOWESS Smoothed Curve



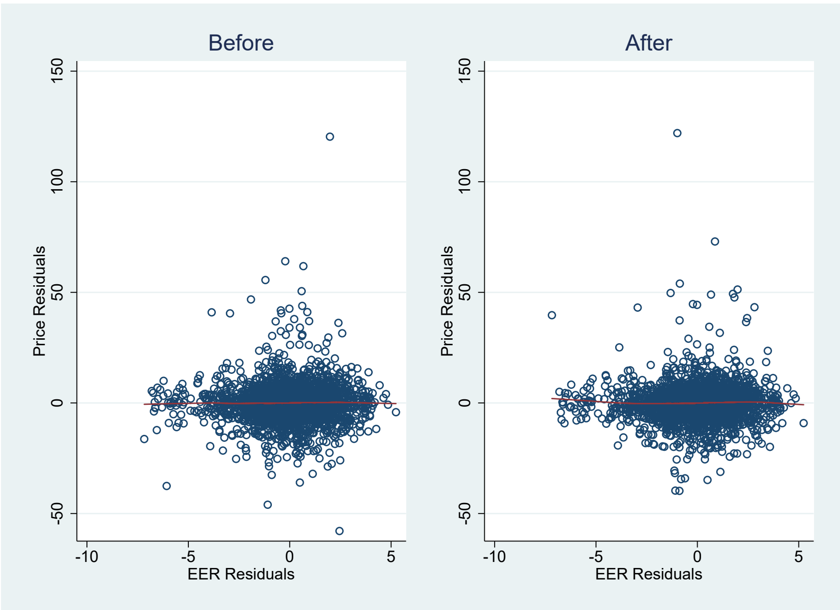
Notes: This diagram shows the residualized price plotted against the residualized negative percent duct leakage for before and after the policy. The solid red lines correspond to LOWESS-smoothed curves that are displayed in a crisper manner in Figure A.8b.

Figure A.6: Scatterplot of Residualized Price on Duct R-value, with LOWESS Smoothed Curve



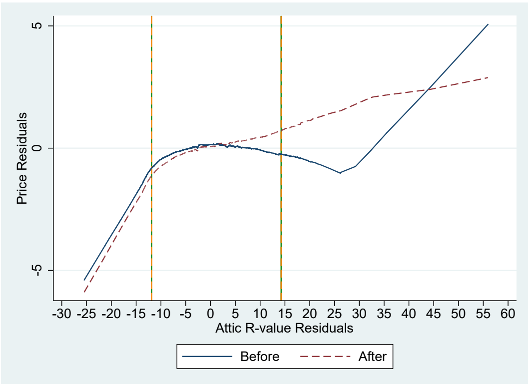
Notes: This diagram shows the residualized price plotted against the residualized Duct R-value for before and after the policy. The solid red lines correspond to LOWESS-smoothed curves that are displayed in a crisper manner in Figure A.8c.

Figure A.7: Scatterplot of Residualized Price on EER, with LOWESS Smoothed Curve

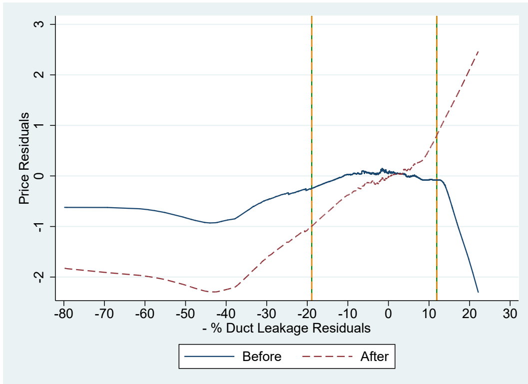


Notes: This diagram shows the residualized price plotted against the residualized EER for before and after the policy. The solid red lines correspond to LOWESS-smoothed curves that are displayed in a crisper manner in Figure A.8d.

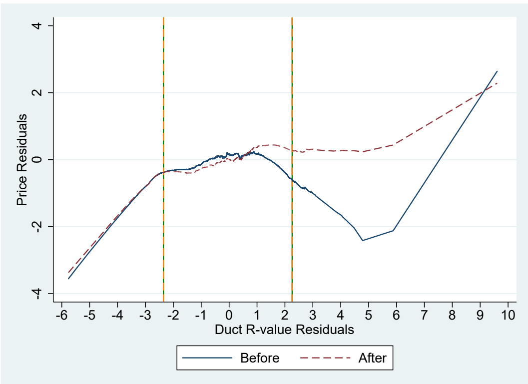
Figure A.8: LOWESS Smoothed Curves for Four Main Audit Measures, Residualized



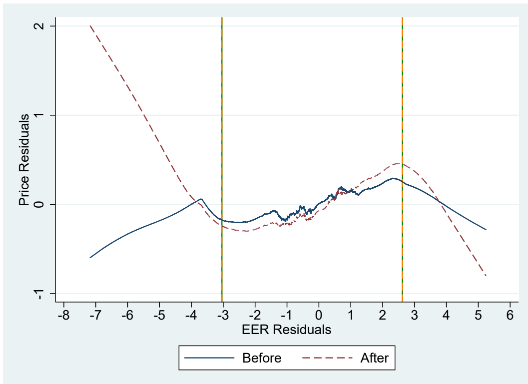
(a) Attic R-value



(b) Negative Duct Leakage



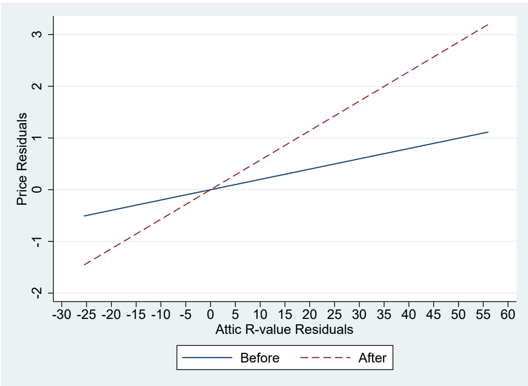
(c) Duct R-value



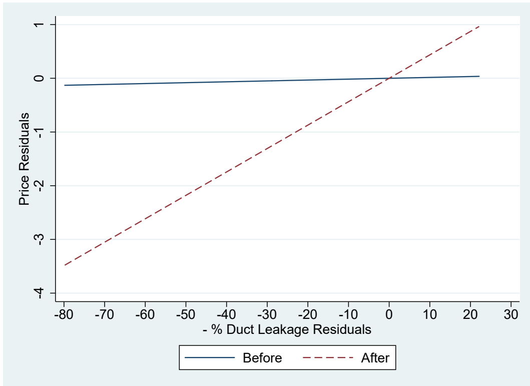
(d) EER

Notes: This diagram shows the relationship between residualized price and residualized audit measures for each of the four main measures. The solid blue lines show the LOWESS-smoothed curves that represents the relationship between price residuals for transactions that occurred before the policy was enacted and each residualized audit measure. The dashed red lines show the LOWESS-smoothed curves that represent the relationship between price residuals for transactions that occurred after the policy was enacted and each residualized audit measure. The solid green lines and dashed orange lines, which almost overlap in all four plots, depict the 5th and 95th percentiles for the residuals of each measure. The solid green lines correspond to the percentiles of the residualized audit measures from the transactions that occurred before the policy was enacted, and the dashed orange lines correspond to the percentiles of the audit residualized measures from the transactions that occurred after the policy was enacted. In this diagram, the LOWESS smoothing uses a bandwidth of 0.8, meaning that 80% of the data around a point is used to estimate the value of the smoothed curve at that point.

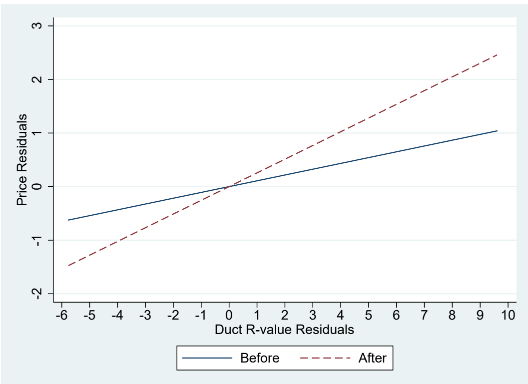
Figure A.9: Lines of Best Fit for Four Main Audit Measures, Residualized



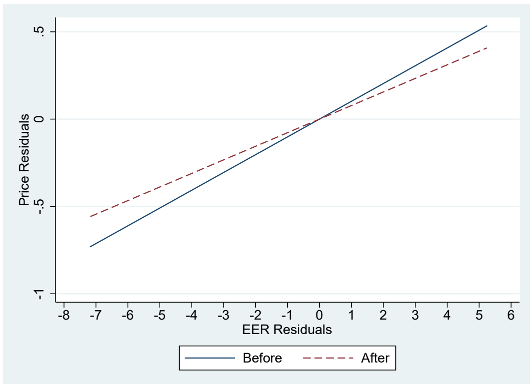
(a) Attic R-value



(b) Negative Duct Leakage



(c) Duct R-value



(d) EER

Notes: This diagram shows the relationship between residualized price and residualized audit measures for each of the four main measures. The solid blue lines show the lines of best fit from a linear regression of price residuals for transactions that occurred before the policy was enacted on each residualized audit measure. The dashed red lines show the line of best fit from a linear regression of price residuals for transactions that occurred after the policy was enacted on each residualized audit measure.