Loss Aversion and Property Tax Avoidance

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Abstract

This paper establishes that loss aversion fundamentally influences the tax avoidance behavior of property taxpayers. Upon receiving notice of a new assessed value, homeowners have the option to appeal, which, if successful, could lower their tax base. I conjecture that a lagged, salient value—a property’s assessed value in the previous year—serves as a natural and prominent reference point to property owners. Guided by a reference-dependent model of assessment protests, I demonstrate various predictions using a sample of 8.7 million administrative property assessment records associated with 1.8 million appeals. First, loss aversion introduces an extensive margin effect around the reference point that induces property owners to disproportionately appeal assessments that have increased relative to the prior tax year. In aggregate, this leads to a sharp kink in the probability of protesting as a function of percent change in assessed value exactly at zero percent change (the threshold separating assessments that increased relative to the prior year, from assessments that decreased relative to the prior year). Second, homeowners not only achieve but also seek out value adjustments that result in a final assessed value precisely at the property’s previous assessed value. Third, a drop in the average reduction received among protesters just barely in the loss domain provides further evidence indicative of an extensive margin effect induced by loss aversion. Overall, evidence is strongest for owner-protesters, for whom the reference point is presumably most relevant. Back-of-the-envelope counterfactuals suggest that loss aversion has a sizable impact on annual household property taxes, particularly among properties constituting the top quartile of value; simultaneously, it causes significant administrative burden.

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1 Introduction

Models of reference-dependent preferences dating back to prospect theory (Kahneman and Tversky, 1979) are a cornerstone of behavioral economics. In these models, loss aversion\(^1\) generates a distinctive set of predictions. Even though many presume that reference points and loss aversion affect decision-making in a variety of contexts, lucidly demonstrating their pervasive influence in organically occurring settings has proven elusive (Barberis, 2013). Considering the essential role of the reference point, surprisingly few field applications precisely pinpoint values that plausibly register as reference points in the minds of individuals.\(^2\) Often, this precludes identification of a broad spectrum of behavior that could be predicted by loss aversion, which to fully distill, necessitates several conditions: (i) a precisely-identified reference point, (ii) a setting involving a choice with both an extensive and intensive margin, and (iii) data precise enough to pinpoint the exact impact of the reference point.\(^3\)

In this paper, using a sample of 8.7 million annual property assessments, I consider a setting that satisfies these criteria and present evidence which establishes that loss aversion fundamentally influences the property tax avoidance behavior of homeowners. Upon receiving notice of a new assessed value, a homeowner typically has the option to appeal\(^4\) her property’s assessed value, the tax base for the *ad valorem* tax. I conjecture that a property’s assessed value in the previous year serves as a salient reference point to property owners, causing them to frame increases in their property’s assessed value as a *loss*, and decreases as a *gain*, insofar as taxes are concerned. Property assessment notices, sent to property owners at the beginning of the tax year, prominently display not only the new, proposed assessed value, but also the property’s assessed value in the previous year—often quite literally side-by-side. This calls attention to a natural reference point that is likely to make *changes* in assessed value especially salient. Detailed administrative property records, which include information on the initial assessed value, protest choice, and final assessed value, allow me to demonstrate effects associated with both the extensive and intensive margin, using discontinuity and bunching methods. At the same time, the heterogeneity of property values allows for precise identification of an individual-specific reference point and granular examination of behavior.

Other features of the setting render the choice to protest an assessment one worthy of investigation. Assessing the value of residential property is challenging for several reasons: goods are heterogenous, comparable market transactions are sometimes infrequently observed, and consumers and taxing authorities may have asymmetric information pertinent to a property’s value. Given that valuations are necessarily noisy, the option to protest serves an important function, providing property owners a mechanism to appeal (and thereby potentially change) what they may feel is an inappropriate assessment. In 2016, the median U.S. homeowner paid approximately $2,150 in real estate property taxes, roughly 3% of annual household income;\(^5\) appealing an assessment can reduce a homeowner’s

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\(^1\)Loss aversion refers to the psychological tendency to be more sensitive to losses relative to a reference point than to gains of equivalent size. In simple terms, an unexpected loss of $100 is felt more acutely than an unexpected gain of $100.

\(^2\)To illustrate with the canonical field application of reference-dependence, Camerer et al. (1997) famously estimate a negative daily income elasticity positing a daily income target, but it would be dubious to suggest that one could pick out the target used by any individual driver.

\(^3\)Certain tests, such as bunching, are also unavailable if the outcome involves substitution to a consumption dimension that differs from that of the reference point, such as in (Mas, 2006) and (Card and Dahl, 2011).

\(^4\)Throughout this paper I use the terms *protest, appeal*, and *challenge* interchangeably.

\(^5\)In total, this amounts to greater than 1.2% of GDP. Note: Author’s estimates based on owners’ reported
tax liability by several hundred dollars or more. Even though appeals are the primary tax avoidance measure available in the setting, and significant economic stakes are involved, little is known about the decision process underlying the choice to protest assessments.\(^6\) This void is somewhat surprising considering that the property tax is commonly cited as the most disliked and unfair tax (Cabral and Hoxby (2018), Sheffrin et al. (2010)).

Figure 1 shows appeal rates as a function of percent change in initial assessed value in the sample I study. The efficacy of the property tax is predicated on an initial valuation and subsequent appeals process that together produce final assessments that reasonably reflect fair market value. Suppose two properties were both initially over-assessed by $20,000. One might think that both owners would be equally likely to protest, even if one property’s assessment increased relative to the prior year, and the other property’s assessment decreased. Both owners stand to gain equally—in monetary terms—from correcting the initial over-assessment; however, the evidence highlighted in the figure suggests that in practice, the property owner whose assessment increased is much more likely to protest. Observing the noise in any individual assessment is difficult, but under standard assumptions, we would expect the average noise in assessed values to be smoothly distributed, even if positively correlated with changes in assessed value. Accepting that as given, it follows that one might reasonably expect appeal rates to be positively related to changes in assessed value, but similarly, smoothly distributed. Figure 1 clearly shows that this does not hold empirically; loss aversion provides an explanation.

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\(^6\)Existing property tax appeals research focuses on assessment accuracy and uniformity (Weber and McMillen (2010), Plummer (2014), McMillen (2013)) and racial disparities in protesting (Doerner and Ihlanefeldt (2014), Grotto (2017)).
I model the decision to protest an assessment, introducing a framework that grounds the empirical analysis. Incorporating loss aversion with respect to previous assessed value into a property owner’s preferences results in a sharp, discontinuous increase in the marginal disutility of paying taxes on an assessed value that exceeds that of the prior year. I focus on two primary behavioral predictions related to the extensive margin and intensive margin, respectively. First, homeowners who receive an initial assessment that increased relative to the prior year will disproportionately appeal, resulting in a probability of protest that kinks sharply upward at zero percent change in initial assessed value. Second, protesting homeowners will disproportionately seek out value adjustments that result in a final assessed value precisely at the reference point. In aggregate, this will result in a distribution of changes in final assessed value (relative to previous assessed value) that exhibits excess mass bunched at zero (i.e. no change).

Auxiliary predictions of the model bolster evidence of the mechanism. The model distinguishes between and predicts both bunching in the distribution of final assessed value and bunching in the distribution of homeowner opinion of value. Two other predictions, discussed further below, solidify evidence of the extensive margin effect induced by loss aversion.

The empirical analysis examines 8.7 million administrative property assessments associated with 1.8 million appeals from two large Texas counties, home to Houston and Austin. I begin by presenting global evidence of a kink using a flexible within-household design. I then formalize the model’s main prediction using regression kink discontinuity methods, estimating an elasticity of protesting with respect to change in initial assessed value that, below the reference point, is close to zero, and above the reference point, is between 0.7-1.0. Using standard bunching techniques, I estimate excess bunching at the reference point on the order of 1.5% to 4% of all protesting households, and document bunching in protesters’ opinion of property value that is even larger. These opinions, elicited at the outset of the protest process, provide direct evidence that homeowners target the previous assessed value.

Loss aversion induces homeowners who otherwise would not protest to seek reductions they would not consider worthwhile if not loss averse. As such, we should observe a drop in the average reduction achieved by those at the margin, which I show empirically. Additionally, because the extensive margin has its greatest effect close to the reference point, the probability of protesting conditional on percent change in assessed value is predicted to kink close to the reference point, but can flatten in regions of the loss domain in which fewer households are marginal. This latter prediction is analogous to a theoretical (but not empirical) point made by Engström et al. (2015); I validate the hypothesis empirically.

Representative third party agents handle a substantial fraction of appeals; however, throughout the analysis, I document evidence that consistently points to behavior that is driven by owner-protesters, for whom we would expect the reference point to be most meaningful.

As a final piece of the analysis, I quantify the effects of loss aversion in terms of annual tax dollars per household and administrative burden. In contrast to Rees-Jones (2018), who infers the revenue effects of loss aversion based on the final distribution of income

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7In so doing, I draw insights from the theoretical literature which discusses reference-dependence, particularly Tversky and Kahneman (1991) and Köszegi and Rabin (2006).

8This provides direct evidence of individuals stating preferences that target a reference point, rather than simply inferring a revealed preference from a final outcome. Only Markle et al. (2015), who show that marathon runners’ stated goal times correlate with their finishing times, provide similar field evidence of substantial scale.
taxes owed, I estimate counterfactuals based on observed behavior, given a homeowner’s initial (rather than final) assessed value. An advantage of this approach is that I do not assume the initial distribution’s shape. A significant fraction of loss aversion’s effect is mediated through the extensive margin. As such, tax dollar effect sizes are best understood conditional on one’s position in the loss domain, but unconditional on protesting. In a sub-sample best suited for the analysis, conservative estimates suggest that loss aversion is related to excess reductions in the loss domain, as large as $40 per household annually among all households (unconditional on protesting). Among properties constituting the top quartile of value, the average effects can be as large as $200 per household annually (again, unconditional on protesting).

This study is the first to suggest, examine, and establish the importance of reference-dependence and loss aversion in the context of property taxation. Identifying reference points has proven to be a challenge in applying prospect theory in economics (Barberis, 2013). By suggesting a setting where loss aversion may be not only important, but also detectable, and by identifying the relevant reference point, I add to a small, but growing number of studies that provide large-scale field evidence of loss aversion.9 One of the most closely related studies, Genesove and Mayer (2001), argues that homeowners, when later selling a house, exhibit loss aversion with respect to the price at which they purchased it. Juxtaposed against that result, the findings in this paper might, at first glance, seem paradoxical, and highlight how seemingly related reference points and frames can result in ostensibly contradictory behavior, depending upon the incentives involved.

My findings complement related work that examines reference-dependent behavioral responses to income taxes. Anecdotally, the idea that tax filers exhibit loss aversion with respect to owing taxes at the end of the fiscal year has been documented at least as far back as Carroll (1990); however, the best evidence to date comes from Engström et al. (2015) and Rees-Jones (2018).1011 Methodologically, I draw upon insights from both,12 but, in addition to highlighting additional evidence concerning both the extensive and intensive margin, I show effects that are substantially more pronounced.13 Several factors could contribute to the difference;14 however, given the particular distaste people have for property taxes (and perhaps with the benefit of hindsight), it may be less surprising, once considered, that the property tax setting is one particularly prone to elicit reference-dependent behavior. Regardless, the evidence presented makes it clear that a property’s previous assessed value is an especially strong reference-point.

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9In addition to those discussed, existing large-scale field evidence of loss aversion comes from the labor supply of taxi-drivers (Camerer et al. (1997), Crawford and Meng (2011), Thakral and Tö (2019)), labor negotiations (Mas, 2006), insurance choice (Sydnor (2010), Barseghyan et al. (2013)), domestic violence resulting from upset football losses (Card and Dahl, 2011), professional golfers’ putting accuracy (Pope and Schweitzer, 2011), mergers and acquisitions activity (Baker et al., 2012), marathon runners’ finishing times (Markle et al. (2015), Allen et al. (2016)), unemployment exit (DellaVigna et al., 2017), and plastic bag taxes (Homonoff, 2018).

10Engström et al. (2018) presents panel evidence similar to the cross-sectional evidence in Engström et al. (2015).

11A number of studies approach the subject theoretically and/or with laboratory experiments, with a particular interest in deduction-taking behavior, evasion, and policy implications associated with income tax-withholding (e.g. Elffers and Hessing (1997), Yaniv (1999), Dhami and Al-Nowaihi (2007), Dhami and Al-Nowaihi (2010)).

12Evidence on the probability of protesting that parallels the deduction behavior of the income tax filers from Engström et al. (2015); bunching-based evidence that parallels Rees-Jones (2018)

13While Engström et al. (2015) show that the probability of claiming an income tax deduction increases by about 2 percentage points in the loss domain, I show that the probability of protesting a property tax assessment increases by at least 6 percentage points in the loss domain. Similarly, while Rees-Jones (2018) estimates excess bunching among income tax filers at zero balance due on the order of 0.05% of all income tax filers, I present estimates of excess bunching at the previous assessed value that are an order of magnitude larger, 0.3-1% (depending upon the sample) of all properties, not just those which owners protested.

14For example, in the case of bunching, differences in the ability to target a specific value.
The property tax setting is particularly suited for the study of reference dependence. While in other settings, liquidity constraints can produce behavior that may be incorrectly attributed to loss aversion, a property owner who unexpectedly finds that he will owe several hundred dollars more than expected will not need to produce what he owes for several months. Another advantage of the property tax setting relates to individual sorting. An income tax filer, for example, has substantial control over the balance he will owe at the end of the tax year, and can affect it by manipulating his automatic withholding or tax payments earlier in the year; by contrast, a property owner has little control over the change in the assessed value of his property, which is instead largely determined by market forces. Because assessors, review arbiters, owners, and agents alike emphasize that tangible and specific evidence warranting a reduction is necessary if a protest is to successfully achieve a reduction, a concern that reductions could conceivably be influenced by actors in the environment other than the taxpayer is minimized.

More broadly, this paper adds to an emerging literature in public finance which underscores the important ways psychological biases and tax morale mediate behavioral responses to taxes. Salience and inattention have proven especially important (Chetty et al. (2009), Finkelstein (2009), Goldin and Homonoff (2013), Taubinsky and Rees-Jones (2017)), and recently, have been brought specifically to the context of property taxes (Cabral and Hoxby (2018), Bradley (2017), Wong (2019)). Though related to these studies by context, this paper directly informs a larger discussion of the determinants of tax compliance and avoidance, as well as the political acceptability of the property tax. I return to these points in the conclusion.

The rest of the paper proceeds as follows. First, I provide a brief background on property assessments and assessment protests in Section 2. In Section 3, I model the property assessment protest decision of a homeowner with reference-dependent preferences, highlighting predictions indicative of loss aversion to be tested in the empirical analysis. I describe the data and discuss institutional features unique to the setting that I study in Section 4. Section 5 contains the main empirical results. Section 6 discusses alternative mechanisms. Section 7 contextualizes the results, speaking to the size of the effects. Section 8 concludes.

2 Background on Property Assessment and Assessment Protests

For readers unfamiliar with property assessment and property assessment protests, a few details are useful to know before introducing a model. The empirical part of this

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15At least in the jurisdictions studied in this paper.
16Though less directly, this paper also relates to work examining heuristic evaluations of taxes (Ito (2014), Rees-Jones and Taubinsky (2019)), and heuristics used in property valuation and transactions (e.g. anchoring-and-adjustment (Northcraft and Neale, 1987), and the use of focal points (Pope et al., 2015)).
17Cabral and Hoxby (2018) argue that paying for property taxes through an escrow account reduces the salience of the tax, and show that property taxes are higher in areas where a higher proportion of homeowners pay for property taxes through an escrow account. Bradley (2017) argues that homebuyers are inattentive to property taxes, and, failing to correctly capitalize future taxes into the value of a property, significantly overpay when purchasing a home. Wong (2019) provides evidence that homeowners fall delinquent and default on mortgages shortly after property tax payment increases, demonstrating how inattention to payment increases can rationalize homeowners’ lack of consumption adjustment in the months preceding a tax increase, despite having presumably received notice of the impending increase several months prior.
18In another related study, Chirico et al. (2019) test the effectiveness of alternative nudge strategies in an effort to increase the successful collection of property taxes in Philadelphia; however, they find that reminders which threaten (conventional) economic sanctions are more effective than reminders which instead cox sentiments intended to increase tax morale.
paper uses data from two large Texas counties. In Section 4, I discuss assessment practices and features idiosyncratic to Texas and the counties I study, but the discussion below is intended to provide a more general overview that is broadly representative of operations in many counties.19

2.1 The Property Assessment Cycle

A typical real estate tax assessment cycle has a timeline that resembles the one illustrated in Appendix Figure A.1. First, there is an Assessment Period, during which the county assessor determines the market value of the property. Even though most properties are subject to taxes from several entities (e.g. county, municipality, school district, hospital district, utility districts), assessments are almost always conducted by a county-level office. Residential properties are assessed using a heavily data-driven process based on the characteristics of the property in question and the sale prices of nearby properties. In-person walk-throughs and drive-bys used to be more common, but many assessors have abandoned them, or, at minimum, reduced the frequency with which they occur.20 Once the market value is determined, owners are notified of the proposed Initial Assessed Value21 for the current tax year, and there is a Protest Period during which they have the option to declare their intent to contest the Initial Assessed Value determined by the county assessor. If contesting, a protest will need to be filed by a pre-specified deadline, which is usually 30-60 days after the notice date. Following the Protest Period is the Resolution Period, during which protests are settled and Final Assessed Values are determined. After that, there is a Payment Period. In the vast majority of states, tax payments are due in one or two installments near the end of the tax year. If a mortgage is paid through an escrow account, homeowners effectively make monthly tax payments, bundled together with their regular mortgage payments and held by the mortgage servicer until payment is due.22 Most escrow accounts are updated once annually, adjusting the borrower’s monthly payments to appropriately offset any changes in estimated property taxes and property insurance premiums, in the month after a tax bill for the current year is due (Wong, 2019).23 As such, neither lump-sum taxpayers, nor escrow-paying taxpayers are likely to face an unexpected shock requiring increased payment immediately after receiving notice of a new assessed value.24

The Protest Period, Resolution Period, and Payment Period usually occur annually, but the Assessment Period described above may or may not. States and counties have different practices, but in most places, reassessment occurs at least once every three years, and may occur as often as every year. Major events like the sale of a home, new construction, or substantial remodeling may trigger a supplementary assessment if a regular reassessment would not otherwise occur, but under normal circumstances, the assessed value of a property may not change in consecutive years. Tax rates may change from year to year, causing a homeowner’s tax liability to change, even if the assessed value does not; however,

19This discussion is likely to be less representative of operations in small, sparsely-populated counties.
20In some localities, law requires one or the other every few assessment cycles, but not every cycle.
21The Initial Assessed Value is often referred to as the Notified Value or Noticed Value.
22Cabral and Hoxby (2018) report that half of all property owners with a mortgage have an escrow account; however, the prevalence of escrow has increased substantially in recent years, with 79% of all mortgages serviced using an escrow account in 2017 (CoreLogic).
23Escrow accounts require payments that leave a buffer to draw upon in the event of increased expenses in the current year.
24Furthermore, any property owner paying taxes through escrow would, at most, be faced with a pro rata increase in the monthly tax (pre-)payment.
rates are usually determined after the *Protest Period*. As such, most property owners will not know their exact tax liability with certainty at the time a protest must be filed.

### 2.2 Assessment Protests

If a homeowner wants to protest an assessment, there are typically two primary channels. Many assessors will discuss a case informally. If the motivation for protest is due to factual inaccuracies or mistakes in the assessor’s records that are obvious or easily verifiable (e.g., typos in the specifications of a property), many assessors will correct the mistake without a formal appeal. Even in more complicated cases, many assessors resolve a significant portion of appeals informally. If an informal appeal is not entertained, is unsuccessful, or is otherwise unsatisfactory, then a homeowner may proceed to a formal stage adjudicated by a board of independent reviewers.\(^2^5\)

In either case, property owners face a cost-benefit analysis. The cost of protesting is primarily effort-based. A document indicating intent to protest must be completed, and homeowners must provide a written explanation detailing the reasons they believe an initial assessment to be incorrect. This requires gathering evidence that substantiates a reduction. Broadly speaking, grounds substantiating successful appeals can be categorized as: (i) factual inaccuracies in the assessor’s records, (ii) idiosyncratic value-based cases, such as documenting unusual depreciation or damage to a property, with descriptions and accompanying photos, or (iii) market-based or uniformity-based appeals, which either argue that the assessor incorrectly valued a neighborhood, or point to discrepancies between an assessed value of a property and the assessed values of comparable properties. Tangible evidence that supports a reduction is essential for the success of an appeal.\(^2^6\) Monetary costs could be involved as well. Many owners hire a lawyer or tax professional to aid in the process.\(^2^7\) Others might hire an independent appraiser to walk through the property, including an appraisal as evidence in support of an appeal. Though some assessors charge a nominal filing fee to file a protest,\(^2^8\) many refund it if an appeal is successful, and sometimes even if unsuccessful, as long as the homeowner (or representing agent) attended all scheduled in-person appearances.

Once a protest is filed, it could take up to several months before a final determination is made. Many protests successfully reduce the assessed value. Unsuccessful protest very rarely results in a higher assessed value, and some jurisdictions explicitly protect homeowners against this possibility. The potential savings from a successful protest will vary, but could be quite substantial. Many appeals result in tax savings of several hundred dollars or more, especially among more valuable properties.\(^2^9\)

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\(^{25}\)Other options may be available beyond the informal and formal appeals process, such as advancing a case to civil court, but those alternatives are rarely exercised.

\(^{26}\)Assessors and review boards both emphasize that evidence is necessary for a reduction, and this is corroborated by first-hand accounts given by property owners as recounted in blogs and online article comments.

\(^{27}\)Payment structures for hired third-party representatives vary. Common structures include (i) fixed fee, (ii) fixed fee if an appeal is successful, and (iii) a percentage of the tax reduction achieved if an appeal is successful.

\(^{28}\)On the order of $10 to $25.

\(^{29}\)Benefits can be even greater if a reduced assessment will remain in place for multiple years, or if local laws are such that lowering an assessment will induce a lower ceiling on future assessments.
3 A Reference-Dependent Model of Property Tax Assessment Protests

3.1 Model Preliminaries

A homeowner has reference-dependent utility over the amount of property taxes she pays \( T_t \) in year \( t \), and simultaneously derives disutility from asserting effort, \( e_t \), if she protests her property’s assessed value in an effort to lower her tax liability. Altogether, her utility is given by,

\[
u(T_t, e_t | r_t) = v(T_t | r_t) - k(e_t) \tag{3.1}
\]

where,

\[
v(T_t | r_t) = \begin{cases} 
-(T_t - r_t) & \text{if } T_t < r_t \\
-\lambda(T_t - r_t) & \text{if } T_t \geq r_t 
\end{cases} \quad \text{(Gain Domain)}
\]

\[
-\lambda(T_t - r_t) \quad \text{(Loss Domain)} \tag{3.2}
\]

represents the gain-loss utility from taxes owed relative to a time-varying reference point, \( r_t \). Appealing to Rabin’s (2000) calibration, this function is assumed to be piecewise linear on either side of the reference point, with coefficient of loss aversion \( \lambda \geq 1 \) capturing the additional marginal disutility associated with losses. If the homeowner protests \( (e_t > 0) \), she incurs an effort cost,

\[
k(e_t) = \begin{cases} 
\kappa + c(e_t) & \text{if } 0 < e_t \leq 1 \\
0 & \text{if } e_t = 0
\end{cases} \quad \text{(Protest)}
\]

\[
0 \quad \text{(No Protest)} \tag{3.3}
\]

which may include a fixed component, \( \kappa \geq 0 \), and a weakly convex marginal cost, \( c(e_t) \geq 0 \), with \( c'(e_t) \geq 0 \). Importantly, the homeowner is atomistic to the overall supply of local amenities, which her property taxes presumably finance.

The homeowner’s tax liabilities in year \( t \) are described by,

\[
T_t = \tau_t \cdot \text{Assessed Value} \tag{3.4}
\]

where a real property tax rate \( \tau_t \in [0, 1] \) is applied to a time-varying Assessed Value,

\[
A_t = V_t + \epsilon_t, \tag{3.5}
\]

which is itself the sum of the True Value, \( V_t \), and a noise term, \( \epsilon_t \), both of which are known to the homeowner.\(^{31}\) The noise term is drawn from distribution \( F(\epsilon_t) \).

The reference point is assumed to be backward-looking and given by,

\[
r_t = \tau_{t-1} \cdot A_{t-1} = T_{t-1}. \tag{3.6}
\]

Tax rates are typically determined after a protest decision must be made; therefore, expectations about the current year’s tax rate (and thereby tax liability) are formed in year \( t \), but before \( \tau_t \) is realized. I impose the restriction that \( E[\tau_t] = \tau_{t-1} \), effectively allowing me to

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\(^{30}\)This piecewise-linearity assumption is consistent with many existing studies, including, but not limited to, Benartzi and Thaler (1995), Card and Dahl (2011), Engstrom et al. (2015), DellaVigna et al. (2017), Homonoff (2018), and Rees-Jones (2018).

\(^{31}\)Terming \( V_t \) as the True Value connotes a meaning that some may quibble with; consequently, some readers may prefer to think of \( V_t \) more agnostically as the component of the assessed value that a protestor will not be able to influence.
drop the time subscript on tax rates (suppressed after the next expression), and to define the reference point solely in terms of Previous Assessed Value, $A_{t-1}$. Doing so, gain-loss utility is given by,

$$v(A_t | A_{t-1}) = \begin{cases} \tau_t (A_{t-1} - A_t) & \text{if } A_t < A_{t-1} \\ \lambda \tau_t (A_{t-1} - A_t) & \text{if } A_t \geq A_{t-1}. \end{cases} \quad (3.7)$$

This happens to be mathematically convenient, but more importantly, is motivated by two institutional features specific to the environment. First, property tax rates often do not change from year to year, which makes the lagged tax rate a reasonable, if intuitive, expectation to hold of the yet-to-be-determined current year’s rate. Second, in addition to prominently displaying both the proposed Initial Assessed Value and the Previous Assessed Value, assessment notices commonly include estimated tax liabilities for the current year calculated assuming the previous year’s tax rates.\footnote{An empirically-equivalent alternate mechanism is that property owners react directly to the Initial Assessed Value and Previous Assessed Value, and derive utility from changes in assessed value itself (rather than changes in tax liabilities per se). This distinction, while (foot)noteworthy, is ultimately inconsequential to any first-order behavior predicted by the model; moreover, viewed through the lens of an as if paradigm, a property owner would presumably only respond to changes in assessed value in this way because they view the assessed value as if it were a sufficient statistic for their tax liability (the outcome we would expect ultimately matters to her).}

### 3.2 The Homeowner’s Protest Choice & Predictions of Minimal Models

I introduce the predictions of the model, progressively increasing the complexity of the mechanics of protesting. Figures 2 and A.4 show a simulation that illustrates the qualitative predictions of the full Stochastic Reduction Model, introduced last. As is evident from the simulation figures, the predictions of simpler models carry through to the more complex Stochastic Reduction Model.

In deciding whether or not to protest her Initial Assessed Value, the homeowner compares the utility from her two alternatives,

(i) \textbf{Protest Initial Assessed Value:}

$$u^P(T_t, \epsilon_t > 0 | r_t) = \begin{cases} \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t)] - k(\epsilon_t) & \text{if } \hat{A}_t < A_{t-1} \\ \lambda \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t)] - k(\epsilon_t) & \text{if } \hat{A}_t \geq A_{t-1} \end{cases}$$

where $\epsilon_t$ represents a new noise term associated with a (revised) Final Assessed Value $\hat{A}_t$.

(ii) \textbf{Accept Initial Assessed Value as Final Assessed Value (Don’t Protest):}

$$u^{DP}(T_t, \epsilon_t = 0 | r_t) = \begin{cases} \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t)] & \text{if } A_t < A_{t-1} \\ \lambda \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t)] & \text{if } A_t \geq A_{t-1} \end{cases}$$

\footnote{It’s worth briefly pointing out some of the model’s underlying assumptions, not yet discussed. First, for simplicity, households do not consider the relationship between income taxes and property taxes. The majority of U.S. households elect to take the standard deduction; for most of them, this consideration is essentially most insofar as federal income taxes are concerned. Even if households consider the relationship between their property tax liabilities and their income tax liabilities, it would not change the model’s essential predictions, only the interpretation of the effective tax rate. Second, the homeowner is fully naïve in the sense that she does not anticipate how actions in the current year will affect gain-loss utility in future years, which would necessitate dynamic optimization. Third, utility contains only a gain-loss component, and not an absolute level-based component. Finally, in order to highlight the predictions motivated by psychology alone, the model does not incorporate features of the property tax that are idiosyncratic to local jurisdictions (e.g. property tax assessment increase limits). Features specific to the data I examine are discussed in the data section.}
3.2.1 Fixed Cost Noise Removal Model

The first prediction of the model relates to a homeowner’s probability of protesting. To begin, consider a minimal Fixed Cost Noise Removal Model, wherein protesting removes the entire noise term from an Initial Assessed Value, at the expense of a fixed cost of effort (and hence no intensive effort margin). Appendix Table C.5 summarizes the conditions under which the homeowner would protest in this minimal model. Appendix Figure A.3 is also instructive, illustrating six assessment type cases, enumerating the possible ways $A_t$, $A_{t-1}$, and $V_t$, could be positioned relative to each other.\footnote{Note that if protesting can only bring the homeowner closer to the true value (as is the case in this Fixed Cost Noise Removal Model), a homeowner will only ever protest when they are over-assessed (Cases 1, 3, and 4 in Appendix Figure A.3 and Appendix Table C.5).}

**Proposition 1.** Given a fixed cost of protesting $\kappa > 0$, and holding constant the noise $\epsilon_t$ in her Initial Assessed Value, a homeowner with $\lambda > 1$ is more likely to protest her property’s Initial Assessed Value if it has increased relative to the property’s Previous Assessed Value, $A_t > A_{t-1}$.

The intuition is straightforward. Loss aversion causes the marginal benefit of assessment reductions to be greater (by a factor of $\lambda$) for each dollar reduced above the property’s Previous Assessed Value. If the Final Assessed Value after reductions is greater than the Previous Assessed Value, then the marginal benefit of all reductions are $\lambda$-inflated; if, alternatively, the Final Assessed Value after reductions is less than the Previous Assessed Value, then only part of the reduction benefit is $\lambda$-inflated.

Proposition 1 proves difficult to test directly since it necessitates conditioning on $\epsilon_t$, which may be unobservable. A naïve modification of this proposition might be to assume that the noise term is equal in expectation for those that receive an increase, and those that receive a decrease; however, if, in year $t$, a homeowner happens to receive a bad (high) noise draw, then not only is it more likely that the protest condition is met, it’s also more likely that her Initial Assessed Value increased relative to the previous year.\footnote{To illustrate this second point under relatively benign assumptions, let $\operatorname{Cov}(\epsilon_t, \epsilon_{t-1}) = 0$ and $\operatorname{Cov}(\epsilon_t, \Delta V_t) = 0$, $\operatorname{Cov}(\epsilon_t, \Delta A_t) = \operatorname{Cov}(\epsilon_t, \epsilon_t) + \operatorname{Cov}(\epsilon_t, \Delta V_t) + \operatorname{Cov}(\epsilon_t, \epsilon_{t-1}) = \operatorname{Var}(\epsilon_t) > 0$.}

As a result, mechanically, the probability of protesting should be positively related to a change in Initial Assessed Value, even in a model without loss aversion (where $\lambda = 1$). By contrast, a model with loss aversion predicts that a homeowner will be disproportionately more likely to protest if her assessment has increased relative to the previous year, as a marginal increase in $\epsilon_t$ will cause a greater change in the probability of protesting if in the loss domain.

**Kink Proposition.** Holding constant the fixed cost of protesting $\kappa$, if $\lambda > 1$ the slope of the expectation of protesting conditional on a homeowner’s percent change in Initial Assessed Value will increase exactly at the reference point, resulting in a probability of protesting that is kinked at zero percent change in Initial Assessed Value. Equivalently, the elasticity of protesting with respect to change in Initial Assessed Value will be discreetly larger above the reference point than below the reference point.

The kink at the reference point is the result of an extensive margin effect related to the portion of a potential reduction benefit expected to be $\lambda$-inflated. Imagine an owner who received an Initial Assessed Value that was only one dollar above her Previous Assessed Value. Though in the loss domain, her protest behavior will not drastically differ from a similar owner that received an Initial Assessed Value one dollar below his Previous Assessed Value; even if she protested and received a reduction, only the first dollar reduced would
be associated with a $\lambda$-inflated marginal benefit. In other words, close to the reference point but moving further into the loss domain, there’s an extensive margin effect coming from the fact that, on average, the $\lambda$-inflated fraction of the benefit associated with potential reductions increases, inducing more owners to protest on the margin.

Eventually this effect subsides, when increases in assessed value are sufficiently large such that any potential reductions will still leave the homeowner in the loss domain. At that point the slope of the conditional expectation of protesting will flatten, but remain steeper than below the reference point, as the same increase in $\epsilon_t$ is still associated with greater disutility.\textsuperscript{36}

Figure 2(A) illustrates the kink prediction presenting both the pattern predicted with loss averse owners ($\lambda > 1$) and the counterfactual pattern predicted without loss averse owners ($\lambda = 1$). In the simulation, individual cost parameters, changes in underlying value, and noise terms are all normally distributed (see figure footnotes for complete details). Individual $\lambda$’s are normally distributed with $\mu_\lambda = 2$ and $\sigma_\lambda = 0.3$. As shown, the probability of protesting increases sharply at zero percent change in assessed value if owners are loss averse, but is smoothly distributed through the reference point if they are not.

3.2.2 Effort-Based Noise Reduction Model

Allowing for an effort margin introduces a second prediction of loss aversion. Minimally extending the fixed cost model above, consider an Effort-Based Noise Reduction Model, which incorporates effort, $e_t \in [0, 1]$, by having the reduction a protester receives be a fraction of the initial noise term, exactly proportional to the effort asserted such that protesting removes $ee_t$ from an initial assessment. If the amount of effort asserted is related to the reduction achieved, then we should expect some loss averse homeowners to pursue reductions only up to the point where the marginal benefit drops.\textsuperscript{37}

**Bunching Proposition.** If $\lambda > 1$, homeowners will seek value reductions that result in a Final Assessed Value exactly at their Previous Assessed Value, resulting in final distribution that exhibits bunching at no change in Final Assessed Value (the reference point).

Above the reference point, each dollar reduction in assessed value is associated with a marginal benefit of $\lambda \tau$; below the reference point, each dollar reduction in assessed value is associated with a marginal benefit of $\tau$. This allows for an interior optimal effort solution associated with pursuing a revised assessed value exactly equal to the Previous Assessed Value, resulting in excess bunching at the Previous Assessed Value in the distribution of Final Assessed Value. Figure 2(B) illustrates the bunching prediction, showing an initial distribution of assessed values (in grey), and a final distribution of assessed values (in blue). The pink line shows the counterfactual final distribution predicted if owners were not loss averse, which, in addition to having a shifted pattern of mass relative to the loss averse case, is clearly void of bunching.

\textsuperscript{36}Engström et al. (2015) present a model that makes a similar prediction about the probability of claiming an income tax deduction, but their focus is a deduction of fixed size $\delta$. In such a case, there will exist a sharp second kink in the loss domain $\tau \delta$ dollars above the reference point, where $\tau$ represents the tax rate. In the present case, a homeowner’s reduction is varying in size based on the random draw $\epsilon_t$; as a result, there is an analogous “second kink” in the conditional probability of protesting, but its position is not well defined, as in the case with a deduction of fixed size.

\textsuperscript{37}Rees-Jones (2018) highlights this idea in his study of income tax filers.
3.3 The Extensive Margin & Conditional Average Reductions

An additional prediction of the reference-dependence model relates to the average reduction received by homeowners that protested. Without loss aversion, we would expect the average reduction received by protesters to be increasing but smooth around the reference point.

Loss aversion induces both an intensive and extensive margin effect. Assuming some margin for effort, holding constant the amount of noise in an assessment, the intensive margin effect induces homeowners that would have protested in the absence of loss aversion to seek a weakly larger reduction. Meanwhile, the extensive margin effect induces homeowners that would not have protested in the absence of loss aversion to seek a reduction—at the margin, for a reduction amount that they would not find worthwhile in the gain domain. If the extensive margin effect is sufficiently large, it can lead to a distinct pattern wherein the average reduction received by protesters (or successful protesters) just barely in the loss domain is less than the average reduction received by those just barely in the gain domain. Panel (C) of Figure 2 illustrates this point, leading to another testable prediction for the empirical analysis.

3.4 Stochastic Reduction Model

While the predictions up to this point provide the basis for the empirical analysis, the minimal models used to introduce the essential ideas ignore the uncertainty a homeowner faces when deciding to protest. Other somewhat unattractive features of the above models are that (i) owners only protest if over-assessed, and (ii) they never achieve a final assessed value below $V_t$.

Adding uncertainty inherent to the protest reduction process, I extend the model by specifying the role of effort and introducing stochastic reductions as follows. As before, a homeowner is provided an Initial Assessed Value in the beginning of the year which they may optionally protest. By protesting, the homeowner can receive a new noise draw $\tilde{\epsilon}_t$, which would replace the initial noise draw $\epsilon_t$, resulting in a Revised Final Assessed Value, $\tilde{A}_t = V_t + \tilde{\epsilon}_t$. The new noise draw is assumed to have a latent value, $\tilde{\epsilon}^\ell_t$, drawn from the same distribution as the original noise draw, with CDF $F(\epsilon_t) = F(\tilde{\epsilon}^\ell_t)$; however, the realized value of the new noise draw is censored above by $\epsilon_t$—the initial noise draw that can be protested—and censored below by the quantile of $(1 - \epsilon_t)$. Formally, letting $Q(p) = F^{-1}(p)$ represent the quantile function, and, $q(p) = Q'(p)$, the realized value of $\tilde{\epsilon}_t$ is given by,

$$\tilde{\epsilon}_t = \begin{cases} 
Q(1 - \epsilon_t) & \text{if } \tilde{\epsilon}^\ell_t \leq Q(1 - \epsilon_t) \\
\tilde{\epsilon}^\ell_t & \text{if } Q(1 - \epsilon_t) < \tilde{\epsilon}^\ell_t < \epsilon_t \\
\epsilon_t & \text{if } \tilde{\epsilon}^\ell_t \geq \epsilon_t.
\end{cases}$$

As such, protesting and exerting effort $\epsilon_t$ will, at worst, result in no change in value, and at best, result in a new $\tilde{\epsilon}_t$ equal to the original draw $\epsilon_t$.

Specified in this way, the model captures several elements of the environment. We can think of $\Delta A_t^O = Q(1 - \epsilon_t) - \epsilon_t$ as the reduction in value that a homeowner argues for during the protest process, superscripted with $O$ to denote a proposed opinion of change in assessed value. At most, she will achieve that change in value; however, the assessor or arbiter may not agree, resulting in a final reduction smaller than the protester’s

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38 And associated PDF $f(\tilde{\epsilon}^\ell_t) = f(\epsilon_t)$.
proposal. All else equal, this results in a probability of successful reduction that increases in conjunction with the original draw \( \epsilon_t \); in other words, the homeowner is more likely to win if over-assessed by a larger amount. Simultaneously, reductions are censored above the original draw to reflect the fact that in most jurisdictions, property owners are implicitly (if not explicitly) protected against increases resulting from the appeals process. Altogether, homeowners face a stochastic environment that may result in a full, partial, or no reduction vis-a-vis their proposed reduction.

### 3.4.1 Expected Benefit of Protesting

Additional details concerning the stochastic reduction model are detailed in Appendix C.3. Here I highlight the essential features. Defining \( A_t^O \equiv V_t + Q(1 - \epsilon_t) \) as the homeowner’s proposed opinion of assessed value, and letting \( \bar{\epsilon}_t = (V_{t-1} + \epsilon_{t-1}) - (V_t) \) represent the threshold \( \bar{\epsilon}_t \) draw that separates the gain domain from the loss domain, the expected utility benefit associated with a reduction in assessed value can be described as follows.

**Case A(i):** \( A_t \geq A_{t-1}, A_t^O \leq A_{t-1} \)

\[
\begin{align*}
(1 - e_t^*) \times [\tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + Q(1 - e_t^*)) \right) + \int_{Q(1 - e_t^*)}^{\bar{\epsilon}_t} \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \bar{\epsilon}_t) \right) dF(\bar{\epsilon}) + \\
\int_{Q(1 - e_t^*)}^{\epsilon_t} \lambda \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t) \right) dF(\epsilon) + [1 - F(\epsilon_t)] \times [\lambda \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t) \right)]
\end{align*}
\]

(3.8)

**Case A(ii):** \( A_t \geq A_{t-1}, A_t^O \geq A_{t-1} \)

\[
\begin{align*}
(1 - e_t^*) \times [\lambda \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + Q(1 - e_t^*)) \right) + \int_{Q(1 - e_t^*)}^{\epsilon_t} \lambda \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t) \right) dF(\epsilon) + \\
[1 - F(\epsilon_t)] \times [\lambda \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t) \right)]
\end{align*}
\]

(3.9)

**Case B:** \( A_t^O < A_t \leq A_{t-1} \)

\[
\begin{align*}
(1 - e_t^*) \times [\tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + Q(1 - e_t^*)) \right) + \int_{Q(1 - e_t^*)}^{\epsilon_t} \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t) \right) dF(\epsilon) + \\
[1 - F(\epsilon_t)] \times [\tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t) \right)]
\end{align*}
\]

(3.10)

In each case, the homeowner will only protest if the expected benefit of protesting, net of the cost of effort, is greater than the alternative status quo utility. Setting aside bunching behavior momentarily, an optimal interior solution will choose effort \( e_t^* \) satisfying the first order condition that equates the marginal cost of effort to the marginal benefit, which as derived in Appendix C.3, is given by

\[
MB_{e_t}^{A(i)}(t) = \tau (1 - e_t^*) \cdot q(1 - e_t^*)
\]

(3.11)

\[
MB_{e_t}^{A(ii)}(t) = \lambda \tau (1 - e_t^*) \cdot q(1 - e_t^*)
\]

(3.12)

\[
MB_{e_t}^{B}(t) = \tau (1 - e_t^*) \cdot q(1 - e_t^*).
\]

(3.13)

As is evident, the expected marginal benefit of attempting to achieve a reduction less than the reference point is lower by a factor of \( \lambda \), as is the case in the simpler minimal models.
The Stochastic Reduction Model gives rise to a second bunching prediction.

**Opinion Bunching Proposition.** If $\lambda > 1$, homeowners will propose Opinions of Assessed Value equal to their Previous Assessed Value, resulting in a distribution of protester’s Opinion of Assessed Value that exhibits bunching at the Previous Assessed Value (the reference point).

The original final outcome based bunching prediction is preserved because bunching in the distribution of opinions leads to bunching in the distribution of final outcomes. Figure 2(D) illustrates the opinion bunching proposition, along with the final-outcome bunching that it generates. It shows the simulated distributions of (i) protesters’ initial assessed values (in grey), (ii) protesters’ opinion of assessed value (outlined in navy), and (iii) protesters’ final assessed values (in red). As specified, bunching in the distribution of opinions is necessarily larger than bunching in the distribution of final assessed values.

## 4 Data & Setting

### 4.1 Overview & Essential Summary Statistics

My empirical analysis is based on annual administrative property assessment records and associated protest records from two Texas counties: Harris County (where Houston is located), and Travis County (where Austin is located). In total, the data include 8.7 million annual assessments and 1.8 million protests. For all intents and purposes, the main sample represents all single-family residential property assessments from Harris County for the years 2005-2016, excluding the crisis years, 2008-2010, and the same from Travis County for the years 2011-2018.

Table 1 shows summary statistics for the main variables of interest, separately by county sample. The principal analyses make use of three essential pieces of information available for each property-year observation in the data (i) the Initial Assessed Value, (ii) the Final Assessed Value, and (iii) whether the homeowner protested the Initial Assessed Value. Together, this allows me to directly measure the behavioral tax avoidance response of each property owner, observing not only if an assessment was protested, but also the exact Value Reduction associated with each protest. In total, 19% of Initial Assessed Values are protested. Homeowners Successfully Protest, achieving a reduction in value, 68% of the time in Harris County and 81% of the time in Travis County. On average, a successful protest achieves a 7-8% reduction in assessed value. With an effective tax rate close to 2% of assessed value in both counties, at the mean of property value, this translates to an approximately $275 tax reduction in Harris County, and a $450 tax reduction in Travis County.

### 4.2 Assessment & Protest Records Description

The data come from the Harris County Appraisal District and the Travis Central Appraisal District (HCAD and TCAD, hereafter), the local public offices that, each year, assess the value of all real property in their county.\(^{39}\) Assessment records provide detailed information on a wide array of factors used to determine each property’s assessed value, taxable value, and tax liability. For each property in each year, the data include ownership

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\(^{39}\)HCAD and TCAD only assess the value of property; they do not collect tax revenue.
information, property characteristics,\textsuperscript{40} address and neighborhood, applicable taxing jurisdictions and associated jurisdiction-level tax rates, as well as the owner’s applicable exemptions (i.e. deductions).

The records also contain information about each protest. In both counties, homeowners are notified of their Initial Assessed Value in early spring. If a homeowner intends to seek a lower assessment using the protest process, she must file a notice of protest declaring her intent soon thereafter.\textsuperscript{41} Pooling both samples, 58\% of protests involve the aid of a third-party representative agent. Many protests are resolved informally, with the sides either agreeing to adjust the value, or, alternatively, with the homeowner agreeing that no change in value is warranted, instead accepting the Initial Assessed Value as final.\textsuperscript{42} If not resolved informally, the case advances to a formal hearing adjudicated by the county’s Appraisal Review Board (ARB, hereafter), an independent three-person panel of arbiters. The homeowner (or agent) and assessor each present their opinion of the property’s value and the ARB determines a Final Assessed Value based on the evidence provided. The ARB does not need to choose one side’s proposed value or the other’s, and in fact, often decides that a value between the two is appropriate.

For a selected subset of protests, I observe an Opinion of Value stated by the protestor, elicited at the time of protest filing. These opinions come from a fill-in-the-blank field that is optional if filing notice of protest offline (by mailing in a physical document), but are required of owners filing notice of protest online. Coverage is superior in the Harris sample, where I observe an Opinion of Value for 84\% of protests. In the Travis sample, I only observe an opinion for 12\% of protests. The difference stems from differences in recordkeeping procedures. Whereas HCAD’s records include all opinions supplied by protesters, TCAD’s records primarily reflect opinions entered by owner-protesters who filed notice of protest online. Opinions supplied by owners that filed notice of protest offline and agent-supplied opinions are rarely observed in the Travis sample.

\subsection{4.3 Harris and Travis Samples: Differences and Comparative Advantages}

The Harris County sample spans the years 2005-2016; the Travis County sample spans the years 2011-2018.\textsuperscript{43} In the main analysis, I establish the importance of reference-dependence, excluding the crisis years, 2008-2010, from the Harris sample; however, I briefly discuss that period in the conclusion.

A key difference between the samples relates to each county’s reassessment practices. In Harris County, properties are reassessed approximately every other year but do not adhere to a strict biennial rule. Meanwhile, the vast majority of Travis County properties are reassessed annually. Texas law requires all property to be assessed “at market value” and at minimum, reassessed once every three years; however, county assessors adopt internally-determined standards for reassessment. The Travis sample circumvents a selection process present in the Harris sample that, while highly unlikely to drive observed effects in the

\textsuperscript{40}Property characteristics include features such as square footage, number of bathrooms, number of stories, quality grade, year built, depreciation, parcel acreage, et cetera.
\textsuperscript{41}The protest deadlines are May 15th (Travis) and May 31st (Harris). Property taxes are not due until January 31st of the following year.
\textsuperscript{42}In recent years, a significant portion of informal protests have been resolved online.
\textsuperscript{43}An earlier version of this paper examined only the Harris County sample. The years associated with each sample are restricted to those that were available at the time each sample was collected.
Harris sample, slightly complicates clean identification of the regression discontinuity tests I examine. In particular, in Harris County, reassessment practices lead to slight differences in observable characteristics of properties precisely near the discontinuity threshold of interest. While possible to control for differences in observable characteristics using fixed effects, an identification strategy that does not rely upon the inclusion of covariates more readily supports the key assumption of a regression discontinuity design—that values are as good as randomly assigned in a neighborhood near the discontinuity. Fortunately, Travis County’s reassessment practices provide variation that does not suffer from covariate imbalance, as is present in the Harris sample. For the main RKD protest probability results, I show that the Harris sample and Travis sample produce similar within-household effects. I also show similar effects in the Travis sample without any controls. Presented together, the Travis sample lends confidence to the main results from both counties.44

By and large, the results from both counties serve to reinforce each other throughout the analysis. As discussed above, the Harris sample has superior coverage of Opinion of Value. The samples differ in other dimensions, but in ways that are second-order to understanding the environment. In the Travis sample, the average property value is higher, agents are more commonly used, and more protests are settled informally. In both counties, less than 40% of property-owner pairs protest during the observed tenure. Homeowners can challenge an assessment even if the property was not reassessed; however, for much of the analysis, I focus attention on only reassessed properties, treating a zero percent change in initial assessed value as fundamentally different from receiving any change in value. While reassessed properties reflect a value determined by computer-assisted mass appraisal (CAMA) software (discussed further below), properties that were not reassessed do not reflect a value that is comparably-determined.45

4.4 Institutional Details

4.4.1 CAMA Assessment Valuation

Both HCAD and TCAD use proprietary computer-assisted mass appraisal (CAMA) systems to determine the value of a property. Exact modeling specifications differ but follow a similar structure. The total assessed value comprises the value of land, improvements (i.e. buildings and structures), and extra features. For most properties, the value of improvements accounts for the bulk of the total assessed value. The CAMA software incorporates a variety of improvement characteristics and first estimates the cost of replacement construction. The cost is then depreciated according to a schedule based on the quality of original construction and the age of improvements. To account for demand-side factors, a neighborhood adjustment factor, calibrated using sales ratio tests, uniformly adjusts the value of all property in a neighborhood (inflating or deflating the depreciated value of improvements as appropriate). By design, properties are grouped into neighborhoods

44The online appendix provides additional details on this covariate imbalance near zero percent change in Initial Assessed Value in the Harris County sample. Conditional upon being reassessed, there do not appear to be inconsistencies in the way properties are valued, once accounting for differences in their observable characteristics. In supplementary results, I am able to estimate (i.e. replicate) the Harris County CAMA model very precisely, and show that there do not appear to be systemic differences in the average residual (measuring the difference between the value I predict the CAMA model to assign and the assessed value actually assigned by the CAMA model), near the cutoff point of interest, conditional on being reassessed.

45Reassessment is determined at the neighborhood-level; in other words, if a property was not reassessed, it’s (typically) because all properties in the neighborhood were not reassessed.
based not only on proximity, but also homogeneity.\footnote{Though neighborhood assignment can switch over time, changes are rare, and almost all properties stay within the same neighborhood for the entire duration of the sample.}

### 4.4.2 Property Taxes in Texas

A few additional institutional details are useful to know to understand the setting. By Texas law, all taxable property must be assessed equitably and uniformly at its Market Value as of January 1st each year.\footnote{Unlike many states, Texas does not apply assessment ratios to market values, which artificially alter the nominal value of the tax base.} The Texas Comptroller of Public Accounts—a state-level office—certifies the valuations of the county assessor, regularly checking that each assessor’s values pass the Comptroller’s standardized ratio tests, providing state-level oversight of county office practices. Specific provisions in the state tax code entitle a property owner to assessment relief if she can successfully show that her property is assessed above market value, or if the assessment fails to satisfy certain “uniform and equal” provisions, including, among others less commonly invoked, one that allows for relief if a property owner can show that the assessed value of the property exceeds the median assessed value of “a reasonable number of comparable properties, appropriately adjusted.”\footnote{Texas Property Tax Code Section 42.26 (a)(3).} Texas is a non-disclosure state, and for that reason, I cannot observe sales prices, which prevents me from conducting sales-assessment ratio analyses, and limits the extent to which I can evaluate assessment practices.\footnote{HCAD and TCAD collect sales prices from a variety of (primarily proprietary) sources in order to conduct sales-ratio tests that enter their models, but these sales prices are not included in public records.}

Texas property owners pay property taxes that are on the high end, relative to the national average.\footnote{There is no state income tax.} Notably, certain properties benefit from a legal provision that restricts the amount by which a property’s taxable assessed value may increase in a single year to no greater than 10%. To be eligible, the property must be an owner-occupied primary residence. If a property’s market value is determined to have increased by more than 10%, the taxable portion can only increase by 10% that year, but may increase the following year to the lesser of the current market value or 10% above the intermediate year’s value.\footnote{For example, if the market value of a property is determined to have increased by 15% in year $t$ and by 2% in year $t+1$, the de facto assessed value (the portion that is taxable) would increase by 10% in year $t$ and 7% in year $t+1$.} To distinguish between these values, I use Assessed Value to refer to the underlying Market Value of the property (as determined by the assessor) and use Capped Assessed Value to refer to the taxable portion in instances where they differ. This assessment increase limit introduces a real kink in the marginal benefit of protesting near the 10% threshold, in addition to the psychological kink that is the focus of this paper. As such, for parts of the analysis, I separately analyze the Cap-Eligible Sample and Cap-Ineligible Sample.

### 4.5 Additional Sample Notes

In constructing each sample, I drop a small minority of observations that fail to satisfy a weak set of inclusion criteria. Additionally, I exclude observations in the year of sale, and in years with new construction or remodeling. None of the results meaningfully change if these criteria are not imposed. Sample construction and variable definitions are discussed in further detail in the online appendix.
5 Empirical Analysis of Assessment Protest Behavior

In this section, I test the predictions introduced in Section 3, establishing evidence that Previous Assessed Value serves as a salient reference point to which property owners are loss averse. I begin with the Kink Proposition, first showing flexibly-modeled, within-household evidence of a kink in the probability of protesting at the reference point, then estimating the kink using a regression kink discontinuity (RKD) design. I then test both bunching propositions, which show clear evidence of excess bunching at the Previous Assessed Value in both the distribution of Final Assessed Value, and the distribution of protesters’ Opinion of Value. Further evidence consistent with the reference-dependent framework is briefly discussed in Section 5.4. I discuss the extent to which alternative mechanisms warrant consideration in Section 6.

As discussed in Section 4, while the Harris County sample is larger and has superior coverage of protesters’ Opinion of Value, Travis County’s reassessment practices provide the best variation for identification; in particular, the vast majority of Travis County properties are reassessed annually. As such, I present the main findings for both counties, but focus attention on the Travis County sample for parts of the analysis.

5.1 Testing the Kink Proposition

5.1.1 Global Kink Evidence

Figure 3 presents straightforward, flexible evidence of a kink in the probability of protesting precisely at the reference point. It plots the coefficients of a linear probability model of protesting as a function of Percent Change in Initial Assessed Value, partitioned into evenly-spaced one-percentage-point-width bins with property-owner pair and year fixed effects. Formally, letting \( \ddot{A}_i t \equiv \log \left( \frac{A_i t}{A_{i-1} t} \right) \), it shows the probability of protest in each of \( J \) Percent Change in Initial Assessed Value bins \( Z_j \), as estimated by,

\[
P_i t = \sum_j \beta_j \cdot 1_{\{ \ddot{A}_i t \in Z_j \}} + \alpha^0 \cdot 1_{\{ \ddot{A}_i t = 0 \}} + \omega_i + \eta_t + \epsilon_i t \tag{5.1}
\]

where \( P_i t \) indicates that household \( i \) protested its Initial Assessed Value in year \( t \), \( \omega_i \) and \( \eta_t \) represent property-owner pair and year fixed effects, respectively, and \( \epsilon_i t \) an error term.

The coefficients are normalized to the probability of protest given a Percent Change in Initial Assessed Value between -1% and 0%.

An indicator associated with exactly no change in Initial Assessed Value (properties that were not reassessed) is included in the estimation to increase the identifying sample for the property-owner pair fixed effects, but excluded from the figure. Indicators associated with a change in Initial Assessed Value (i) greater than 40%, and (ii) less than -40% are also included in the estimation but not in the figure (i.e. extreme values are binned at ±40%, respectively).

52Technically, \( \ddot{A}_i t \in (-0.01, 0) \). Note that throughout the empirical analysis, all estimates are based on the log points. For many figures, I multiply the log points by 100 for ease of communication and information consumption.

53In other words, the “first” bin in the gain domain, just to the left of the reference point.

54Properties receiving exactly zero percent change in Initial Assessed Value were not reassessed, and thus are not assigned a value that is comparable to properties for which the assessed value changed. As such, properties receiving exactly no change can be systematically different from those that are reassessed. The identifying assumption is that properties are comparable, conditional on being reassessed.

55Terms specifying the precise definition of these binned endpoints at ±40% are suppressed in Equation (5.1).
I cluster standard errors at the neighborhood level to allow for correlation in errors both spatially and over time.\footnote{Clustering at the property level is inappropriate given that each property’s assessed value is partially determined by an annually-calibrated market adjustment factor applied to all properties in a neighborhood.}

Figure 3 provides global evidence of a kink in the probability of protest exactly at the reference point in both Harris County (Panel A) and Travis County (Panel B). Below zero percent change in Initial Assessed Value—\textit{in the gain domain}—the estimated coefficients are, for the most part, statistically indistinguishable from zero, meaning a homeowner was as likely to protest, for example, an Initial Assessed Value that was 10\% lower than the Previous Assessed Value as they were to protest an Initial Assessed Value that was 0.5\% lower than their Previous Assessed Value (an observation that would be contained in the omitted bin). The Travis County sample shows estimated coefficients that are positive for very large reductions in Initial Assessed Value, but as shown by the histogram in Figure 8(B)(i), those estimates are based on a portion of the distribution with limited observations.\footnote{This is also evident from the instability of the estimates and the size of the confidence intervals.} By contrast, immediately to the right of zero percent change in Initial Assessed Value—\textit{in the loss domain}—the slope of the conditional expectation increases sharply, indicative of a change in the elasticity of protesting with respect to percent change in Initial Assessed Value.

Figure 4 contains plots analogous to Figure 3, but separates each county sample into a \textit{Cap-Eligible Sub-Sample} and \textit{Cap-Ineligible Sub-Sample}. The reason to do so is twofold. First, as is evident from the figure, the kink in the probability of protesting near the reference point is present among both Cap-Eligible homeowners and among Cap-Ineligible homeowners, lending confidence to the idea that the psychological kink (near zero) is not somehow related to the real kink associated with the assessment increase limit. Second, as discussed in Section 3, a reference-dependent model predicts a conditional expectation that has a slope that is steepest close to the reference point, but that flattens as the extensive margin effect of loss aversion applies to fewer and fewer property owners. While confounded with the real kink in the benefit of protesting above +10\% for Cap-Eligible homeowners, the Cap-Ineligible Sub-Sample shows a probability that becomes noticeably flatter for larger increases in Initial Assessed Value, providing suggestive evidence consistent with a waning extensive margin effect predicted by the reference-dependent model.

Figure 5 plots the probability of protesting split along a different dimension, separately estimating owner protests and agent protests. Splitting protests in this way, it is clear that the kink in the probability of protesting near zero percent change in Initial Assessed Value appears strongest for owner-protests. The left-hand panels (Panels 5A(i) and 5(B)(i)) show a distinct kink in the probability of owner-protests in both counties. Meanwhile, the evidence for agent-protests is somewhat mixed: in the Harris County sample, the probability of an agent protesting (on behalf of an owner) appears to be smooth through the reference point, exhibiting no reference-dependent kink; however, in the Travis County sample, there appears to be a kink. In Section 6, I discuss the extent to which the evidence as a whole suggests that observed protest behavior is driven by homeowners’ preferences (as specified by the model), and not other factors in the environment; these results provide a first piece of evidence favoring that view.
5.1.2 Local Linear Regression Kink Discontinuity (RKD) Estimates

To formally estimate the kink visually evident in Figures 3, 4, and 5, I employ local linear regression kink discontinuity (RKD) methods (à la Card et al. (2015)). The selection process governing reassessment in Harris County hinders clean identification of kink in that sample, as is evident from slight differences in observable characteristics near the threshold of interest. For that reason, I begin by presenting RKD estimates from the Travis County sample without any controls, and complementary evidence of covariate balance in the Travis County sample. I then go on to present RKD estimates from both counties (separately) that include property-owner pair and year fixed effects, thus aligning with the global evidence previously discussed. Presented together, the Travis County no-covariate RKD estimates lend confidence to the within-household RKD estimates from both counties. Reassuringly, the results are quite similar to each other.

The RKD design estimates the (semi-)elasticity of protesting with respect to percent change in Initial Assessed Value on either side of the reference point, within a symmetric bandwidth \((-h, h)\) as specified by the local linear model,

\[
P_i^j = \mathbf{1}_{\{-h \leq \hat{A}_i \leq 0\}} \cdot \left[ \alpha^- + \beta^- \cdot \hat{A}_i \right] + \mathbf{1}_{\{0 < \hat{A}_i \leq h\}} \cdot \left[ \alpha^+ + \beta^+ \cdot \hat{A}_i \right] + \epsilon_i. \tag{5.2}
\]

As indicated, \(\beta^-\) identifies the elasticity below the reference point, and \(\beta^+\) identifies the elasticity above the reference point. Estimating the kink amounts to testing for a difference in these elasticities, \(\beta^+ - \beta^- > 0\).

The identifying assumption in the RKD design is that unobserved determinants of protesting are smoothly distributed with respect to the running variable. In the context of the analytical model, this requires that the (unobservable) noise term and (unobservable) effort cost parameters be distributed continuously and with continuous first derivatives in a neighborhood around the reference point. Appendix Figure A.5 and Appendix Table B.1 provide diagnostic covariate balance tests for key variables that determine the CAMA-model-assigned Initial Assessed Value. Visually, observable property characteristics appear to be balanced near the threshold of interest. Placebo RD and RKD regressions estimates using the CCT-selected bandwidth from the RKD estimate of the main outcome of interest (presented next, and shown in Figure 6(A)) are shown in Appendix Table B.1. Using conventional standard errors (clustered at the neighborhood level), only Year Built has a placebo RD estimate marginally significant at the 5% level; similarly, only CDU Grade shows placebo RKD that is marginally significant at the 5% level. By and large, these diagnostic checks provide evidence of covariate balance, and assurance to the RKD design.

58 In Harris County, properties are selectively reassessed in a way that leads to slight differences in observable time-invariant characteristics of properties precisely near the threshold of interest (see Section 4 for additional comments). Of course, by including property-owner pair fixed effects in the main results in Figure 3, estimated effects should be interpreted as holding time-invariant factors fixed, thus controlling for theses differences; however, if differences in observable characteristics are indicative of differences in unobservable characteristics that are not controlled by the fixed effects strategy, the comparability of households on either side of the reference point may not be as good as randomly assigned in the Harris County sample, potentially indicative of a threat to identification. Given that covariate balance appears be a potential concern in the Harris County sample, I only present local RKD results for the Travis County sample.

59 Although a kink in the first derivative could be estimated with a higher order polynomial, Gelman and Imbens (2019) suggest that lower-order polynomial models are less likely to lead to incorrect inference. In the main results, I show the quadratic-robust biased-corrected standard errors suggested by Calonico et al. (2014).

60 Some covariates have placebo RD estimates that are significant with respect to the CCT quadratic-robust confidence interval; but none show a significant RKD estimate using the CCT quadratic-robust confidence interval.
Figure 6 shows the RKD protest elasticity kink estimates, as estimated by Equation 5.2 in the Travis County sample. Each sub-figure shows a bandwidth sensitivity analysis, plotting the estimated kink, $\beta^+ - \beta^-$, from separate regressions, each estimated using a different bandwidth $h \in [0.02, 0.10]$. For transparency, no controls are included in these estimates. Each figure also shows the MSE-optimal bandwidth selected by the procedure suggested by Calonico et al. (2015) (indicated on each sub-figure with the dashed pink line), as well as quadratic-robust confidence intervals suggested by Calonico et al. (2014) for the CCT-bandwidth (shown overlaying the dashed pink line). Overall, the figures show substantial evidence of a kink, which is strongest among protests by owners (Panel D). Table B.2 shows the estimates underlying three of the kink estimates in Panel A (which includes the full Travis sample). Both $\beta^-$ and $\beta^+$—which can be interpreted directly as (semi-)elasticities—are estimated as larger when using a smaller bandwidth, and attenuate at wider bandwidths.

Figure 7 shows estimates produced by an RKD design that includes property-owner pair and year fixed effects. In order to increase the sample identifying the property-owner pair fixed effects, I include observations outside of the kink-estimating bandwidth and properties that were not reassessed, essentially combining Equations (5.1) and (5.2), and estimating,

$$P_i = 1\{-h \leq A_i \leq 0\} \cdot \left[\alpha^- + \beta^- \cdot \bar{A}_i\right] + 1\{0 < A_i \leq h\} \cdot \left[\alpha^+ + \beta^+ \cdot \bar{A}_i\right] + 1\{A_i \in Z_j\} \cdot \sum_j \beta_j \cdot 1\{A_i \in Z_j\} + \alpha^0 \cdot 1\{A_i = 0\} + \omega_i + \eta_t + \epsilon_i.$$ (5.3)

Like the standard approach above, $\beta^+ - \beta^-$ identifies the kink estimated by this within-household procedure, which produces a stable estimate of the kink close to 0.7 in the Harris County sample, and an estimate of the kink that hovers between 0.8 and 1.0 in the Travis County sample. In both samples, estimates of $\beta^-$ are close to zero, leading estimates of the kink to be very close to estimates of $\beta^+$. Across both samples, $\beta^+$ is estimated to be between 0.7-1.0, meaning that to the right of the reference point—in the loss domain—a one percent increase in Initial Assessed Value is associated with a 0.7-1.0 percent increase in the probability of protesting. Altogether, the results from both the no-covariate Travis bandwidth tests, and the within-household bandwidth tests show estimated kinks that suggest a difference in elasticities between approximately 0.6 and 1.0, as shown in the figures.

5.2 Testing the Bunching Proposition

To test the Bunching Proposition, I estimate the excess mass at no change in Final Assessed Value in the distribution of log change (i.e. percent change) in Final Assessed Value,$^{63}$ using techniques similar to those developed by Saez (2010), Chetty et al. (2011), and later applied by Rees-Jones (2018). For this analysis I use only the Re-assessed Sub-Sample, excluding households that mechanically received an Initial Assessed Value equal to their Previous Final Assessed Value because the property was not re-assessed.

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$^{61}$The main RKD results are estimated using a uniform kernel. The online appendix contains versions of these figures using a triangular kernel, and also versions of these figures that include year fixed effects (separately by kernel type).

$^{62}$All results are estimated using the rdrobust package associated with Calonico et al. (2017).

$^{63}$That is, the log of Final Assessed Value divided by the Previous Final Assessed Value.
Partitioning observations into equal-sized bins according to their percent change in Final Assessed Value, I estimate the distribution of log change (i.e. percent change) in Final Assessed Value within a bandwidth near the reference point using a P-degree polynomial, and allowing for excess mass at the reference point. I do this in two different ways, first restricting the polynomial to be symmetrically estimated on either side of the reference point by estimating,

$$B_j = \sum_{k=0}^{P} \beta_k \cdot (Z_j)^k + \gamma \cdot 1[Z_j = R] + \epsilon_j,$$  \hspace{1cm} (5.4)

and, alternatively, allowing the polynomial to be separately estimated on either side of the reference point by estimating,

$$B_j = \sum_{k=0}^{P} 1_{Z_j < R} \cdot \beta_k^L \cdot (Z_j)^k + \gamma \cdot 1[Z_j = R] + 1_{Z_j > R} \cdot \beta_k^R \cdot (Z_j)^k + \epsilon_j.$$  \hspace{1cm} (5.5)

In both cases, $B_j$ is a count of households in Final Assessed Value bin $j$, $Z_j$ represents the final assessment bin value, $R$ is the reference point (i.e. the bin associated with no change in Final Assessed Value), and $\epsilon_j$ an error term. With the symmetric polynomial model specified in Equation (5.4), the excess mass is identified by $\gamma$. With the asymmetric polynomial model specified in Equation (5.5), the excess mass as calculated from the left is identified by $\gamma$ less the predicted mass in the bin just to the left of the reference point, and excess mass as calculated from the right is identified by $\gamma$ less the predicted mass in the bin just to the right of the reference point. For the baseline specifications, I use a 7th-degree polynomial and a bin width of 5 basis points (0.05%), which translates to approximately one tax dollar for the median Harris County property, and approximately two tax dollars for the median Travis County property.

Table 2 contains estimates of excess bunching at the reference point in the distribution of (i) all households, (ii) protesters, and (iii) successful protesters, as well as for (iv) owner protesters and (v) agent protesters. The left-hand panel shows the estimates using the symmetric polynomial model specified by Equation (5.4); the right-hand panel shows the estimates using the asymmetric polynomial model specified by Equation (5.5). For each of these groups and models, I show estimates of excess mass using a 0.10 log point bandwidth; however, the results are not sensitive to the choice of bandwidth or bin size.

Figure 9 illustrates the estimation underlying the estimated excess mass for two of the specifications in the table. The top panel shows the final distribution of Harris County protesters; the bottom panel shows the final distribution of Travis County protesters. Both show unambiguous bunching at the Previous Assessed Value. Turning back to Table 2, in the Harris County sample, the excess mass represents 0.9% of all reassessed households, or equivalently, 4.2% of (reassessed) protesters, or 5.5% of (reassessed) successful protesters. In the Travis County sample, the excess mass represents 0.3% of all reassessed households, 1.5% of (reassessed) protesters, and 1.8% of (reassessed) successful protesters. Owners that protest appear more likely to end at their Previous Assessed Value than agent protesters, and notably, the excess mass is larger in the Harris County sample. I discuss both of these later observations further in Section 6.

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64The online appendix shows robustness versions that use alternate bandwidth and bin sizes.
5.3 Testing the Opinion Bunching Proposition

Turning to the Opinion Bunching Proposition, I examine protesters’ stated Opinion of Value, elicited at the time of protest filing before informal or formal review. While an imperfect measure, protesters’ Opinion of Value provides evidence that homeowner preferences drive the patterns observed. In Section 3, I introduce $A^O$ as the homeowner’s proposed opinion of assessed value into the stochastic analytical model, assuming a particular structure and role. Using the structure of the model as a guide, I view empirically-observed homeowner opinions as, at minimum, correlated with their model counterpart. Coverage of Opinion of Value is imperfect in both samples, but far superior in Harris County. In both counties, the observed sample is selected, as providing an Opinion of Value is optional at the time of protest. Furthermore, due to recordkeeping procedures, coverage of Opinion of Value is low in the Travis County sample, even conditional on supplying an opinion. Most observed opinions come from owner-protests filed electronically (rather than on paper). Agent provided opinions are rarely recorded in the Travis sample.

With those caveats in mind, evidence clearly points to strong bunching tendencies. Table 3 contains estimates of excess bunching at Previous Assessed Value in the distribution of protesters’ Opinion of Value among (i) all protesters, (ii) owner protesters, and (iii) agent protesters, in the Re-assessed, Opinion-Stated Sub-Sample from Harris, and for all protesters in the Travis sample. In the Harris County sample, among those that stated an opinion, the estimated excess mass represents 11% of all protesters, 12.7% of owner protesters, and 9.5% of agent protesters. Exercising more caution with the Travis sample, evidence still points to substantial bunching, with 5.5% of all opinion-stated protesters bunching at the Previous Assessed Value.

Appendix Table A.2 further reinforces the importance of Previous Assessed Value for protesters’ valuations. The left-hand panel shows a histogram of Opinion of Value relative to the Previous Assessed Value in dollars (rather than percent differences); the right-hand panel shows a histogram of Opinion of Value relative to the Initial Assessed Value. Comparing these histograms, protesters are clearly much more likely to state an Opinion of Value that is an exact round-dollar-amount multiple away from the Previous Assessed Value than they are to state an Opinion of Value that is an exact round-dollar-amount multiple away from their Initial Assessed Value. While also indicative of a heuristic anchoring-and-adjustment process at play, this shows clear evidence that Previous Assessed Value is at the fore of protesters’ attention.

Notably, there is more bunching in the Opinion of Value distribution than in the Final Assessed Value distribution. The model makes the same prediction, and furthermore predicts that bunching in the distribution of Final Assessed Value is a direct consequence of opinion bunching. Appendix Table B.4 shows correlational regression estimates from the Harris sample that relate bunching in the distribution of Final Assessed Value to opinions. While there exists bunching in the distribution of Final Assessed Value among protesters that did not state an opinion equal to their Previous Assessed Value, the estimates clearly show that final value bunching is more common among protesters that did.
5.4 Conditional Average Assessment Reductions Near the Reference Point

Figure 11 plots the average percent reduction received by successful protesters, estimated analogously to Equation (5.1) with individual and year fixed effects, and larger values corresponding to larger reductions. Coefficients are normalized to the average reduction given a percent change in Initial Assessed Value between -1% and 0%. The top panel shows successful protesters in the Harris sample; the bottom panel shows successful owner-protesters in the Travis sample. Both plots show that the average reduction received by successful protesters drops for those just barely in the loss domain, consistent with an extensive margin effect induced by loss aversion. The Travis County sample excludes agent-protesters, as the effect is only pronounced when the sample is limited to owner-protesters.

An assumption of the model is that the average noise in assessments is smoothly distributed around the reference point. If, arbitrarily, properties that increased in value were disproportionately more likely to be over-assessed by a greater amount, we would expect a kink in the probability of protesting at the reference point, but we would also expect those homeowners to receive larger reductions on average. Instead, we see the opposite, a result consistent with the reference-dependence framework.

6 Alternative Mechanisms & Robustness of Results

Having established evidence consistent with tax avoidance behavior driven by loss aversion, I now address the extent to which alternative mechanisms warrant consideration in understanding the observed behavior.

6.1 Owner vs. Agent Preferences

Third-party agent representatives handle more than half of all protests. Conceivably, agents could be loss averse. While interesting in and of itself, one would expect the reference point to weigh most heavily on homeowners themselves; if there were evidence suggesting the contrary, that would give pause to the purported theory. I do not attempt to separate the preferences of agents from the preferences of the homeowners they represent in agent-protested cases, but we can examine differences between agent-protested cases and owner-protested cases. In particular, (i) the extensive margin evidence is most clear in owner-protested cases (kinks in Figures 5 and 6, and average reductions in Figure 11), (ii) owner-protesters are more likely to achieve a Final Assessed Value at the Previous Assessed Value (Table 2), and, (iii) at least in Harris County, owners are more likely to state that their Opinion of Value is equal to their Previous Assessed Value (Table 3). Together, while not ruling out the possibility that reference-dependence has some bearing for agents, on balance, evidence points to reference-dependent actions being most associated with owners. In fact, this evidence could suggest that third-party agents in fact de-bias property owners, influencing them to act less loss averse than they otherwise might.

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65Percent reductions defined as $100 \cdot \log \left( \frac{A_{t}^{\text{Init}}}{A_{t}^{\text{Final}}} \right)$.
6.2 Reviewer Preferences & Differences in the Probability of Successfully Protesting

The kink and bunching evidence could result from the protest process itself if it is difficult to convince a reviewer (be it an assessor or review board) to lower an assessment below the Previous Assessed Value. Figure A.6 plots the probability of winning, conditional upon protesting, with homeowner and year fixed effects. Coefficients are normalized to the probability of winning given a change in Initial Assessed Value between -1% and 0%. In both county samples, there appears to be a slight increase in the probability of winning a protest to the right of the reference point, particularly in the Travis sample. While seemingly indicative of a potential dynamic involving differences in the marginal cost of achieving a reduction above the Previous Assessed Value, it is important to recognize that the baseline probability of winning is quite high. Choosing 2011 as a common base year, the baseline probabilities of success are 80% in Harris and 83% in Travis. Given the high baseline likelihood of winning, differences in the probability of winning on either side of the reference point are unlikely to drive the observed pattern in the probability of protesting, especially in the Harris County sample, where the difference is minimal. Furthermore, differences in the probability of winning near the kink could also result from homeowner loss aversion. While in my analytical model effort does not affect the probability of winning a protest, one could imagine a margin for effort that influences the probability of winning.

6.3 Salience, Heuristics, Reviewer Preferences & Previous Assessed Value as a Bargaining Point

The amount of bunching generated from reference-dependent behavior depends on the ability to target a specific value. In the present context, bunching is quite substantial. In part, the observed bunching may be biased to the extent that the process determining final values (or opinions too, for that matter) disproportionately yields a final value (or opinion) that is, in one way or another, heuristically determined. In supplementary results, I show that there is excess bunching at round dollar values, and at round-dollar-amount multiples away from both the Previous Assessed Value and Initial Assessed Value. That said, similar to the distribution of opinions shown in Appendix Figure A.2, bunching at the Previous Assessed Value dwarfs bunching at other notable values.

Without complementary evidence on protesters’ Opinion of Value, one might wonder if final outcome bunching at the Previous Assessed Value is driven by reviewer preferences. Certainly, strategic concerns may influence some protesters’ opinions; however, because reductions need to be accompanied by supporting evidence, the margin for bargaining is limited. Appendix Figure A.7 shows how Final Assessed Value compares to both the Initial Assessed Value and Opinion of Value in the Harris sample. Splitting the difference between Opinion of Value and Initial Assessed Value appears to occur slightly more that randomness would predict (as indicated by the excess mass at 0.5), but it is certainly not the norm. Overall, the large and significant amount of excess bunching in protester Opinion of Value suggests that protester preferences significantly impact the amount of bunching observed in the distribution of Final Assessed Value.

Intricacies introduced by these additional dynamics warrant future research, but their impact is likely marginal, and furthermore, limited to the intensive margin.
6.4 Liquidity Constraints

A final alternative explanation relates to liquidity constraints, which could seemingly drive similar results if households do not budget for potential increases in their property taxes. This is an unlikely explanation for at least two reasons. Property assessments must be challenged in the beginning of the fiscal year, but property taxes are not paid until the end. A liquidity constrained income tax filer who, close to the filing deadline, unexpectedly discovers that she owes income tax in excess of what was already withheld, may only have a few weeks or days to absorb the shock and come up with the necessary payment; by contrast, a property tax filer will have several months.

Direct behavioral evidence also points to liquidity constraints as an unlikely explanation. A reference-dependence framework predicts an elasticity of protesting with respect to percent change in Initial Assessed Value that may eventually flatten, as I show empirically. A model with liquidity constraints would instead produce a probability of protesting that continually increases, at least without further assumptions. Furthermore, in the next section, I point out that owners of more valuable properties, who we would expect to be less likely to be liquidity constrained, are much more likely to protest.

7 Contextualizing the Ultimate Effects of Loss Aversion

To contextualize the ultimate impact of loss aversion, I now shift my focus, briefly highlighting a few informally calculated counterfactuals. For this exercise, I focus again on the Travis County sample to avoid any issues arising from selection into reassessment, potentially present in the Harris sample. The aim is to provide back-of-the-envelope estimates for four outcomes of interest: (i) the excess protests induced by loss aversion, (ii) the administrative burden of handling these excess protests, (iii) the revenue lost due to loss aversion, and (iv) an effect size in tax dollars per household-year observation. The essence of this exercise is to first empirically estimate areas equivalent to the shaded regions shown in simulation Figures 2(A) and A.4(C), and then to use those estimates to calculate the aforementioned outcomes. The shaded region in Figure 2(A) shows the excess probability of protesting in the loss domain; the shaded region in Figure A.4(C) shows the excess percent reduction in property value among all households, not just those that protest, which singularly captures the total effect, comprised of both an intensive and extensive margin effect associated with loss aversion.

In order to err significantly towards understating the effects of loss aversion, I restrict attention to, and only calculate counterfactuals for, a region of the distribution close to the reference point. Because these counterfactuals rely on estimated behavior in the gain domain extrapolated into the loss domain, reasonable people will disagree about the bandwidth within which we can confidently estimate counterfactuals that reasonably reflect the true counterfactual. With that caveat in mind, I proceed with the analysis, choosing as a bandwidth those properties for which the percent change in initial assessed value was between ±10%. Intentionally, this represents exactly the region of the loss domain below the 10% cap in assessed value (and a symmetric region of the gain domain). Simultaneously it strikes a balance between refraining from extrapolation far from the reference point, while still covering a substantial portion of the distribution.

The approach to estimating counterfactuals is straightforward. Partitioning the data into bins with width equal to five basis points, I first estimate the probability of protest in
the gain domain, estimating,

\[ P_j = \sum_{k=0}^{K} \beta_k^G \cdot (Z_j)^k + \epsilon_j \quad \text{if } -h < Z_j \leq 0 \]  

(7.1)

and then extrapolate the fitted values from the gain domain to predict a counterfactual probability of protesting in the loss domain,

\[ \hat{P}_{j}^{CF} \equiv \sum_{k=0}^{K} \hat{\beta}_k^G \cdot (Z_j)^k \quad \text{if } 0 < Z_j < h. \]  

(7.2)

The excess probability of protest in each bin \( \hat{P}_j \) is then defined as the deviation between actual probability of protest and the counterfactual,

\[ \hat{\mu}_j^P \equiv P_j - \hat{P}_{j}^{CF} \quad \text{if } 0 < Z_j < h. \]  

The excess percent reduction achieved is calculated in an exactly parallel fashion, first estimating the average percent reduction in gain domain,

\[ \Delta A_j = \sum_{k=0}^{K} \beta_k^G \cdot (Z_j)^k + \epsilon_j \quad \text{if } -h < Z_j \leq 0, \]  

(7.3)

then extrapolating the fitted values from the gain domain to predict a counterfactual average percent reduction in the loss domain,

\[ \Delta \hat{A}_{j}^{CF,\lambda=1} = \sum_{k=0}^{K} \hat{\beta}_k^G \cdot (Z_j)^k \quad \text{if } 0 < Z_j < h \]  

(7.4)

and defining the excess reductions in each bin \( \hat{\mu}_j^{Red} \) as the deviation between the actual mean reduction and the counterfactual,

\[ \hat{\mu}_j^{\Delta A} = \Delta A_j - \Delta \hat{A}_{j}^{CF,\lambda=1} \quad \text{if } 0 < Z_j < h. \]  

With \( \hat{P}_j \) and \( \hat{\mu}_j^{Red} \), one can readily calculate an aggregate or per household effect by appropriately weighting these objects.\(^{66}\)

Figures 12 and 13 illustrate the results of this exercise. To align with the more formal local linear RKD results in section 5, I present the counterfactual estimates derived from linear estimations (\( K = 1 \)), which, at minimum, deliver a first-order approximation; the online appendix includes a version of these figures based instead on quadratic polynomial estimates (\( K = 2 \)). The top panel of Figure 12 shows the excess probability of protest in the loss domain among all reassessed households in Travis County. In total, the bandwidth covers 55% of all reassessed properties. Following the procedures outlined

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\(^{66}\)For example, with \( n_j \) representing the number of observations in bin \( j \), \( \Delta \text{Total Protests} = \sum_j \hat{P}_j \times n_j \), and \( \Delta \text{Total Assessed Value} = \sum_j \hat{A}_j \times \bar{A}_j \times n_j \).
above, and accounting for the underlying distribution, I estimate that loss aversion increases the number of protests filed (among those in this portion of the loss domain) by 50%, representing an additional 5,000 protests per year, and 5% of all households in the bandwidth.

Making crude, but reasoned assumptions, I estimate that each additional protest incurs an administrative cost (to the county) of at least $14.38, based upon a handling time I assume, and actual labor costs (detailed in Appendix D). It almost surely understates the true administrative cost of a protest, which, if more comprehensively estimated, would also include non-labor expenses. Taking this estimate at face value, it suggests that the excess protests induced by loss aversion burdens Travis county with an administrative cost of at least $72,000 annually.

Figure 13 shows the excess average percent reduction in assessed value in the loss domain among all households. Following the procedures outlined above, and accounting for the underlying distribution, I estimate that loss aversion increases the value of reductions received (among those in the portion of the loss domain shown) by 66%. The counterfactual difference in terms of assessed value averages $91 million per year, or, in terms of tax dollars, $2 million per year. Figure 13(A) shows how this estimate translates into an effect size per household-year observation. Overall, estimates suggest that loss aversion induces property owners in this portion of the loss domain to secure reductions in their tax liability averaging $25 annually, unconditional on protesting; however, that singular estimate is a bit misleading, as the size of the effect depends substantially on one’s position in the loss domain.

The right-hand panels of Figures 12 and 13 show the results of the same exercise, but limited to a sample of properties that constituted the top quartile of initial assessed value for each given year. The mean initial assessed value in this sub-sample is $693,000, and those properties account for 45% of all protests. As shown by the counterfactual estimates in the figures, this group largely drives the effects estimated from the full sample. Figure 13(B) further contextualizes the effect of loss aversion, showing that loss aversion induces property owners in this portion of the loss domain to secure reductions in their tax liability averaging $96 annually, unconditional on protesting. Meanwhile, among top-quartile households that experienced a 10% increase in assessed value—a substantial, but not extraordinary increase—the average unconditional tax liability effect size is close to $200.

8 Discussion & Conclusion

This paper unveils the importance of reference-dependence and loss aversion in understanding property tax avoidance. In doing so, I add to an emerging literature in public finance that examines psychological bias and tax morale as a determinant of tax compliance.

Compared to other taxes, morale for the property tax is especially low. Between 1988 and 2005 (the most recent year available), the fraction of survey respondents in a Gallup poll that cited the property tax as the worst or least fair tax rose from 24% to 42%. In all likelihood, the increasing dislike relates to the substantial increase in home prices (and corresponding property taxes) that occurred during that period. That tax increases are

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67 The loss domain portion of the bandwidth averages 74,000 property observations per year.
68 For example, ARB members must be trained, and hearings require office space. In 2019, TCAD purchased 72,720 square feet of office space specifically acquired to handle the large volume of protest cases.
disliked is hardly surprising; however, recognizing the acute role played by loss aversion helps to explain why contempt for property taxes is particularly emotive. Indirectly, the findings in this paper suggest further explanation for the popularity of property tax limit measures, such as California’s famous Proposition 13, because they not only allow taxpayers to avert taxes but also limit feelings of loss. Furthermore, by setting expectations for future tax increases, feelings of loss are ameliorated.

The extent to which loss aversion influences avoidance may be substantially greater in the property tax setting as compared with an income tax setting for the simple reason that with property taxes, individuals are more likely to find themselves in the loss domain. Whereas the majority of income tax filers receive a refund at the end of the year, even without any avoidance measures, historically, housing prices have steadily increased, leading to a distribution of value changes that, more often than not, is centered in the loss domain.

Unearthing reference-dependence as both critical and transparently observable in the property tax setting could also aid the future research of reference-dependence more generally. Protest behavior from the crisis years 2008-2010 provides suggestive evidence of a partially-adaptive reference point during that period. While beyond the scope of this paper, in future research the property tax setting may prove useful in further understanding the endogeneity of reference points, or the simultaneous influence of multiple reference points.

Understanding the psychology of reference dependence and loss aversion could inform policy-relevant practices that subvert its effects. Assessment notices prominently feature the property’s Previous Assessed Value. Including additional, equally prominent reference points on assessment notices may significantly affect household protest behavior. For example, a homeowner upset that his taxes have increased, may be less upset if his notice also makes clear that his neighbors’ taxes have increased as well. Indeed, similar strategies have been shown to change behavior in residential energy usage (Allcott, 2011). Conversely, to ensure fairness and, potentially, to increase trust in the institution, it might be prudent to remind homeowners on their tax notice that a property may still be overvalued despite a decline in assessment, and hence warrant protest.

Establishing loss aversion’s significance may also shed new light on open questions related to property tax appeals and administration. For example, if people have systematic differences in the tendency to behave in a manner consistent with loss aversion, it may lead to nonuniform or inequitable assessments. Finally, a question this research raises is whether any localities attempt to exploit loss aversion to raise additional revenue, perhaps especially if financially strained. In principle, a tax assessor could systematically over-assess property that has decreased in value, leveraging the fact that households are unlikely to protest assessments as long as they do not increase. In all likelihood, this would place undue burden on households that are already financially strained.
References


Figure 2: Model Simulation: Illustrating the Effect of Loss Aversion on the Probability of Protest, the Distribution of Assessed Values, and the Assessment Value Reductions Received.

(A) Probability of Protest
(B) Initial and Final Assessed Values
(C) Average Reduction (%) | Successful Protest
(D) Protesters’ Initial, Opinion, and Final Assessed Values
(E) Average Reduction (%) | All Households

Notes: These figures illustrate the results of a simulation \( N = 1,800,000 \) of the Stochastic Reduction Model outlined in Section 3 parameterized as follows: \( \gamma = 0.022 \), \( \lambda = V_{t-1} = 150,000 \), Initial \( A_t = V_{t-1} + \Delta V_t + \epsilon_t \) where \( \Delta V_t \sim N(3000,15000) \) and \( \epsilon_t \sim N(0,15000) \), and \( \lambda \sim N(2.0, 0.3) \). The cost function is given by \( \kappa + \phi \times e^{\gamma} \) with \( \kappa \sim \text{Lognormal}(4.9, 1.5) \), \( \phi \sim N(500, 150) \), and \( \gamma \sim N(1.3, 0.1) \). In the simulation, 16.4% of agents protest, and 1.8% of agents state an opinion at the Previous Final Assessed Value leading to an excess mass of households in the distribution of Final Assessed Values at the Previous Final Assessed Value equal to 0.7% of all households.
Figure 3: Probability of Protest by Percent Change in Initial Assessed Value.

Notes: Estimated coefficients from a linear probability model of protesting given percent change in Initial Assessed Value, binned into one percentage point bins, with property-owner pair and year fixed effects. Coefficients are normalized to the probability of protest given a percent change in Initial Assessed Value between -1% and 0%. An indicator associated with exactly no change in Initial Assessed Value is included in the regression to increase the identifying sample for the individual fixed effects, but is omitted from the figure; likewise, indicators associated with a change in Initial Assessed Value (i) greater than 40%, and (ii) less than -40% are included in the regression but not in the figure (i.e. extreme values are binned at ±40%, respectively). Crisis years defined as 2008-2010. Standard errors are clustered at the neighborhood level.
Figure 4: Probability of Protest by Percent Change in Initial Assessed Value splitting Cap-Eligible and Cap-Ineligible properties.

Notes: Analogous to Figure (3) but splitting homeowners into sub-samples that are (i) eligible to benefit from a capped assessed value provision (at 10%), and (ii) ineligible to benefit from a capped assessed value. Estimated coefficients from a linear probability model of protesting given percent change in Initial Assessed Value, binned into one percentage point bins, with property-owner pair and year fixed effects. Coefficients are normalized to the probability of protest given a percent change in Initial Assessed Value between -1% and 0%. An indicator associated with exactly no change in Initial Assessed Value is included in the regression to increase the identifying sample for the individual fixed effects, but is omitted from the figure; likewise, indicators associated with a change in Initial Assessed Value (i) greater than 40%, and (ii) less than -40% are included in the regression but not in the figure (i.e. extreme values are binned at ±40%, respectively). Crisis years defined as 2008-2010. Standard errors are clustered at the neighborhood level.
Figure 5: Probability of Protest by Percent Change in Initial Assessed Value splitting Owner-Protested and Agent-Protested Cases.

Notes: Analogous to Figure (3) but splitting protests into those that are (i) protested by owners, and (ii) protested by representing agents. Estimated coefficients from a linear probability model of protesting given percent change in Initial Assessed Value, binned into one percentage point bins, with property-owner pair and year fixed effects. Coefficients are normalized to the probability of protest given a percent change in Initial Assessed Value between -1% and 0%. An indicator associated with exactly no change in Initial Assessed Value is included in the regression to increase the identifying sample for the individual fixed effects, but is omitted from the figure; likewise, indicators associated with a change in Initial Assessed Value (i) greater than 40%, and (ii) less than -40% are included in the regression but not in the figure (i.e. extreme values are binned at ±40%, respectively). Crisis years defined as 2008-2010. Standard errors are clustered at the neighborhood level.
Figure 6: Regression Kink Discontinuity Estimates of the Difference in the Elasticity of Protesting with respect to Percent Change in Initial Assessed Value in the Travis County sample.

(A) Travis County

(B) (i) Travis County: Cap-Eligible Sub-Sample

(B) (ii) Travis County: Cap-Ineligible Sub-Sample

(C) (i) Travis County: Protests by Owner

(C) (ii) Travis County: Protests by Representing Agents

Notes: The figures above show regression kink discontinuity (RKD) estimates of the difference in the elasticity of protesting above and below the reference point. Each plot is a bandwidth sensitivity test, showing the RKD estimates of separate regressions at symmetric bandwidths \( k \in [2\%, 10\%] \) around the reference point. The CCT-selected bandwidth and (quadratic) robust confidence intervals are shown at the dashed-pink line (Calonico et al., 2014). No controls included in regression estimates; standard errors are clustered at the neighborhood level; uniform kernel. The online appendix contains several robustness versions of these figures: (i) including year fixed effects, (ii) using a triangular kernel, (iii) including year fixed effects and using a triangular kernel.
Figure 7: Regression Kink Discontinuity Estimates of the Difference in the Elasticity of Protesting with respect to Percent Change in Initial Assessed Value with Property-Owner Pair and Year Fixed Effects.

Notes: The figures above show regression kink discontinuity (RKD) estimates from regressions that include both individual and year fixed effects, showing the difference in the elasticity of protesting above and below the reference point. Both plots show a bandwidth sensitivity test, showing the RKD estimates of separate regressions at symmetric bandwidths $k \in [2\%, 10\%]$ around the reference point. For ease of reading the figure, the estimate from the smallest bandwidth regression is excluded from the Travis County sample figure. In each underlying regression, values outside of the kink-estimating bandwidth are included (modeled flexibly by binning observations into one percentage point bins by percent change in Initial Assessed Value outside of the kink-estimating bandwidth) in order to increase the sample identifying the individual fixed effects; similarly, an indicator associated with exactly no change in Initial Assessed Value is included in the regression to increase the identifying sample for the individual fixed effects, but is excluded from the kink estimate. Standard errors are clustered at the neighborhood level; uniform kernel.
Figure 8: The distribution changes in *Initial Assessed Value* and *Final Assessed Value* among all reassessed households, and separately among reassessed households that protested and stated an *Opinion of Value*.

Notes: The left-hand panel shows both (i) the distribution of percent change in *Initial Assessed Value*, and (ii) the distribution of percent change in *Final Assessed Value*, among all reassessed households (excluding property which mechanical received no change in *Initial Assessed Value*). The right-hand panel shows (i) the distribution of percent change in *Initial Assessed Value*, and (ii) the distribution of percent change in *Final Assessed Value*, and (iii) the distribution of percent change in *Opinion of Value* relative to *Initial Assessed Value*, among protesters for whom an *Opinion of Value* is observed (constituting 84% of Harris protests, and 12% of Travis protests).
Figure 9: Distribution of Final Assessed Value and Estimated Bunching at Previous Final Assessed Value among protesters in the Reassessed Subsample.

Notes: The figure plots (i) the distribution of \(\log(\text{Final Assessed Value} / \text{Previous Final Assessed Value})\) within 0.10 log points of the Previous Assessed Value, and (ii) a 7th-degree polynomial estimate of this distribution symmetrically-fitted on either side of the reference point, allowing for excess mass at the reference point. Bin size 5 basis points. Reassessed Subsample (excludes properties with no initial change).
Figure 10: Distribution of *Opinion of Value* and Estimated Bunching at *Previous Final Assessed Value* in Reassessed Subsample.

Notes: The figure plots (i) the distribution of log(*Opinion of Value / Previous Final Assessed Value*) within 0.10 log points of the *Previous Assessed Value*, and (ii) a 7th-degree polynomial estimate of this distribution on either side of the reference point, allowing for excess mass at the reference point. Bin size 5 basis points. *Reassessed Subsample* (excludes properties with no initial change). Note that *Opinion of Value* is only observed for 84% of Harris protests, and 12% of Travis protests.
Figure 11: Average Reduction of Successful Protesters by Percent Change in Initial Assessed Value.

Notes: Outcome variable is $100 \times \log(\text{Initial Assessed Value} / \text{Final Assessed Value})$, which measures percent reduction in value (with higher values associated with larger reductions). Coefficients show estimated size of reduction (conditional on winning) given a percent change in Initial Assessed Value, binned into one percentage point bins, with individual and year fixed effects. Coefficients are normalized to the average reduction given a percent change in Initial Assessed Value between -1% and 0%. The coefficient associated with no change in Initial Assessed Value is omitted. Standard errors are clustered at the neighborhood level. The top panel shows all successful protesters in Harris County; the bottom panel shows successful owner-protesters in Travis County.
Figure 12: Excess protests in the loss domain estimated in a bandwidth around the reference point using the Reassessed Subsample from Travis County.

Notes: These figures and those in Figure 13 illustrate back-of-the-envelope calculations of the ultimate impact of loss aversion. Shown above are estimates of counterfactual protests as detailed in Section 7. The top figure shows estimates based on all reassessed properties. The bottom figure shows estimates based only on reassessed properties that constituted the top quartile of initial assessed value for each given year; these appear to drive the overall results. The figures show the excess protests (in blue) among reassessed households in the loss domain, as estimated by deviations from a counterfactual extrapolation of protest behavior in the gain domain. The figures also show an estimate of the labor-related administrative cost associated with handling the excess protests (incurred by the government), conservatively assuming a cost-per-protest of $14.38—see Appendix for additional details. All estimates are based only on the portion of the distribution of value shown (i.e. changes in Initial Assessed Value between -10% and +10%), which contains 55% of the reassessed distribution in (A) and 58% of the reassessed distribution in (B).
Figure 13: Excess average reductions in the loss domain and counterfactual revenue estimated in a bandwidth around the reference point using the Reassessed Sub-sample from Travis County.

(A) ALL REASSESSED PROPERTIES

(B) REASSESSED PROPERTIES IN TOP QUARTILE OF VALUE (BY YEAR)

Notes: These figures and those in Figure 12 illustrate back-of-the-envelope calculations of the ultimate impact of loss aversion. Shown above are estimates of counterfactual reductions, and thereby revenue (overall and per household) as detailed in Section 7. The left-hand figures show estimates based on all reassessed properties. The right-hand figures show estimates based only on reassessed properties that constituted the top quartile of initial assessed value for each given year; these appear to drive the overall results. The top panels show the excess average reductions (in blue) in assessed value achieved through protesting among reassessed households in the loss domain, as estimated by deviations from a counterfactual extrapolation of reductions in the gain domain. All reductions are estimated based on both protesters and non-protesters to capture both an intensive and extensive margin effect induced by loss aversion. The bottom panels show the excess reductions per household (unconditional on protesting), translated into tax dollars. All estimates are based only on the portion of the distribution of value shown (i.e. changes in Initial Assessed Value between -10% and +10%), which contains 55% of the reassessed distribution in (A) and 58% of the reassessed distribution in (B).
Table 1: Summary statistics for the key variables of interest in the Harris County and Travis County samples.

<table>
<thead>
<tr>
<th></th>
<th>Harris County</th>
<th>Travis County</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005-2016 (Ex. Crisis Years)</td>
<td>2011-2018</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Property-Year Pairs</td>
<td>7.09 Million</td>
<td>1.65 Million</td>
</tr>
<tr>
<td>Property-Owner Pairs</td>
<td>1.41 Million</td>
<td>0.34 Million</td>
</tr>
<tr>
<td>Protests</td>
<td>1.30 Million</td>
<td>0.36 Million</td>
</tr>
<tr>
<td><strong>Property-Year Level</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Property-Year Pairs</td>
<td>5.0 2.9 2 5 8</td>
<td>4.8 2.7 2 5 8</td>
</tr>
<tr>
<td>Protests</td>
<td>0.92 1.80 0 0 1</td>
<td>1.07 1.88 0 0 1</td>
</tr>
<tr>
<td><strong>Protest Level</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Successful Protest</td>
<td>0.68 0.47</td>
<td>0.81 0.39</td>
</tr>
<tr>
<td>Owner-Protested</td>
<td>0.44 0.50</td>
<td>0.83 0.47</td>
</tr>
<tr>
<td>Ended At Informal Stage</td>
<td>0.39 0.49</td>
<td>0.71 0.46</td>
</tr>
<tr>
<td>Opinion of Value</td>
<td>0.84 0.37</td>
<td>0.12 0.32</td>
</tr>
<tr>
<td>Assessment Reduction (1000s)</td>
<td>-20.8 42.7 -22.0 -10.9 -5.2</td>
<td>-35.1 55.5 -40.8 -22.0 -10.8</td>
</tr>
<tr>
<td>Assessment Reduction (Log Chg.)</td>
<td>-0.079 0.071 -0.104 -0.060 -0.031</td>
<td>-0.068 0.050 -0.091 -0.058 -0.033</td>
</tr>
</tbody>
</table>

Notes: Crisis years excluded from the main Harris County sample defined as 2008-2010. Neighborhood counts in each county are 5,343 (Harris) and 2,672 (Travis).
Table 2: Estimates of excess bunching at the reference point in distribution of \(\text{Final Assessed Value} \) among (i) All Households, (ii) Protesters, and (iii) Successful Protesters, (iv) Owner Protesters and (v) Agent Protesters in the Re-assessed Sub-sample by number of households and as a percent of the distribution.

<table>
<thead>
<tr>
<th></th>
<th>Symmetric Polynomial</th>
<th>Polynomial Separately Estimated -/+ of Bunch Point</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bandwidth</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Harris County</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Households</td>
<td>0.10</td>
<td>37,668***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(433.1)</td>
</tr>
<tr>
<td>Protesters</td>
<td>0.10</td>
<td>36,989***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(135.5)</td>
</tr>
<tr>
<td>Successful Protesters</td>
<td>0.10</td>
<td>38,532***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(136.3)</td>
</tr>
<tr>
<td>Owner Protesters</td>
<td>0.10</td>
<td>20,272***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(72.4)</td>
</tr>
<tr>
<td>Agent Protesters</td>
<td>0.10</td>
<td>15,741***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(66.6)</td>
</tr>
<tr>
<td><strong>Travis County</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Households</td>
<td>0.10</td>
<td>4,780***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(337.0)</td>
</tr>
<tr>
<td>Protesters</td>
<td>0.10</td>
<td>5,184***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(30.9)</td>
</tr>
<tr>
<td>Successful Protesters</td>
<td>0.10</td>
<td>5,200***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(28.3)</td>
</tr>
<tr>
<td>Owner Protesters</td>
<td>0.10</td>
<td>1,821***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(14.6)</td>
</tr>
<tr>
<td>Agent Protesters</td>
<td>0.10</td>
<td>3,362***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(23.3)</td>
</tr>
</tbody>
</table>

Notes: Estimates of excess bunching at the reference point in the distribution of \(\log(\text{Final Assessed Value} / \text{Previous Final Assessed Value})\) by number of households and as a percent of the distribution. SEs in parentheses. Symmetric bandwidth defined in terms of log change. Bin size 5 basis points. Samples restricted to only Re-assessed properties. Supplementary results in the online appendix show that these estimates are not meaningfully sensitive to the choice of bandwidth or bin size.
Table 3: Estimates of excess bunching at the reference point in distribution of Opinion of Value in the Re-assessed, Opinion-Stated Sub-Sample by number of households and as a percent of the distribution.

<table>
<thead>
<tr>
<th></th>
<th>Symmetric Polynomial</th>
<th>Polynomial Separately Estimated -/+ of Bunch Point</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Harris County</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protesters</td>
<td>0.10</td>
<td>81,644***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(249.9)</td>
</tr>
<tr>
<td>Owner Protesters</td>
<td>0.10</td>
<td>44,098***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(127.3)</td>
</tr>
<tr>
<td>Agent Protesters</td>
<td>0.10</td>
<td>37,546***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(130.4)</td>
</tr>
<tr>
<td><strong>Travis County</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protesters</td>
<td>0.10</td>
<td>2,323***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(16.0)</td>
</tr>
</tbody>
</table>

Notes: Estimates of excess bunching at the reference point in the distribution of log(\(\text{Opinion of Value} / \text{Previous Final Assessed Value}\)) by number of households and as a percent of protesters with stated value opinions. Travis County results do not separate owner-protesters and agent-protesters; nearly all observed opinions in the Travis sample come from owner-protesters (see Section 4). SEs in parentheses. Bandwidth in terms of log change and symmetric. Bin size 5 basis points. Re-assessed Sub-sample (excludes HHs with no initial change). Supplementary results in the online appendix show that these estimates are not meaningfully sensitive to the choice of bandwidth or bin size.
Figure A.1: A Typical Property Assessment Cycle.

Notes: This diagram illustrates a typical assessment cycle as discussed in Section 2. In most places, property taxes are due in either one or two payments at the end of the tax year.
Figure A.2: Histograms of (i) Opinion of Value minus Previous Final Assessed Value, and (ii) Opinion of Value minus Initial Assessed Value among Opinion-Stated Protesters in the Reassessed Sub-sample (separately by county).

Notes: The left-hand panels show histograms of protesters’ Opinion of Value relative to their Previous Final Assessed Value. The right-hand panels show histograms of protesters’ Opinion of Value relative to their Initial Assessed Value. Protesters are much more likely to state an Opinion of Value that is an exact round-dollar-amount multiple away from the Previous Final Assessed Value than they are to state an Opinion of Value that is an exact round-dollar-amount multiple away from their (new) Initial Assessed Value (e.g. Anchor Value ± $k \times 10,000). Binwidth: $100.
Figure A.3: Illustrations of six assessment cases with a normal noise distribution.

**Case 1:** Assessed Value Increased, Over-Assessed, True Value in Loss Domain

**Case 2:** Assessed Value Increased, Under-Assessed, True Value in Loss Domain

**Case 3:** Assessed Value Increased, Over-Assessed, True Value in Gain Domain

**Case 4:** Assessed Value Decreased, Over-Assessed, True Value in Gain Domain

**Case 5:** Assessed Value Decreased, Under-Assessed, True Value in Gain Domain

**Case 6:** Assessed Value Decreased, Under-Assessed, True Value in Loss Domain
Figure A.4: Model Simulation: Illustrating the Effects of Loss Aversion.

Notes: These figures illustrate the results of a simulation \((N = 1,800,000)\) of the Stochastic Reduction Model outlined in Section 3 parameterized as follows: \(\tau_t = 0.022\), \(A_{t-1} = V_{t-1} = 150,000\), Initial \(A_t = V_{t-1} + \Delta V_t + \epsilon_t\) where \(\Delta V_t \sim N(3000,15000)\) and \(\epsilon_t \sim N(0,15000)\), and \(\lambda \sim N(2.0,0.3)\). The cost function is given by \(\kappa + \phi \times e^{\gamma}\) with \(\kappa \sim \text{Lognormal}(4.9,1.5)\), \(\phi \sim N(500,150)\), and \(\gamma \sim N(1.3,0.1)\). In the simulation, 16.4% of agents protest, and 1.8% of agents state an opinion at the Previous Final Assessed Value leading to an excess mass of households in the distribution of Final Assessed Values at the Previous Final Assessed Value equal to 0.7% of all households.
Figure A.5: Travis County RKD diagnostic checks for covariate balance near zero percent change in Initial Assessed Value.

(A) Covariate Balance: Square Feet

(B) Covariate Balance: HVAC Square Feet

(C) Covariate Balance: Number of Bathrooms

(D) Covariate Balance: Year Built

(E) Covariate Balance: CDU Grade (Numeric Conversion)

Note: "CDU Grade converted to numerical value"
Figure A.6: Probability of Successful Protest by Percent Change in Initial Assessed Value.

Notes: Estimated coefficients from a linear probability model of successfully achieving a reduction in value, conditional on protesting, given a percent change in Initial Assessed Value, binned into one percentage point bins, with individual and year fixed effects. Coefficients are normalized to the probability of winning given a percent change in Initial Assessed Value between -1% and 0%. The coefficient associated with no change in Initial Assessed Value is omitted. Standard errors are clustered at the neighborhood level. Choosing 2011 as a based year, the baseline probabilities in the omitted bin are, (A) 0.80 and (B) 0.83.
Figure A.7: Final Assessed Value vs. Opinion of Value and Initial Assessed Value in Harris County sample.

Notes: Histogram of \((\text{Opinion of Value} - \text{Final Assessed Value}) / (\text{Opinion of Value} - \text{Initial Assessed Value})\). A value of one indicates that Final Assessed Value equals Initial Assessed Value; in other words, no reduction was achieved. A value of zero indicates that Final Assessed Value equals Opinion of Value; in other words, the property owner received a “full reduction,” insofar as their stated opinion is concerned. Opinion-Stated Sub-Sample. Top Panel: 1.54% of observations with a value less than zero are omitted from figure. Binwidth is 0.01. Bottom Panel: Values 0 and 1 also excluded. Binwidth is 0.005.
## Appendix Tables

Table B.1: Travis County RKD diagnostic checks for covariate balance near zero percent change in *Initial Assessed Value*.

<table>
<thead>
<tr>
<th>Observable Covariate</th>
<th>Test</th>
<th>Est.</th>
<th>SE</th>
<th>p-value</th>
<th>BC CI LB</th>
<th>BC CI UB</th>
<th>BC p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square Feet</td>
<td>Jump</td>
<td>-90.49</td>
<td>84.25</td>
<td>0.28</td>
<td>-454.13</td>
<td>-29.37</td>
<td>0.03</td>
</tr>
<tr>
<td>HVAC Sq. Ft.</td>
<td>Jump</td>
<td>-71.77</td>
<td>82.03</td>
<td>0.38</td>
<td>-427.01</td>
<td>3.40</td>
<td>0.05</td>
</tr>
<tr>
<td>Bathrooms</td>
<td>Jump</td>
<td>-0.10</td>
<td>0.07</td>
<td>0.13</td>
<td>-0.36</td>
<td>-0.06</td>
<td>0.01</td>
</tr>
<tr>
<td>Year Built (1st)</td>
<td>Jump</td>
<td>-4.69</td>
<td>2.30</td>
<td>0.04</td>
<td>-11.92</td>
<td>-0.81</td>
<td>0.02</td>
</tr>
<tr>
<td>CDU Grade</td>
<td>Jump</td>
<td>-0.01</td>
<td>0.02</td>
<td>0.63</td>
<td>-0.06</td>
<td>0.02</td>
<td>0.31</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observable Covariate</th>
<th>Test</th>
<th>Est.</th>
<th>SE</th>
<th>p-value</th>
<th>BC CI LB</th>
<th>BC CI UB</th>
<th>BC p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square Feet</td>
<td>Kink</td>
<td>-5169.44</td>
<td>3769.19</td>
<td>0.17</td>
<td>-38621.70</td>
<td>14374.28</td>
<td>0.37</td>
</tr>
<tr>
<td>HVAC Sq. Ft.</td>
<td>Kink</td>
<td>-6073.83</td>
<td>3821.00</td>
<td>0.11</td>
<td>-37296.67</td>
<td>16493.31</td>
<td>0.45</td>
</tr>
<tr>
<td>Bathrooms</td>
<td>Kink</td>
<td>-4.15</td>
<td>2.79</td>
<td>0.14</td>
<td>-29.21</td>
<td>7.45</td>
<td>0.24</td>
</tr>
<tr>
<td>Year Built (1st)</td>
<td>Kink</td>
<td>-198.47</td>
<td>104.17</td>
<td>0.06</td>
<td>-915.38</td>
<td>543.35</td>
<td>0.62</td>
</tr>
<tr>
<td>CDU Grade</td>
<td>Kink</td>
<td>2.09</td>
<td>1.03</td>
<td>0.04</td>
<td>-6.15</td>
<td>3.19</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Notes: This table shows the results of RD and RKD placebo regressions estimated using the CCT-selected bandwidth from the main estimate of the kink in the probability of protesting around zero percent change in *Initial Assessed Value* from Figure 6(A) (bandwidth = 0.03371 log points). Table shows both the conventional SE and conventional p-value, as well as CCT-suggested (quadratic) robust confidence intervals. No controls included in placebo regression estimates; standard errors are clustered at neighborhood level; uniform kernel.
Table B.2: RKD and RD estimates of the Probability of Protesting by Percent Change in Initial Assessed Value in the Travis County sample, corresponding to Figure 6(A).

<table>
<thead>
<tr>
<th>Bandwidth (Log Points)</th>
<th>0.0337†</th>
<th>0.05</th>
<th>0.10</th>
</tr>
</thead>
<tbody>
<tr>
<td>α−</td>
<td>0.120</td>
<td>0.115</td>
<td>0.111</td>
</tr>
<tr>
<td>(0.006) (0.005) (0.004)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>α+</td>
<td>0.127</td>
<td>0.127</td>
<td>0.147</td>
</tr>
<tr>
<td>(0.008) (0.007) (0.006)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>β−</td>
<td>0.952</td>
<td>0.595</td>
<td>0.431</td>
</tr>
<tr>
<td>(0.257) (0.154) (0.065)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>β+</td>
<td>1.841</td>
<td>1.805</td>
<td>1.042</td>
</tr>
<tr>
<td>(0.407) (0.217) (0.113)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Jump α+ − α− | 0.007   | 0.013 | 0.036 |
| (0.008) (0.007) (0.006) |        |       |       |

Kink β+ − β− | 0.890   | 1.210 | 0.612 |
| (0.507) (0.268) (0.133) |        |       |       |

†CCT-selected bandwidth

Notes: This table shows the full set of parameter estimates from three of the regressions of underlying Figure B.2, specified by Equation 5.2. No controls included; sample limited to Reassessed households. Conventional SEs clustered at the neighborhood level shown in parentheses.

Table B.3: RKD estimates of the elasticity of Protesting with respect to Percent Change in Initial Assessed Value using the within-household approach, corresponding to Figure 7.

<table>
<thead>
<tr>
<th>Bandwidth (Log Points)</th>
<th>Harris Sample</th>
<th>Travis Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kink</td>
<td>β+</td>
</tr>
<tr>
<td>0.03</td>
<td>0.639</td>
<td>0.692</td>
</tr>
<tr>
<td></td>
<td>(0.142)</td>
<td>(0.094)</td>
</tr>
<tr>
<td>0.05</td>
<td>0.727</td>
<td>0.717</td>
</tr>
<tr>
<td></td>
<td>(0.07)</td>
<td>(0.043)</td>
</tr>
<tr>
<td>0.10</td>
<td>0.689</td>
<td>0.719</td>
</tr>
<tr>
<td></td>
<td>(0.031)</td>
<td>(0.02)</td>
</tr>
</tbody>
</table>
Table B.4: Probability of bunching at Previous Assessed Value among Harris County Opinion-Stated Protesters for which Initial Assessed Value increased (i.e., limited to those with an initial increase). Binary dependent variable indicates Final Assessed Value equals Previous Assessed Value.

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Opinion = Previous</td>
<td>0.142***</td>
<td>0.105***</td>
<td>0.137***</td>
<td>0.101***</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.004)</td>
<td>(0.003)</td>
<td>(0.003)</td>
</tr>
<tr>
<td>(b) Owner Protested</td>
<td>0.004***</td>
<td>-0.003*</td>
<td>-0.002***</td>
<td>-0.009***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.002)</td>
<td>(0.001)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>(c) Opinion = Final</td>
<td>0.099***</td>
<td>0.098***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.004)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) &amp; (b)</td>
<td>0.016***</td>
<td>0.021***</td>
<td>0.012***</td>
<td>0.020***</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td>(0.005)</td>
<td>(0.003)</td>
<td>(0.004)</td>
</tr>
<tr>
<td>(b) &amp; (c)</td>
<td>0.038***</td>
<td>0.052***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.005)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cons.</td>
<td>0.059***</td>
<td>0.121***</td>
<td>0.042***</td>
<td>0.094***</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.005)</td>
<td>(0.002)</td>
<td>(0.005)</td>
</tr>
</tbody>
</table>

| %ΔA<sub>init</sub> 4th-Polynomial | X | X | X | X |
| Year FEs                  |   | X |   |   |
| Prop-Own Pair FEs         | X | X |   |   |

<table>
<thead>
<tr>
<th>Adj. R&lt;sup&gt;2&lt;/sup&gt;</th>
<th>0.055</th>
<th>0.109</th>
<th>0.091</th>
<th>0.144</th>
</tr>
</thead>
</table>

Notes: This table shows linear probability estimates relating bunching in the distribution of Final Assessed Value to bunching in the distribution of Opinion of Value.
C Model Notes & Derivations

C.1 Fixed Cost Noise Removal Model Notes

Table C.5: Protest conditions in a Fixed Cost Noise Removal Model.

<table>
<thead>
<tr>
<th>Case</th>
<th>Case-Defining Parameters</th>
<th>Protest Condition</th>
<th>Never Protest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>$A_t &gt; A_{t-1}$ $\epsilon_t &gt; 0$ $V_t &gt; A_{t-1}$</td>
<td>$\kappa &lt; \lambda \tau \epsilon_t$</td>
<td>$\kappa$</td>
</tr>
<tr>
<td>Case 2</td>
<td>$A_t &gt; A_{t-1}$ $\epsilon_t &lt; 0$ $V_t &gt; A_{t-1}$</td>
<td>$\kappa &lt; \lambda \tau \epsilon_t$</td>
<td>$X$</td>
</tr>
<tr>
<td>Case 3</td>
<td>$A_t &gt; A_{t-1}$ $\epsilon_t &gt; 0$ $V_t &lt; A_{t-1}$</td>
<td>$\kappa &lt; \lambda \tau \epsilon_t - (\lambda - 1)\tau [(V_{t-1} + \epsilon_{t-1}) - (V_t)]$</td>
<td>$\kappa$</td>
</tr>
<tr>
<td>Case 4</td>
<td>$A_t &lt; A_{t-1}$ $\epsilon_t &gt; 0$ $V_t &lt; A_{t-1}$</td>
<td>$\kappa &lt; \tau \epsilon_t$</td>
<td>$X$</td>
</tr>
<tr>
<td>Case 5</td>
<td>$A_t &lt; A_{t-1}$ $\epsilon_t &lt; 0$ $V_t &lt; A_{t-1}$</td>
<td>$\kappa &lt; \tau \epsilon_t$</td>
<td>$X$</td>
</tr>
<tr>
<td>Case 6</td>
<td>$A_t &lt; A_{t-1}$ $\epsilon_t &lt; 0$ $V_t &gt; A_{t-1}$</td>
<td>$\kappa &lt; \tau \epsilon_t + (\lambda - 1)\tau [(V_{t-1} + \epsilon_{t-1}) - (V_t)]$</td>
<td>$\kappa$</td>
</tr>
</tbody>
</table>

Table C.5 summarizes the conditions under which a homeowner will protest in a model with a fixed cost of protesting and deterministic assessment reductions that result in the (full) removal of an initial noise term $\epsilon_t$. The six cases below are illustrated in Figure A.3. Full derivations follow for the cases in which protest is possible (over-assessment); the other three cases are analogous.

Case 1: $V_t > A_{t-1}$, $\epsilon_t > 0$, $A_t > A_{t-1}$

$$\lambda \tau [(V_{t-1} + \epsilon_{t-1}) - V_t] - k > \lambda \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t)]$$
$$-k > -\lambda \tau \epsilon_t$$
$$k < \lambda \tau \epsilon_t$$

Case 3: $V_t < A_{t-1}$, $\epsilon_t > 0$, $A_t > A_{t-1}$

$$\tau [(V_{t-1} + \epsilon_{t-1}) - (V_t)] - k > \lambda \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t)]$$
$$\tau [(V_{t-1} + \epsilon_{t-1}) - (V_t)] - \lambda \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t)] > k$$
$$(1 - \lambda)\tau [(V_{t-1} + \epsilon_{t-1}) - (V_t)] + \lambda \tau \epsilon_t > k$$
$$k < \lambda \tau \epsilon_t - (\lambda - 1)\tau [(V_{t-1} + \epsilon_{t-1}) - (V_t)]$$

Case 4: $V_t < A_{t-1}$, $\epsilon_t > 0$, $A_t < A_{t-1}$

$$\tau [(V_{t-1} + \epsilon_{t-1}) - V_t] - k > \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t)]$$
$$-k > -\lambda \tau \epsilon_t$$
$$k < \tau \epsilon_t$$
### C.2 Effort-Based Noise Reduction Model Notes

#### Table C.6: Protest Conditions in an Effort-Based Noise Reduction Model.

<table>
<thead>
<tr>
<th>Case</th>
<th>Case-Defining Parameters</th>
<th>Protest Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>( A_t &gt; A_{t-1} ), ( \epsilon_t &gt; 0 ), ( V_t &gt; A_{t-1} )</td>
<td>( \kappa + c(e_t^<em>) &lt; e_t^</em> \lambda \tau \epsilon_t )</td>
</tr>
<tr>
<td>Case 3A: ( A_t &lt; A_{t-1} )</td>
<td>( A_t &gt; A_{t-1} ), ( \epsilon_t &gt; 0 ), ( V_t &lt; A_{t-1} )</td>
<td>( \kappa + c(e_t^<em>) &lt; (\lambda - (1 - e_t^</em>)) \tau \epsilon_t - (\lambda - 1) \tau [ (V_{t-1} + \epsilon_{t-1}) - (V_t) ] )</td>
</tr>
<tr>
<td>Case 3B: ( A_t \geq A_{t-1} )</td>
<td>( A_t &gt; A_{t-1} ), ( \epsilon_t &gt; 0 ), ( V_t &lt; A_{t-1} )</td>
<td>( \kappa + c(e_t^<em>) &lt; e_t^</em> \lambda \tau \epsilon_t )</td>
</tr>
<tr>
<td>Case 4</td>
<td>( A_t &lt; A_{t-1} ), ( \epsilon_t &gt; 0 ), ( V_t &lt; A_{t-1} )</td>
<td>( \kappa + c(e_t^<em>) &lt; e_t^</em> \tau \epsilon_t )</td>
</tr>
</tbody>
</table>

Table C.6 shows the conditions under which a homeowner will protest in a model with a fixed cost protesting, a marginal cost of effort and deterministic assessment reductions that result in removal of an initial noise term \( \epsilon_t \). The cases are illustrated in Figure A.3. Full derivations follow for the cases in which protest is possible (over-assessment).

**Case 1:** \( V_t > A_{t-1}, \epsilon_t > 0, A_t > A_{t-1} \)

\[
\lambda \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + (1 - e_t)\epsilon_t)] - \kappa - c(e_t) > \lambda \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t)] \\
-\lambda \tau (1 - e_t)\epsilon_t - \kappa - c(e_t) > -\lambda \tau \epsilon_t \\
\kappa + c(e_t^*) < e_t^* \lambda \tau \epsilon_t
\]

**Case 3:** \( V_t < A_{t-1}, \epsilon_t > 0, A_t > A_{t-1} \)

**Case 3A:** \( A_t < A_{t-1} \)

\[
\tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + (1 - e_t)\epsilon_t)] - \kappa - c(e_t) > \lambda \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t)] \\
\tau [(V_{t-1} + \epsilon_{t-1}) - (V_t)] - \lambda \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t)] + \lambda \tau \epsilon_t - (1 - e_t)\tau \epsilon_t > \kappa + c(e_t) \\
(1 - \lambda) \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t)] + (\lambda - (1 - e_t))\tau \epsilon_t > \kappa + c(e_t) \\
\kappa + c(e_t^*) < (\lambda - (1 - e_t^*)) \tau \epsilon_t - (\lambda - 1) \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t)]
\]

**Case 3B:** \( A_t \geq A_{t-1} \)

\[
\lambda \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + (1 - e_t)\epsilon_t)] - \kappa - c(e_t) > \lambda \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t)] \\
-\lambda \tau (1 - e_t)\epsilon_t - \kappa - c(e_t) > -\lambda \tau \epsilon_t \\
\kappa + c(e_t^*) < e_t^* \lambda \tau \epsilon_t
\]

**Case 4:** \( V_t < A_{t-1}, \epsilon_t > 0, A_t < A_{t-1} \)

\[
\tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + (1 - e_t)\epsilon_t)] - \kappa - c(e_t) > \tau [(V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t)] \\
-\tau (1 - e_t)\epsilon_t - \kappa - c(e_t) > -\tau \epsilon_t \\
\kappa + c(e_t^*) < e_t^* \tau \epsilon_t
\]
C.3 Stochastic Reduction Model Notes

Below, I more fully detail the stochastic reduction model introduced in Section 3.4, which is also the basis for the simulation figures shown.

C.3.1 Expected Benefit of Reductions

Case 1A: $A_t \geq A_{t-1}, A^O_t \leq A_{t-1},$

\[
(1 - \epsilon^*_t) \times \left[ \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + Q(1 - \epsilon^*_t)) \right) \right] + \int_{Q(1 - \epsilon^*_t)}^{\epsilon^*_t} \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \tilde{\epsilon}_t) \right) dF(\tilde{\epsilon}) + \int_{\epsilon^*_t}^{\epsilon^*_t} \lambda \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \tilde{\epsilon}_t) \right) dF(\tilde{\epsilon}) + [1 - F(\epsilon_t)] \times \left[ \lambda \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t) \right) \right]
\]

or equivalently,

\[
\tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t) \right) + [1 - F(\epsilon_t)] \times \left[ \lambda \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t) \right) \right] - \tau(1 - \epsilon^*_t) \times Q(1 - \epsilon^*_t) - \int_{Q(1 - \epsilon^*_t)}^{\epsilon^*_t} \tau \tilde{\epsilon}_idF(\tilde{\epsilon}) - \int_{\epsilon^*_t}^{\epsilon^*_t} \lambda \tau \tilde{\epsilon}_idF(\tilde{\epsilon}) - [1 - F(\epsilon_t)] \times [\lambda \tau \epsilon_t]
\]

Case 1B: $A_t \geq A_{t-1}, A^O_t \geq A_{t-1},$

\[
(1 - \epsilon^*_t) \times \left[ \lambda \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + Q(1 - \epsilon^*_t)) \right) \right] + \int_{Q(1 - \epsilon^*_t)}^{\epsilon^*_t} \lambda \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \tilde{\epsilon}_t) \right) dF(\tilde{\epsilon}) + [1 - F(\epsilon_t)] \times \left[ \lambda \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t) \right) \right]
\]

or equivalently,

\[
\lambda \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t) \right) - \lambda \tau(1 - \epsilon^*_t) \times Q(1 - \epsilon^*_t) - \int_{Q(1 - \epsilon^*_t)}^{\epsilon^*_t} \lambda \tau \tilde{\epsilon}_idF(\tilde{\epsilon}) - [1 - F(\epsilon_t)] \times [\lambda \tau \epsilon_t]
\]

Case 2: $A^O_t < A_t \leq A_{t-1},$

\[
(1 - \epsilon^*_t) \times \left[ \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + Q(1 - \epsilon^*_t)) \right) \right] + \int_{Q(1 - \epsilon^*_t)}^{\epsilon^*_t} \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \tilde{\epsilon}_t) \right) dF(\tilde{\epsilon}) + [1 - F(\epsilon_t)] \times \left[ \tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t + \epsilon_t) \right) \right]
\]

or equivalently,

\[
\tau \left( (V_{t-1} + \epsilon_{t-1}) - (V_t) \right) - \tau(1 - \epsilon^*_t) \times Q(1 - \epsilon^*_t) - \int_{Q(1 - \epsilon^*_t)}^{\epsilon^*_t} \tau \tilde{\epsilon}_idF(\tilde{\epsilon}) - [1 - F(\epsilon_t)] \times [\tau \epsilon_t]
\]

C.3.2 FOCs and Marginal Benefit

Note that $q(p) = 1/f(Q(p))$. Taking first order conditions of the expected benefit of reductions results in the following.

Case 1A: $A_t \geq A_{t-1}, A^O_t \leq A_{t-1},$

\[
\tau \left[ Q(1 - \epsilon^*_t) + (1 - \epsilon^*_t) \cdot q(1 - \epsilon^*_t) - Q(1 - \epsilon^*_t) \cdot f(Q(1 - \epsilon^*_t)) \cdot q(1 - \epsilon^*_t) \right]
\]

\[
MB^1_{\epsilon^*_t} = \tau(1 - \epsilon^*_t) \cdot q(1 - \epsilon^*_t)
\]
Case 1B: $A_I \geq A_{I-1}$, $A^O_I \geq A_{I-1}$,

$$\lambda \tau [Q(1 - e_I^*) + (1 - e_I^*) \cdot q(1 - e_I^*) - Q(1 - e_I^*) \cdot f(Q(1 - e_I^*)) \cdot q(1 - e_I^*)]$$

(C.9)

$$MB^B_{e_I^*} = \lambda \tau (1 - e_I^*) \cdot q(1 - e_I^*)$$

(C.10)

Case 2: $A^O_I < A_I \leq A_{I-1}$,

$$\tau [Q(1 - e_I^*) + (1 - e_I^*) \cdot q(1 - e_I^*) - Q(1 - e_I^*) \cdot f(Q(1 - e_I^*)) \cdot q(1 - e_I^*)]$$

(C.11)

$$MB^2_{e_I^*} = \tau (1 - e_I^*) \cdot q(1 - e_I^*)$$

(C.12)

C.3.3 Protest Conditions

Case 1A: $A_I \geq A_{I-1}$, $A^O_I \leq A_{I-1}$,

Equating marginal benefit to marginal cost, the homeowner will protest with effort $e_I^*$ satisfying,

$$\tau (1 - e_I^*) \cdot q(1 - e_I^*) = k'(e_I^*)$$

(C.13)

if, in addition, the expected benefit of protesting net of cost is better than the alternative,

$$(1 - e_I^*) \times \tau (\lambda e_I - Q(1 - e_I^*)) + \int_{Q(1-e_I^*)}^{\hat{e}_I^*} \tau (\lambda e_I - \hat{e}_I^*) dF(\hat{e}) + \int_{\hat{e}_I^*}^{e_I^*} \lambda \tau (e_I - \hat{e}_I^*) dF(\hat{e}) - F(\hat{e}_I^*) \times (\lambda - 1) \tau [(V_{I-1} + e_I - (e_I - k^*(e_I^*) \geq \lambda \tau [A_{I-1} - A_I]).$$

(C.14)

Note that for an opinion exactly at the reference point this collapses to,

$$F(\hat{e}_I^*) \times \lambda \tau (e_I - \hat{e}_I^*) + \int_{\hat{e}_I^*}^{e_I^*} \lambda \tau (e_I - \hat{e}_I^*) dF(\hat{e}) - k^*(e_I^*) \geq \lambda \tau [A_{I-1} - A_I].$$

(C.15)

Case 1B: $A_I \geq A_{I-1}$, $A^O_I \geq A_{I-1}$,

Equating marginal benefit to marginal cost, the homeowner will protest with effort $e_I^*$ satisfying,

$$\lambda \tau (1 - e_I^*) \cdot q(1 - e_I^*) = k'(e_I^*)$$

(C.16)

if, in addition, the expected benefit of protesting net of effort cost is better than the alternative,

$$(1 - e_I^*) \times \lambda \tau (e_I - Q(1 - e_I^*)) + \int_{Q(1-e_I^*)}^{\hat{e}_I^*} \lambda \tau (e_I - \hat{e}_I^*) dF(\hat{e}) - k^*(e_I^*) \geq \lambda \tau [A_{I-1} - A_I].$$

(C.17)

Case 2: $A^O_I < A_I \leq A_{I-1}$,

Equating marginal benefit to marginal cost, the homeowner will protest with effort $e_I^*$ satisfying,

$$\tau (1 - e_I^*) \cdot q(1 - e_I^*) = k'(e_I^*)$$

(C.18)

if, in addition, the expected benefit of protesting net of effort cost is better than the alternative,

$$(1 - e_I^*) \times \tau (e_I - Q(1 - e_I^*)) + \int_{Q(1-e_I^*)}^{\hat{e}_I^*} \tau (e_I - \hat{e}_I^*) dF(\hat{e}) - k^*(e_I^*) \geq \lambda [A_{I-1} - A_I].$$

(C.19)
D Additional Notes

D.1 Wage-Related Administrative Cost Per Protest

To estimate the wage-related cost per protest in Travis County, I first determine the average hourly wage of assessors and ARB panel arbiters. Using annual salary information from TCAD’s published annual budget, I calculate an average hourly wage equal to $28.46 for assessors, weighting appropriately by pay grade (job titles Assessor I-IV). Using per diem ARB arbiter pay statistics published by the Texas Comptroller, I estimate an average hourly wage equal to $22.50 for ARB arbiters. Empirically, 29% of protests advance to an ARB hearing. A panel of three arbiters will be present and the allotted time slots are 15 minutes. As such, estimating the labor cost associated with ARB panelists is relatively straightforward.

Determining the average handling time that each protest requires of an assessor is murkier, and undoubtedly varies from case to case. Some protests are likely resolved with very little work on the part of an assessor. Others will require only an informal meeting, only a formal hearing, or both an informal meeting and a formal hearing, each requiring an assessor’s time. While imperfect, I assume an average assessor handling time of 20 minutes per case, which reflects an average assessor handling time close to that of an ARB case, plus additional time for minimal preparation.

Together, this results in an estimated administrative cost-per-protest equal to 28.46/3 + (0.29)(3 × (22.50/4)) = $14.38, which almost surely understates the true administrative cost-per-protest, which also involves non-labor expenses. While by no means a perfect estimate, this provides a useful metric to calibrate an administrative burden associated with the additional protests induced by loss aversion.