# The Pricing of Property Tax Revenues*

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**Abstract**

A property tax can be thought of as a *capital structure*, which divides a stream of rents into components accruing to the homeowner and to the government. Near-term rents mainly accrue to homeowners, and far-term rents mainly accrue to governments. This characterization implies that the value of property tax revenues is very sensitive to interest rates, that governments funded by tax revenues have future-biased incentives to invest in public goods, and that taxed homeowners have present-biased incentives for investment.

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# 1 Introduction

Governments in many countries collect annual *property taxes* from homeowners based on the market value of homes. This paper analyzes property tax streams as financial assets. An untaxed house is a claim to future rents. A property tax is a recurring claim to a fraction of house prices. Property taxes should thus also be claims to future rents, replicable using portfolios of rent futures contracts. What is the nature of the rent claim implicit within property taxes?

We show that property taxes can be thought of as a *capital structure* imposed on a stream of future rents. Analogous to the way debt and equity partition the cash flows of a firm, property taxes partition a sequence of future rents into two financial assets: a *taxed house* held by the homeowner, and a *tax stream* held by a government. Under a 2% annual property tax, the tax stream is a claim to approximately 2% of rents in the first year, 4% in the second, and so on; the homeowner owns 98% of rents in the first year, 96% in the second, and so on. The fair market prices of taxed houses and tax streams can be calculated simply as the expected discounted present values of these rent claims.

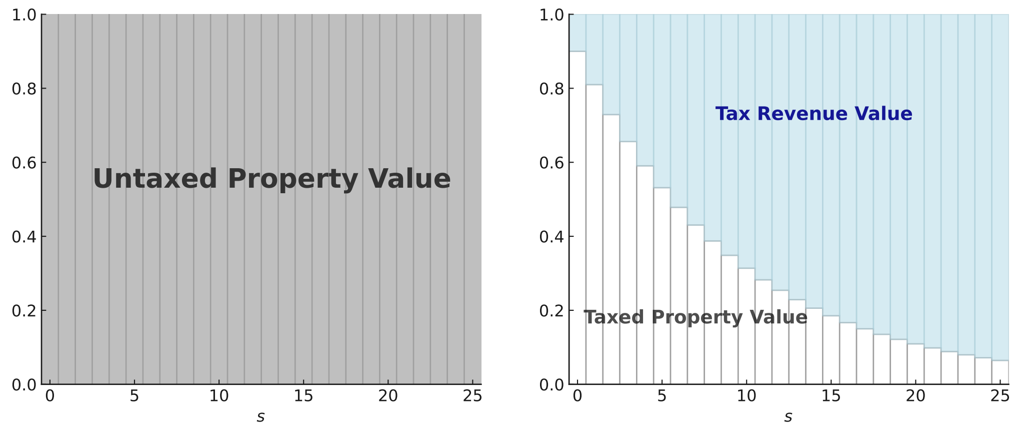
There is a simple informal intuition for our result, illustrated in Figure 1. An untaxed house, shown on the left plot, is a claim to the full stream of future rents. A one-time property tax of 2% thus extracts approximately 2% of first-year rents, 2% of second-year rents, and so on. If the house is taxed again in the second year, after the first year's rent is realized, the tax extracts an *additional* 2% of second-year rents, 2% of third-year rents, and so on. When the property is repeatedly taxed, the government effectly collects a share $\tau$ of year-$T$ rents a total of $T$ times, appropriating roughly a share $T\tau$ of these rents, and leaving a share $1 - T\tau$ to the homeowner. This sum is illustrated by the blue area in the right panel: the government owns a larger share of longer-horizon rents because these rents are taxed more times before their value is realized. Correspondingly, the taxed homeowner owns a larger share of near-term rents, and a smaller share of far-term rents.

Capital structure determines the division of future cash flows. Our results imply that seemingly small property tax rates capture a large fraction of the value of future rents. Suppose the discount rate is 5%: a 2.5% annual property tax thus extracts *one third* of the entire value of rental service flows generated by the house. Equivalently, house prices would be 50% higher if the 2.5% annual property tax were removed. We are not the first to make this point; Fama (2020*a*) and Fama (2020*b*) similarly argue that small taxes on "stock" quantities are equivalent to large taxes on "flows".

In the US, what share of the present value of rents are captured by property taxes?

Figure 1: Untaxed Houses, Taxed Houses, and Tax Streams as Rent Claims

This figure depicts how property taxes divide a stream of rents into components which accrue to property taxes and taxed houses. Each vertical bar represents a claim to rents $t$ periods in the future. The left plot represents an untaxed house, which consists of a claim to 100% of rents in each future period $t$. The right plot shows how these rents are divided between the taxed house – the white bars – and the stream of tax revenues captured by the local government – the blue bars. The taxed house represents a *frontloaded* claim, to a larger share of near-term rents, and a geometrically decaying share of far-term rents. The tax stream represents a *backloaded* claim, to smaller shares of near-term rents, and larger shares of far-term rents. Together, the taxed house and the tax stream add up to the entire stream of rents. Formally, if the tax rate is $\tau$, we will show that the taxed house is a claim to a fraction $\left(\frac{1}{1+\tau}\right)^{t+1}$ of period-$t$ rents, and the tax stream is a claim to the residual fraction $\left(1-\left(\frac{1}{1+\tau}\right)^{t+1}\right)$ of period-$t$ rents.




Average property tax rates in the US appear fairly low, with a county-level median of 1.43%, 25th percentile of 1.07% and a 75th percentile of 2.26%. But taxes extract a large share of the value of future rents in almost all counties: the median extraction rate is 25.15%, and the 25th and 75th percentiles are 17.88% and 35.76%, respectively. In other words, in the median county, 25.15% of the present value of future rents accrues to governments through property taxes, implying that house prices would be 33.6% higher in the absence of property taxes.

Beginning with George (1884), a large literature has normatively argued that it is efficient to fund local governments through land taxation. Our analysis suggests that US state and local governments are, quantitatively, already Georgist to a substantial degree: across states, local governments appropriate between a fifth and a third of the value of all future rent flows through property taxes.

Capital structure determines risk exposures. Property taxes, and taxed houses, have exposures to economic risks equal to the aggregated risk exposures of their constituent rent claims. Thus, property taxes facilitate risk sharing between governments and homeowners. Property taxes are *backloaded* rent claims, and taxed houses are corresponding frontloaded claims: governments holding property taxes effectively hold larger fractions of rents further in the future. The value of tax streams is thus very sensitive to changes in interest rates. At a 5% discount rate, assuming rents do not grow over time, the duration of property tax revenues is 35.21: that is, tax revenues are as sensitive to interest rates as 35.21 *year zero-coupon bonds.*

American state and local governments are adversely affected by declines in interest rate through their pension obligations: since defined-benefit pensions are fixed and long-duration nominal liabilities, their present value increases as interest rates decrease. However, using data and estimates from the pension literature, we find that property tax revenues are around three times higher duration, and similarly as large in flow terms, as pension liabilities. Thus, when interest rates decrease, the present value of property tax revenues increase by around $3.77 for each dollar that pension liabilities increase. Thus, after accounting for property taxes, almost all state and local governments *benefit* fiscally from a fall in interest rates.

Besides interest rates, local governments are also fiscally exposed to any risk factors that affect local rents. We derive simple expressions for how the factor betas of property tax streams depend on the factor betas of present and future rents, allow local governments to hedge fiscal exposure to various sources of economic risk.

Capital structure determines investment incentives. The owner of an untaxed house captures the full value of any investment she makes in improving the house, and thus has efficient investment incentives. However, without property taxes, local governments have no direct ownership over future rents, and thus have no financial incentives to invest in amenities that may increase future rents. Property taxes give both homeowners and governments equity claims to future rents: both parties thus have positive investment incentives, though neither party fully internalizes the positive spillovers their investments generate on the component of rents they do not own.

Property taxes introduce *intertemporal* distortions in investment incentives. Taxed homeowners have a frontloaded claim to rents, so they have diminished incentives to make investments that pay off further in the future. Thus, in areas with high property taxes, homeowners may not invest enough in long-term maintenance of their houses, and home-builders may underinvest in the durability of new housing. Governments have a backloaded claim to rents, implying they have *future-biased* investment incentives, pushing against the present-bias present in many political-economy models of governments' incentives. Under standard assumptions about the depreciation rate of housing investments, we find that homeowners capture only around 73% to 86% of the present value of their investments in home improvement, and governments recapture around 14% to 27% of the dollar value of amenity investments they make in increased property tax revenues.

Our framework offers a speculative explanation for why "shared-equity" capital structures are rare in housing markets: property taxes may already implement an investment-efficient form of equity sharing. Equity provides investment incentives, so it should be allocated to parties whose actions most affect asset values. Homeowners influence short-run rents through upkeep; local governments shape long-run rents through amenity provision. Property taxes divide house cashflows accordingly, assigning short-run payoffs mainly to homeowners, and longer-run payoffs increasingly to governments. Third parties who have less influence on house values should not hold equity stakes, since this would simply dilute homeowners' and governments' investment incentives; third-parties thus participate in housing capital structures mainly through mortgage debt.

Our baseline model makes strong and stylized assumptions, and we briefly discuss a number of possible model extensions. If the market imperfectly capitalizes property taxes into house prices, property taxes are slightly higher in present value than in our baseline model; the tax stream remains a high-duration asset, and investment incentives are similarly distorted. If tax assessments do not update instantly when house prices change, governments have further diminished incentives for near-term amenity investment, whereas households' investment incentives are slightly increased. If local governments' balance sheets are fully segregated, so the entire value of property taxes is spent frictionlessly on amenity provision, our results on value extraction and government investment incentives are not valid, but our results on the magnitude of value channeled through property taxes, and its exposure to macroeconomic risks, remain valid. Finally, our results are robust to assuming there are transaction costs in housing markets.

This paper's main contribution is to analyze property taxes through the lens of classic models of asset pricing (Cochrane, 2009; Duffie, 2010; Campbell, 2017) and capital structure (Modigliani and Miller, 1958; Jensen and Meckling, 1976). Technically, we show that, when a flow tax is repeatedly charged on the market price of a dividend paying asset, both the taxed asset price, and the tax stream, are replicable using portfolios of dividend forward contracts. This result is elementary and straightforward to derive; however, to our knowledge, it is new to the literature. The main applied implications of this result for property taxes – the duration of property taxes revenues, and the distortions property taxes induce in governments' and homeowners' investment incentives – are to our knowledge also new to the literature.

Our paper relates to a literature on US local government finances (Ahern, 2021), and in particular, the exposure of local governments to interest rate risk. A number of papers analyze the duration exposures of *pension liabilities* (Bodie, 2011; Giesecke and Rauh, 2023*a*,*b*). We estimate that property tax revenues are three to four times more sensitive to interest rates than pension liabilities. More generally, we fit into a recent literature using tools from asset pricing to analyze government fiscal capacity (Jiang et al., 2023).

Our investment results build on Glaeser (1996), who analyzes the incentive effects of property taxes in a two-period model. Glaeser shows that a myopic government, focused solely on current-period revenues, has incentives to invest in amenities due to their impact on future property values. We extend this insight by analyzing a forward-looking forwards which maximizes the present value of tax revenues; such a government has *backloaded* incentives for amenity investment, relative to a social planner. Our analysis is also related to a result of Holmstrom (1982) on the generic inefficiency of budget-balanced sharing rules, and to the effects of "depreciating licenses" on investment incentives analyzed in Weyl and Zhang (2022).

Our paper also relates to a recent literature analyzing property taxes. Arnott and Petrova (2006) characterizes deadweight losses induced by various property taxes in a model without uncertainty. Oates (1969) is an early paper to analyze the degree to which property taxes are capitalized into prices empirically; this literature is surveyed in Bloom et al. (1988) and Sirmans, Gatzlaff and Macpherson (2008). Our model imposes a strong set of assumptions, but allows us to attain the powerful results that taxed houses and tax streams can simply be thought of as claims to future rents, in a setting where future rents are general random variables with arbitrary risk premia. To our knowledge, this characterization is new to the literature.

Coven et al. (2024) shows that property taxes can substantially increase homeownership rates among younger households, by lowering house prices and thus downpayment requirements, and show – prior to our findings – that price-rent ratios tend to be lower in high-tax areas. Avenancio-León and Howard (2022*b*) and Avenancio-León and Howard (2022*a*) analyze racial differences in property tax rates. Amornsiripanitch (2020), Berry (2021), and McMillen and Singh (2023) show that property taxes are typically regressive. Giesecke (2022) analyzes how shocks to local labor markets affect local government finances through their effects on house prices and property taxes.

While we focus on the property tax setting in this paper, nothing in our baseline model is specific to housing. Our results may also have implications for other settings in which flow taxes are charged on stock quantities, such as wealth taxes and endowment taxes.

The paper proceeds as follows. Section 2 contains our model and main result. Section 3 discusses the magnitude of property tax revenues. Section 4 discusses the risk exposures of taxed houses and tax streams, and Section 5 discusses how property taxes shape investment incentives. Section 6 discusses various extensions of our model. We discuss our results and conclude in Section 7. Proofs are presented in Appendix A, and details on data sources we use are in Appendix B.

# 2 Model

We construct a simple model in which rents $D_t$ are exogeneous random variables realized in discrete time periods $t = 0, 1 \ldots$. We can then calculate the price of taxed houses as the present value of rents net of property taxes, and we can calculate the present value of tax streams based on our expressions for taxed house prices. For generality, we will present our results in a canonical no-arbitrage asset-pricing framework. However, the basic intuitions behind our results can be obtained either assuming there are no risk premia, so replacing all risk-neutral expectations $\mathbb{E}^{\mathbb{Q}}\left[D_t \mid \mathcal{F}_s\right]$ with simple expectations $\mathbb{E}\left[D_t \mid \mathcal{F}_s\right]$; or in the even simpler case that rents are nonrandom constants, thus replacing $\mathbb{E}^{\mathbb{Q}}\left[D_t \mid \mathcal{F}_s\right]$ with constants $D_t$. While we frame our model in the housing setting, the results hold for any asset which can be thought of as generating a stream of exogeneous dividends $D_t$.

In the most general version of the model, we work in a filtered probability space:

$$\left(\Omega, \mathcal{F}, \left(\mathcal{F}_t\right)_{t=0}^{\infty}, \mathbb{P}\right) \tag{1}$$

There is a constant risk-free rate $r$. We assume markets are complete and there are no arbitrage opportunities, so there exists a risk-neutral measure $\mathbb{Q}$ under which all discounted asset prices are $\mathbb{Q}$-martingales. There is a single kind of homogeneous house, which produces a unit of rent services in each period. The market price of period-$t$ rental services is an $\mathcal{F}_t$-measurable random variable $D_t$.

Let $V_t$ be the price of the house in period $t$, in the absence of any property taxes.

**Proposition 1.** *The price of an untaxed house is:*

$$V_t = \sum_{s=0}^{\infty} \frac{\mathbb{E}^{\mathbb{Q}}\left[D_{t+s} \mid \mathcal{F}_t\right]}{(1+r)^s} \tag{2}$$

Intuitively, Proposition 1 simply states that house prices in period $t$ are equal to the sum of risk-adjusted expected discounted future rents, conditional on period-$t$ information $\mathcal{F}_t$. We illustrate this result in the following simple examples.

**Example 1.** (No uncertainty). Suppose rents are nonrandom constants $d_0, d_1 \ldots$. Then (2) reduces to the discounted present value formula:

$$V_t = \sum_{s=0}^{\infty} \frac{d_{t+s}}{(1+r)^s}$$

**Example 2.** (Uncertainty without risk premia). Suppose rents are general random variables, but $\mathbb{Q} = \mathbb{P}$, so the pricing kernel is nonstochastic and the economy admits no risk premia. Then (2) reduces to the expected discounted present value formula:

$$V_t = \sum_{s=0}^{\infty} \frac{\mathbb{E}^{\mathbb{P}}\left[D_{t+s} \mid \mathcal{F}_t\right]}{(1+r)^s} \tag{3}$$

**Example 3.** (Binomial tree). As a simple example of risk premia, suppose rents follow a *binomial tree process.* Rents $D_t$ are a Markov process, either increasing by $u$ or decreasing by $d$ with possibly different physical and risk-neutral probabilities $\pi^{\mathbb{P}}, \pi^{\mathbb{Q}}$:

$$D_{t+1} = \begin{cases} (1+u)\, D_t & \pi^{\mathbb{P}}, \pi^{\mathbb{Q}} \\ (1-d)\, D_t & 1-\pi^{\mathbb{P}}, 1-\pi^{\mathbb{Q}} \end{cases} \tag{4}$$

We then have:

$$V_t = \sum_{s=0}^{\infty} \frac{\mathbb{E}^{\mathbb{P}}\left[D_{t+s} \mid \mathcal{F}_t\right]}{(1+\tilde{r})^s} \tag{5}$$

Where $\tilde{r}$ can be thought of as a risk-adjusted discount rate:

$$\tilde{r} \equiv (1+r)\, \frac{\pi^{\mathbb{P}}(1+u) + \left(1-\pi^{\mathbb{P}}\right)(1-d)}{\pi^{\mathbb{Q}}(1+u) + (1-\pi^{\mathbb{Q}})(1-d)} - 1 \tag{6}$$

When $\pi^{\mathbb{P}} = \pi^{\mathbb{Q}}$, so the risk-neutral and physical probabilities are equal and rents have no risk premia, (5) reduces to (3) of Example 2. In general, the adjusted discount rate $\tilde{r}$ accounts for any correlation between future rents and the *pricing kernel*: for example, if future rents are correlated with the stock market or other sources of systematic risk, customers may demand a higher rate of return from houses to account for the risk exposures of future rent streams.

Examples 1, 2, and 3 illustrate the generality of our framework: we can capture simple cases where rents are constant, as well as arbitrary stochastic processes for rents, which may involve systematic risk exposures that generate risk premia.

We define a period-$t$ *rent forward contract* as a simple security which pays $D_t$ in period $t$, and nothing in all other periods. Let $F(t_1, t_2)$ represent the price of a $t_2$-forward contract in $t_1$ dollars. No-arbitrage implies that forward contract prices are simply discounted $\mathbb{Q}$-conditional expectations:

$$F(t, t+s) = \frac{\mathbb{E}^{\mathbb{Q}}\left[D_{t+s} \mid \mathcal{F}_t\right]}{(1+r)^s} \tag{7}$$

While rent forward contracts are rarely traded in practice, they are useful theoretically, since we can think of any asset that ultimately derives its value from rents as a portfolio of rent forward contracts. Holding equity in a firm is equivalent to holding an infinite sequence of forward contracts on the firm's future profits; analogously, within the frictionless universe of our model, owning an untaxed house is equivalent to owning forward contracts paying the infinite sequence of rents that the house generates. The core message of our paper is that this property generalizes: both *taxed houses* and *streams of property taxes* can similarly be thought of as portfolios of rent forward contracts.

Suppose a local government requires homeowners to pay a fraction $\tau$ of their house's price in property taxes to the government each period. Let $P_t$ denote the price of the taxed house in period $t$; this will generally differ from the untaxed house price, $V_t$, due to the tax burden imposed on the house. The net monetary payoff delivered by the house in period $t$ is rents minus property taxes:

$$D_t - \tau P_t$$

At time $t$, the local government holds a claim to a sequence of future tax payments:

$$\tau P_t, \tau P_{t+1}, \tau P_{t+2} \ldots$$

We can think of the government's *tax stream* as a financial asset: formally, let $T_t$ denote the price of an asset which pays $\tau P_t$ in each period $t$. While tax streams are rarely traded in practice, we can calculate an implied no-arbitrage price of $T_t$: this can be thought of roughly as the tax stream's present value, or the price at which the government could sell the right to collect property taxes in a frictionless market.

**Proposition 2.** *Property taxes are a capital structure, which divides the full stream of rents captured by an untaxed house, $V_t$, into components which accrue to the taxed house $P_t$ and the tax stream $T_t$:*

$$P_t + T_t = V_t \tag{8}$$

$$P_t = \sum_{s=0}^{\infty} \frac{1}{(1+r)^s} \frac{1}{(1+\tau)^{s+1}} E^{\mathbb{Q}}\left[D_{t+s} | \mathcal{F}_t\right] \tag{9}$$

$$T_t = \sum_{s=0}^{\infty} \frac{1}{(1+r)^s} \left(1 - \frac{1}{(1+\tau)^{s+1}}\right) E^{\mathbb{Q}}\left[D_{t+s}|\mathcal{F}_t\right] \tag{10}$$

The intuition for this result is that Proposition 2 implies that property taxes can be thought of as a *capital structure*. Debt and equity represent two claims that add up to the stream of expected future profits of a firm; analogously, a taxed house $P_t$ and the property tax stream $T_t$ add up to the entire stream of future rents generated by a house. Proposition 2 can be thought of as a version of the Modigliani and Miller (1958) result in our setting: changes in the tax rate $\tau$ influence how future cash flows are divided between $P_t$ and $T_t$, but does not change the fact that their sum is equal to $V_t$.

The capital structure imposed by property taxes divides each future rent $D_{t+s}$ into components that accrue to $P_t$ and $T_t$. Expressions (9) and (10) can be interpreted as saying that homeowner owns a share $\frac{1}{(1+\tau)^{s+1}}$ of $D_{t+s}$, the rent flow $s$ periods in the future, and the tax stream owns the residual share $\left(1 - \frac{1}{(1+\tau)^{s+1}}\right)$. We plot these coefficients in Figure 1. A simple intuition is that, at an annual tax rate of 2%, the tax stream is a claim to approximately 2% of today's rents, 4% of tomorrow's rents, and so on; the tax-encumbered homeowner is left with a claim to 98% of today's rents, 96% of tomorrow's rents, and so on. Property taxes thus induce an intertemporally varying equity structure on rents: $P_t$ has a frontloaded claim to rents, and $T_t$ has a backloaded claim.

A further technical result is that $P_t$ and $T_t$ can be *replicated* by trading rent forward contracts.

**Proposition 3.** *$P_t$ and $T_t$ can both be replicated using rent forward contracts: rent forward contracts can be traded in a way that delivers identical payoffs, in all future states of the world, to directly holding $P_t$ and $T_t$.*

Technically, the replication result of Proposition 3 drives the pricing result in Proposition 2: a classic result in asset pricing theory is that a security's price is fully determinate under the $\mathbb{Q}$-measure generated by a set of claims if and only if its payoff can be replicated by this set of claims.

The results in Propositions 1, 2, and 3 are fairly elementary and straightforward to derive. They are not specific to property taxes, and apply to any setting in which a repeated tax is charged on the market price of a dividend-paying asset. However, to our knowledge, these results are new to the literature.

# 3 How Large is the Present Value of Property Tax Revenues?

Our framework gives a simple intuition behind the idea, discussed in Fama (2020*a*) and Fama (2020*b*), that small property taxes extract a large fraction of the value of houses. Visually, Figure 1 illustrates that, as $s$ increases, increasingly large fractions of future rents accrue to $T_t$ rather than $P_t$. To quantitatively illustrate this point, we solve explicitly for the values of $V_t, P_t, T_t$ assuming that risk-neutral expected rents grow at a constant geometric rate.

**Proposition 4.** *Suppose for any* $s, t \geq 0$, $\mathbb{E}^{\mathbb{Q}}\left[D_{s+t} \mid \mathcal{F}_t\right] = (1+g)^s D_t$ *with* $g < r$. *We then have:*

$$V_t = \sum_{s=0}^{\infty} \left(\frac{1}{1+r}\right)^s (1+g)^s D_t = \frac{D_t (1+r)}{r-g} \tag{11}$$

$$P_t = \frac{D_t (1+r)}{(1+r)(1+\tau) - (1+g)} \tag{12}$$

$$T_t = \frac{D_t (1+r)^2 \tau}{(r-g)\left((1+r)(1+\tau) - (1+g)\right)} \tag{13}$$

$$\frac{T_t}{V_t} = \frac{\tau (1+r)}{(1+r)(1+\tau) - (1+g)} = \tau \cdot \frac{P_t}{D_t} \tag{14}$$

$$\frac{P_t}{V_t} = \frac{r-g}{(1+r)(1+\tau) - (1+g)} \tag{15}$$

We define the *extraction ratio* $\eta$ as:

$$\eta_t \equiv \frac{T_t}{V_t} = \frac{T_t}{T_t + P_t}$$

That is, $\eta$ is the fraction of the total present value of the rent stream which accrues to $T_0$. Equivalently, in a counterfactual world where property taxes were removed, our model predicts that house prices would increase by a factor $\frac{\eta}{1-\eta}$.[1] If $r, g, \tau$ are all small, we can disregard the $(1+r)$ in the numerator of (14) and the $\tau r$ term in the denominator, so (14) and (15) simplify to:

$$\eta_t = \frac{T_t}{V_t} \approx \frac{\tau}{\tau + r - g}, \quad \frac{P_t}{V_t} \approx \frac{r-g}{\tau + r - g} \tag{16}$$

In words, the ratios $\frac{T_t}{V_t}$ and $\frac{P_t}{V_t}$ depend on the relative size of taxes and the real interest rate, $r - g$. If the real interest rate is 2%, a 2% property tax extracts *half* of the entire value of future rent flows. If the 2% property tax were removed, property prices would *double*.

[1] This calculation naively assumes that the revenue raised by property taxes is not spent on amenity provision, and thus does not influence house prices; we discuss relaxing this assumption in Subsection 6.3.

Expression (14) also implies that, if we are willing to make the strong assumption that price-rent ratios are constant over time, $\eta$ is equal to the tax payment $\tau P_t$ divided by rental flow $D_t$, which is also equal to the tax rate $\tau$ multiplied by the price-rent ratio $\frac{P_t}{D_t}$. This has the intuitive empirical interpretation of the median homeowner's tax payment divided by the median renter's rental payment. We use this approach to crudely estimate county-level extraction ratios, taking estimated county-level property tax rates as a fraction of market values of houses from Baker, Janas and Kueng (2023), and median home values and median rents from the American Community Survey; details on the data we use are described in Appendix B.1.[2]

Figure 2 plots the distribution of tax rates from Baker, Janas and Kueng (2023) on the left panel, and the distribution of estimated extraction ratios on the right panel. The left panel shows that annual property tax rates in the US appear fairly low on average. The population-weighted median value of $\tau$ is 1.43%, the 25th percentile is 1.07%, and the 75th percentile is 2.26%. However, these seemingly small tax rates lead to fairly large extraction ratios. On the right panel, the population-weighted median extraction ratio is 31.64%; the 25th percentile is 22.65%, and the 75th percentile is 43.28%. Population-weighted percentiles are somewhat higher than equal-weighted percentiles, since tax rates tend to be somewhat higher in high-population counties: the unweighted quartiles of the extraction ratio across counties are 17.88%, 25.15%, and 35.76%.

Residential real estate in the US is often viewed as basically privately owned, under perpetual and essentially unrestricted use rights. Figure 2 quantitatively challenges this view: the median US household makes property tax payments equal to around 25% of what they would pay in rents in similar areas. The NPV of property tax revenues is as large as if governments imposed a 25% tax on imputed flow rents on all properties, or if governments conducted a one-time seizure and re-sale of 25% of the housing stock, and charged no taxes thereafter.

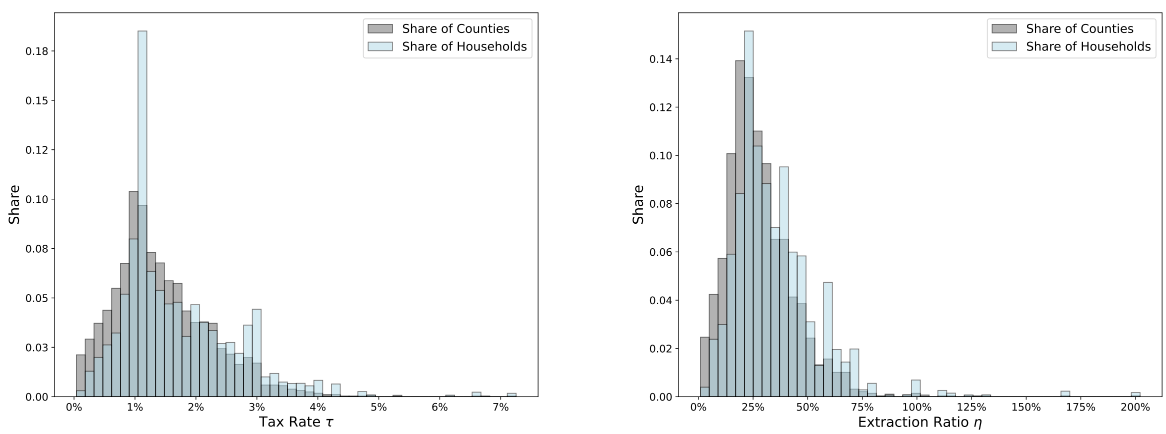
# 4 Risk Exposures

An untaxed house is a stream of claims to future rents, so its risk exposures are the weighted sum of the risk exposures of future rents. Proposition 2 implies that taxed houses $P_t$ and tax streams $T_t$ likewise inherit the risk exposures of the rent streams that they are derived

[2] An important caveat is that this empirical approach is formally valid when the price-rent ratio is measured for identical houses, whereas rented houses and owned houses in the ACS are not fully comparable in terms of characteristics. If we assume rented houses tend to be lower-quality than owned houses, our approach would tend to overestimate extraction ratios.

Figure 2: Magnitudes of County Level Extraction Ratios (2011 ~ 2015)

This figure depicts the magnitude of property tax extraction ratios. Extraction ratios are computed at the county level, according to $\eta = \frac{\text{Median Home Value}}{\text{Annualized Median Rent}} \times \text{tax rate}$. Median home value and median rent are taken from the American Community Survey 5 year estimates from 2011 to 2015. County-level property tax rates as a fraction of the dollar value of houses are computed as the average property tax rate of each county over 2011 to 2015, given by Baker, Janas and Kueng (2023). The number of households in each county is taken from the ACS, and share of households is computed as the number of households in a county as a share of total number of households summed across counties in our data. The number of counties in our data is 2880, after dropping counties with missing values.



from. We use this idea to analyze the interest rate risk exposures of $P_t$ and $T_t$, and then risk exposures more generally.

## 4.1 Interest Rate Risk

**Proposition 5.** *The percentage exposures of* $V_0, P_0, T_0$ *to interest rate changes are respectively:*

$$-(1+r)\frac{\frac{\partial V_0}{\partial r}}{V_0} = \frac{\sum_{t=0}^{\infty}\left[\frac{\mathbb{E}^{\mathbb{Q}}[D_t]}{(1+r)^t}\right]t}{\sum_{t=0}^{\infty}\frac{\mathbb{E}^{\mathbb{Q}}[D_t]}{(1+r)^t}} \tag{17}$$

$$-(1+r)\frac{\frac{\partial P_0}{\partial r}}{P_0} = \frac{\sum_{t=0}^{\infty}\left[\frac{\mathbb{E}^{\mathbb{Q}}[D_t]}{(1+r)^t(1+\tau)^{t+1}}\right]t}{\sum_{t=0}^{\infty}\left[\frac{\mathbb{E}^{\mathbb{Q}}[D_t]}{(1+r)^t(1+\tau)^{t+1}}\right]} \tag{18}$$

$$-(1+r)\frac{\frac{\partial T_0}{\partial r}}{T_0} = \frac{\sum_{t=0}^{\infty}\left[\frac{1}{(1+r)^t}\left(1-\frac{1}{(1+\tau)^{t+1}}\right)E^{\mathbb{Q}}\left[D_t\right]\right]t}{\sum_{t=0}^{\infty}\frac{1}{(1+r)^t}\left(1-\frac{1}{(1+\tau)^{t+1}}\right)E^{\mathbb{Q}}\left[D_t\right]} \tag{19}$$

*We also have:*

$$T_0\frac{\frac{\partial T_0}{\partial r}}{T_0} + P_0\frac{\frac{\partial P_0}{\partial r}}{P_0} = V_0\frac{\frac{\partial V_0}{\partial r}}{V_0} \tag{20}$$

$$-\frac{\frac{\partial P_0}{\partial r}}{P_0} \leq -\frac{\frac{\partial V_0}{\partial r}}{V_0} \leq -\frac{\frac{\partial T_0}{\partial r}}{T_0} \tag{21}$$

Expressions (17), (18), and (19) are the standard *duration formulas* applied to $V_0, P_0, T_0$. We show the $(1+r)$ terms on the left-hand side following convention in the fixed-income literature. Intuitively, Proposition 5 states that the sensitivity of each asset to interest rates is proportional to the present-value-weighted average maturity $t$ of cash flows, which are the weights in Propositions 1 and 2 times the risk-neutral expectations of rents $\mathbb{E}^{\mathbb{Q}}[D_s]$. Since $P_0$ and $T_0$ add up to $V_0$, the interest rate risk exposures of the components $P_0$ and $T_0$ also add up to the exposures of the rent stream as a whole, $V_0$: thus, (20) says that the value-weighted average of durations of $P_0$ and $T_0$ is equal to the duration of $V_0$. Finally, the fact that $P_0$ is a decreasing claim to rents, and $T_0$ is an increasing claim, allows us to prove (21): the taxed house $P_0$ is less sensitive to interest rates than the untaxed house, $V_0$, which is less sensitive than the tax stream $T_0$. An intuition behind (20) and (21) is that the tax stream $T_0$ "steals" duration from the house $P_0$, by taking larger fractions of future rents, causing the house to become a more frontloaded claim, and thus decreasing the house's sensitivity to interest rates.

### 4.1.1 Property Taxes and Price Growth in the Cross-Section of Counties

Amaral et al. (2024) argues that the large increase in house prices in the US, over the past few decades, is partly a result of the fall of real interest rates. If this is the case, our model predicts that house prices and price-rent ratios should have increased less in areas with higher tax rates, since interest rates should have a lower effect on $P_0$ in these areas. We show evidence consistent with this prediction in Figure 3; details on data sources and variable construction are in Appendix B.2.

The left panel shows a simple test of (12) of Proposition 4 in the previous section: price-rent ratios should be lower in counties where tax rates are higher, since a larger share of future rents accrues to local governments through $T_0$. Consistent with our model's predictions, price-rent ratios from the 2015-2019 American Community Survey 5-year sample are substantially lower in high-tax counties; the relationship is strong and basically monotonic. This result is consistent with earlier findings by Coven et al. (2024), using slightly different data and measurement approaches. The right panel of Figure 3 then plots percentage *growth* in price-rent ratios, calculated based on the ACS and the 1990 Census data. As Proposition 5 predicts, growth in price-rent ratios was also substantially lower in counties with higher property tax rates.

Appendix Figure B.1 shows that the results are qualitatively similar if we use price-income ratios instead, to account for the concern that price-rent ratios from the ACS and census in principle suffer from composition bias: owned and rented houses are not the same in terms of characteristics. A caveat to our results is that our property tax rate data, from Baker, Janas and Kueng (2023), is measured over 2003-2015; we do not have data on tax rates over the entire period 1990-2019, so our analysis implicitly assumes that counties which have high tax rates tended to have high tax rates throughout the period 1990-2019. With these caveats in mind, the results in Figure 3 and Appendix Figure B.1 are consistent with our model's predictions.

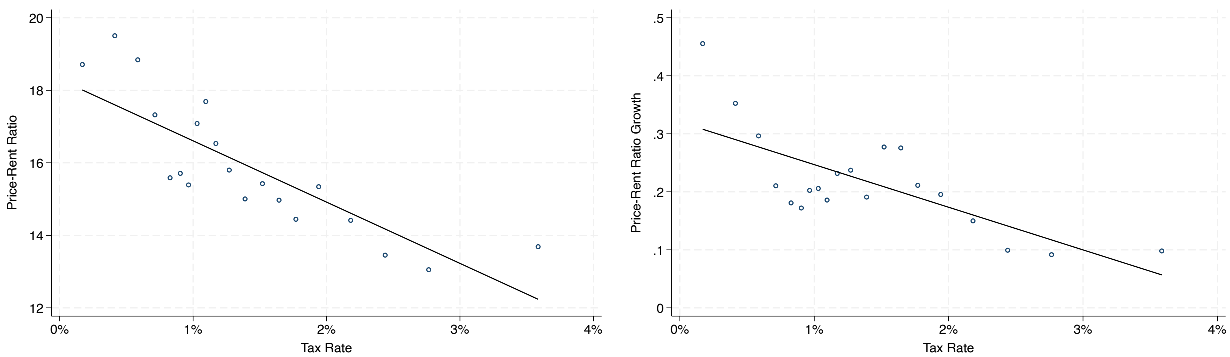
### 4.1.2 Estimating the Duration of Property Tax Revenues

Quantitatively, tax streams are very high-duration assets. A first intuition for the high duration of $T_0$ is that it is a backloaded claim to future rents. A second intuition, based on the cash flows $T_0$ delivers, is that a tax stream behaves like a *double perpetuity*. $T_0$ pays the stream of payments:

$$\tau P_0, \tau P_1 \ldots$$

Figure 3: Tax Rates, Price-Rent Ratios, and Price-Rent Ratio Growth

This figure depicts binned scatterplots illustrating the relationships between county-level property tax rates and the level and growth rates of price-rent ratios. The sample consists of 3022 counties. The left panel shows median house values divided by median rent, using 2015-2019 ACS 5-year data. The right panel shows the percentage growth in price-rent ratios, from the 1990 Census data, to the 2015-2019 ACS 5-year data. In both panels, the x-variable is property tax rates from Baker, Janas and Kueng (2023).




Where $P_t$ itself also behaves like a perpetuity, paying (approximately) rents each future period. $T_0$ thus behaves like a perpetuity whose payments also vary with interest rates: when $r$ decreases, future payments are discounted less, and house prices $P_t$ also rise, increasing the nominal value of each future payment $\tau P_t$. The following example calculates the duration of property taxes assuming that risk-neutral expected rents grow at a constant rate.

**Example 4.** Suppose for any $s, t \geq 0$, $\mathbb{E}^{\mathbb{Q}}\left[D_{s+t} \mid \mathcal{F}_t\right] = (1+g)^s D_t$ with $g < r$. Then the tax duration formula (19) simplifies to:

$$-(1+r)\frac{\frac{\partial T_0}{\partial r}}{T_0} = \frac{(1+g)(2(r-g)+\tau(1+r))}{(r-g)(r-g+\tau(1+r))}. \tag{22}$$

When $g = 0$, we have:

$$-(1+r)\frac{\frac{\partial T_0}{\partial r}}{T_0} = \frac{1}{r+\tau(1+r)} + \frac{1}{r} \approx \frac{1}{r+\tau} + \frac{1}{r}.$$

As a simple numerical example, if $r = 0.05, g = 0$, the duration of a 30-year 2% coupon bond is 19.01, and the duration of a perpetuity is 21.0. The duration of a 30-year zero coupon bond – an object almost never used in financial markets in practice – is 30. The duration of $T_0$ at $\tau = 0.015$, approximately the median tax rate in the US, is 35.21: that is, property tax streams are as sensitive to interest rates as *a* 35.21 *year zero-coupon bond.* Thus, at realistic tax rates, property tax streams are more sensitive to interest rates than almost all other common financial assets.

### 4.1.3 Property Taxes and Local Governments' Interest Rate Exposures

State and local governments fiscally suffer from falls in interest rates because of their *pension obligations*, which are long-duration nominal liabilities. These interest rate exposures are potentially offset by the high duration of governments' property tax revenues. We show in an extended back-of-envelope calculation that property taxes are both longer-duration, and larger in present value, than pension obligations; thus, local governments on net fiscally *benefit* from falls in interest rates.

The ideal exercise that showcases governments' interest rate exposure is to compare the duration weighted present value of pension liabilities to property tax revenue. However, the value of property tax revenue is hard to estimate because it requires a strong stance on future tax revenue flow projections. Therefore, we compare the duration weighted *flows* of pension payments and property taxes. As in our empirical exercise in Section 3, this quantification is informative to the extent that the ratio of these two cash flows is stable over time.

Previous literature estimates the duration of state and local pension liabilities to be between 10 and 15 (Novy-Marx and Rauh, 2011; Giesecke and Rauh, 2023*b*); Giesecke and Rauh (2023*b*) gives a point estimate of 11.3. Giesecke and Rauh (2023*a*,*b*) show that service costs – defined as the present value of future pension benefits that employees earn in a fiscal year – account for approximately 8.8% of own source revenue[3] on average, with this ratio ranging from 3.1% to 20.9% across different states. We compute the property tax revenue flow as a percentage of own source revenue using the Annual Survey of State and Local Government Finances. More details regarding the definition and construction of variables are available in the Appendix B.3.

We can thus approximate the dollar sensitivity of local governments' property tax revenues and pension liabilities to interest rates through the ratio:

$$\frac{\text{Property Tax Duration} \times \text{Property Tax Flow as \% of Own Source Revenue}}{\text{Pension Duration} \times \text{Service Cost as \% of Own Source Revenue}} \tag{23}$$

At the national median property tax rate $\tau = 0.015$, assuming $g = 0$, and discounting at $r = 0.05$, we find that the ratio (23) is 3.77. That is, when interest rates fall, the present value of governments' property tax revenues rises by \$3.77 for each dollar increase in the value of governments' pension liabilities. This is because, under our assumptions, $T_0$ has

[3] Own source revenue refers to government revenues that are not generated from receiving intragovernmental transfers.

roughly the same size as pension liabilities in flow terms, but has approximately three times higher duration.

## 4.2 Inflation

Another implication of our results is that, since $T_0$ is a claim to future rents, $T_0$ is essentially a real asset, and is thus relatively insensitive to inflation. Taking (13) and ignoring a $(1+r)^2$ term in the numerator and a $\tau r$ term in the denominator, we have that:

$$T_t \approx \frac{D_t \tau}{(r-g)\left((r-g)+\tau\right)}$$

Thus, for small $r, g, \tau$, $T_t$ depends mainly on the real interest rate $r-g$; an increase in interest rates accompanied by an increase in expected rent growth does not change $T_t$. Taking pension liabilities into account, local governments could potentially fiscally benefit from an increase in inflation, which would decrease the value of nominal pension obligations, while having a smaller effect on the value of property tax revenues.

## 4.3 General Risk Exposures

Beyond interest rates, let $X_1$ be any $\mathcal{F}_1$-measurable real-valued random variable, which can be thought of as a source of economic risk, such as the aggregate stock market, or local labor market conditions. We can define the *factor beta* of the house price $P_1$ with respect to $X_1$ as:

$$\beta^P \equiv \frac{Cov\left[X_1, P_1\right]}{Var\left[X_1\right]}$$

Analogously, we can define factor betas $\beta^T$ for the tax stream $T_1$, and $\beta^V$ for the untaxed price $V_1$. An alternative way to think about factor betas is that they allow us to decompose returns into factor-based components and idiosyncratic risk, such as:

$$T_1 = \beta^T X_1 + \varepsilon_1^T \tag{24}$$

where $\varepsilon_1^T$ is uncorrelated with $X_1$. (24) then suggests that the government can optimally hedge the fiscal exposure of property taxes to the risk factor $X_1$ – in the sense of minimizing the variance of the hedged portfolio's payoff – by shorting $\beta^T$ units of a claim which pays the realized value of $X_1$.

The factor betas $\beta^V, \beta^P, \beta^T$ admit simple representations in terms of covariances of risk factors with expected future rents.

**Proposition 6.** *We have:*

$$\beta^P + \beta^T = \beta^V \tag{25}$$

$$\beta^V = \frac{1}{Var\left(X_1\right)} \sum_{s=1}^{\infty} \frac{Cov\left[X_1, \mathbb{E}^{\mathbb{P}}\left[D_s \mid \mathcal{F}_1\right]\right]}{\left(1+r\right)^s} \tag{26}$$

$$\beta^P = \frac{1}{Var\left(X_1\right)} \sum_{s=1}^{\infty} \frac{1}{\left(1+\tau\right)^{s+1}} \frac{Cov\left[X_1, \mathbb{E}^{\mathbb{P}}\left[D_s \mid \mathcal{F}_1\right]\right]}{\left(1+r\right)^s} \tag{27}$$

$$\beta^T = \frac{1}{Var\left(X_1\right)} \sum_{s=1}^{\infty} \left(1 - \frac{1}{\left(1+\tau\right)^{s+1}}\right) \frac{Cov\left[X_1, \mathbb{E}^{\mathbb{P}}\left[D_s \mid \mathcal{F}_1\right]\right]}{\left(1+r\right)^s} \tag{28}$$

Expression (25) is a simple consequence of the linearity of covariances: since $T_0$ and $P_0$ collectively add to the entire stream of rents $V_0$, the risk exposures of $T_0$ and $P_0$ also add up to the risk exposures of $V_0$. Intuitively, (25) states that the risks associated with the rent stream $V_0$ are divided among the taxed house $P_0$ and the tax stream $T_0$. Expressions (26), (27), and (28) then simply state that all these factor betas are equal to weighted sums of the correlation between the risk factor $X_1$, and the weighted stream of conditional expectations of future rents $\mathbb{E}^{\mathbb{P}}\left[D_s \mid \mathcal{F}_1\right]$. While the notation is tedious, the intuition is that, if the stock market increases by 1% next year, the increase in $T_0$ is simply equal to the weighted sum of how much this changes our estimate of each future rent $D_s$, times the ownership weights of these rents in $T_0$. As a result, any economic model of the risk exposures of rents is also a model of the risk exposures of property taxes, through the simple formulas in Proposition 6.

One caveat to our results is that we discuss duration mainly from a *present value* perspective; this is related to, but slightly distinct from, a *cash flow* perspective on interest rate exposures. A portfolio of assets may have positive present value, but incur negative cash flows for many periods. The cash flow perspective may be more directly relevant for local government decision-making in some settings, depending on institutional details of local governments' borrowing costs and constraints. Another caveat is that our discussions of risk exposures also assume prices and taxes respond fully and instantaneously to shifts in interest rates and other factors; we explore relaxing these assumption in various ways in Section 6.

# 5 Investment Incentives

Governments and homeowners can both influence the value of houses: homeowners invest in maintaining and improving their properties, and governments invest in local amenities which affect the value of the local housing stock. Capital structure determines investment incentives: property taxes, in dividing the rent payoff stream generated by a house between the homeowner and the local government, also apportion investment incentives in a certain way between these two parties.

To analyze investment efficiency, we use the marginal utility representation of the pricing kernel (Cochrane, 2009; Duffie, 2010; Campbell, 2017). For any payoff $X_t$, we think of the risk-neutral measure as arising from market equilibrium among risk-averse investors; we then have:

$$E^{\mathbb{Q}}\left[\frac{X_t}{(1+r)^t}\right] = E^{\mathbb{P}}\left[\frac{\beta^t u_t'}{u_0'} X_t\right] \tag{29}$$

where $\beta$ is the investor's discount rate, and $\frac{u_t'}{u_0'}$ is a random variable capturing the marginal investors' state-dependent marginal utility.

## 5.1 Investment Incentives Without Taxes

We first consider investment incentives generated by untaxed houses. Substituting expression (29) into (2) of Proposition 1, we have:

$$V_0 = \sum_{t=0}^{\infty} E^{\mathbb{P}}\left[\frac{\beta^t u_t'}{u_0'} D_t\right] \tag{30}$$

In words, the house's price in period-0 dollars is simply equal to the sum of $\mathbb{P}$-expectations of the product of future payoffs $D_t$, and the ratio of $\beta^t u_t'$, the consumer's possibly random marginal utility of period-$t$ consumption, and $u_0'$, the marginal utility of consumption today.

Suppose the homeowner can invest to increase the monetary value of period-$t$ rents by $i_t^H$, at a convex cost of $c_H\left(i_t^H\right)$ in period-0 dollars. We assume markets are complete, so the owner optimally invests to maximize the period-0 price of the house net of her investment cost. Since investment $i_t^H$ only influences a single $D_t$ term in (30), the owner solves:

$$\max_{i_t^H} E^{\mathbb{P}}\left[\frac{\beta^t u_t'}{u_0'}\left(D_t + i_t^H\right)\right] - c\left(i_t^H\right) \tag{31}$$

The owner's first-order condition is:

$$c_H'\left(i_t^H\right) = \frac{E^{\mathbb{P}}\left[\beta^t u_t'\right]}{u_0'} \tag{32}$$

Expression (32) is both privately and socially optimal: the owner invests until $c_H'\left(i_t^H\right)$, the marginal rate at which period-$t$ dollars are generated using period-0 dollars, is equal to the expected discounted marginal utility of period-$t$ dollars, $E^{\mathbb{P}}\left[\beta^t u_t'\right]$, divided by marginal utility of dollars today, $u_0'$.

Local governments, however, have no fiscal incentives to invest in the house's value under this capital structure. Suppose a local government can invest $i_t^G$ in amenities improving the house's value, at cost $c_G\left(i_t^G\right)$. The socially optimal level for them to invest is analogous to (32):

$$c_G'\left(i_t^G\right) = \frac{E^{\mathbb{P}}\left[\beta^t u_t'\right]}{u_0'} \tag{33}$$

However, without property taxes, local governments do not capture any of the future rents generated by houses, and thus have no monetary incentives to make amenity investments.

## 5.2 Property Taxes and Investment Incentives

Property taxes are a capital structure which divides future rents into components $P_0, T_0$, which accrue to the homeowner and to the government; investment incentives are likewise apportioned between parties. Analogous to (31), the taxed homeowner solves:

$$\max_{i_t^H} E^{\mathbb{P}}\left[\frac{1}{(1+\tau)^{t+1}}\frac{\beta^t u_t'}{u_0'}\left(D_t + i_t^H\right)\right] - c_H\left(i_t^H\right) \tag{34}$$

The FOC is:

$$c_H'\left(i_t^H\right) = \left(\frac{1}{(1+\tau)^{t+1}}\right)\frac{E^{\mathbb{P}}\left[\beta^t u_t'\right]}{u_0'} \tag{35}$$

Suppose a local government holds the claim $T_t$, and chooses amenity investment $i_t^G$ purely to maximize the value of the tax revenue stream $T_0$; this is obviously stylized, but serves to illustrate the fiscal incentives generated by property tax revenues. The government's FOC is:

$$c_G'\left(i_t^G\right) = \left(1 - \frac{1}{(1+\tau)^{t+1}}\right)\frac{E^{\mathbb{P}}\left[\beta^t u_t'\right]}{u_0'} \tag{36}$$

Intuitively, homeowners' and governments' investment incentives are proportional to their ownership stakes in period-$t$ rents, which are the $\tau$ terms in (9) and (10), illustrated in Figure 1. For any positive property tax rate, both homeowners' and governments' investment incentives are positive, add to one, and thus are lower than the socially optimal level in (32). In the language of Holmstrom (1982), the capital structure is a *budget-balanced sharing rule*, and thus cannot induce efficient investment incentives. For any $t$, any increase in $D_t$ accrues partially to the homeowner and partially to the government, so neither party fully internalizes the value of any improvements they make to the asset.

Property taxes give homeowners a frontloaded claim to rents, and governments a backloaded claim. Homeowners thus have higher incentives to make near-term investments, and local governments have higher incentives to make far-term investments. Define the *investment wedge* $\kappa_t^H$ for homeowners as the ratio of (35) and (32); this is equal to homeowners' ownership share of period-$t$ rents:

$$\kappa_t^H = \frac{1}{(1+\tau)^{t+1}} \tag{37}$$

Thus, homeowners' investment incentives are *present-biased*: investments that pay off for small $t$ are nearly optimal, and investments further in the future are increasingly downwards-distorted relative to the social optimum. Intuitively, any investments a homeowner makes will tend to increase house prices, and thus taxes owed to the government; if an investment pays off further in the future, the homeowner must pay increased taxes on the investment for more periods, effectively "leaking" a larger share of the value generated by the investment to the government. Investment distortions apply to any party which pays property taxes: this could include homeowners, as well as homebuilders. An interesting testable prediction of our model is that homebuilders may tend to build less durable housing in high-tax areas, since longer-term payoffs from the house increasingly accrue to governments through taxes.

Taking the ratio of (36) and (33), governments' investment wedge is:

$$\kappa_t^G = 1 - \frac{1}{(1+\tau)^{t+1}} \tag{38}$$

Governments' investment incentives are thus *future-biased*: governments have essentially no incentive to invest in near-term rents, where they have a near-zero ownership stake, but have sharply increasing incentives to invest in rents further in the future.

There is a simple cash-flow based intuition for the future bias in governments' investment incentives. Suppose the government considers immediately running a local festival, which would raise rent by \$1 at $t = 0$: this would increase taxes collected by only around \$0.02. However, if the government commits to holding a festival in $t = 5$, which similarly increases rent at $t = 5$ by \$1, prices will increase from now until $t = 5$, allowing the government to collect increased property taxes for 5 years before the festival realizes. Expression (38) shows that the government collects around \$0.094 in present value of increased taxes by raising rents by \$1 in $t = 5$, giving the government more than four times higher incentives to invest. In general, investments that raise rents $t$ periods into the future increase house prices immediately, and for $t$ periods until the increased amenity values are realized; this allows the government to collect increased property taxed $P_t\tau$ for $t$ periods.

A common view is that property taxes give local governments efficient fiscal incentives to make socially valuable investments, since local governments essentially hold a fiscal claim to share of future rents. Our result points to a subtle flaw in this logic. A stream of property taxes does not amount to a *constant* fraction of future rents: it is an *increasing* claim to rents further in the future. A government which holds a stream of property taxes thus has substantially future-biased incentives for investment. Many political economy models tend to find that governments tend to be present-biased (Alesina and Tabellini, 1990); it is thus interesting that local governments funded by property taxes have a fiscal incentive to be *more patient* than the social planner, in terms of the payoff horizons of their investments.

It is somewhat implausible that local governments are actually sophisticated enough to fully calculate the value of $T_0$, and optimally invest in the way we describe. Our goal in this paper is to illustrate the distortions facing optimizing governments within a stylized model, rather than to model the extent to which local governments are sophisticated in practice.

## 5.3 Durable Investments

As a numerical example, we consider a more realistic setting where investments require an upfront cost and generate rent increases which depreciate over time. This could be thought of as representing, for example, home improvements by homeowners, or structure amenities such as parks built by governments.

**Example 5.** (Durable investment). Suppose governments and households make period-0 investments $i^H, i^G$ that depreciate at rate $\delta$:

$$i_t^H = i^H (1-\delta)^t$$

$$i_t^G = i^G (1-\delta)^t$$

The social planner sets the marginal discounted present value of investment equal to marginal cost:

$$c'_H \left(i_t^H\right) = c'_G \left(i_t^G\right) = \sum_{t=0}^{\infty} \frac{(1-\delta)^t}{(1+r)^t} = \frac{1+r}{(1+r)-(1-\delta)} \tag{39}$$

Aggregating (35) and (36) across periods, the homeowner and government FOCs are respectively:

$$c'_H (i_t) = \sum_{t=0}^{\infty} \frac{(1-\delta)^t}{(1+r)^t (1+\tau)^{t+1}} = \frac{1+r}{(1+r)(1+\tau)-(1-\delta)} \tag{40}$$

$$c_G'\left(i_t^G\right)=\sum_{t=0}^{\infty}\frac{(1-\delta)^t}{(1+r)^t}\left(1-\frac{1}{(1+\tau)^{t+1}}\right)=$$
$$\frac{1+r}{(1+r)-(1-\delta)}-\frac{1+r}{(1+r)(1+\tau)-(1-\delta)} \quad (41)$$

Dividing the FOCs (40) and (41) by the social planner's FOC (39), the homeowner's and governments' investment wedges are thus respectively:

$$\kappa^H=\frac{r+\delta}{(1+r)(1+\tau)-(1-\delta)} \quad (42)$$

$$\kappa^G=1-\frac{r+\delta}{(1+r)(1+\tau)-(1-\delta)} \quad (43)$$

Intuitively, (40) and (41) simply calculate the net present value of investments which accrue to homeowners and governments respectively, under given interest rates, depreciation rates, and tax rates. Homeowners' and governments' investment wedges (42) and (43) are determined by the share of the present value of their investments that they capture. As in the analysis of one-period investments, we have $\kappa^H+\kappa^G=1$.

Using (42) and (43), we can roughly evaluate the magnitudes of homeowners' and governments' investment wedges in practice. We assume $r=0.05$, and set the depreciation rate to $\delta=0.015$, following Kaplan, Mitman and Violante (2020). At 25th, 50th, and 75th percentile property tax rates of 1.07%, 1.43%, and 2.26%, $\kappa_H$ respectively is 85.26%, 81.23%, and 73.26%: homeowners capture around 73% to 86% of the present value of their investments in home improvement. $\kappa_G$ is respectively 14.74%, 18.77%, and 26.74%: governments recapture between 14% to 27% of the value of their amenity investments in increased taxes over time. Thus, under realistic depreciation rates, homeowners' investment incentives are nontrivially downwards-distorted relative to the planner's, and correspondingly the government has nontrivial revenue recapture through property taxes.

## 5.4 State-Dependent Investments

Standard firms are financed with a combination of debt and equity. This capital structure influences the division of surplus across states of the world, and generates state-dependent investment distortions: equityholders have full investment incentives whenever the firm is solvent, and no investment incentives when the firm is guaranteed to be insolvent. In contrast, the capital structure induced by property taxes is equity-like for both $P_t$ and $T_t$: both securities are linear claims to future rents, without any explicit state dependence. Thus, property taxes do not distort either governments' or households' investment incentives across states of the world.

To illustrate this simply, we consider a simple model where rents $D_1$ may be "good" with probability $p_G$, or "bad" otherwise. The owner can invest $i_G^H$ and $i_B^H$, respectively, to improve $G$ and $B$ state rents. The taxed homeowner's investment problem is:

$$\max_{i_t} \frac{\beta}{u_0'} \frac{1}{(1+\tau)^2} \left[ p_G u_{1,G}' \left( D_{1,G} + i_G^H \right) + (1-p_G) u_{1,B}' \left( D_{1,B} + i_B^H \right) \right] - c_H \left( i_G^H \right) - c_H \left( i_B^H \right)$$

The first-order conditions are:

$$c_H' \left( i_G^H \right) = \frac{p_G \beta^t u_{1,G}'}{(1+\tau)^2 u_0'}, \; c_H' \left( i_B^H \right) = \frac{(1-p_G) \beta^t u_{1,B}'}{(1+\tau)^2 u_0'} \tag{44}$$

The social planner's first-order condition is:

$$c_H' \left( i_G^H \right) = \frac{p_G \beta^t u_{1,G}'}{u_0'}, \; c_H' \left( i_B^H \right) = \frac{(1-p_G) \beta^t u_{1,B}'}{u_0'} \tag{45}$$

Comparing (45) and (44), the taxed homeowner has downwards-distorted investment incentives relative to the planner, but the wedge $\frac{1}{(1+\tau)^2}$ does not vary across states of the world. In contrast, an owner of a mortgaged home, like an equityholder in a firm, faces a "debt overhang" distortion: when the value of her house is sufficiently low that she is "underwater", she is no longer the residual claimant on investment, and thus has greatly diminished incentives to maintain the value of the house.[4]

As an application of our results, *land redevelopment* is a setting in which both state- and time-dependent distortions are potentially relevant. Suppose a piece of land has no value if undeveloped; if the owner pays $C$ upfront to develop the land, it pays random rents $D_1, D_2 \ldots$. The investment is socially valuable if:

$$\sum_{t=0}^{\infty} \left( \frac{1}{1+r} \right)^t E^{\mathbb{P}} \left[ u' D_1 | \mathcal{F}_t \right] > C \tag{46}$$

The landowner is willing to make the investment if:

$$\sum_{t=0}^{\infty} \frac{1}{(1+r)^t} \frac{1}{(1+\tau)^{t+1}} E^{\mathbb{P}} \left[ u' D_1 | \mathcal{F}_t \right] > C \tag{47}$$

Thus, there is a range of costs such that the investment is socially valuable, but the owner's

[4]In practice, houses face both property taxes and mortgage obligations. We will not explicitly analyze investment incentives in the presence of both factors, since the results are essentially a combination of our findings and standard results on the distortions induced by debt as a capital structure.

private payoff from investing is not sufficient to justify the upfront costs. The landowner efficiently incorporates uncertainty about the value of the investment in her decision – the $E^{\mathbb{P}}\left[u' D_1 | \mathcal{F}_t\right]$ terms in (46) and (47) are identical. However, the landowner captures only $\frac{1}{(1+\tau)^{t+1}}$ of every dollar of rents her investment generates in period $t$. Likewise, local governments' amenity investment decisions are uniformly lower than is socially optimal, but are not distorted across states of the world.

## 5.5 Investment Incentives in Alternative Tax Systems

### 5.5.1 One-Time Stock Taxes, or Flow Taxes

Consider a local government which imposes a one-time tax on homeowners, which extracts a fraction $\tau$ of period-0 house prices in revenues. Equilibrium prices and tax revenues are then:

$$P_0^{OneTimeTax} = \sum_{t=0}^{\infty} (1-\tau) E^{\mathbb{P}} \left[ \frac{\beta^t u_t'}{u_0'} D_t \right] \tag{48}$$

$$T_0^{OneTimeTax} = \sum_{t=0}^{\infty} \tau E^{\mathbb{P}} \left[ \frac{\beta^t u_t'}{u_0'} D_t \right] \tag{49}$$

This capital structure gives homeowners a share $(1-\tau)$, and governments a share $\tau$, of future rents; investment incentives are thus distorted by these same factors. (48) and (49) also illustrate that a *one-time* tax on house prices has an equivalent effect to a repeated tax of $\tau$ on flow rents: the tax stream $T_0^{OneTimeTax}$ represents a claim to a constant share $\tau$ of each future rent $D_t$. In such settings, governments' investments incentives are distorted downwards, but the distortion is uniform both across states and over time. The core difference between our setting and this setting is that we analyze a more realistic *repeated tax* on house prices. This has a qualitatively different effect from a one-time tax or a flow tax, extracting a larger share of later-term rents, and thus generating an interesting future-bias in the tax recipient's investment wedge.

### 5.5.2 House Price Maximization

Suppose the government collects property taxes, but chooses amenity investments to maximize house prices $P_0$, rather than the value of property tax revenues $T_0$. Governments' investment incentives would then be inefficiently *frontloaded*, identically to homeowners in our model: since $P_0$ increasingly fails to capitalize rents further in the future, governments which invest to maximize $P_0$ tend to under-invest in longer-run rents.

In our model, a government which invested to target the unweighted sum of $T_0$ and $P_0$ would in fact have incentives that are perfectly aligned with the social planner. An interesting possibility is that the combination of fiscal incentives to increase $T_0$, and political-economic pressures on governments to increase local house prices $P_0$, could in theory drive local governments to optimize some combination of $T_0$ and $P_0$, approximating the optimal investment scheme. We leave detailed exploration of how property tax-generated investment incentives interact with the political economy of local governments to future work.

### 5.6 Investment-Efficient Equity Structures

Residential real estate is commonly financed through mortgages or other debt-like structures; "shared equity" structures are fairly rare in housing markets. Interestingly, our analysis suggests that residential real estate in many countries *is already financed* through a shared-equity structure: in any system where property taxes are implicitly or explicitly set to the market values of houses, the government is an implicit equityholder in all taxed property. Why, then, are property taxes so widely adopted, when other shared-equity designs have struggled to gain traction.

A very speculative answer, based on our analysis, is that concentrating equity stakes in homeowners and local governments may be optimal for aligning investment incentives. Homeowners influence house values through upkeep and investment; local governments, through amenities and infrastructure. Other parties potentially have disproportionately less influence on property values. Capital structure determines investment incentives: efficient capital structures allocate residual profits to parties whose actions influence these profits most. It is thus natural for equity stakes to be concentrated in the hands of homeowners and governments, and for investment incentives not to be diluted by granting equity stakes to other parties. Building on the idea of "investment-efficient capital structures", equity-sharing arrangements may tend to work better in settings where a single party, other than homeowners and governments, has substantial influence over the values of property in a neighborhood; this may be true, for example, in "land value capture" schemes, where a developer owns land around public-transit systems which add value to the land.

Again, speculatively, suppose homeowners' decisions influence house values more in the shorter run, whereas local governments' actions matter more in the longer run. It would then be efficient to give equity stakes in short-term rents primarily to homeowners, and longer-term rents primarily to governments; this is exactly what property taxes accomplish. Given enough structure on the magnitudes of these effects, it may be possible to solve for a property tax rate which optimally divides investment incentives; we leave further exploration of this idea to future work.

# 6 Extensions

## 6.1 Imperfect Capitalization

Our baseline model assumes that property taxes are perfectly capitalized into prices. A large empirical literature, surveyed in Sirmans, Gatzlaff and Macpherson (2008) and Yinger, Bloom and Boersch-Supan (2013), has shown that capitalization appears imperfect in practice Sirmans, Gatzlaff and Macpherson (2008). In this appendix, we consider model outcomes when prices do not fully reflect the tax burden imposed on houses. Subsection 6.1 analyzes the related case where prices and taxes eventually shift to reflect changes in primitives, but do so with a lag.

In our baseline model, we model imperfect capitalization by assuming simply that house prices are a convex combination of the taxed and untaxed house prices:

$$P_t^{ImpCap} = (1-\theta) P_t + \theta V_t \tag{50}$$

$\theta = 0$ represents perfect capitalization of property taxes; $\theta = 1$ represents no capitalization, that is, house prices are simply equal to the discounted present value of rents as in (2), and taxes do not factor into house prices at all. Proposition 7 characterizes $T_0$ as a function of $\theta$.

**Proposition 7.** *If prices are described by (50), we have:*

$$T_0^{ImpCap} = \sum_{t=0}^{\infty} \left[ (1-\theta) \left( 1 - \frac{1}{(1+\tau)^{t+1}} \right) + \theta (t+1) \tau \right] \frac{E^{\mathbb{Q}}[D_t]}{(1+r)^t} \tag{51}$$

$T_0^{ImpCap}$ *is increasing in* $\theta$.

Proposition 7 states that $T_0$ is actually higher when $\theta$ is higher, and taxes are capitalized less. This is intuitive: if taxes are not capitalized into property prices, prices are higher, making taxes themselves also higher. However, expression (51) shows that $T_0$ is still equal in this case to a slightly modified stream of claims to future rents: intuitively, rather than *geometrically* taking fractions of future rents, under imperfect capitalization, taxation *arithmetically* extracts future rent pieces. This implies, however, that our claims still hold under expression (51). Local governments have slightly higher incentives to invest on the whole, since they collect greater tax revenues; however, their investment incentives remain heavily future-biased.[5]

[5] The analysis of homeowners' investment incentives is more complicated, since imperfect capitalization of

The duration of $T_0$ is still very high, since $T_0$ remains an increasing claim to rents further in the future. Together, this analysis shows that imperfect tax capitalization *increases* the magnitude of $T_0$, and otherwise does not qualitatively change our conclusions regarding local governments' investment incentives and the duration of property tax revenues.

Imperfect capitalization weakens the intuition that property taxes impose a capital structure on future rents. The implicit capital structure generated by property taxes relies on the market's ability to price property taxes rationally, so that the property taxes exactly make up the gap between the taxed house value and the full present value of discounted future rents. If the market fails to perfectly capitalize taxes into prices, $T_0$ plus $P_0$ will generally *exceed* the present value of future rents – the difference is implicitly made up by imperfectly rational homeowners, who purchase taxed houses at a price $P_t^{ImpCap}$ in (50), that is higher than the ultimate value of the rent stream, less property taxes, that the house is a claim to. This result also implies that the "extraction ratios" we calculate are more difficult to interpret in the case of imperfect capitalization.

## 6.2 Assessment Lags

In our baseline model, we assumed that changes in parameters such as future rent values or interest rates are immediately and completely incorporated into house prices and thus property tax revenues. This is unrealistic for two reasons. Firstly, for a variety of institutional reasons, tax assessments of houses may respond slowly to changes in house prices. Secondly, house prices themselves do not respond quickly and immediately to shifts in macro variables such as interest rates, as well as local conditions such as changes in amenity values.

Assessment lags would lower governments' fiscal incentives to invest, since property values, and thus property tax revenues, do not immediately update to reflect the value of government amenity investments. This effect is more severe for frontloaded investments: in the extreme case where an amenity investment realizes its value entirely before house prices can update, governments do not fiscally capture any of the value generated by the investment. The government also has diminished incentives for longer-term amenity investment, but the distortion is smaller, since prices and property tax payments have a longer time to incorporate the value of these investments.

The analysis of assessment lags for households is slightly more complex. In our model,

property taxes implies some degree of irrationality on homeowners' behalf. If taxes are imperfectly capitalized into house prices, prices are too high in the sense that homeowners achieve higher utility from renting than owning, in our model. Since some homeowners must make suboptimal choices in such a model, it is difficult to think about homeowners' investment choices in a principled way.

property taxes decrease households' investment incentives, effectively because investing increases the house price, and thus tax payments owed to the government. Suppose that, after improvements to houses are made, prices and thus tax payments do not immediately update; households thus have *increased* incentives to invest, since the tax-increase effect is muted. As in the government case, assessment lags primarily change short-run investment incentives; long-run incentives are less affected, since prices have more time to update to reflect increased values.

Related to assessment lags, our results on interest rate risk calculations are most relevant only for *long-run* shifts in interest rates, such as the secular decline in interest rates we analyze in Figure 3. Assessments respond slowly to house price changes, and house prices also respond slowly to interest rates. Thus, sharp increases and decreases in interest rates within shorter time horizons are unlikely to have large effects on property tax revenues, and our results on interest rate risk exposures are thus unlikely to accurately model the short-run response of property taxes to interest rates.

## 6.3 Amenity Investment

In our baseline analysis, we assumed rents are exogeneous, analyzing investment incentives in Section 5. Here, we consider an extreme case of amenity investment, in which local governments commit to immediately and specifically spending all property taxes on frictionlessly providing amenities. Specifically, suppose that when a government collects $\tau P_t$ in taxes, this revenue is immediately spent in a way which increases time-$t$ rent $D_t$ by $\tau P_t$. The net monetary payoff delivered by the house in period $t$ is then trivially:

$$D_t - \underbrace{\tau P_t}_{Tax\ Payment} + \underbrace{\tau P_t}_{Amenity\ Provision} = D_t$$

Clearly, the house is worth exactly as much as an untaxed house, so the taxed house must be worth $V_t$, exactly the price of the untaxed house. This follows intuitively from our results. Figure 1 shows that property taxes divide the untaxed asset into a taxed asset, and a stream of tax revenues. If tax revenues are invested in a way which generates amenities for homeowners of equal NPV to the tax revenues, then the entire stream of tax revenues is effectively taken and then refunded to homeowners, so taxes ultimately do not affect the market value of houses. This case also does not allow for useful analysis of local governments' fiscal incentives: all tax revenues are refunded to homeowners entirely through amenity provision, so the "local government" in this model has a trivial balance sheet.

While this result is stark and pushes against many of our results, we do not think the underlying assumptions represent a reasonable model of local government behavior in general. At least in the US, local governments' balance sheets do not seem fully segregated in practice. A recent literature on local public finance in the US shows that pension liabilities (Zhang, 2021) and financing costs (Posenau, 2021; Yi, 2021) influence local public goods provision. This is consistent with the view that property tax revenues are commingled with other assets and liabilities of local governments, and is harder to rationalize under the simpler view that amenity-provision revenues are segregated from other components of local governments' balance sheets.

More abstractly, the main goal of our paper is to document the properties of tax streams as financial assets; the correctness of this exercise does not hinge on where the value of these financial assets ultimately accrues to. In the extreme case where tax streams are frictionlessly refunded to homeowners through amenity provision, then property taxes do not affect house prices, and it does not make sense to talk about "extraction ratios" as we do in Section 3. If the local government is restricted to mechanically refunding taxes to households through amenity provision, it does not make sense to model local governments as investing to optimize some objective function, as we do in Section 5. However, our results still correctly describe the fraction of future rent values that is extracted through property taxes and refunded through amenity provision, and also how this value varies depending on macroeconomic factors such as interest rates.

## 6.4 Transaction Costs and Search Frictions

We have assumed transacting in houses is frictionless, and all potential buyers have homogeneous values for houses. In reality, buying and selling houses involves transaction costs, and different agents may have different values for the same house. In a model with homogeneous valuations, but "liquidity shocks" that force agents to bear transaction costs occasionally, untaxed house prices would be equal to expected rents minus the discounted present value of expected liquidity shocks; the basic conclusions of our model would continue to hold.

The situation is more complex if we assume that housing markets have matching frictions, and homebuyers are also differentiated, as in many search models. In such models, prices tend to be approximately equal to discounted values of average future owners' values for houses, but the relationship is analytically more complex than our simple setting due to heterogeneity in homeowners' valuations. We do not think the subtleties of equilibria in search models would interact with property taxes in ways that dramatically change any of the conclusions we make in this paper. However, this case is complex enough that we leave detailed analysis of this interaction to future work.

### 6.5 Time- and State-Depedennt Tax Rates

We have assumed a constant tax rate; realistically, local governments may vary the tax rate depending on fiscal conditions, so $\tau$ may be time-varying and may depend on the evolution of $D_t$. In theory, for any process specified for the evolution of $\tau$, our approach can be applied to calculate the value of property taxes. However, it is unclear that this value in general can be thought of as a a backloaded claim to rents as in our paper: for example, if local governments raised the property tax rate when rents realize below expectations, property taxes may behave like a call option on rent realizations, rather than a portfolio of rent forward contracts. Our model is a reasonable approximation in settings where tax rates do not change substantially over time: in Appendix B.2, we show briefly that tax rates do not vary too much within counties over the period 2003-2015, using data from Baker, Janas and Kueng (2023). Our framework and findings are likely to be less useful in settings where tax rates may vary more substantially over time and across states of the world.

## 7 Conclusion

We have shown that property taxes can be thought of as a capital structure, which divides a stream of future rents into a frontloaded component that accrues to homeowners, and a backloaded component that accrues to local governments. Our analysis is elementary, but delivers surprising results about the exposure of property taxes to economic risk factors, and the way that property taxes shape the investment incentives of homeowners and local governments.

While we have focused our discussion on property taxes, the analysis applies to any setting in which a repeated tax is applied to the market value of a "stock" quantity. Some examples of such taxes are wealth taxes, as well as recent proposals to apply repeated taxes on university endowments.[6]

[6] For example, see Bloomberg.

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# Internet Appendix

## A Proofs

Throughout the proofs, we impose two assumptions. First, we assume all outcome variables $V_t, P_t, T_t$ satisfy transversality conditions.

**Assumption 1.** *We assume that* $V_t$ *satisfies*

$$\lim_{N\to\infty} (1+r)^{-N}\, \mathbb{E}^{\mathbb{Q}}\left[V_{t+N}|\mathcal{F}_t\right] = 0 \tag{52}$$

*for any fixed* $t$*, and likewise for* $P_t$ *and* $T_t$*.*

Second, we assume the discounted sum of expected future rents likewise satisfies a transversality condition.

**Assumption 2.** *We assume that* $D_t$ *satisfies*

$$\lim_{N\to\infty} \sum_{s=N}^{\infty} \frac{1}{(1+r)^s} \mathbb{E}^{\mathbb{Q}}[D_{t+s}|\mathcal{F}_t] = 0 \tag{53}$$

*for any fixed* $t$*.*

### A.1 Proof of Proposition 1

Suppose the house is purchased in period $t$, held for one period, and sold thereafter. In order for the risk-neutral return to equal $r$, we must have:

$$V_t = D_t + \frac{1}{1+r}\mathbb{E}^{\mathbb{Q}}[V_{t+1}|\mathcal{F}_t]. \tag{54}$$

Iterating forward Equation 54 for $N$ periods, and applying the law of iterated expectations, we see that the price of an untaxed house is simply the discounted sum of future rents:

$$V_t = \underbrace{D_t + \frac{1}{1+r}\mathbb{E}^{\mathbb{Q}}[D_{t+1}|\mathcal{F}_t] + \frac{1}{(1+r)^2}\mathbb{E}^{\mathbb{Q}}[D_{t+2}|\mathcal{F}_t] + \ldots + \frac{1}{(1+r)^N}\mathbb{E}^{\mathbb{Q}}[D_{t+N}|\mathcal{F}_t]}_{\text{discounted sum of expected rents for next } N \text{periods}} + \underbrace{\frac{1}{(1+r)^{N+1}}\mathbb{E}^{\mathbb{Q}}[V_{t+N+1}|\mathcal{F}_t]}_{\text{discounted termination price in } N+1 \text{ periods}} \tag{55}$$

Taking the limit as $N \to \infty$, the transversality condition (52) implies that the termination price term in (55) converges to 0. We thus obtain (2). Assumption 2 ensures that this solution satisfies the transversality condition (52).

## A.2 Derivations for Example 3

Under the physical probability measure $\mathbb{P}$, we have:

$$E^{\mathbb{P}}\left[D_{t+1} \mid D_t\right] = \left(\pi^{\mathbb{P}}\left(1+u\right) + \left(1-\pi^{\mathbb{P}}\right)\left(1-d\right)\right) D_t$$

where we write $D_t$ in the conditioning, because the Markovian nature of the binomial tree means that $D_t$ contains all the relevant conditioning information in $\mathcal{F}_t$. We thus have, for example,

$$\begin{aligned} E^{\mathbb{P}}\left[D_{t+2} \mid D_t\right] &= E^{\mathbb{P}}\left[E^{\mathbb{P}}\left[D_{t+2} \mid D_{t+1}\right] \mid D_t\right] \\ &= E^{\mathbb{P}}\left[\left(\pi^{\mathbb{P}}\left(1+u\right) + \left(1-\pi^{\mathbb{P}}\right)\left(1-d\right)\right) D_{t+1} \mid D_t\right] \\ &= \left(\pi^{\mathbb{P}}\left(1+u\right) + \left(1-\pi^{\mathbb{P}}\right)\left(1-d\right)\right)^2 D_t \end{aligned}$$

And through a somewhat tedious induction argument, we have:

$$E^{\mathbb{P}}\left[D_{t+s} \mid D_t\right] = \left(\pi^{\mathbb{P}}\left(1+u\right) + \left(1-\pi^{\mathbb{P}}\right)\left(1-d\right)\right)^s D_t$$

Analogously under the risk-neutral measure $\mathbb{Q}$, we have:

$$E^{\mathbb{Q}}\left[D_{t+s} \mid D_t\right] = \left(\pi^{\mathbb{Q}}\left(1+u\right) + \left(1-\pi^{\mathbb{Q}}\right)\left(1-d\right)\right)^s D_t$$

Thus,

$$\frac{E^{\mathbb{P}}\left[D_{t+s} \mid D_t\right]}{E^{\mathbb{Q}}\left[D_{t+s} \mid D_t\right]} = \left(\frac{\pi^{\mathbb{P}}\left(1+u\right) + \left(1-\pi^{\mathbb{P}}\right)\left(1-d\right)}{\pi^{\mathbb{Q}}\left(1+u\right) + \left(1-\pi^{\mathbb{Q}}\right)\left(1-d\right)}\right)^s \tag{56}$$

This is the intuitive statement that the $\mathbb{P}$- and $\mathbb{Q}$-measure expectations of rents grow at different constant rates, so their ratio $s$ periods in the future from $t$, conditional on period-$t$ information, is the ratio of these constant rates to the power of $s$. Defining $\tilde{r}$ as in (6), we have:

$$\left(1+\tilde{r}\right) = \left(1+r\right)\frac{\pi^{\mathbb{P}}\left(1+u\right) + \left(1-\pi^{\mathbb{P}}\right)\left(1-d\right)}{\pi^{\mathbb{Q}}\left(1+u\right) + \left(1-\pi^{\mathbb{Q}}\right)\left(1-d\right)}$$

Thus,

$$\frac{E^{\mathbb{Q}}\left[D_{t+s} \mid D_t\right]}{\left(1+r\right)^s} = \frac{E^{\mathbb{P}}\left[D_{t+s} \mid D_t\right]}{\left(1+\tilde{r}\right)^s}$$

where $\tilde{r}$ is defined in (6). Combining this with the expression for the price of $V_t$ in (2) of Proposition 1, we get (5) of Example 3.

### A.3 Proof of Proposition 2

We consider solutions that satisfies $0 \leq P_t \leq V_t$ and $0 \leq T_t \leq V_t$ where $V_t$ denotes the untaxed house price. This automatically implies that $P_t, T_t$ also satisfy transversality conditions $\lim_{N\to\infty}(1+r)^{-N}\mathbb{E}^{\mathbb{Q}}[P_{t+N}|\mathcal{F}_t] = 0$ and $\lim_{N\to\infty}(1+r)^{-N}\mathbb{E}^{\mathbb{Q}}[T_{t+N}|\mathcal{F}_t] = 0$ for any fixed $t$.

Again, suppose the house is purchased in period $t$, held for one period, and sold thereafter. In order for the risk-neutral return to equal $r$, we must have:

$$P_t = D_t - \tau P_t + \frac{1}{1+r}\mathbb{E}^{\mathbb{Q}}[P_{t+1}|\mathcal{F}_t]. \tag{57}$$

By iterating (57) forward, we have:

$$P_t = \sum_{s=0}^{N-1} \frac{E^{\mathbb{Q}}\left[D_{t+s}|\mathcal{F}_t\right]}{(1+\tau)^{s+1}(1+r)^s} + \frac{E^{\mathbb{Q}}\left[P_{t+N}|\mathcal{F}_t\right]}{(1+\tau)^N(1+r)^N} = \sum_{s=0}^{\infty} \frac{E^{\mathbb{Q}}\left[D_{t+s}|\mathcal{F}_t\right]}{(1+\tau)^{s+1}(1+r)^s} \tag{58}$$

Where the last equality uses the transversality condition (52), taking $N \to \infty$.

The tax stream $T_t$ pays:

$$\tau P_t, \tau P_{t+1}, \tau P_{t+2} \ldots$$

In order for the risk-neutral return on $T_t$ to equal $r$, we must have:

$$T_t = \tau P_t + \frac{1}{1+r}\mathbb{E}^{\mathbb{Q}}[T_{t+1}|\mathcal{F}_t]. \tag{59}$$

Iterating (59) forward, we have:

$$T_t = \tau \sum_{s=0}^{N-1} \frac{E^{\mathbb{Q}}\left[P_{t+s}|\mathcal{F}_t\right]}{(1+r)^s} + \tau \frac{E^{\mathbb{Q}}\left[T_{t+N}|\mathcal{F}_t\right]}{(1+r)^N} = \tau \sum_{s=0}^{\infty} \frac{E^{\mathbb{Q}}\left[P_{t+s}|\mathcal{F}_t\right]}{(1+r)^s}$$

Where, again, we use the transversality condition (52), taking $N \to \infty$. Plugging in the previous expression for $P_t$, we have:

$$T_t = \sum_{s=0}^{\infty}\sum_{l=0}^{\infty} \frac{\tau E^{\mathbb{Q}}\left[D_{t+s+l}|\mathcal{F}_t\right]}{(1+r)^{l+s}(1+\tau)^{l+1}} = \sum_{k=0}^{\infty} \frac{\tau E^{\mathbb{Q}}\left[D_{t+k}|\mathcal{F}_t\right]}{(1+r)^k(1+\tau)} \left(\sum_{l=0}^{k} \frac{1}{(1+\tau)^l}\right)$$

$$= \sum_{k=0}^{\infty} \frac{E^{\mathbb{Q}}\left[D_{t+k}|\mathcal{F}_t\right]}{\left(1+r\right)^k}\left(1-\frac{1}{\left(1+\tau\right)^{k+1}}\right)$$

This proves (10). (8) follows directly from (2), (9), and (10).

## A.4 Proof of Proposition 3

Denote the price of a date $l-$forward contract at date $t$ as $F\left(t,l\right)$. Recall from (7) that the price of the rent forward contract is given by $F\left(t,l\right) = \frac{\mathbb{E}^{\mathbb{Q}}\left[D_l|\mathcal{F}_t\right]}{\left(1+r\right)^{l-t}}$. We observe that a taxed house's price and payoffs can be replicated period-by-period with a continuously adjusted portfolio of rent forward contracts, where the number of $s-$forward contracts held in the portfolio at date $t$ is given by $\frac{1}{\left(1+\tau\right)^{l-t+1}}$, for any $t = 0, 1, ...$and $l = t, t+1, ...$ We next show that this portfolio (i) has value equal to $P_t$ and (ii) has period $t$ net payoff equal to $D_t - \tau P_t$.

To see (i), note that the price of the portfolio is given by

$$\tilde{P}_t = \sum_{l=t}^{\infty} \frac{F\left(t,l\right)}{\left(1+\tau\right)^{l-t+1}} = \sum_{s=0}^{\infty} \frac{E^{\mathbb{Q}}\left[D_{t+s}|\mathcal{F}_t\right]}{\left(1+r\right)^s\left(1+\tau\right)^{s+1}} = P_t.$$

To see (ii), note that the net payoff of the portfolio in period $t$ is given by the payoff of the $t-$forward contract that realizes in period $t$ net of the cost from adjusting the number of contracts held in the portfolio to satisfy period $t+1$ definition. The payoff of the $t-$forward contract realization is given by

$$\frac{1}{1+\tau}D_t$$

while the adjustment cost is given by

$$\tilde{C}_t = \sum_{l=t+1}^{\infty}\left[\frac{1}{\left(1+\tau\right)^{l-t}} - \frac{1}{\left(1+\tau\right)^{l-t+1}}\right]F\left(t,l\right) = \tau\sum_{l=t+1}^{\infty}\frac{F\left(t,l\right)}{\left(1+\tau\right)^{l-t+1}}.$$

The net payoff is thus given by

$$\text{Net payoff} = \frac{1}{1+\tau}D_t - \tau\sum_{l=t+1}^{\infty}\frac{F\left(t,l\right)}{\left(1+\tau\right)^{l-t+1}} = D_t - \tau\sum_{l=t}^{\infty}\frac{F\left(t,l\right)}{\left(1+\tau\right)^{l-t+1}} = D_t - \tau P_t.$$

By analogous arguments, the price and payoffs of a tax stream $T_t$ can also be replicated period-by-period with a portfolio that holds $1 - \frac{1}{\left(1+\tau\right)^{l-t+1}}$ number of $l-$forward contracts at date $t$ for $l = t, t+1, ....$

## A.5 Proof of Proposition 5

Expressions (17), (18), and (19) follow immediately from differentiating (2), (9), and (10) of Proposition 2. (20) follows immediately.

Intuitively, (21) holds because $P_0$ is strictly more "frontloaded" than $V_0$, and $T_0$ is strictly more "backloaded", so $P_0$ has lower percentage interest rate exposure, and $T_0$ has higher exposure, than $V_0$. We now demonstrate this technically. We write $P_0(r), V_0(r)$ to emphasize the dependence of both quantities on $r$. Fixing some $r_0$, define:

$$\tilde{P}_0(r) = \sum_{t=0}^{\infty} \frac{1}{(1+r)^t} a E^{\mathbb{Q}}[D_t] \tag{60}$$

where $a$ is chosen so that $\tilde{P}_0(r_0) = P_0(r_0)$; $a$ is thus a constant which depends on $r_0$. Intuitively, $\tilde{P}_0(r)$ is just a linearly scaled claim to future rents, scaled so it has the same price as $P_0(r)$ at $r_0$. (60) implies that $\tilde{P}_0(r)$ is also just a scaled version of the untaxed house price:

$$\tilde{P}_0(r) = aV_0(r) \ \ \forall r$$

Clearly, $\tilde{P}_0(r)$ thus has the same duration as $V(r)$:

$$\frac{\frac{\partial \tilde{P}_0}{\partial r}|_{r=r_0}}{\tilde{P}_0(r_0)} = \frac{\frac{\partial V_0}{\partial r}|_{r=r_0}}{V_0(r_0)} \tag{61}$$

Now, we can write:

$$P_0(r_0) = \tilde{P}_0(r_0) + \left(P_0(r_0) - \tilde{P}_0(r_0)\right)$$

Giving us that:

$$\frac{\frac{\partial P_0}{\partial r}|_{r=r_0}}{P_0(r_0)} = \frac{\frac{\partial \tilde{P}_0}{\partial r}|_{r=r_0}}{\tilde{P}_0(r_0)} + \frac{\frac{\partial\left(P_0-\tilde{P}_0\right)}{\partial r}|_{r=r_0}}{\tilde{P}_0(r_0)}$$

Where we used that $P_0(r_0) = \tilde{P}_0(r_0)$. Now, substituting (61), we have:

$$\frac{\frac{\partial P_0}{\partial r}|_{r=r_0}}{P_0(r_0)} = \frac{\frac{\partial V_0}{\partial r}|_{r=r_0}}{V_0} + \frac{\frac{\partial\left(P_0-\tilde{P}_0\right)}{\partial r}|_{r=r_0}}{\tilde{P}_0(r_0)}$$

Hence, to show the inequality for $P_0$ in (21), we need only show that

$$-\frac{\partial\left(P_0 - \tilde{P}_0\right)}{\partial r}|_{r=r_0} \leq 0 \tag{62}$$

To show this, we use the definition of $P_0(r)$ in (60), to write $\left(P_0(r) - \tilde{P}_0(r)\right)$ as a claim to rents:

$$0 = P_0(r_0) - \tilde{P}_0(r_0) = \sum_{t=0}^{\infty} \frac{1}{(1+r_0)^t} \left( \frac{1}{(1+\tau)^{t+1}} - a \right) E^{\mathbb{Q}}[D_t] \tag{63}$$

Now, the sequence of coefficients:

$$\frac{1}{(1+\tau)^{t+1}} - a \tag{64}$$

is strictly decreasing in $t$, and $E^{\mathbb{Q}}[D_t]$ is always nonnegative. Thus, for (63) to equal 0, the coefficient (64) must be strictly positive below some cutoff $\bar{t}$, where $E^{\mathbb{Q}}[D_t]$ is positive at least somewhere, and strictly negative equal to or above $\bar{t}$, where $E^{\mathbb{Q}}[D_t]$ is positive at least somewhere. Together with the fact that $P_0(r_0) - \tilde{P}_0(r_0) = 0$, this is sufficient to demonstrate (62); intuitively, this is because the positive and negative components of (63) have equal present value, and the negative components are supported on a disjoint interval of values of $t \geq \bar{t}$ relative to the positive components, which are supported on $t < \bar{t}$.

To show this formally, we define:

$$\Delta^+(r) \equiv \sum_{t=0}^{\bar{t}-1} \frac{1}{(1+r)^t} \left( \frac{1}{(1+\tau)^{t+1}} - a \right) E^{\mathbb{Q}}[D_t] \tag{65}$$

$$\Delta^-(r) \equiv \sum_{t=\bar{t}}^{\infty} \frac{1}{(1+r)^t} \left( a - \frac{1}{(1+\tau)^{t+1}} \right) E^{\mathbb{Q}}[D_t] \tag{66}$$

as the positive and negative components of the difference $P_0(r) - \tilde{P}_0(r)$, at $r = r_0$. Clearly, both $\Delta^-(r)$ and $\Delta^+(r)$ are strictly positive claims to rents, with:

$$P_0(r) - \tilde{P}_0(r) = \Delta^+(r) - \Delta^-(r)$$

Hence

$$\begin{aligned} \frac{\partial\left(P_0 - \tilde{P}_0\right)}{\partial r}|_{r=r_0} > 0 &\iff \frac{\partial \Delta^+}{\partial r}|_{r=r_0} - \frac{\partial \Delta^-}{\partial r}|_{r=r_0} > 0 \\ &\iff \frac{\frac{\partial \Delta^+}{\partial r_0}|_{r=r_0}}{\Delta^+(r_0)} - \frac{\frac{\partial \Delta^-}{\partial r_0}|_{r=r_0}}{\Delta^-(r_0)} > 0 \end{aligned} \tag{67}$$

where we have used that $P_0(r_0) - \tilde{P}_0(r_0) = 0$, hence $\Delta^-(r_0) = \Delta^+(r_0)$. That is, the sign of $\frac{\partial\left(P_0 - \tilde{P}_0\right)}{\partial r}|_{r=r_0}$ depends on the relative durations of the terms $\Delta^+(r)$ and $\Delta^-(r)$, at $r = r_0$. But from (65), $\Delta^+(r_0)$ is a claim to cash flows at most $\bar{t}-1$ periods in the future, hence has duration at most:

$$-\frac{\frac{\partial \Delta^+}{\partial r_0}|_{r=r_0}}{\Delta^+(r_0)} < \frac{1}{1+r}\left(\bar{t}-1\right)$$

and from (66), $\Delta^-(r_0)$ is a claim to cash flows at least $\bar{t}$ periods in the future, hence has duration at least:

$$-\frac{\frac{\partial \Delta^-}{\partial r_0}|_{r=r_0}}{\Delta^-(r_0)} \geq \frac{1}{1+r}\bar{t}$$

We have thus proved (67), and thus the $P_0$ component of the inequality in (21). The $T_0$ component of (21) follows through an analogous argument.

## A.6 Proof of Proposition 7

*Proof.* The tax stream $T_0^{ImpCap}$ pays:

$$\tau P_1^{ImpCap}, P_2^{ImpCap} \ldots$$

Hence has market value:

$$\sum_{t=0}^{\infty} \frac{E^{\mathbb{Q}}\left[\tau P_t^{ImpCap}\right]}{(1+r)^t}$$

$$= \sum_{t=0}^{\infty} \frac{E^{\mathbb{Q}}\left[\tau\left((1-\theta) P_t + \theta V_t\right)\right]}{(1+r)^t}$$

$$= \underbrace{(1-\theta) \sum_{t=0}^{\infty} \frac{E^{\mathbb{Q}}[\tau P_t]}{(1+r)^t}}_{A} + \underbrace{\theta \sum_{t=0}^{\infty} \frac{E^{\mathbb{Q}}[\tau V_t]}{(1+r)^t}}_{B} \tag{68}$$

Now, term $A$ in (68) is exactly the value of the standard tax stream $T_t$ multiplied by $(1-\theta)$, and we thus have, from Proposition 2:

$$(1-\theta) \sum_{t=0}^{\infty} \frac{E^{\mathbb{Q}}[\tau P_t]}{(1+r)^t} = (1-\theta) \sum_{t=0}^{\infty} \frac{1}{(1+r)^t} \left(1 - \frac{1}{(1+\tau)^{t+1}}\right) E^{\mathbb{Q}}[D_t]$$

To calculate term $B$, we substitute expression (5) for $V_t$:

$$\sum_{t=0}^{\infty} \frac{E^{\mathbb{Q}}[V_t]}{(1+r)^t} = \sum_{t=0}^{\infty} \sum_{s=0}^{\infty} \frac{\mathbb{E}^{\mathbb{Q}}[D_{t+s}]}{(1+r)^{t+s}} = \sum_{t=0}^{\infty} (t+1) \frac{\mathbb{E}^{\mathbb{Q}}[D_t]}{(1+r)^t}$$

Plugging this into (68), we get (51). Moreover, we have for any $\tau > 0$:

$$(t+1)\tau \geq 1 - \frac{1}{(1+\tau)^{t+1}}$$

implying that $T_0^{ImpCap}$ is increasing in $\theta$. □

# B Data Description

## B.1 Data Details for Figure 2

To construct Figure 2, we compute the extraction ratio using the following variables:

$$\eta_i = \frac{\text{Median Home Value}_i}{12 \times \text{Median Contract Rent}_i} \times \tau_i$$

where $i$ indicates county, the variables Median Home Value$_i$ and Median Rent$_i$ are taken directly from the 2011–2015 American Community Survey 5-year estimates. Rent is defined as contractual rent, for more details, see the Subject Definitions section of the ACS codebook. Variable codes are B25077 and B25058, available on Social Explorer. $\tau_i$ is computed as the average property tax rate of county $i$ from 2011 to 2015, based on data in Baker, Janas and Kueng (2023). Baker, Janas and Kueng (2023) computes tax rates – tax payments as a fraction of the dollar value of houses, as in our model – by multiplying tax rates on the assessed values of houses by the estimated average ratio of assessed prices to house transaction prices.

To construct the household share histograms, we weight county-level average tax rates and extraction ratios by the number of households in each county. Number of Households$_i$ is also taken directly from 2011-2015 ACS 5-year estimates.

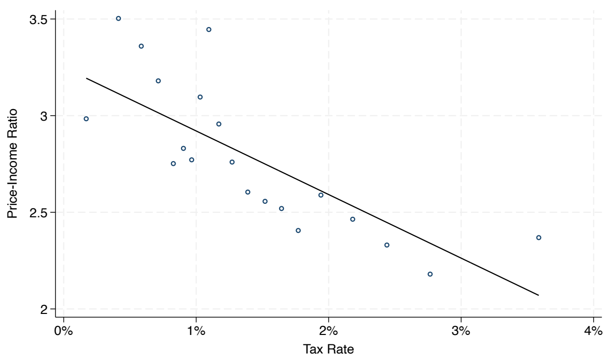
## B.2 Data Details for Figures 3 and B.1

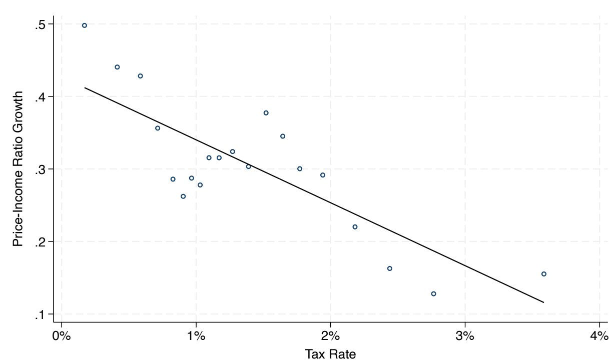
The data sources for Figure 3 and Appendix Figure B.1 are the 1990 Census and the 2015-2019 ACS 5-year sample. We compute the price-to-rent and price-to-income ratios in 1990 using the 1990 Census data, taking the ratio between Median House Value and Median Gross Rent, and Median House Value and Median Household Income respectively. Variable codes are T164, T167 and T088 available on Social Explorer. For the period 2015-2019, we compute the price-to-rent and price-to-income ratios using 2015-2019 American Community Survey 5-Year Estimates, by dividing Median Value by Median Gross Rent, and Median House Value by Median Household Income respectively. Variable codes are B25077, B25064 and B19013 available on Social Explorer. Note that gross rent is defined as the sum of contractual rent and utilities, including fuel. We use gross rent instead of contractual rent because contractual rent is not available in the 1990 Census data. County level tax rates are computed as the average property tax rate of a given county, over the period covered by data from 2003 to 2015 in Baker, Janas and Kueng (2023). It is worth noting that in the Baker, Janas and

Kueng (2023) data, there is relatively little variation in tax rates over time for a given county. The standard deviation of tax rates divided by the mean of tax rates is 0.06 for the median county, and 0.11 at the 75th percentile.

Figure B.1: Tax Rates, Price-Income Ratios, and Price-Income Ratio Growth

This figure depicts binned scatterplots illustrating the relationships between county-level property tax rates and the level and growth rates of price-income ratios. The sample consists of 3022 counties. The left panel shows median house values divided by median household income, using 2015-2019 ACS 5-year data. The right panel shows the percentage growth in price-income ratios, from the 1990 Census data, to the 2015-2019 ACS 5-year data. In both panels, the x-variable is property tax rates from Baker, Janas and Kueng (2023).




## B.3 Data Details for Government Balance Sheet Duration Calculation

We compute the state-level property tax revenue flow as a percentage of own-source revenue using the US Census Annual Survey of State and Local Government Finances (ASSLGF). Own-source revenue refers to "general revenue from own sources," which excludes intergovernmental transfers as a source of revenue. To compute the state level property tax, we aggregate over all governmental entities within a state, including state, county, municipal, school district, special entity governments, as they are treated separately within ASSLGF. We then average over the period 2010 to 2019. Our estimate of average state level property tax revenue flow as a percentage of own source revenue is roughly 11%, ranging from 9% to 14% over different years. This aligns with other estimates available in the literature; for example, see numbers computed by Tax Foundation.