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Welfare Effects of Property Taxation

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Abstract. We analyze the welfare implications of property taxation. Using a sufficient statistics approach, we show that the tax incidence depends on how housing prices, labor and other types of incomes as well as public services respond to property tax changes. Empirically, we exploit the German institutional setting with 5,200 municipal tax reforms for identification. We find that higher taxes are fully passed on to rental prices after three years. The pass-through is lower when housing supply is inelastic. Combining reduced form estimates with our theoretical framework, we simulate the welfare effects of property taxes and show that they are regressive.

Keywords: property taxation, welfare, tax incidence, local labor markets, rental housing
JEL Codes: H22, H41, H71, R13, R31, R38

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1 Introduction

Property taxes account for about one third of total capital tax revenues in the United States and the European Union (Zucman, 2015). Despite over a century of economic research, our understanding of the effects of property taxes is still in a "sad state" (Oates and Fischel, 2016, p. 415). This assessment seems particularly true when it comes to the welfare effects of property taxation. Theoretically, two competing views on the incidence of the property tax—the new view vs. the benefit view—offer very different answers to the question of who bears the burden of property taxes. Empirically, institutional settings and data availability make identification challenging: long (and wide) panels of local property tax rates and housing prices have been relatively scarce, clean policy variation is hard to isolate with frequent, non-random re-assessments of property values, and property taxes and expenditures on important local public goods and services oftentimes move simultaneously.

We add to the understanding of the incidence[1] of property taxes by exploiting the institutional setting in Germany, where municipalities adjust tax rates, while tax bases remain fixed and property tax revenues are of secondary importance for local public services. Leveraging micro data on offered rents and house prices we derive clean estimates on the direct effect of property taxes on the price of housing. We feed these quasi-experimental estimates into a novel sufficient statistic representation of commonly used spatial equilibrium models to calculate the welfare effects of property taxes across the distribution.

The paper consists of three parts. In the first, theoretical part, we suggest a sufficient statistics approach to analyze the incidence of the property tax. Starting from a simple and general utility function, where a household can be (a combination of) a renter, landlord, and firm owner, we rely on standard envelope conditions and Roy's identity to show that marginal utility effects of a change in property taxes depend on three factors: the pass-through of the tax on the price of housing, the effect of higher taxes on local public goods, and general equilibrium effects on other markets.[2] Which other markets are affect depends on how the model is specified. We demonstrate the sufficient statistics properties of our framework by connecting it to the recent literature specifying structural spatial equilibrium models in labor, public, and urban economics (Kline, 2010, Moretti, 2011, Ahlfeldt et al., 2015, Suárez Serrato and Zidar, 2016). In this class of models, the sufficient statistics formula of the welfare effect of property taxes typically also depends on the general equilibrium effects on local labor markets as captured by wages and firm profits.

In the second, empirical part, we use the German institutional set-up as a laboratory to estimate the relevant elasticities that determine the incidence of the property tax. German municipalities may autonomously adjust local property tax rates (*Grundsteuer*) via municipality-specific scaling factors to a federal tax rate. Each year, more than ten percent of the 8,481 West German municipality change their local property tax rate, resulting in a large amount of tax

[1] Throughout the paper, we use the term incidence to describe the welfare effects of property taxation. We refer to price effects as pass-through. In a simple model, pass-through and incidence can be identical.

[2] For the empirical implementation, we use the term public goods in a broad sense, referring to all expenditures on publicly provided goods and services independent of whether they are non-excludable and/or non-rival.

reforms that we can exploit for identification. Important for identification, this is the only channel through which municipalities can influence the tax burden. Assessed property values remain fixed over time; new buildings are assessed by authorities at the (higher) state level based on historical price indices. All other rules determining the tax base are set at the federal level. We demonstrate that property tax changes are not systematically driven by housing market shocks or local business cycles. Instead, municipalities increase taxes to consolidate the fiscal balance. While revenues increase after a tax reform, there is little significant effect on local public expenditures as municipalities improve their fiscal balance.

We combine administrative data on the universe of municipalities and their local property tax rates with detailed microdata on rental prices from *ImmobilienScout24* (the German Zillow) between 2007 and 2020 and various other commercial and administrative data sources on housing and labor markets. We implement a series of event studies exploiting the within-municipality variation in tax rates over time to estimate reduced form effects of property taxes on housing and labor prices as well as municipal expenditures as a proxy for responses of local public goods. The event study designs enable us to assess the dynamics of the treatment effects. In addition, we can test the exogeneity of tax reforms by investigating pre-reform trends. In the absence of a pre-trend, the identifying assumption is that there is no systematic regional factor driving both municipal property tax rates and outcome variables. We explicitly test this assumption. In our baseline, we account for annual shocks at the level of the commuting zone (CZ). We assess the sensitivity of our estimates by controlling for local shocks at less (e.g., state) or more detailed (e.g., county) levels of aggregation and confirm that our estimates are robust as soon as we account for local shocks at a sufficiently low geographical level. Moreover, we show that estimates are very stable when including (lagged) local business cycle variables (GDP, unemployment, population) as controls. Based on these findings, we calculate bounds in the spirit of Oster (2019) and show that unobservables are unlikely to render our estimates insignificant. Last, we use a peculiarity arising from the fiscal equalization schemes implemented at each respective German federal state to set up an instrumental variables approach, which again yields similar findings.

Our reduced form results are as follows: We show that gross rents increase moderately in the short run implying that part of the tax burden is on the landlord. In the medium run, starting three years after a tax hike, gross rents further increase to a level implying a full pass-through of the property tax on gross rents. We test for various heterogeneous effects, finding that the pass-through is higher in municipalities that have (i) a lower share of developed land, (ii) a lower share of physically undevelopable land, (iii) smaller population levels, (iv) a higher share of private (rather than public) housing. In line with Saiz (2010), these findings point at differences in housing supply elasticities driving the results, as supply should be less elastic in densely populated areas with a higher share of land unusable for additional construction. We further show that neither local wages nor firm profits are affected by property tax increases. Municipal expenditures do not increase following a tax increase—if anything there is a slight decrease.

In the third part of the paper, we combine the theoretical framework with the empirical reduced form findings to assess the welfare effects of property taxation. The sufficient statistics approach allows us to go beyond representative agent representations to calculate the relative burden of the tax increase. We can implement the predicted welfare effects at the household level directly using rich distributional household-level data from the German Income and Expenditure Survey. This approach enables us to not only provide average statements on the incidence of property taxes but to study the welfare effects over the full distribution of German households.

We find that property taxes are regressive. Utility losses due to a one percentage point increase in the property tax are relatively larger for households at the bottom of the distribution and increase inequality in consumption. Households from the first decile have relative utility losses of around 1.1 percent, while households in the top decile lose only around 0.3 percent. This pattern already emerges when using only the partial-equilibrium textbook model of tax incidence that abstracts from general equilibrium effects on wages, business incomes or public goods. The full general equilibrium model leads to similar welfare losses at the ends of the distribution but smaller negative effects in the middle. Running counterfactual simulations we show that property taxes could be progressive, i.e., the utility loss would increase in household consumption, if there was zero pass-through from landlords to renters.

Related Literature. Our paper speaks to various strands of the literature. Empirically, we provide reduced form evidence on the effects of property taxes on housing prices using administrative tax data from German municipalities and microdata on housing prices. We thereby add to the existing empirical literature on the pass-through of the property tax on rents, which has predominantly focused on the United States. The previous literature has offered a wide range of estimates for the pass-through of property taxes on rents: Orr (1968, 1970, 1972), Heinberg and Oates (1970), Hyman and Pasour (1973), Dusansky et al. (1981), and Carroll and Yinger (1994) estimate that between 0–115 percent of the tax is shifted onto renters. Our results also show the dynamics of the property tax incidence in the short and medium run, which is particularly important for housing markets (England, 2016). We find that property tax increases lead to lower house prices, which is evidence of capitalization into house values (Palmon and Smith, 1998, de Bartolomé and Rosenthal, 1999). Last, the observed decrease in building permits offers evidence that property tax increases reduce housing investments, an effect also demonstrated by Lyytikäinen (2009) for Finland and Lutz (2015) for the state of New Hampshire in the U.S.

Theoretically, we provide a new perspective on the incidence of property taxation by looking through the lens of a local labor market model. These models, which have become the "workhorse of the urban growth literature" (Glaeser, 2009, p. 25), extend the Rosen-Roback model (Rosen, 1979, Roback, 1982) to account for location-specific preferences of workers and differential productivity of firms, relaxing the perfect mobility assumption in traditional models (Moretti, 2011, Kline and Moretti, 2014, Suárez Serrato and Zidar, 2016, Fajgelbaum et al., 2019). We add to the literature by introducing a sufficient statistics approach (Chetty, 2009, Kleven, 2021) and pointing out the empirical responses that are necessary to quantify the incidence of property taxation. Within this framework, it is easy to increase the complexity of the underlying model from a partial textbook incidence model to a full-fledged spatial equilibrium model with location-specific preferences of mobile workers with a general utility function (Albouy and Stuart, 2020), location-specific productivity of mobile firms that are subject to the property tax, a construction sector (Ahlfeldt et al., 2015), absent or non-absent landlords as well as endogenous fiscal and non-fiscal amenities (Diamond, 2016, Brülhart et al., 2021).

Our results inform the long-standing debate of the capital tax (or new) view vs. benefit view. The capital tax view adopts a general equilibrium perspective in closed economy and argues that the national average burden of the property tax is borne by capital owners, i.e., typically richer landlords (Mieszkowski, 1972, Mieszkowski and Zodrow, 1989). Hence, the tax is progressive. We deviate from the assumption of a fixed capital stock in the economy and assume global capital markets and perfect mobility of capital such that higher property taxes may reduce the overall housing capital stock in the society, a channel that has been neglected in the previous literature (Oates and Fischel, 2016). The benefit view builds on a Tiebout (1956) model with perfect zoning and mobile individuals, who choose among municipalities offering different combinations of tax rates and local public goods (Hamilton, 1975, 1976). The tax is equivalent to a user fee for local public services. We add three results to the debate. First, an increase in property taxes decreases utility across the income distribution. Second, a very high preference for local public good would be needed to turn results welfare-neutral. Third, the property tax is regressive, i.e., the utility losses are higher for poorer households rather than richer landlords.

Finally, we touch upon a literature that studies the value and optimal provision of local public goods (Samuelson, 1954). In the United States, the most important type of local public goods financed through property taxes is public schooling and there is a large literature studying the valuation of housing amenities—most often local school quality (see, e.g., Bradbury et al., 2001, Bayer et al., 2007, Cellini et al., 2010, Ferreira, 2010, Boustan, 2013). Brülhart et al. (2021) study the case of Switzerland, where local (income) tax revenues are mostly spent on schools as well. Schönholzer and Zhang (2017) show that residents also value other types of local amenities, most notably public security. In Germany, both schools and police are financed at the state level. While German municipalities do spend part of their property tax revenues within their local jurisdictions, we exploit a setting where the public good channel is arguably less important relative to the effects on local housing and labor markets.

The remainder of this paper is organized as follows. In Section 2 we set up the theoretical framework. Section 3 provides the institutional background of property taxation in Germany and information on the used data. We set up our empirical model in Section 4 and present reduced-form results in Section 5. Section 6 discusses the welfare effects of the tax. Section 7 concludes.

2 Modeling the Welfare Effects of Property Taxation

In this section, we propose a general framework to quantify the welfare effects of property taxes. In Section 2.1, we describe our framework to characterize the household-level welfare costs of local property tax increases. In Section 2.2, we explain in detail the links to other approaches in the literature, notably the large literature on spatial equilibrium models (Epple and Sieg, 1999, Kline, 2010, Moretti, 2011, Ahlfeldt et al., 2015, Suárez Serrato and Zidar, 2016).

2.1 Household Welfare in Spatial Equilibrium Models

The economy consists of a continuum of households $i \in \mathcal{H}$ who choose to live in one out of many small cities across the country (indexed by c). Cities differ in size, productivity, and local amenities g_c, which includes both geographical amenities such as sunshine hours and local public goods like safety, parks or infrastructure. Municipalities levy a property tax t_c on real estate and land, and use (parts of) the revenues for public good provision. Cities vary in the pre-tax price of housing per square meter r_c (producer price) and thus also in the tax-inclusive consumer price denoted by r_c^C.

We assume that households derive utility from local amenities g_c, housing consumption h_i, and composite good consumption x_i. Households have different preferences $u_i(h_i, x_i, g_c)$ and characteristics, including occupation, disposable income y_i, and also household composition. The budget constraint is given by $r_c^C h_i + x_i = y_i$, with the price of the composite good being normalized to one. Households maximize utility and we denote household i's indirect utility function by $v_i(r_c^C, y_i, g_c)$. Assuming that the economy is in equilibrium (with the corresponding equilibrium prices and quantities indicated by superscript stars) we derive the following result:

Proposition 1 (Household Welfare)**.** *The money-metric effect of a small increase in city c's property tax t_c on household i's utility is given by:*

$$\Delta W_i = -h_i^* \frac{\mathrm{d}r_c^{C*}}{\mathrm{d}t_c} + \frac{\mathrm{d}y_i^*}{\mathrm{d}t_c} + \delta_i^g \frac{\mathrm{d}g_c^*}{\mathrm{d}t_c} \qquad \textit{with } \delta_i^g = \frac{\partial v_i / \partial g}{\partial v_i / \partial y}. \tag{1}$$

This proposition follows directly from the envelope theorem and Roy's identity (see Appendix C.1 for a formal derivation). The welfare consequences of a small tax increase for household i are governed by three effects: (i) the pass-through of tax increases on gross-of-tax housing expenditures, (ii) the impact on household income, and (iii) the change in local public good provision. The latter effect is weighted according to household i's relative preference for public vs. private goods. Importantly, following from the standard envelope condition, changes in behavior have no first-order consequences for utility as long as tax reforms are small.

The outlined framework provides a direct mapping between theory and empirical applications while imposing minimal structure on the economy. Proposition 1 characterizes the welfare implications of property tax increases in terms of estimable sufficient statistics (Chetty, 2009, Kleven, 2021), namely the reduced-form effects of property taxes on equilibrium rents, incomes, and local public good provision. In Section 5, we estimate the effects of property tax changes, exploiting the institutional setting in Germany with numerous small tax reforms at the local level. We connect theory and empirics to simulate the welfare effects of tax increases at the household level in Section 6.

Partial Equilibrium Model. The result in Proposition 1 nests the standard textbook model of tax incidence in a partial equilibrium setting. To see this, consider a world with only two households R and L, and abstract from public goods. Household R has fixed income and consumes housing h at price r_c^C. Household L lives abroad and receives rental income $y_L = r_c h$ from renting out real estate to R. The loss in household R's utility after introducing property taxes t_c increases (i) in the amount of floor space rented and (ii) the pass-through of taxes on consumer price rents. Similarly, landlord L's welfare loss depends on (i) the amount of floor space rented out and (ii) the pass-through of taxes on net rents, i.e., producer prices. With quasi-linear preferences in consumption, these welfare effects are equivalent to changes in consumer and producer surplus, respectively.

Local Public Goods. We extend the partial model by incorporating a key mechanism of the *benefit view* of property taxation, where taxes act like user fees for local public services (Hamilton, 1976). A standard partial-equilibrium analysis would neglect the fact that municipalities around the world use property taxes to finance local public goods. The welfare consequences of property tax reforms thus crucially depend on the use of the tax revenues. This idea is reflected in the third part on the right-hand side of the equation in Proposition 1: if tax increases translate into higher levels of local public good provision ($\mathrm{d}g_c^*/\mathrm{d}t_c > 0$), households are compensated for higher costs-of-living (in proportion to their relative preferences for public goods, δ_i^g). If rent increases and public good provision exactly offset each other, property taxes will have no impact on household welfare. Households could then move across municipalities to find their preferred mix of taxes and amenities (Tiebout, 1956).

General Equilibrium Effects. The proposed framework further differs from the textbook model by incorporating potential interactions with other markets. A classic example highlighted in the *capital tax view* of property taxation are general-equilibrium effects on the capital market (Mieszkowski, 1972). With property taxes reducing the after-tax yield on capital in the housing market, capital owners are expected to shift their investment to other, more profitable uses. This shift away from the housing sector reduces the demand for construction services and land for building, potentially hurting workers and owners of construction companies as well as land owners. Higher costs for commercial real estate also create an incentive for local firms to substitute towards other production factors. Under certain conditions (e.g., a fixed capital supply in the economy), property tax increases may also reduce the overall return on capital and thus capital incomes. Such equilibrium effects on different markets would trigger additional welfare effects that need to be taken into account. We subsume these general-equilibrium effects in the proposition above via their impact on household income ($\mathrm{d}y_i^*/\mathrm{d}t_c$). Importantly, these effects are likely heterogeneous among the population as some households suffer while others gain depending on household characteristics and the nature of these spillovers.

Mobility Across Space. The third departure from the standard tax incidence model lies in the spatial dimension—studying mobile agents locating in one out of many small cities—which is very similar to the local labor market and spatial equilibrium literature (see, e.g., Redding and Rossi-Hansberg, 2017, for a survey). Assuming that households, firms, and capital are mobile across space gives rise to further equilibrium responses and capitalization effects in local prices and incomes. One prime example for such a spatial equilibrium mechanism is the assumption of labor mobility (Brueckner, 1981). If workers can avoid a city's rising property tax by moving to another place, local firms will have to pay a compensating differential for workers to stay in the city (in a model without commuting, $\mathrm{d}y_i^*/\mathrm{d}t_c > 0$). The capitalization of tax increases in local equilibrium prices and incomes will then depend strongly on the degree of mobility of the different agents in the economy. Proposition 1 reflects the welfare impact of these various mechanisms in the reduced-form effects on rents $\mathrm{d}r_c^{C*}/\mathrm{d}t_c$ and incomes $\mathrm{d}y_i^*/\mathrm{d}t_c$.

2.2 Relation to Standard Spatial Equilibrium Models

The outlined framework characterizes the welfare effects of property tax changes using a number of reduced-form effects as sufficient statistics. We argue that the proposed approach makes four contributions. First, the framework introduced above is very general. Structural approaches have been criticized for, e.g., relying heavily on Cobb-Douglas utility functions or specific distributions of taste parameters (Proost and Thisse, 2019, Albouy and Stuart, 2020). The sufficient statistics approach allows to abstract from specific functional forms of household utility, firm production, and construction activity. We only assume differentiability, separability, and positive and decreasing marginal utilities.

Second, the generalized approach allows for an arbitrary level of heterogeneity in household characteristics, choices, and preferences, which have been assumed homogeneous in many previous applications. For example, households may combine different occupations and receive income from various sources at the same time in our framework, whereas workers, firm owners, and landlords have been modeled as distinct representative agents before. We also abstain from the usual requirement that firm owners and landlords are absent from the city.

Third, we provide a micro-founded derivation of welfare effects that can be quantified at the household level or aggregated using social marginal welfare weights (Saez and Stantcheva, 2016). The theoretical framework can be applied to conduct straightforward counterfactual simulations of welfare effects using household microdata (see Section 6). The previous literature had to rely on more restrictive formulations and stylized welfare evaluations given the limited degree of heterogeneity in order to keep the model analytically tractable.

Fourth, sufficient statistics approaches are very convenient when being used in a setting with clean quasi-experimental variation that enables researchers to estimate causal reduced-form effects of a policy change (Chetty, 2009, Kleven, 2021). In the context of this study, the reduced-form estimates can be directly plugged into Proposition 1 to calculate the welfare effects with a minimal model structure.

A Structural Representation. The drawback of sufficient statistics approaches is that it is not possible to quantify equilibrium prices and quantities, and analyze the mechanisms behind the welfare effects by studying comparative statics (Chetty, 2009). For these exercises, we need a structural representation of the underlying model and corresponding additional assumptions. In Appendix A, we recast our model economy in a fully specified structural framework (see Appendices A.1–A.3). We build on Suárez Serrato and Zidar (2016), whose model includes mobile workers and firms with idiosyncratic location preferences and location-firm specific productivity shifters, respectively; firms operate under monopolistic competition and have non-zero profits. We augment this model in two dimensions. First, we add a construction sector as in Ahlfeldt et al. (2015) to model the supply of real estate in more detail. Second, we endogenize the public good provision by modeling local governments which use property tax revenues to fund local public goods (similar to Fajgelbaum et al., 2019). We solve this model analytically and derive theoretical predictions on the welfare effects for the different representative agents, i.e., workers, firm owners, and landlords. By virtue of the sufficient statistics, the structural welfare predictions correspond closely to the results of Proposition 1 (see Appendix A.4 for a detailed comparison).

Comparative Statics. Looking at the model mechanisms, we provide an intuition on the sign and size of the reduced-form effects in Proposition 1 using the structural representation (see Appendix A.5 for a thorough discussion). The impact of tax increases on gross housing costs per m^2 ($\mathrm{d}r_c^{C*}/\mathrm{d}t_c$) can be decomposed in two effects: (i) the direct effect measuring the pass-through that depends on the housing supply and demand elasticities as in the textbook incidence model, and (ii) an indirect effect operating through the transmission of tax revenues into local public good provision and the capitalization of public goods in local rents. The more mobile households are and the more elastic housing demand, the lower the direct pass-through of tax increases in consumer prices, and the stronger the reduction in net rents. The indirect effect counteracts the decrease in housing demand triggered by the tax increase, thereby alleviating the reduction in net-of-tax rents.

We model income from three sources in the Appendix (cf. $\mathrm{d}y_i^*/\mathrm{d}t_c$ in Proposition 1). First, landlord income changes proportionally to the change in producer prices, i.e., net rents. Decreasing net rents thus translates into lower profits for landlords. Second, we model the effect on workers' wage earnings, which is theoretically ambiguous and depends on the degree to which firms (i) have to compensate workers to keep them in the city and (ii) reduce their labor demand in response to rising input factor costs. Third, the impact on firms' profits ultimately also depends on whether labor demand or supply are more elastic.

3 Institutions and Data

We rely on the institutional setting of local property taxation in Germany to identify the sufficient statistics needed to quantify the household level welfare effects. Section 3.1 describes the relevant features of property taxation in Germany. Section 3.2 gives an overview on the data used in our empirical analysis.

3.1 Property Taxation in Germany

The German property tax (*Grundsteuer B*) is a one-rate tax that applies to the land and built structures. Residential and commercial properties are both subject to the same property tax regulations. The tax rate is levied by the municipality and local property tax revenues are one of the most important revenue sources for German municipalities, amounting to a total of 12 billion EUR for all municipalities in 2013. Importantly, the only thing municipalities can adjust is the local tax rate. All other legal regulations of the property tax, i.e., the definition of the tax base, as well as legal norms regarding the property assessment, are set at the federal level and have been unchanged for decades.[3]

The property tax liability is calculated according to the following formula:

$$\textit{Tax Liability} = \textit{Assessed Value} \times \underbrace{\textit{Federal Tax Rate} \times \textit{Municipal Scaling Factor}}_{\text{Local Property Tax Rate}}. \tag{2}$$

We discuss the different elements of the formula below.

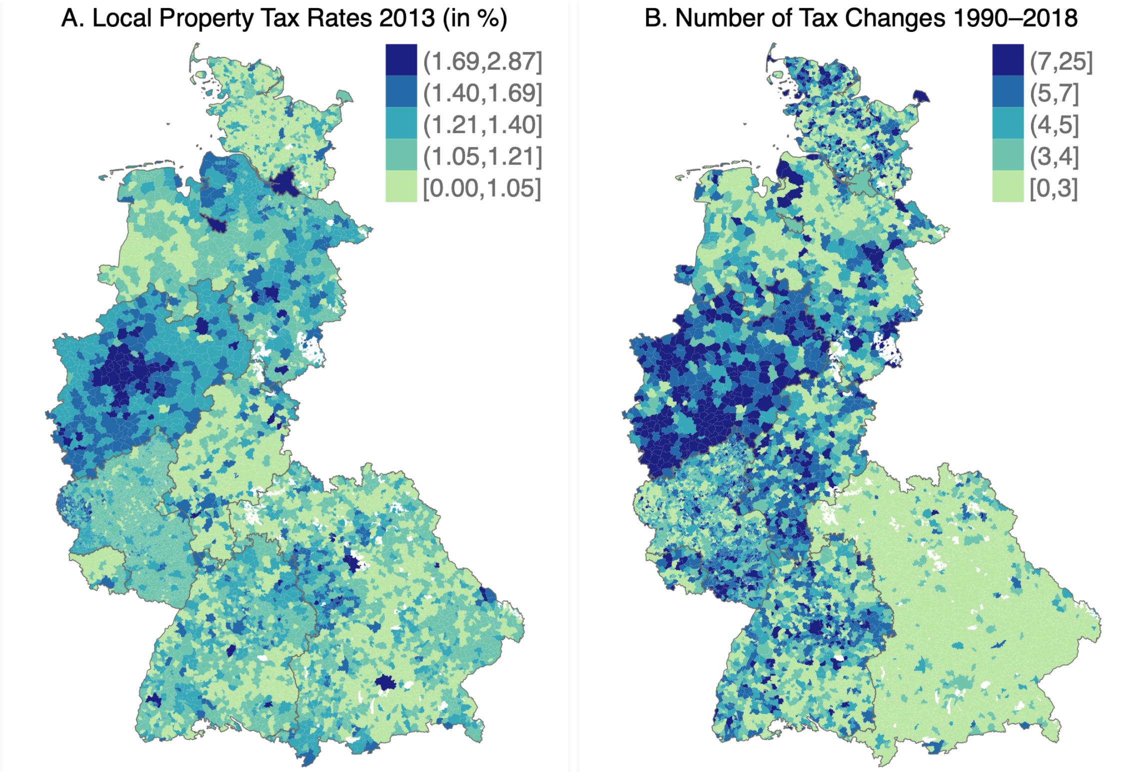
Assessed Values. The property value (*Einheitswert*) is assessed by the state tax offices (not by the municipality) when the property is built and, importantly, remains fixed over time. The last general assessment of property values in Germany took place in 1964. In order to make the assessment comparable for new buildings, property valuation is based on prices as of 1964 using historical rent indices. There is no regular reassessment of properties to adjust the assessed value to current market values or inflation. Neither are assessed values updated when the property is sold. Reassessments only occur if the owner creates a new building or substantially improves an existing structure on her land.[4] As a consequence, assessed values differ from current market values. The average assessed value for West German homes was 39,136 EUR in 2013, roughly a fifth of the reported current market value (EVS, 2013). Assessment notices do not provide any detail on how specific parts of the building contribute to the assessed value. This practice makes the assessment barely transparent for house owners, landowners, and renters. There is also no deduction for mortgage payments or debt services in the German property tax.

Federal Tax Rates. The federal tax rate (*Grundsteuermesszahl*) is set at 0.35 percent for all property types in West Germany with only two exceptions. First, the federal tax rate for single-family homes is 0.26 percent up to the value of 38,347 EUR; and 0.35 percent for every euro the assessed value exceeds this threshold. Second, the federal tax rate for two-family houses is 0.31 percent.

[3] See Spahn (2004) for a more detailed discussion. All legal regulations can be found in the *Grundsteuergesetz*.

[4] The improvement has to concern the "hardware" of the property, such as adding a floor. Maintaining the roof or installing a new kitchen does not lead to a reassessment. Lock-in effects or assessment limits are thus not an issue in the German context other than in some U.S. states (see, e.g., Ferreira, 2010, Bradley, 2017).

Figure 1: Variation in Local Property Taxes



Notes: The left panel of this figure shows the local property tax rates in 2013 for all West German municipalities, assuming a federal tax rate of 0.32 percent. The right panel depicts the number of local property tax changes by municipality in the period 1990–2018. Municipalities are grouped into population-weighted quintiles and shaded according to the tax rate or the number of tax changes, respectively. Jurisdictional boundaries are as of December 31, 2015. Gray lines indicate federal state borders. White areas indicate unpopulated unincorporated areas (*gemeindefreie Gebiete*). See Appendix B for detailed information on all variables. *Maps:* © GeoBasis-DE / BKG 2019.

Municipal Scaling Factors. Municipal councils decide annually on the local scaling factor (*Realsteuer-Hebesatz*). The decision is usually made at the end of the preceding year and most tax changes become effective on January 1st. Figure 1 demonstrates the substantial cross-sectional and time variation in local property tax rates induced by differences and changes in scaling factors. The left panel of the figure shows local tax rates for all West German municipalities in 2013, assuming an average federal tax rate of 0.32 percent. Depicted local property tax rates vary between 0.8 and 2.2 percent (bottom and top one percent). Annual mean and median tax rates increased steadily from around 0.9 in 1990 to 1.4 percent in 2018. The right panel of Figure 1 demonstrates the number of municipal scaling factor changes in the period from 1990 to 2018. Over this period, more than ninety percent of all municipalities have changed their local tax rate at least once, while less than six percent of municipalities still have the same scaling factor as in 1990. On average, municipalities changed the factor four times during this period, i.e., every seven years. Many municipalities experienced even more changes. One percent of municipalities changed their property tax multiplier more than ten times since 1990. Around 95 percent of all tax changes during this period are tax increases. We show in Section 4 that reforms are not driven by local business cycles. While neither expenses nor revenues show a pre-trend (see also Fuest et al., 2018, for a similar assessment in the case of business taxes), we show below that municipalities use the reform to reshuffle the structure of their finances, even decreasing expenditures in the short run (up to three years after the reform).

Statutory Incidence and Ancillary Costs. The statutory incidence of the property tax is on the property owner, i.e., the landlord. However, a salient legal regulations on operating costs (*Betriebskostenverordnung*) stipulates that property taxes for rental housing are part of the ancillary costs that renters have to pay to their landlords on top of net rents. By this regulation, landlords are directed to include the tax payments in the ancillary bill that renters receive at the end of each year. Other typical ancillary costs are fees for garbage collection, water supply, or janitor and cleaning services.

Municipal Revenues and Local Public Goods. Property (and business) tax revenues are an important source of revenue for German municipalities because they are the only instruments at the disposal of municipalities to raise tax revenues. In 2013, the average (median) annual revenues of municipalities was 2,691 (2,353) euro per capita. 28% of the revenues are coming from local business and property taxes that are directly controlled by the municipalities. Per capita property tax revenues average to 155 euro (21% of local taxes).[5] Compared to the U.S., revenues raised at the state and local level are much lower in Germany. According to the U.S. Census Bureau, state and local revenue per capita amounted to 7,000 dollars per capita—with 5,000 dollars p.c. coming from taxes and about 17% thereof from property taxes.

The lower amount of municipal revenues are reflected on the expenditure side. In Germany, local jurisdictions are much less important when it comes to public services. Unlike in the U.S., important types of public goods such as schooling, police, or high and freeways are financed at the level of the states or the federal level. About 80% of the expenditures are spent on keeping up the usual administrative duties, that is to pay municipal employees, maintain the existing buildings, co-finance public firms (waste, energy, and public transport) and cover housing costs of welfare recipients as mandated by federal law. About 15% of the expenditures are used for investment projects, rebuilding the city hall, replacing street lamps or extending parks.

Given that (i) local property taxes make up only 5% of total municipal revenues, (ii) public goods provided by the municipality are of second order compared to the U.S., and (iii) only a small share of municipal expenditures will affect the stock of local public goods, we conjecture that the local public good channel is of secondary importance in the context of Germany. We confirm this empirically, both in terms of reduced form evidence (Section 5) and when using our theoretical model to run counterfactual simulations (Section 6).

3.2 Data and Descriptive Statistics

We combine housing market microdata with administrative data on the fiscal and economic situation of German municipalities, and administrative wage and employment data from social security registers. Based on these sources, we construct an annual panel data set for

[5] Other important revenues come from federal level taxes. Municipalities receive a share of the personal income tax revenues and the value added tax revenues, based on the number of tax payers.

the universe of all 8,423 West German municipalities spanning the years from 2007 to 2018.[6] This section gives an overview on the data used for our empirical analysis and the estimation sample. Appendix B provides more details on the definition and the sources of all variables.

Housing Market Microdata. Our main data source is a microdata set with real-estate advertisements covering apartments and houses offered for rent and for sale on the platform *ImmobilienScout24* (the German Zillow). This website is by far the largest online real estate platform in Germany. The data includes real-estate advertisements from 2007 until 2020, yielding on average more than three million ads per year. The data is provided by the research data center FDZ Ruhr at RWI (Boelmann and Schaffner, 2019).

The most important information we extract from this data set is the consumer price of housing. As common for data from internet platforms prices are offered and not transaction prices. Our main variable is the gross-of-tax rent per square meter, which includes property tax payments and all other ancillary costs (*Bruttowarmmiete*).[7] Besides prices, the dataset contains a vast set of characteristics such as the living space, the number of rooms, the quality, and the construction year. In order to generate a comparable measure of rental and sales prices per square meter, we focus on apartments with a living space between 40 and 100 square meters and houses with a living space of 100 to 200 square meters, roughly dropping properties below the 10th and above 90th percentiles for both dwelling types. Moreover, we drop properties with unrealistic prices per square meter (bottom and top 0.5 percent) and unrealistic reported ancillary cost to net rent ratio. Last, the data contains information on the location of the advertised object including municipality identifiers. This regional information allows us to link ads to the corresponding municipalities, the respective property tax rates, and various other fiscal and economic indicators.

German Municipality Data. We compile a comprehensive municipality-year panel using data from various administrative sources. The largest part of this municipality-level data is provided by Federal Statistical Office and the Statistical Offices of the Länder. The most important variable in the context of this study are municipal property tax rates since the 1990s. In addition, we make use of additional economic and fiscal indicators. We use municipal budgets to back out business profits at the level of the municipality. Furthermore, our data include municipal annual expenditures as a proxy for local public goods. We also observe annual population figures, land use within the municipality, and statistics about the owners of the local housing stock (cross-sectional data on types of landlords).

Besides data from the Statistical Offices, we compile data on the local number of individuals registered as unemployed as well as county-level GDP to proxy and control for fluctuations

[6] We exclude East Germany from our analysis for two reasons. First, there has been a substantial amount of municipal mergers within East Germany from the mid-1990s until the late 2000s, which induces measurement error in the main regressors (Fuest et al., 2018). Second, the federal tax rate in East Germany is different from West Germany (cf. Section 3). This implies that the same increase in the local scaling factor would lead to different increases in the total property tax rate in East and West Germany. However, we also test the sensitivity of our results to this exclusion and find that results are similar when including East Germany (see Section 5.4).

[7] We also study offered sales prices as an outcome, but clearly transacted and offered price should differ more when it comes to real-estate sales, so our main focus will be on rental housing.

in the local business cycle. We make use of social security data provided by Institute for Employment Research (IAB) on municipal-level average wages. Annual wages are based on the universe of workers subject to social security. Last, the Federal Institute for Research on Building, Urban Affairs and Spatial Development provides us with definitions of commuting zones that are defined according to commuting flows (*Arbeitsmarktregionen*).

Estimation Sample. We combine housing market and municipality data to build an estimation sample with municipality-year observations spanning the period from 2008 to 2015. The sample period is narrower than the original data coverage since we include leads and lags of property tax rate changes as main explanatory variable (see Section 4.1). In the baseline sample, we require a minimum number of 15 rental ads per municipality-year cell to be included in the sample, which leaves us with around 1,500 municipalities per year. In Section 5.4, we experiment with the minimum number of ads per municipality and year and show that our results are robust to various alternative thresholds.

Appendix Table B.2 provides descriptive statistics of our baseline sample listing all outcome variables, main regressors, and control variables used in the empirical analysis.

4 Empirical Strategy

4.1 Empirical Model

As derived from the theoretical framework, we are interested in the effects of property taxes on the following outcome variables: rents, incomes, and municipal expenditures. We make use of an event study design similar to Suárez Serrato and Zidar (2016) to investigate the effects of property tax changes with $\bar{j}$ lags and $\underline{j}$ leads of the treatment variable. Using the distributed-lag representation in a first-differences setting, our empirical model is given by:

$$\Delta \ln Y_{m,t} = \sum_{j=-\underline{j}+1}^{\bar{j}} \gamma_j \Delta PropertyTaxRate_{m,t-j} + \psi \Delta \boldsymbol{X}_{m,t} + \theta_{r,t} + \varepsilon_{m,t}, \tag{3}$$

where we regress the first difference of outcome variable Y (in logs) in municipality m, commuting zone r, and year t on leads and lags of year-to-year changes in the local property tax rate, $\Delta PropertyTaxRate_{m,t}$. Municipal control variables, which are included depending on the specification (see below), are denoted by $\boldsymbol{X}_{m,t}$. In the baseline specification, we include leads and lags of the local business tax rate, the other tax instrument at the disposal of German municipalities. The error term is denoted by $\varepsilon_{m,t}$.

This specification is equivalent to using a standard event study where treatment indicators for tax changes are scaled with the size of the tax change and treatment indicators at the endpoints of the effect window ($j = -\underline{j}, \bar{j}$) are binned (Schmidheiny and Siegloch, 2020). First-differencing wipes out time-invariant municipal confounders. The model further includes commuting zone-by-year fixed effects $\theta_{r,t}$, controlling flexibly for annual shocks at the level of commuting zones (CZ, *Arbeitsmarktregionen*).

Since equation (3) is specified as a distributed-lag model, we need to cumulate the resulting estimates $\widehat{\gamma}_j$ of year-to-year effects over j to make them interpretable in a canonical event study logic. We thus sum the distributed-lag estimates to recover the treatment effect estimates $\widehat{\beta}_j$ relative to the pre-treatment period. Normalizing effects to one period prior to the property tax reform, i.e., setting $\widehat{\beta}_{-1} = 0$, treatment effect estimates $\widehat{\beta}_j$ can be uniquely recovered:

$$\widehat{\beta}_j = \begin{cases} -\sum_{k=j+1}^{-1} \widehat{\gamma}_k & \text{if } -\underline{j} \leq j \leq -2 \\ 0 & \text{if } j = -1 \\ \sum_{k=0}^{j} \widehat{\gamma}_k & \text{if } 0 \leq j \leq \bar{j}. \end{cases} \tag{4}$$

The event-study nature of the empirical setup enables us to investigate dynamic treatment effects of property taxes on the respective outcomes and thereby account for lagged responses and potential delays in housing market adjustment (England, 2016). Our baseline specification includes four leads and lags, i.e., $\underline{j} = 4$ and $\bar{j} = 4$, respectively. We calculate the average of the two last estimates, $\widehat{\beta}_3$ and $\widehat{\beta}_4$, to provide a take-away number of the medium-run impact of property tax changes on the respective outcomes. The choice of the event window is determined by data availability over time. Our baseline specification is a compromise between the length of the event window and statistical power. We experimented with other event window definitions, finding very similar results (see Section 5.4).

Inference is based on cluster-robust standard errors accounting for arbitrary correlation of unobserved components within municipalities over time. The results are not sensitive to whether we allow for clustering at the municipal level or the level of commuting zones.

4.2 Identifying Variation and Identification Challenges

The identifying variation is coming from around 5,200 tax reforms. In order to obtain causal estimates, we need pre-trends to be flat and statistically indistinguishable from zero. While the first differences setup controls for time-invariant confounders, our estimates are biased if local shocks affect both municipal fiscal policies and the respective outcomes.

A first important question in this regard is why municipalities change tax rates. In order to partly answer this question, we inspect what happens to municipal revenues and expenditures after an increase in the property tax rate. Panels A and B of Appendix Figure C.7 shows that property tax revenues increase instantaneously and persistently as one would expect given the rather inelastic tax base. Overall, total revenues increase slightly and according to the share of property taxes in total revenues (cf. Section 3.1). Next, we turn to the expenditure side. Strikingly, Panel C of Appendix Figure C.7 shows decreasing total expenditures in the first three years after a reform, which is mostly driven by decreases in ongoing expenditures like personnel (Panel D) and investments. At the same time municipalities increase spending on debt services (Panel E). These measures lead to an increase in the fiscal balance (inverse hyperbolic sine transformed) as shown in Panel F of Appendix Figure C.7. In summary, municipalities raise taxes to increase long-run fiscal balances while there is no significant effect on local public good expenditures.

Importantly, we do not detect any significant pre-trend in the fiscal variables, which would violate our identifying assumption. We provide four further tests to challenge our identifying assumption (see Section 5.2 for the results).

(1) Flexible Controls for Local Shocks. Our baseline model includes a rich set of CZ-by-year fixed effects, controlling flexibly for local shocks at the level of 201 commuting zones. To assess the relevance of confounders at the local level and the robustness of our results, we run several alternative specifications accounting for region-by-year fixed effects at higher and lower geographical levels. We start out with the least demanding empirical model including pure year fixed effects, i.e., only absorbing common shocks at the national level. We then introduce state-by-year fixed effects (there are eight states in the main sample). Next we account for shocks at the level of 28 administrative districts (NUTS II, *Regierungsbezirke*), followed by a specification accounting for shocks at the level of the 72 metropolitan statistical areas (MSA, *Raumordnungsregionen*). We also estimate a more demanding specification with separate fixed effects for each of the 315 counties (*Kreise*). Results are very similar across specifications once we account for MSA-by-year fixed effects.

(2) Testing for Municipal Confounders. Flexible regional time trends can only account for shocks at the respective level but will not detect shocks occurring even more locally within municipalities. A major concern is that such local municipality-specific business cycles drive both municipal property tax rates and local housing market outcomes. We directly test this mechanism using municipal unemployment, GDP per capita at the county level, and municipal population levels as outcome variables in the event study regression in equation (3). Appendix Figure C.6 shows flat pre-trends for all three outcomes. Analogously, pre-trends for municipal revenues or expenditures are flat (see Appendix Figure C.7). Moreover, we run additional sensitivity analyses by adding the same local business cycle measures as (lagged) control variables to our baseline specification. Results are robust to the inclusion of business cycle controls.

(3) Assessing the Role of Selection on Unobservables. While municipal business cycle are the prime suspect for confounding variables at the local level, there might be other, unobservable confounders that bias our estimates. In order to assess the sensitivity of our empirical results, we follow Oster (2019) and calculate bounds comparing how estimates and goodness-of-fit measures change when including local business cycle controls. These bounds indicate the robustness of our baseline estimates with regard to unobserved confounders of similar importance. Again, the implied bounds are very close to our main estimates.

(4) Instrumental Variables. In the baseline empirical model, we exploit the substantial variation in property tax rates within municipalities over time to identify treatment effects. While tax reforms are never truly exogenous, the tests discussed above are intended to validate the identification strategy by assessing whether tax reforms are systematically driven by changes in the housing market, local business cycles, or other local shocks.

As a fourth and alternative endogeneity check, we purify the variation in local tax rates by applying an instrumental variables strategy. To this end, we exploit a specific feature of the German system of fiscal federalism. Each state has its own fiscal equalization scheme through which resources are redistributed across municipalities within states (see, e.g., Buettner, 2006). In each state, municipalities receive transfers depending on their fiscal need relative to their fiscal capacity. Fiscal need refers to the mandatory public services a municipality has to deliver and are largely determined by municipal population size. Fiscal capacity measures a municipality's ability to raise tax revenues. To assess this capacity, the property tax base of a municipality is multiplied with a standard tax rate instead of the actual one (and similarly for the local business tax).[8] This standard tax rate is common for all municipalities within a state and supposed to reflect the average local tax rate in this state. As municipal tax rates increase over time (cf. Section 3.1), standard tax rates typically increase during our sample period as well—in some states annually and formula-based, in others in an unsystematic and discretionary rhythm.[9]

This fiscal equalization mechanism creates two incentives for local policymakers. First, once states raise their standard tax rates, they incentivize subordinate municipalities to increase local tax rates as well (see Egger et al., 2010, Baskaran, 2014, Rauch and Hummel, 2016, who study these incentive effects in the context of the German fiscal equalization schemes). Second, since fiscal equalization transfers are calculated based on relative differences within the state, increases in the state-wide standard tax rates create an additional incentive depending on the relative differences between standard and actual tax rates. The higher the new standard tax rate relative to a municipalities' actual one, the stronger the incentive for subsequent local tax increases (see Appendix C.2 for a formal theoretical discussion of both predictions).

We exploit these two incentives to construct our instrument as follows:

$$IV_{m,t} = StandardTaxRateIncrease_{s,t} \cdot \frac{StandardTaxRate_{s,t} - PropertyTaxRate_{m,t-1}}{PropertyTaxRate_{m,t-1}} \tag{5}$$

The instrument interacts a dummy variable indicating an increase in state s's standard tax rate in year t with a measure capturing the relative difference between the new standard tax rate and the old local tax rate in municipality m in year $t-1$. Although the instrument still relies on a municipality-specific component, we argue that the implied shock is exogenous from the standpoint of local policymakers for three reasons. First, municipalities are small and atomistic compared to the size and number of municipalities per state. On average, there are around 1,000 municipalities per state, and no single municipality is dominating within states. Second, the instrument exploits only the relative difference between standard and local property tax

[8] The standard tax rate is composed of the federal tax rate and a state-level standard scaling factor (see equation (2)). State-specific standard tax rates are known as *Fiktive Hebesätze*, *Nivellierungshebesätze*, or *Durchschnittshebesätze*.

[9] We exclude the states of Baden-Württemberg and Saarland from this part of the analysis as the former did not change its standard tax rate in past decades and the latter implemented a large-scale municipal fiscal consolidation program at the same time, making it impossible to isolate the effects of standard tax rate changes.

rates, i.e., cross-sectional variation across municipalities rather than changes at the local level. Third, we fix local property tax rates in the year before the increase in the standard tax rate, which further alleviates the potential for endogenous responses at the local level.

We formally estimate the following distributed-lag model as first stage event study:

$$\Delta PropertyTaxRate_{m,t} = \sum_{j=-\underline{j}+1}^{\bar{j}} \eta_j IV_{m,t-j} + \delta \Delta \mathbf{X}_{m,j} + \zeta_{r,t} + \epsilon_{m,t}, \tag{6}$$

where we again sum estimates $\widehat{\eta}_j$ over years j to recover the cumulative treatment effects relative to the pre-reform period (similar to equation (4)). Appendix Figure C.1 shows the resulting first-stage relationship confirming the theoretical predictions. After an increase in the state-wide standard tax rate, municipalities respond by increasing their own property tax rates within the next three years and leveling off thereafter. Effects are stronger for municipalities with larger relative differences between the new standard tax rate and their old own tax rate. The medium-run estimate is equal to 0.49 (and statistically significant with standard error 0.06), which implies that local property tax rates increase by half a percentage point for each one percentage point increase in the relative difference to the standard tax rate. As expected, the figure also shows that local property tax rates decline in the instrument prior to standard tax rate increases. Note that this pre-trend emerges by construction of the instrument.[10] We show below that the implied IV estimates are very similar to our baseline measure.

5 Reduced-Form Effects of Property Tax Changes

This section presents the reduced-form effects of property tax changes using the outlined empirical approach. In Section 5.1 we present the baseline results for the effect of property taxes on rental prices. We test the identification in Section 5.2. Next we investigate heterogeneous effects in Section 5.3. Finally, Section 5.4 presents several robustness checks.

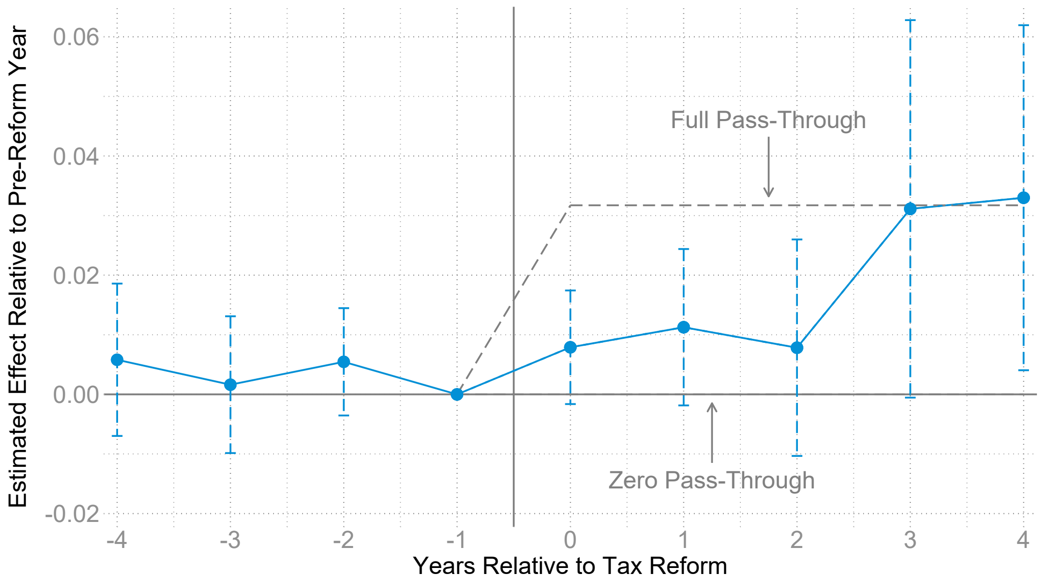
5.1 Property Taxes and Rental Prices

Figure 2 shows the baseline result for the effect of property taxes on gross rents, that is the tax-inclusive consumer price of housing. The event study graph shows small and flat pre-treatment trends, which are statistically indistinguishable from zero. At the time of the tax change, indicated by the solid vertical line, gross rents first increase slightly to an effect size of 0.01 and then converge to an estimate of 0.03 three to four years after the tax reform.

These log-level estimates imply that a one percentage point increase in the local property tax rate (which corresponds roughly to an 80 percent increase in the tax rate) leads to a three percent increase in gross rents. We compare these point estimates to the average ratio

[10] Consider two municipalities A and B in the same state experiencing an increase in the state-wide standard tax rate in some year t. Four years before this reform, A and B had the same property tax rate, $PropertyTaxRate^A_{t-4} = PropertyTaxRate^B_{t-4}$. Municipality B raised its tax rate subsequently, such that in the pre-reform year, municipality A had a lower property tax rate, i.e., $PropertyTaxRate^A_{t-1} < PropertyTaxRate^B_{t-1}$. It follows that $IV_{A,t} > IV_{B,t}$ and we should see a declining pre-trend relative to the pre-reform year $t-1$.

Figure 2: Effect of Property Taxes on Gross Rents



Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year. The underlying econometric model is described in equations (3) and (4). The specification also accounts for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. Dashed gray lines indicate the implied estimates for either zero or full shifting of taxes from landlords to tenants based on the corresponding average tax-to-rent ratio reported in the German Income and Expenditure Survey (EVS, 2013). See Appendix B for detailed information on all variables.

of property taxes to gross rents of approximately four percent in our sample (EVS, 2013) to determine the pass-through of property taxes from landlords to tenants. The dashed gray lines in Figure 2 illustrate the two polar scenarios of no shifting and full shifting, respectively. In the short-run—i.e., up to two years after the policy change—around one third of the additional property tax due is passed-through to consumer prices. In the medium to long-run—i.e., after three years—the point estimates imply full path-through of tax payments.[11] A potential explanation for the slow adjustment path could be that housing supply is relatively inelastic in the short run. Also, our data reflects self-reported figures in rental ads, which may be updated with some time lag and often include approximate values from past years.

When looking at net rents, i.e., rents exclusive of taxes, we see the mirror image: net rents are relatively lower in the first three years compared to the pre-reform year and then revert back to the pre-reform level of zero (see Appendix Figure C.2).[12] A similar picture emerges when studying dynamics in offered sales prices: there is an indicative dip in the short run, but no significant differences relative to the pre-reform period in the medium run (see Appendix Figure C.3). Last, we investigate quantity responses by looking at housing permits (Lutz, 2015). Appendix Figure C.4 shows that building permits decrease.

[11] Statistically, we can of course only reject the null hypothesis of zero shifting from landlords onto tenants.

[12] This pattern in net rents corresponds to the finding we reported in an early version of this paper (Löffler and Siegloch, 2018), which was based on data on net rent indices in large cities published by the association of German real estate agents (IVD) as our main outcome measure.

5.2 Probing Identification

While the estimated pre-trends are reassuringly flat in our baseline specification, we further test whether the treatment effects in Figure 2 depict the causal effect of property tax changes. As discussed in Section 4.2, we run four major checks. We present the resulting estimates of these tests in Figure 4. To improve readability, we summarize pre-treatment effects (leads of up to four years prior to a tax change), and medium-run effects (three to four years after a policy change) by calculating the average over the respective estimates. All corresponding event study graphs are presented in Appendix C.3.

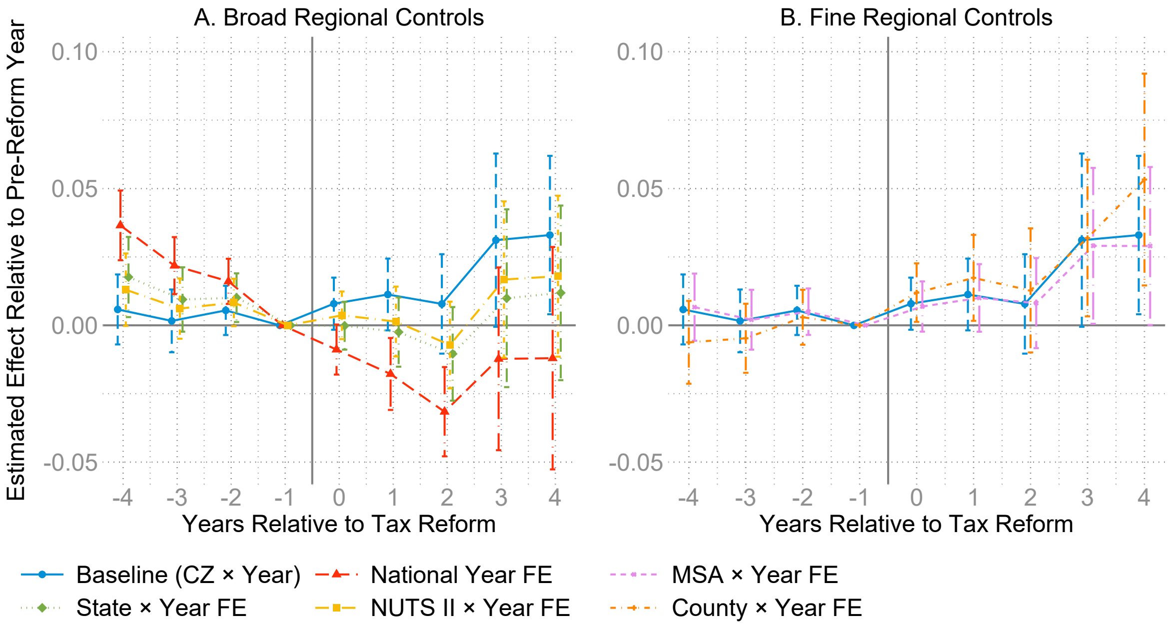
(1) Regional Confounders. The first identification check concerns the geographic definition of the control group and the influence of regional shocks. In the baseline specification, we include CZ-by-year fixed effects, which implies that we identify treatment effects only within commuting zones. Regional shocks occurring at the CZ-level or even broader geographical levels should thus not drive our results. To test the importance of flexible regional controls, we estimate a series of specifications including either broader or finer region-by-year-fixed effects. Figure 3 and the summary measures reported in Figure 4 show the results. The finer we control for regional shocks, the flatter the estimated pre trends and the larger the estimated post-reform treatment effect (see Panel A in Figure 3). As soon as we exploit only the variation within metropolitan statistical areas, estimates are stable both before and after the tax reform (see Panel B). This pattern reveals the substantial heterogeneity in regional trends in Germany and implies that confounders at broader regional levels lead to a downward bias.

(2) Municipal Confounders. A remaining threat to identification arises from time-variant confounders at the municipal level. Clearly, we cannot account for them using region-by-year fixed effects as our identifying variation is at the municipal level. As an alternative, we add the most likely confounding variables—relating to local business cycles—as controls in the regression. More specifically, we control for unemployment, population, and GDP. We estimate two alternative specifications: first, we include these variables using contemporaneous values. Second, due to the obvious bad-control problem, we estimate a specification controlling for these variables lagged by two years. Figure 4 shows that the results are almost unchanged (see Appendix Figure C.5 for detailed event study results).

To further alleviate endogeneity concerns with regard to local business cycles, we also put these variables at the left hand side of our event study model in equation (3) and test for potential pre-trends in these measures. In line with Fuest et al. (2018), we find no economically relevant evidence that the local business cycles are driving local tax rate changes after conditioning on CZ-by-year fixed effects (see Appendix Figure C.6).

(3) Selection on Unobservables. In the previous check, we tested for observable municipal confounders confounding our estimates. While variables picking up local business cycles are prime suspects when it comes to potential confounders, systematic unobserved municipal confounders might still compromise identification. To investigate the relevance of this potential

Figure 3: Importance of Regional Confounders

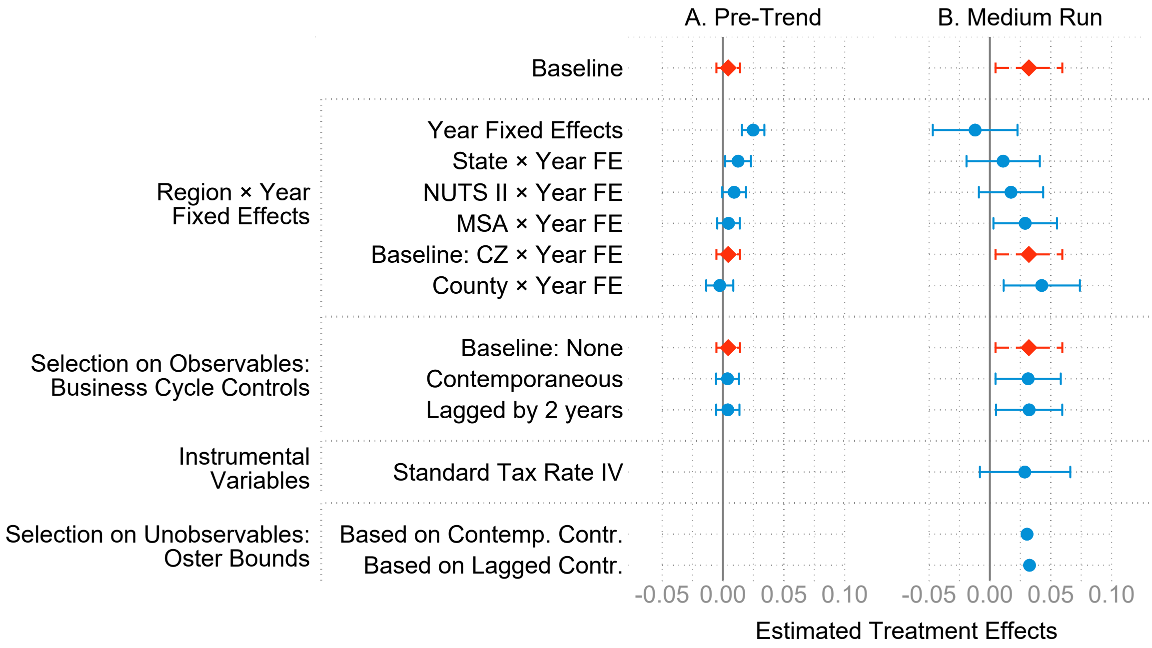


Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year using various alternative regional time trend specifications. The underlying econometric model is described in equations (3) and (4). The specification also accounts for leads and lags in the local business tax rate and year fixed effects at various regional levels (see legend). Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

source of endogeneity, we follow Oster (2019) and calculate bounds for our estimates when accounting for unobserved confounders. These bounds approximate the maximum treatment effects that could potentially result assuming that the inclusion of unobserved confounders would move our estimates in the same direction as accounting for observable control variables (see previous paragraph). Using standard parameters for the calibration ($\delta = 1$ and $R^2_{max} = 1.3 \cdot R^2_{controlled}$), we find that the resulting bounds are close to our baseline estimate and thus unlikely to overturn our results. Bounded coefficients are reported in Figure 4 (see Appendix Table C.1 for more details on this check).

(4) Instrumental Variables. The fourth threat to identification originates from the fact that tax reforms are never truly exogenous. To tackle this classic endogeneity concern, we pursue an instrumental variable strategy exploiting changes in state-wide standard tax rates for identification (see Section 4.2 and Appendix C.2 for more details). Using leads and lags of the instrumental variable derived in equation (5) as main regressors in the baseline event study model from equation (3), we estimate the reduced form effect. Figure 5 presents the corresponding event study results. We find a pattern similar to the baseline effects shown in Figure 2. Pre-treatment trends in the years before changes in the standard tax rate are flat. After the reform, it takes three to four years until a positive effect on gross rents materializes, which is also in line with the lagged response of local property tax rates (see first stage relationship in Appendix Figure C.1). Moreover, estimates are not sensitive to including more

Figure 4: Probing Identification



Notes: This figure presents the results for the four identification checks outlined in Section 4.2. Estimates depict the estimated treatment effect of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year. The baseline result corresponding to Figure 2 is shown in red, results from alternative specifications are depicted in blue. Panel A presents summary estimates of pre-treatment trends, i.e., the average coefficient in the four years prior to a tax reform. Panel B shows the medium-run effect measured as the average estimate of the third and fourth lag in the property tax rate. All regressions also account for leads and lags in the local business tax rate. Observations are weighted by average population levels over the sample period. Horizontal bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

or less fine region-by-year fixed effects. Dividing the medium-run reduced-form estimates (lags three and four) by the medium-run first stage estimates, we back out a two-stage least squares estimate of 0.03, which is of similar magnitude compared to the baseline estimate (see Figure 4).

Confidence intervals for these second-stage estimates are based on the empirical distribution of estimated coefficients using 1,000 bootstrap replications.

Figure 5: Effect of Standard Tax Rate Changes on Gross Rents

Notes: This figure illustrates the estimated reduced-form effect of the standard tax rate IV defined in equation (5) on gross rents (in logs) relative to the year before a standard tax rate increase. The underlying econometric model is analogous to equations (3) and (4). The specification also accounts for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Municipalities in the states Baden-Württemberg and Saarland are excluded from the estimation sample. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

5.3 Heterogeneous Effects

In this section we study heterogeneous effects by municipality type. To this end, we group municipalities according to different indicators and interact these indicator variables with all leads and lags of the property tax rate in equation (3).[13] We follow the studies by Saiz (2010) and Hilber and Vermeulen (2016) and investigate whether the pass-through to consumer prices can be explained with differences in local housing supply constraints. To this end, we use two measures of physical supply constraints (in 2007). First, we use the share of already developed land relative to the total developable area of a municipality. While this measure yields a proxy for the availability of land for new construction, it is driven by past housing supply and hence potentially endogenous. To address this concern, we secondly group municipalities according to their share of physically undevelopable land (i.e., areas that are undevelopable because they are wetland, water bodies, wasteland, or mining areas). Panels A and B of Figure 6 present the corresponding results. We find stronger price effects in less supply-constrained municipalities (blue) and hardly any pass-through in municipalities with more severe housing supply restrictions (red). This pattern is in line with the standard tax incidence prediction, i.e., that the pass-through to consumer prices increases with the housing supply elasticity.

Next we test for heterogeneous effects by municipal size. Larger cities are typically also more

[13] The different group indicators are not independent from each other (e.g., think of supply constraints and city size). Heterogeneity patterns should thus be taken as suggestive evidence for different types of municipalities.

Figure 6: Heterogeneous Effects

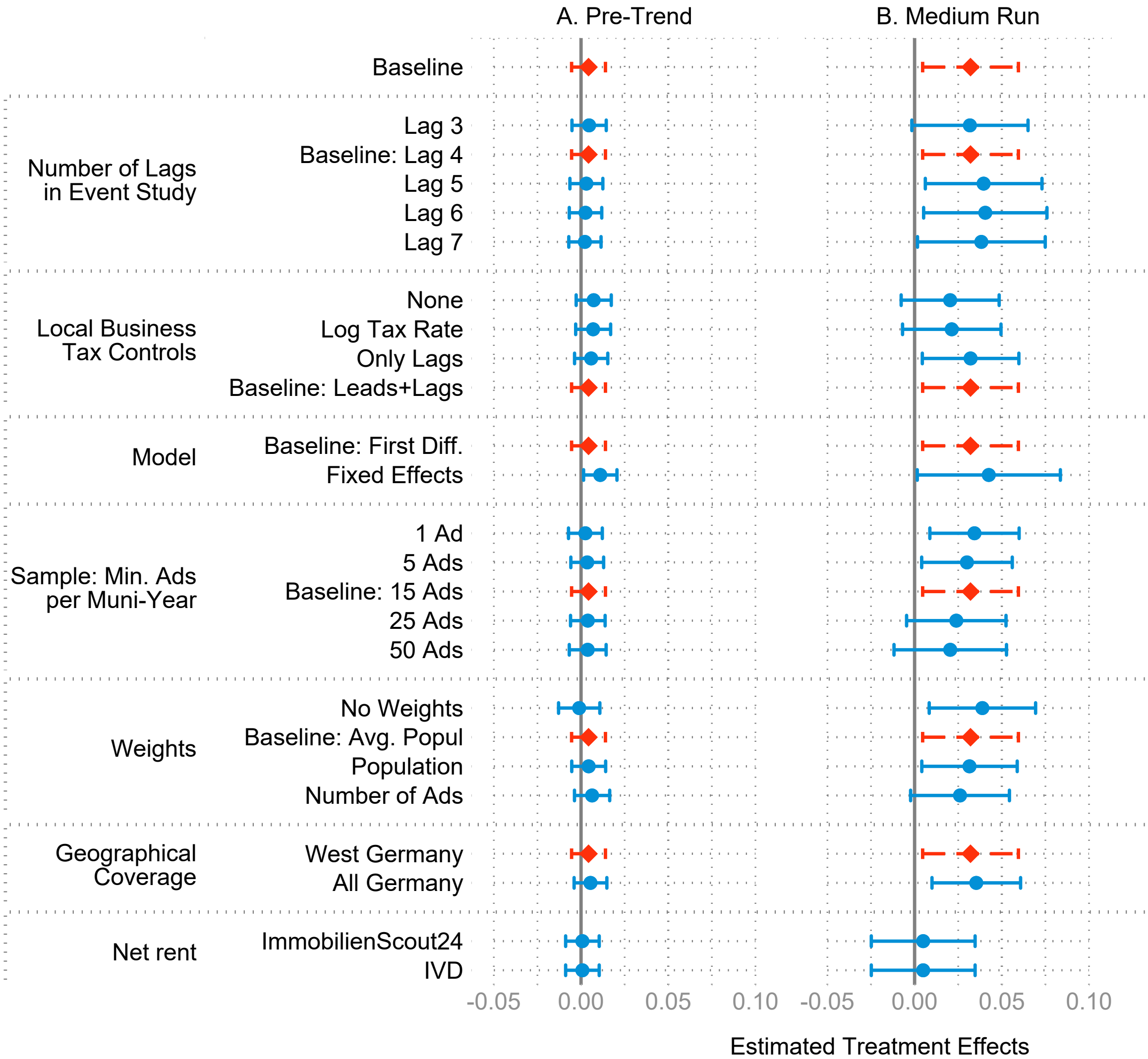
Notes: This figure illustrates heterogeneous treatment effects of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year. The underlying econometric model is described in equations (3) and (4). We interact all leads and lags of the property tax rate with indicators for the different groups (see panels) and also add group-by-year fixed effects. The specification also accounts for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

dense and thus more supply constraint. In line with this argument, we find basically no effect for municipalities with more than 30,000 inhabitants, strong effects for small municipalities with less than 10,000 inhabitants, and modest effects for municipalities in between (see Panel C). Finally, we group municipalities according to the dominating type of ownership. Relying on cross-sectional census data from 2011, we distinguish municipalities for which the housing stock is largely publicly and largely privately owned. Panel D presents the corresponding effects, showing that the pass-through of property tax increases on gross rents is especially strong in municipalities with relatively more private and for-profit landlords.

5.4 Sensitivity Checks

Finally we demonstrate that our baseline effects are not driven by specific modeling choices. To this end, we implement seven sets of robustness checks. First, we experiment with the

Figure 7: Robustness Checks



Notes: This figure presents the results from various sensitivity analyses. Estimates depict the estimated treatment effect of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year. The baseline result corresponding to Figure 2 is shown in red, results from alternative specifications are depicted in blue. Panel A presents summary estimates of pre-treatment trends, i.e., the average coefficient in the four years prior to a tax reform. Panel B shows the medium-run effect measured as the average estimate of the third and fourth lag (and potentially later lags) in the property tax rate. Horizontal bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

number of lags included in the event-study specification, contrasting the baseline specification which accounted for four lags with alternative models relying on (i) only three, or alternatively (ii) five, (iii) six, or (iv) seven lags. Second, we vary the way how we control for changes in the local business tax rate. Instead of using the full set of leads and lags, we run three alternative specifications: (i) excluding the business tax rate completely from the set of regressors, (ii) controlling for the log business tax rate only, and (iii) accounting for lags in the business tax rate while omitting leads. Third, we rerun the baseline regression but estimate the model using municipality fixed effects instead of the first differences specification. Fourth, we present results for different cut-off values regarding the minimum number of rental ads per municipality-year cell. We compare our baseline threshold of 15 ads to four alternative limits: (i) one ad, (ii) five ads, (iii) 25 ads, or (iv) 50 ads. Fifth, we vary the weights employed in the regression (baseline: average population levels over the sample period) and test three alternative weighting procedures: (i) discarding weights, (ii) using annual population levels, and (iii) weighting by the number of rental ads in a municipality per year. Sixth, we extend the estimation sample and include municipalities in East Germany (baseline: West Germany only). Finally, we test whether the medium-run effect on net rents in our estimation sample and in the alternative IVD dataset are indeed zero, implying full pass-through from landlords to tenants if the producer price excluding taxes remains unaffected (Löffler and Siegloch, 2018).

For each of these checks, we present summary estimates of the pre trends as well as the medium-run effects after three or more years. Figure 7 presents the corresponding results. The plot illustrates that our findings are robust with respect to these tests. Medium-run estimates hover around our baseline estimate and are statistically significantly different from zero in most cases. Pre-trends are notably flat in virtually all specifications with only one exception: the fixed effects model. This small but significant difference is driven by the binned endpoint at the fourth lead, i.e., reflecting some difference four or more years prior to tax reforms. All underlying event study results are presented in Appendix Figures C.8–C.13.

6 Welfare Simulations

In this section, we feed the reduced-form evidence into our theoretical framework to simulate the welfare effects of property taxation. We start by explaining how we implement the simulation in Section 6.1. In Section 6.2, we present the corresponding results and show how property taxes affect household welfare. Finally, we run counterfactual simulations to investigate the welfare effects of property taxation in different institutional contexts (Section 6.3).

6.1 Data and Calibration

We base our simulation on the 2013 wave of the German Income and Expenditure Survey (EVS, 2013), a representative cross-sectional household study conducted every five years by the German Federal Statistical Office. In line with the empirical analysis in Section 5, we focus on respondents from West Germany, which leaves us with a sample of $|\mathcal{H}| = 32{,}458$ households.[14] The survey includes information on the household context, incomes from various sources, and basic housing characteristics, in particular the tenancy status and square meter of the main residence. In addition, the Federal Statistical Office reports rental payments for renters and imputed rents as well as property tax payments in case of owner-occupied housing.

Equation (7) yields the starting point for the empirical implementation of Proposition 1. We rewrite the money-metric change in household i's utility in response to an increase in the

[14] We perform all simulations at the household level accounting for household sampling weights and using the OECD-modified equivalence scale to adjust for differences in household size throughout our analysis.

property tax rate as:

$$\Delta W_i = -h_i \Delta r_i^C + \Delta y_i^L + \Delta y_i^W + \Delta y_i^F + \delta_i^g \Delta g, \qquad \text{for } i \in \mathcal{H}, \tag{7}$$

where h_i denotes the observed floor area of household i's apartment or house. The operator Δ indicates simulated changes in gross per m^2 housing prices r_i^C, landlord income y_i^L, wage earnings y_i^W, business income y_i^F, and public good provision g, respectively.

We provide more details on the empirical implementation of the different components in Table 1. Panel A illustrates how the simulated changes of equation (7) relate to the reduced-form evidence on the effects of a one percentage point increase in the property tax rate. Panel B shows the estimates for the different semi-elasticities used in the simulation. These estimates represent medium-run effects using the model from equations (3)–(4) and gross rents, average wages in the municipality, and profits of local firms, and municipal expenditures as outcomes (in logs). Precisely, we calculate the implied medium-run semi-elasticities from the respective event studies, averaging the estimated coefficients in years three and four after a tax change.

As discussed in Section 2.1, the household welfare effect consists of three components: First, we simulate the impact of property tax changes on housing expenditures $h_i r_i^C$ using reported living space and gross rents from the data and the semi-elasticity of gross rents with respect to a one percentage point increase in the property tax rate estimated in Section 5. In case of owner-occupied housing, we simulate the change in tax payments based on imputed rents.

Second, we account for changes in household income. To predict the impact on rental income, Δy_i^L, we multiply the estimated semi-elasticity of gross rents with respect to the property tax rate by observed total landlord income and subtract landlords' additional property tax payments using the average tax-to-rent ratio from the data. Since additional landlord income is subject to income taxation, we further multiply this figure by the marginal net-of-income-tax rate to arrive at the change in net rental income.

In addition to landlord income, household income effects also include changes in wages and business income (see equation (7)). We estimate the effects of property taxes on these two outcomes using our empirical model defined in equations (3) and (4). Appendix Figure C.14 shows the corresponding results. Overall, wages and business incomes are hardly affected by property tax changes, medium-run effects are close to zero (see also the summary estimates in Panel B of Table 1). Based on the estimate for wages, we simulate the change in household's earnings, Δy_i^W, using observed wage income and the marginal tax wedges from income taxes and social-security contributions. Similarly, we predict the change in business income, Δy_i^F, based on the estimated semi-elasticity of profits with respect to the property tax rate, reported self-employment income, and the marginal net-of-income tax rate.

The third component concerns the transmission of property taxes in public good provision, denoted by Δg. To simulate the welfare effects of changes in local public goods, we need the average municipal expenditures per capita (EUR 2,463 in 2013) and the semi-elasticity estimate of municipal expenditures per capita with respect to the property tax rate (see Panel C of Appendix Figure C.7 and the summary estimate in Panel B of Table 1).[15] In order to transform

[15] We proxy locally provided public services using per capita expenditures of the municipality, which is a common

Table 1: Mapping of Theory and Empirics for Welfare Simulation

	Term	Implementation	Description
Panel A – Simulated Changes at Household Level			
(1)	Gross Rent per m^2	$\Delta r_i^C = r_i^C\,\widehat{\varepsilon}_{r^C}$	Reported/imputed gross rent per m^2 times estimated semi-elasticity of log gross rents with respect to the property tax rate
(2)	Landlord Income	$\Delta y_i^L = ([1-\tau_i^I]\,\widehat{\varepsilon}_{r^C} - \overline{t/r})\,y_i^L$	Net of income tax rate times semi-elasticity of log gross rent with respect to the property tax rate times reported gross rental income (minus additional property tax payments)
(3)	Wage Earnings	$\Delta y_i^W = (1-\tau_i^W)\,y_i^W\,\widehat{\varepsilon}_{y^W}$	Net of income tax and social-security contributions rate times reported wage earnings times semi-elasticity of log wages with respect to the property tax rate
(4)	Business Income	$\Delta y_i^F = (1-\tau_i^I)\,y_i^F\,\widehat{\varepsilon}_{y^F}$	Net of income tax rate times reported self-employment income times semi-elasticity of log profits with respect to property tax rate
(5)	Public Good Provision	$\Delta g = g\,\widehat{\varepsilon}_g$	Average municipal expenditures per capita times semi-elasticity of log public expenditures with respect to the property tax rate
Panel B – Estimated Property Tax Rate Semi-Elasticities (Medium-Run Effects)			
(6)	Gross Rents	$\widehat{\varepsilon}_{r^C} = 0.032$ (0.014)	Estimated semi-elasticity of log gross rents per square meter with respect to the property tax rate (cf. Figure 2)
(7)	Wage Earnings	$\widehat{\varepsilon}_{y^W} = 0.006$ (0.009)	Estimated semi-elasticity of log average local wages with respect to the property tax rate (cf. Panel A of Figure C.14)
(8)	Firm Profits	$\widehat{\varepsilon}_{y^F} = 0.009$ (0.145)	Estimated semi-elasticity of log average firm profits with respect to the property tax rate (cf. Panel B of Figure C.14)
(9)	Public Goods	$\widehat{\varepsilon}_g = -0.034$ (0.038)	Estimated semi-elasticity of log municipal expenditures per capita with respect to property tax rate (cf. Panel C of Appendix Figure C.7)
Panel C – Calibrated Simulation Parameters			
(10)	Relative Preference for Public Goods	$\delta_i^g = \frac{\delta}{1-\delta} = 0.079$ (with $\delta = 0.073$)	Calibrated homogeneously across households using average ratio δ of total municipal expenditures relative to local GDP

Notes: This table provides details on the implementation of the welfare simulation based on equation (7). All effects are evaluated for a one percentage point increase in the property tax rate. $\widehat{\varepsilon}_{r^C}$, $\widehat{\varepsilon}_{y^W}$, $\widehat{\varepsilon}_{y^F}$, and $\widehat{\varepsilon}_g$ denote estimated reduced-form semi-elasticities of logged outcomes with respect to property tax rates based on the empirical setup from Section 5 and equation (3). r_i^C refers to reported gross rents per m^2 in case of rental housing and imputed gross rents in case of owner-occupied housing (imputed by the Federal Statistical Office). Variables y_i^L, y_i^W, and y_i^F represent different components of household income reported in the EVS, namely landlord income, wage earnings, and income from self-employment, respectively. We denote average municipal expenditures per capita by g. The parameter δ_i^g refers to households' relative preference for public over private goods. The ratio $\overline{t/r}$ refers to the average ratio of reported property tax payments to (imputed) gross rents across households evaluated for a one percentage point increase in the tax rate. Tax wedges τ_i^I and τ_i^W denote the marginal income tax rate and the combined tax wedge from income taxes and social-security contributions for household i, respectively.

these changes in public expenditures to money-metric utility changes at the household level, we require information about the relative preference for public over private goods, δ_i^g. We calibrate this parameter to the relative income share devoted to public over private goods, i.e., $\delta_i^g = \delta/(1-\delta)$, where δ denotes the expenditure share on public goods. Following Fajgelbaum et al. (2019) we set δ to the ratio of municipal expenditures relative to local GDP ($\delta = 0.073$ in our case). It follows that $\delta_i^g = 0.079$ (see Panel C of Table 1).

6.2 Property Taxes and Household Welfare

In the following, we simulate the money-metric utility change due to a one percentage point increase in the property tax rate as laid out in equation (7). We calculate utility changes for each household in the EVS survey and scale this money metric by each household's consumption level to derive relative utility changes. We then divide the sample in percentiles according to households' equivalence-weighted consumption expenditures and present averages within percentiles. Figure 8 illustrates the results over the consumption distribution.[16] A one percentage point increase in the property tax rate results in an increasing pattern of utility changes over the distribution. While households in the bottom decile lose 1.14 percent of their consumption, households from the top decile lose less than half a percent due to the tax increase (-0.27 percent on average). The burden for poor households is more than four times as large as the relative utility loss for rich households. On average, households lose 0.6 percent of their consumption (similar for the median household). Our simulation thus shows that property taxes are regressive and increase inequality in consumption.

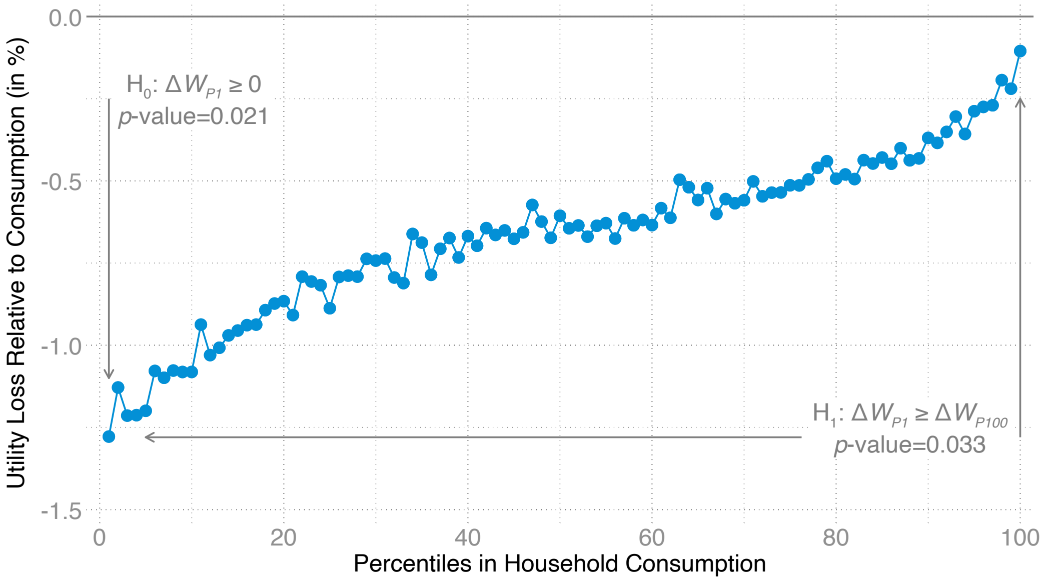
Inference. We draw inference from these results based on 1,000 bootstrap replications simulating the full and the partial model (see Appendix Figure C.16). Confidence intervals for the full model are wide and often include zero, reflecting the imprecise estimates for wages and business incomes. We still reject the null hypothesis of no welfare loss at the bottom of the distribution ($F(\Delta W_{P1} \geq 0) = 0.021$ using the empirical distribution of predicted welfare losses). Bounds for the partial model are tighter and exclude zero for all percentiles in each permutation. For both simulation variants, we statistically also reject the hypothesis that relative utility changes at the bottom of the distribution are greater or equal to the welfare change at the top, underlining the regressive impact of property taxes ($F(\Delta W_{P1} \geq \Delta W_{P100}) = 0.033$ in the full model, $F(\Delta W_{P1} \geq \Delta W_{P100}) = 0.022$ in the partial model).

Decomposing Model Channels. The illustration in Figure 8 is based on the full model outlined in Section 2.1, i.e., incorporating the partial equilibrium model as well as local public goods and general equilibrium effects. In the following, we decompose the results from the baseline model into its different components shown in equation (7). Figure 9 provides the corresponding

proxy for public goods (see, e.g., Brülhart et al., 2021). It captures consumption of public goods if the utility value of public goods is related to the level of expenditures, which seems reasonable. Using per capita values seems intuitive given that public goods can be congested (e.g., public parks, swimming pools, etc).

[16] We present absolute money-metric utility changes in Appendix Figure C.15. The impact is then clearly negative and decreasing across percentiles as richer households tend to reside in larger and more expensive dwellings.

Figure 8: Property Tax Increases and Household Utility



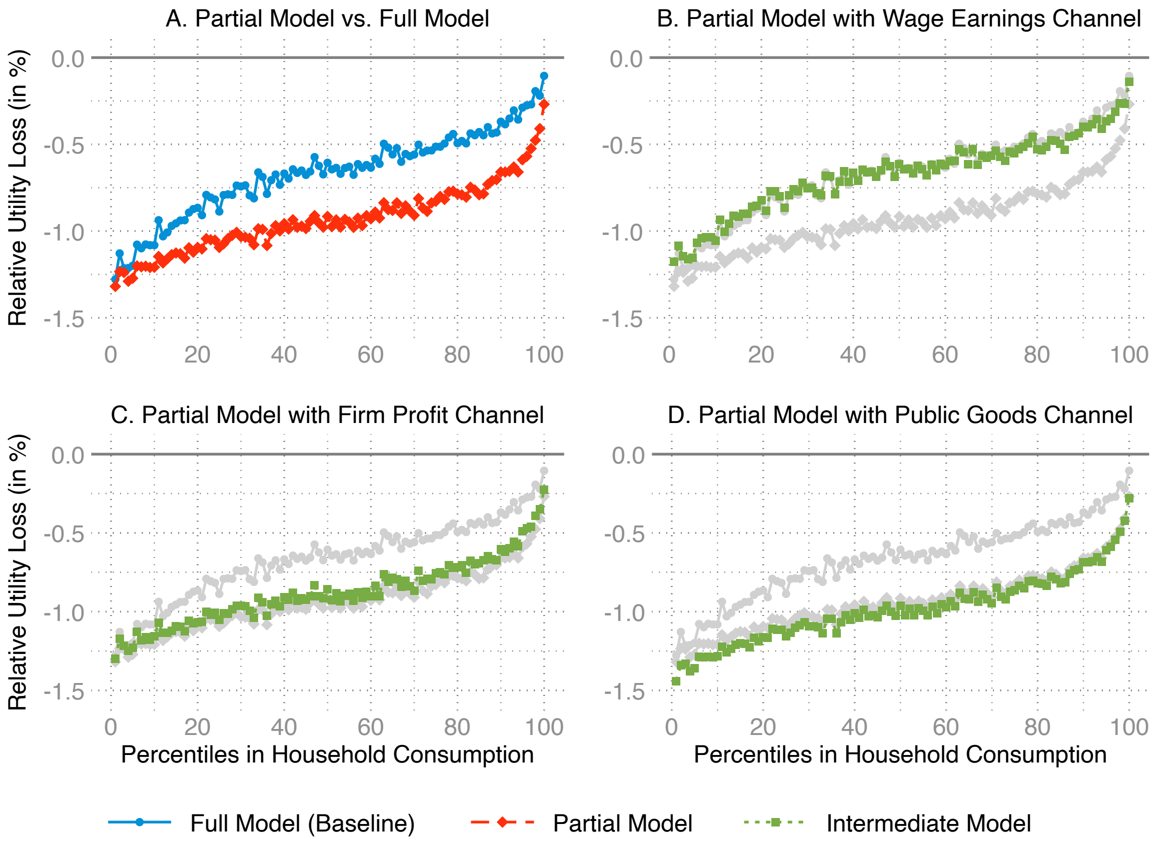
Notes: This figure illustrates the relative utility consequences of a one percentage point increase in the local property tax over the household consumption distribution (in percent). We calculate relative utility losses as money-metric utility changes in euro per year divided by total household consumption. We simulate money-metric utility changes as presented in equation (7) and Table 1 for each household in the German Income and Expenditure Survey (EVS, 2013). The curves are based on average changes within percentiles of the consumption distribution across households using sampling weights and the OECD-modified equivalence scale. Depicted *p*-values for hypothesis tests are based on the empirical distribution of predicted welfare losses using 1,000 bootstrap replications (see paragraph "Inference" for details and Appendix Figure C.16 for the respective empirical confidence bounds). See Appendix B for detailed information on all variables.

results. Panel A contrasts the simulated welfare consequences in the full model (in blue) with the partial-equilibrium textbook model (in red). In the latter model, we only simulate utility losses due to changes in housing prices, discarding other income channels and local public goods. While utility losses at both ends of the distribution are similar, the simulation for the partial model deviates for households in the middle of the distribution: the partial model indicates higher losses for most households, which is also reflected in a higher average and median utility loss of around -0.9 percent.

In Panel B, we add wage effects to the partial model. The resulting picture is very similar to the full model, indicating that most of the difference between partial and full model is due to adjustments in wage earnings. Adding business incomes (Panel C) or public goods (Panel D) to the partial model only has a negligible effect on welfare. The small public good effect is driven by a small response of public goods to changes in property taxes (see Panel B of Table 1) and a low relative preference for public goods. As particularly the former reason might be due to the German institutional setting (see Section 3.1), we run counterfactual simulations in Section 6.3 where we assume larger public goods elasticities and higher preferences.

Overall we conclude that the impact of property tax increases is regressive with substantially larger relative utility losses for households at the bottom end of the distribution. While quantities differ, the welfare effects can largely be explained with a partial-equilibrium model, in which the incidence of property taxation is determined by (i) the pass-through of tax payments from landlords to tenants, and (ii) the housing expenditure share in consumption.

Figure 9: Decomposition of Welfare Effects



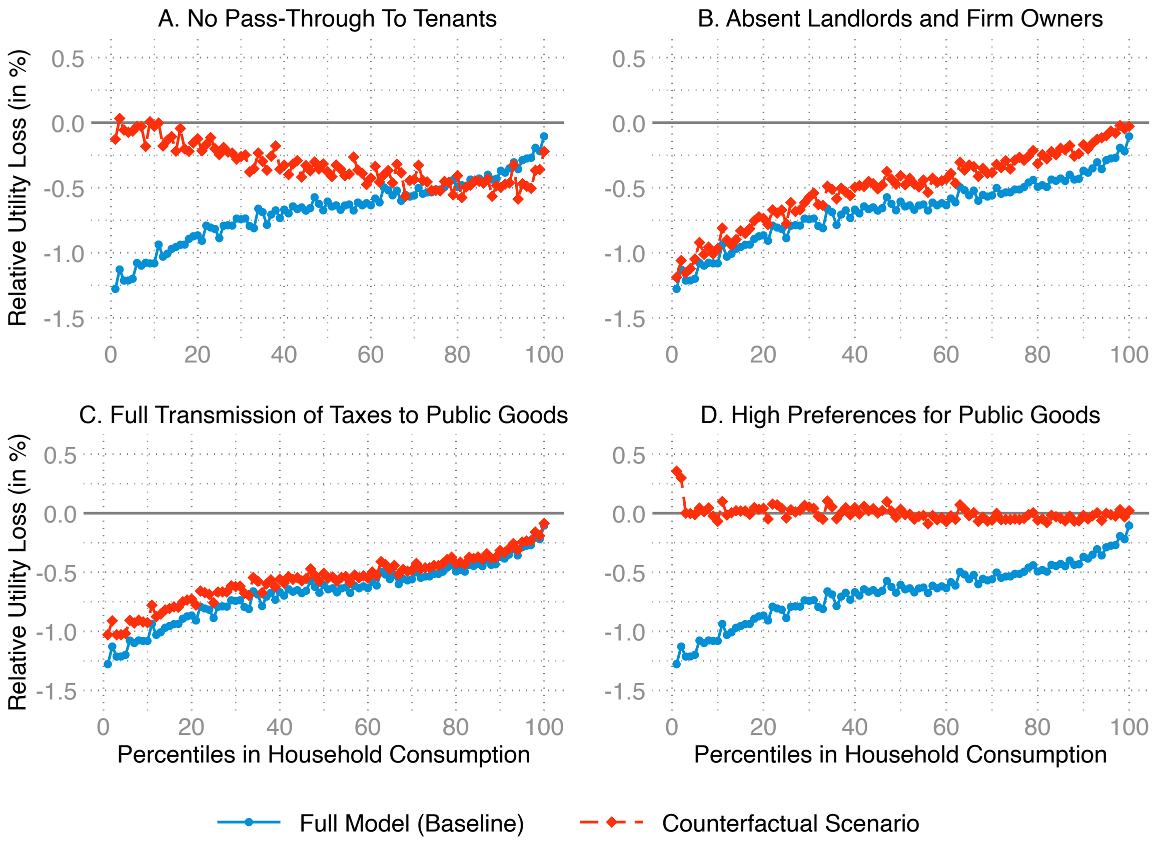
Notes: This figure illustrates the utility consequences of a one percentage point increase in the local property tax over the distribution of household consumption (in percent). Panel A depicts the full model combining housing market responses as well as local public good responses and adjustments in wage earnings and business incomes (in blue). In red, the panel illustrates the partial equilibrium model based on housing market adjustments only. Panel B–D present intermediate scenarios, enriching the partial model by compensating wage responses (Panel B), business profit adjustments (Panel C), or local public goods adjustments (Panel D), respectively, and discarding other channels. We simulate money-metric utility changes as presented in equation (7) and Table 1 for each household in the German Income and Expenditure Survey (EVS, 2013) and normalize by total household consumption. The depicted curves are based on average utility changes within percentiles of the consumption distribution across households using sampling weights and the OECD-modified equivalence scale. See Appendix B for detailed information on all variables.

Sensitivity Checks. The simulations are based on a set of modeling assumptions. In Appendix C.5, we provide a detailed discussion of the different assumptions and the sensitivity of our results to modeling choices. In particular, we assess to what extent our results differ when (i) using alternative ways to calculate the additional tax burden, (ii) scaling by household income instead of consumption, (iii) employing different tax schedule imputations, (iv) including East Germany as well, and (v) using different calibrations for the relative valuation of public vs. private goods. Results are rather insensitive to these robustness checks and if anything yield more regressive results compared to the baseline simulation.

6.3 Counterfactual Simulations

In a last step, we run various counterfactual scenarios. First, we ask how the welfare effects of property tax increases would change if we imposed a zero pass-through of taxes from landlords

Figure 10: Counterfactual Simulation Results



Notes: This figure illustrates the simulation results for various counterfactual scenarios (in red) in contrast to the baseline simulation from Figure 8 (in blue). In Panel A, we simulate the case of no pass-through of taxes to tenants setting the semi-elasticity of gross rents to zero, i.e., $\hat{\varepsilon}_{rC} = 0$. In Panel B, we assess the welfare effects if business owners (households with income from self-employment) and landlords (households with rental income) were absent from the city and thus unaffected by housing expenditure, wage, or public good adjustments. In Panel C, we assume that local public good provision increases by the same amount as per capita property tax revenues increase. In Panel D, we also simulate full transmission of property tax revenues into public good spending but also raise the relative valuation of public vs. private goods to $\delta_i^g = 0.938$. We simulate money-metric utility changes as presented in equation (7) and Table 1 for each household in the German Income and Expenditure Survey (EVS, 2013) and normalize by total household consumption. The depicted curves are based on average utility changes within percentiles of the consumption distribution across households using sampling weights and the OECD-modified equivalence scale. See Appendix B for detailed information on all variables.

to tenants. We analyze this scenario in a ceteris paribus setting, holding all other effects constant and only setting the semi-elasticity of gross rents with respect to the property tax rate to zero. Panel A of Figure 10 depicts the results of this exercise. We find increasing relative utility losses over the consumption distribution. With zero pass-through from landlords to tenants, property taxes would be largely progressive. The resulting pattern reflects the stylized fact that homeowners and landlords—who still have to pay the additional tax burden—are usually to be found in higher percentiles.

Second, we investigate the welfare effects if we assume that landlords and firm owners are absent—a standard assumption in the structural spatial equilibrium literature to ensure analytical tractability. In our baseline, we assume that all households are residents irrespective of whether they are workers, business owners, or landlords.[17] In the counterfactual scenario, we now assume that (i) households with positive rental income are only affected via changes in rental income, and (ii) households with income from self-employment only by changes in business profits; we set all other channels to zero for these households. Panel B of Figure 10 shows the corresponding results. While this alternative scenario has little impact at the bottom of the distribution, it reduces the utility losses for most households in the middle and upper part of the distribution, yielding a more regressive impact of the tax.

Third, we impose the counterfactual assumption that additional property tax revenues are fully transmitted into higher public good spending. Based on average municipal per-capita property tax revenues and the estimated semi-elasticity of tax revenues with respect to a one percentage point increase in the tax rate, we simulate annual municipal public good spending to increase by 87 EUR per capita (cf. Panel B of Appendix Figure C.7). Panel C of Figure 10 illustrates the simulation results along the distribution of consumption expenditures. As expected, relative utility losses are smaller for all percentiles and particularly so at the lower end of the distribution. However, the resulting pattern is still regressive and qualitatively quite similar to our baseline simulation.

The reason for the small effect of the counterfactual shown in Panel C is that the relative preference for local public goods in the baseline model is low. While we used a revealed preference approach following Fajgelbaum et al. (2019) to calibrate the public good preference, we might underestimate individuals' preferences for public goods if the local public expenditures over GDP share is inefficiently low and the public good is under-provided. This would clearly lead to an underestimate of the utility gains associated with a higher public good level as implied by the benefit view (Tiebout, 1956, Hamilton, 1976). To assess the relevance of this possibility, we simulate a counterfactual scenario in which we calibrate the parameter δ_i^g such that resulting utility changes average to zero (see Panel D of Figure 10), which corresponds to the assumption maintained in the benefit view of property taxation. It turns out that the relative preferences would have to be as high as $\delta_i^g = 0.938$, i.e., an order of magnitude larger than our baseline calibration and more than three times as large as the upper bound estimate in Fajgelbaum et al. (2019). Municipal expenditures would have to make up for almost half of local GDP to explain such high preferences via the revealed preferences approach.

7 Conclusion

We study the welfare effects of property taxation. We propose a new theoretical angle on this question by using a local labor market model in the spirit of Ahlfeldt et al. (2015) and Kline and Moretti (2014). We show that the incidence of property taxation can easily be derived using a sufficient statistics approach, in which the welfare effects of the tax depend on the changes in the price of housing, public goods, and various sources of income like wages, business or landlord income that might be affected by property taxes. In a next step, we estimate these

[17] This is still an approximation given the heterogeneity in where households work, earn business income, rent out dwellings, or consume public goods. The EVS survey includes no information on the respective locations.

behavioral responses exploiting the German institutional setting of property taxation, in which we observe more than 5,200 property tax reforms over the period 2007–2018. Specifically, there is no re-assessment of housing values and public goods financed by local property taxes play a minor role. We find that property taxes are fully passed through to rental prices after three years. This central finding is robust to various sensitivity checks, including an IV strategy and a test for selection on unobservables. Wages, business incomes, and local public goods are only weakly affected by changes in the property tax rate.

In a last step, we combine the sufficient statistics formula with our quasi-experimental reduced-form evidence. Our simple welfare expression enables us to go beyond a representative agent approach and simulate the welfare effects of property taxes across the income distribution taking into account that households can simultaneously be renters, landlords, workers, and business owners. We find that property taxes are regressive with poorer households showing an up to four times larger welfare loss following an increase in the property tax compared to rich households. We also show that a partial equilibrium model that only focuses on the price of housing reproduces the welfare prediction of the full fledged spatial equilibrium model reasonably well. Last, we run a counterfactual scenario in which we increase the importance of local public goods—both by assuming a higher responsiveness and increasing the relative preferences for those goods. While the regressive nature of property taxes is somewhat alleviated, we show that we would need unrealistically high preferences for local public goods to fully make up for the utility losses induced by the price effects of a property tax increase.

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A Theoretical Appendix

In this appendix, we provide a detailed description of the structural representation of the spatial equilibrium framework introduced in Section 2 of the paper. It includes all derivations and intermediate steps needed to solve the model and analyze the equilibrium properties. We introduce local property taxation into a Rosen-Roback type general equilibrium model of local labor markets (Suárez Serrato and Zidar, 2016). The model consists of four groups of agents: workers, firms producing tradable goods, construction companies producing floor space, and land owners. Workers and firms are mobile and locate in one out of C cities, indexed by c.

First, we outline the model in Section A.1. Second, we solve for the spatial equilibrium (Sections A.2). In Section A.3, we derive welfare effects of tax changes and show how marginal welfare effects relate to the key elasticities of the model in this context. We compare the welfare effects from the structural model to those from the sufficient statistics approach in Section A.4. Finally, we use comparative statics to show how changes in the property tax rate affect the equilibrium outcomes, i.e., population size, floor space, land use, rents, wages, and land prices (see Section A.5).

A.1 Agents and Markets

A.1.1 Workers

There are $N = 1$ workers indexed by i. We assume that labor is homogeneous and each worker provides inelastically one unit of labor, earns a wage y_c^W, and pays rent r_c for residential floor space.[18] Each municipality c has a specific unproductive consumption amenity A_c that is exogenously given. In addition, there are endogenous local public goods g_c provided by the local government. Workers maximize utility over floor space h_i, a composite good bundle x_i of non-housing goods and locations c. We normalize the aggregate price of the composite good bundle to one. Workers are mobile across municipalities, but mobility is imperfect due to individual location preferences, so that local labor supply is not necessarily infinitely elastic. In addition to the net house price, there is a property tax in each city, denoted by t_c, with the statutory incidence on the user of the housing service.[19] We assume that households have preferences for public goods measured by $\delta \in (0, 1)$.

The household's maximization problem in a given municipality c is given by:

$$\max_{h_i, x_i} U_{ic} = A_c g_c^{\delta} \left(h_i^{\alpha} x_i^{1-\alpha} \right)^{1-\delta} e_{ic} \qquad \text{s.t. } r_c(1 + t_c)h_i + px_i = y_c^W \tag{A.1}$$

with the bundle x_i of non-housing goods Z and the normalized aggregate price index p defined

[18] We assume that there is only one homogeneous housing good and do not differentiate between owner-occupied and rental housing in this structural model (Poterba, 1984).

[19] For simplicity, we assume that property is taxed *ad valorem*. Our main theoretical prediction regarding the tax incidence is however unchanged when modeling the property tax as a specific tax instead.

as in Melitz (2003):

$$x_i = \left(\int_{z \in Z} x_{iz}^{\rho} \, \mathrm{d}z \right)^{\frac{1}{\rho}} \qquad\qquad p = \left(\int_{z \in Z} p_{iz}^{-\frac{\rho}{1-\rho}} \, \mathrm{d}z \right)^{-\frac{1-\rho}{\rho}} = 1 \tag{A.2}$$

and $h_i, x_{iz}, A_c, g_c, r_c, y_c^W, t_c, p_{iz}, e_{ic} > 0$ and $\alpha, \rho \in (0, 1)$. The parameter ρ relates to the elasticity of substitution between any two composite goods, which is given by $\frac{1}{1-\rho}$ (Dixit and Stiglitz, 1977). The Lagrangian reads:

$$\begin{aligned}
\max_{h_i, x_i} \mathcal{L} = \ln A_c + \delta \ln g_c + \alpha(1-\delta) \ln h_i + (1-\alpha)(1-\delta) \ln x_i + \ln e_{ic} \\
+ \lambda \left(y_c^W - r_c[1 + t_c] h_i - x_i \right)
\end{aligned} \tag{A.3}$$

and first-order conditions of the household problem are given by:

$$\begin{aligned}
\frac{\partial \mathcal{L}}{\partial h_i} &= \frac{\alpha(1-\delta)}{h_i} - \lambda r_c(1 + t_c) \stackrel{!}{=} 0 \\
\frac{\partial \mathcal{L}}{\partial x_i} &= \frac{(1-\alpha)(1-\delta)}{x_i} - \lambda \stackrel{!}{=} 0 \\
\frac{\partial \mathcal{L}}{\partial \lambda} &= y_c^W - r_c(1 + t_c) h_i - x_i \stackrel{!}{=} 0
\end{aligned}$$

Now we can solve by substitution. The optimal floor space consumption is then given by:

$$\begin{aligned}
\frac{\alpha(1-\delta)}{h_i} &= \lambda r_c(1 + t_c) \\
&= \frac{(1-\alpha)(1-\delta)}{x_i} r_c(1 + t_c) \\
h_i &= \frac{\alpha}{1-\alpha} \frac{x_i}{r_c(1 + t_c)} \\
&= \frac{\alpha}{1-\alpha} \frac{y_c^W - r_c(1 + t_c) h_i}{r_c(1 + t_c)} \\
&= \frac{\alpha}{1-\alpha} \left(\frac{y_c^W}{r_c(1 + t_c)} - h_i \right) \\
h_i^* &= \alpha \frac{y_c^W}{r_c(1 + t_c)}
\end{aligned} \tag{A.4}$$

and we can solve for the optimal consumption level of the composite good bundle:

$$\begin{aligned}
x_i &= y_c^W - r_c(1 + t_c) h_i \\
&= y_c^W - r_c(1 + t_c) \alpha \frac{y_c^W}{r_c(1 + t_c)} \\
x_i^* &= (1-\alpha) y_c^W
\end{aligned} \tag{A.5}$$

where α is the share of the household's budget spent for housing. Household i's demand of good variety z is then given by $x_{iz}^{*} = (1-\alpha) y_c^W p_{iz}^{-\frac{1}{1-\rho}}$. Using the optimal consumption quantities, log indirect utility is defined as:

$$
\begin{aligned}
V_{ic}^H &= \ln U(h_i^*, x_i^*, A_c, g_c, e_{ic}) \\
&= \alpha(1-\delta)\ln h_i^* + (1-\alpha)(1-\delta)\ln x_i^* + \ln A_c + \delta \ln g_c + \ln e_{ic} \\
&= \alpha(1-\delta)\ln\left(\alpha \frac{y_c^W}{r_c(1+t_c)}\right) + (1-\alpha)(1-\delta)\ln\left([1-\alpha] y_c^W\right) + \ln A_c + \delta \ln g_c + \ln e_{ic} \\
&= \underbrace{(1-\delta)\left(\alpha \ln \alpha + [1-\alpha]\ln[1-\alpha]\right)}_{=a_0} + \ln A_c + \delta \ln g_c + \ln e_{ic} \\
&\quad + (1-\delta)(\alpha \ln y_c^W - \alpha \ln r_c - \alpha \ln[1+t_c] + (1-\alpha)\ln y_c^W) \\
V_{ic}^H &= a_0 + \underbrace{(1-\delta)(\ln y_c^W - \alpha \ln r_c - \alpha \ln[1+t_c]) + \ln A_c + \delta \ln g_c}_{=V_c^H} + \ln e_{ic}. \qquad \text{(A.6)}
\end{aligned}
$$

We defined a constant term $a_0 = (1-\delta)(\alpha \ln \alpha + [1-\alpha]\ln[1-\alpha])$ that is the same for all workers in the economy to simplify the notation. The individual (indirect) utility is a combination of this constant a_0, a common term V_c^H identical to all workers in the municipality, and the idiosyncratic location preferences e_{ic}. As in Kline and Moretti (2014), we assume that the logarithm of e_{ic} is independent and identically extreme value type I distributed with scale parameter $\sigma^H > 0$. The corresponding cumulative distribution function is $F(z) = \exp\left(-\exp[-z/\sigma^H]\right)$. Due to these city preferences, workers are not fully mobile between cities and real wages $y_c^W/(r_c[1+t_c])$ do not fully compensate for different amenity levels A_c across municipalities (other than in Brueckner, 1981). The greater σ^H, the stronger workers' preference for given locations and the lower workers' mobility. There is a city-worker match that creates a positive rent for the worker and decreases mobility. A worker i will prefer municipality a over municipality b if and only if:

$$
\begin{aligned}
V_{ia}^H &\geq V_{ib}^H \\
V_a^H + \ln e_{ia} &\geq V_b^H + \ln e_{ib} \\
V_a^H - V_b^H &\geq \ln e_{ib} - \ln e_{ia}.
\end{aligned}
$$

Given the distribution of $\ln e_{ic}$, it follows that the difference in preferences between two municipalities follows a logistic distribution with scale parameter σ^H, i.e., $\ln e_{ib} - \ln e_{ia} \sim logistic(0, \sigma^H)$. The probability that worker i locates in municipality c when choosing between C cities is then:

$$
N_c = \Pr\left(V_{ic}^H \geq V_{ij}^H, \forall j \neq c\right) = \frac{\exp\left(V_c^H/\sigma^H\right)}{\sum_{k=1}^C \exp\left(V_k^H/\sigma^H\right)}.
$$

This expression is equivalent to the share of workers locating in municipality c given that we normalize the total number of workers N to one. Note that the term a_0 cancels out as it is constant across municipalities. Taking logs we arrive at the (log) labor supply curve in municipality c:

$$\ln N_c^S = \frac{V_c^H}{\sigma^H} \underbrace{- \ln\left(C\pi^H\right)}_{=a_1}$$

$$\ln N_c^S = \underbrace{\frac{1-\delta}{\sigma^H}}_{=\epsilon^{\text{NS}}} \ln y_c^W \underbrace{- \frac{\alpha(1-\delta)}{\sigma^H}}_{=1+\epsilon^{\text{HD}}} \ln r_c \underbrace{- \frac{\alpha(1-\delta)}{\sigma^H}}_{=1+\epsilon^{\text{HD}}} \ln \tau_c + \underbrace{\frac{1}{\sigma^H}}_{=\epsilon^{\text{A}}} \ln A_c + \frac{\delta}{\sigma^H} \ln g_c + a_1 \qquad \text{(A.7)}$$

where we define all terms constant across municipalities as $a_1 = -\ln\left(C\pi^H\right)$ with $\pi^H = \frac{1}{C}\sum_{k=1}^{C} \exp\left(V_k^H/\sigma^H\right)$ being the average utility across all municipalities and we rewrite the property tax rate as $\tau_c = 1 + t_c$. Note that C is given, and for large C, a change in V_c^H does not affect the average utility π^H. The labor supply elasticity is given by:

$$\frac{\partial \ln N_c^S}{\partial \ln y_c^W} = \frac{1-\delta}{\sigma^H} = \epsilon^{\text{NS}} > 0. \qquad \text{(A.8)}$$

Floor Space Demand. Demand for residential housing in city c is determined by the number of workers in city c and their individual housing demand as indicated by equation (A.4):

$$H_c = N_c h_i^* = N_c \alpha \frac{y_c^W}{r_c(1+t_c)}$$

$$\ln H_c = \ln N_c + \ln \alpha + \ln y_c^W - \ln r_c - \ln \tau_c. \qquad \text{(A.9)}$$

It follows that the intensive margin housing demand elasticity conditional on location choice is equal to -1. In addition, there is an extensive margin with people leaving the city in response to higher costs of living. The aggregate residential housing demand elasticity is given by:

$$\frac{\partial \ln H_c}{\partial \ln r_c} = \frac{\partial \ln N_c}{\partial \ln r_c} - 1 = -\frac{\alpha(1-\delta) + \sigma^H}{\sigma^H} = \epsilon^{\text{HD}} < 0.$$

A.1.2 Firms

Firms $j = 1, ..., J$ are monopolistically competitive and produce tradable consumption goods. Each firm produces a different variety Y_{jc} using labor N_{jc} and commercial floor space M_{jc}. Firms have different productivity across places, due to exogenous local production amenities measured by B_c, and idiosyncratic productivity shifters ω_{jc}. Firm j's profits in city c are then given by:

$$y_{jc}^F = p_{jc} Y_{jc} - y_c^W N_{jc} - r_c^M (1+t_c)\kappa M_{jc} \qquad \text{(A.10)}$$

$$Y_{jc} = B_c \omega_{jc} N_{jc}^{\beta} M_{jc}^{1-\beta}$$

with $Y_{jc}, N_{jc}, M_{jc}, p_{jc}, y_c^W, r_c^M > 0$. y_c^W and r_c^M denote the factor prices of labor and commercial floor space, respectively. The scale parameter $\kappa > 0$ allows property taxes on commercial rents to differ from residential property taxes. Following Melitz (2003), we substitute the final good price p_{jc} by the inverse of product j's aggregate demand function:

$$Y_{jc} = Q\left(\frac{p_{jc}}{p}\right)^{-\frac{1}{1-\rho}}$$

with price index $p = 1$ as normalized above, and $Q > 0$ as total product demand in the economy. The parameter ρ relates to the elasticity of substitution between any two varieties. We define the exponent $-\frac{1}{1-\rho}$ as the constant product demand elasticity $\epsilon^{\text{PD}} < -1$. We can rewrite firm j's profits as:

$$y^F_{jc} = \underbrace{Q^{1-\rho} Y_{jc}^{-(1-\rho)}}_{=p_{jc}} Y_{jc} - y^W_c N_{jc} - r^M_c (1+t_c)\kappa M_{jc}.$$

Using the production function for Y_{jc} we can rewrite this expression as:

$$y^F_{jc} = Q^{1-\rho} \underbrace{\left(B_c \omega_{jc} N_{jc}^{\beta} M_{jc}^{1-\beta}\right)^{\rho}}_{=Y_{jc}} - y^W_c N_{jc} - r^M_c (1+t_c)\kappa M_{jc} \tag{A.11}$$

with $B_c, \omega_{jc} > 0$ and $\beta \in (0,1)$.

Profit maximizing behavior leads to the following first-order conditions for labor and floor space:

$$\begin{aligned}
\frac{\partial y^F_{jc}}{\partial N_{jc}} &= \rho\beta Q^{1-\rho} B_c^{\rho} \omega_{jc}^{\rho} N_{jc}^{\rho\beta-1} M_{jc}^{\rho(1-\beta)} - y^W_c \overset{!}{=} 0 \\
\frac{\partial y^F_{jc}}{\partial M_{jc}} &= \rho(1-\beta) Q^{1-\rho} B_c^{\rho} \omega_{jc}^{\rho} N_{jc}^{\rho\beta} M_{jc}^{\rho(1-\beta)-1} - r^M_c (1+t_c)\kappa \overset{!}{=} 0.
\end{aligned}$$

Again, we shorten notation by using $\tau_c = (1+t_c)$. Taking logs of the second condition we can derive the floor space demand of firms conditional on labor input, factor prices and local productivity:

$$\begin{aligned}
\ln\left(r^M_c \tau_c \kappa\right) &= \ln\rho + \ln(1-\beta) + (1-\rho)\ln Q + \rho \ln B_c + \rho \ln \omega_{jc} + \rho\beta \ln N_{jc} \\
&\quad - (1-\rho[1-\beta]) \ln M_{jc} \\
\ln M_{jc} &= \Big(\ln\rho + \ln[1-\beta] + [1-\rho]\ln Q + \rho \ln B_c + \rho \ln \omega_{jc} + \rho\beta \ln N_{jc} \\
&\quad - \ln r^M_c - \ln[\tau_c \kappa]\Big) \Big/ \Big(1 - \rho[1-\beta]\Big).
\end{aligned} \tag{A.12}$$

We can derive log labor demand from the first first-order condition using the conditional factor demand for commercial floor space from equation (A.12):

$$\begin{aligned}
\ln y^W_c &= \ln\rho + \ln\beta + (1-\rho)\ln Q + \rho \ln B_c + \rho \ln \omega_{jc} - (1-\rho\beta)\ln N_{jc} + \rho(1-\beta)\ln M_{jc} \\
\ln N_c &= \Big(\ln\rho + \ln\beta + [1-\rho]\ln Q + \rho \ln B_c + \rho \ln \omega_{jc} + \rho(1-\beta)\ln M_{jc} - \ln y^W_c\Big) \Big/ \Big(1-\rho\beta\Big)
\end{aligned}$$

$$
\begin{aligned}
&= \Big(\ln\rho + \ln\beta + [1-\rho]\ln Q + \rho\ln B_c + \rho\ln\omega_{jc} \\
&\quad + \rho[1-\beta]\Big[\ln\rho + \ln\{1-\beta\} + \{1-\rho\}\ln Q + \rho\ln B_c + \rho\ln\omega_{jc} + \rho\beta\ln N_{jc} \\
&\qquad - \ln r_c^M - \ln\{\tau_c\kappa\}\Big] \Big/ \Big[1-\rho\{1-\beta\}\Big] - \ln y_c^W\Big) \Big/ \Big(1-\rho\beta\Big)
\end{aligned}
$$

$$
\begin{aligned}
\ln N_{jc}^* = &\Big(\ln\rho + [1-\rho+\rho\beta]\ln\beta + \rho[1-\beta]\ln[1-\beta] + [1-\rho]\ln Q + \rho\ln B_c \\
&- [1-\rho+\rho\beta]\ln y_c^W - \rho[1-\beta]\ln r_c^M - \rho[1-\beta]\ln[\tau_c\kappa] + \rho\ln\omega_{jc}\Big) \Big/ \Big(1-\rho\Big) \quad \text{(A.13)}
\end{aligned}
$$

Using equation (A.12) from above and firm j's labor demand in city c we can also solve for the commercial floor space demand of firm j:

$$
\begin{aligned}
\ln M_{jc}^* = &\Big(\ln\rho + \rho\beta\ln\beta + [1-\rho\beta]\ln[1-\beta] + [1-\rho]\ln Q + \rho\ln B_c - \rho\beta\ln y_c^W \\
&- [1-\rho\beta]\ln r_c^M - [1-\rho\beta]\ln[\tau_c\kappa] + \rho\ln\omega_{jc}\Big) \Big/ \Big(1-\rho\Big) \quad \text{(A.14)}
\end{aligned}
$$

Equations (A.13) and (A.14) define the factor input demand conditional on local productivity and factor prices. We can now substitute the factor demand in the firm profit equation (A.11) and rewrite profits as a function of factor prices:

$$
\begin{aligned}
y_{jc}^F &= Q^{1-\rho} \underbrace{\Big(B_c\omega_{jc}N_{jc}^{\beta}M_{jc}^{1-\beta}\Big)^{\rho}}_{=Y_{jc}} - y_c^W N_{jc} - r_c^M \tau_c\kappa M_{jc} \\
y_{jc}^F(N_{jc}^*, M_{jc}^*) &= B_c^{\frac{\rho}{1-\rho}} \omega_{jc}^{\frac{\rho}{1-\rho}} y_c^{W^{-\frac{\rho\beta}{1-\rho}}} r_c^{M^{-\frac{\rho(1-\beta)}{1-\rho}}} (\tau_c\kappa)^{-\frac{\rho(1-\beta)}{1-\rho}} Q\rho^{\frac{\rho}{1-\rho}} \beta^{\frac{\rho\beta}{1-\rho}} (1-\beta)^{\frac{\rho(1-\beta)}{1-\rho}} (1-\rho)
\end{aligned}
$$

The term $1-\rho > 0$ at the end of the expression indicates that profits are a markup over costs. As defined before, this term is equivalent to the inverse of the absolute product demand elasticity, i.e., $1-\rho = -1/\epsilon^{\mathrm{PD}}$. The more elastic product demand ($\epsilon^{\mathrm{PD}} \downarrow$), the lower the markup and the lower firms' profits in the tradable good sector. Following Suárez Serrato and Zidar (2016) we define the value of firm j in city c in terms of factor costs and local productivity:

$$
\begin{aligned}
V_{jc}^F &= \frac{1-\rho}{\rho}\ln y_{jc}^F(N_{jc}^*, M_{jc}^*) \\
V_{jc}^F &= b_0 + \underbrace{\ln B_c - \beta\ln y_c^W - (1-\beta)\ln r_c^M - (1-\beta)\ln(\tau_c\kappa)}_{=V_c^F} + \ln\omega_{jc} \quad \text{(A.15)}
\end{aligned}
$$

with constant $b_0 = \frac{1-\rho}{\rho}\ln Q + \ln\rho + \beta\ln\beta + (1-\beta)\ln(1-\beta) + \frac{1-\rho}{\rho}\ln(1-\rho)$. We assume that idiosyncratic productivity shifters $\ln\omega_{jc}$ are i.i.d. and follow an extreme value type I distribution with scale parameter σ^F. As before in the context of household location choice, we normalize the total number of firms to $F = 1$. Using the log-profit equation and the distributional assumption on $\ln\omega_{jc}$ we denote the share of firms locating in city c by:

$$
F_c = \Pr\Big(V_{jc}^F \geq V_{jk}^F, \forall k \neq c\Big) = \frac{\exp\left(V_c^F/\sigma^F\right)}{\sum_{g=1}^{C}\exp\Big(V_g^F/\sigma^F\Big)}. \quad \text{(A.16)}
$$

The number of firms in city c from equation (A.16) (extensive margin) and the firm-specific labor demand from equation (A.13) (intensive margin) define the aggregate log labor demand in city c:

$$\begin{aligned}
\ln N_c^D &= \ln F_c + \mathrm{E}_{\omega_{jc}}\left[\ln N_{jc}^*\right] \\
&= \frac{1}{\sigma^F}\ln B_c - \frac{\beta}{\sigma^F}\ln y_c^W - \frac{1-\beta}{\sigma^F}\ln r_c^M - \frac{1-\beta}{\sigma^F}\ln(\tau_c\kappa) - \ln\left(C\pi^F\right) \\
&\quad + \frac{\rho}{1-\rho}\ln B_c - \frac{1-\rho+\rho\beta}{1-\rho}\ln y_c^W - \frac{\rho(1-\beta)}{1-\rho}\ln r_c^M - \frac{\rho(1-\beta)}{1-\rho}\ln(\tau_c\kappa) \\
&\quad + \frac{1}{1-\rho}\ln\rho + \frac{1-\rho+\rho\beta}{1-\rho}\ln\beta + \frac{\rho(1-\beta)}{1-\rho}\ln(1-\beta) + \ln Q + \frac{\rho}{1-\rho}\mathrm{E}_{\omega_{jc}}\left[\ln\omega_{jc}\right] \\
\ln N_c^D &= \underbrace{\left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right)}_{=\epsilon^{\mathrm{B}}}\ln B_c \underbrace{-\left(1+\beta\left[\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right]\right)}_{=\epsilon^{\mathrm{ND}}}\ln y_c^W \underbrace{-(1-\beta)\left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right)}_{=1+\epsilon^{\mathrm{MD}}}\ln r_c^M \\
&\quad \underbrace{-(1-\beta)\left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right)}_{=1+\epsilon^{\mathrm{MD}}}\ln(\tau_c\kappa) + b_1
\end{aligned} \tag{A.17}$$

as a function of local productivity B_c, wages y_c^W, and the (gross) factor price costs of commercial floor space $r_c^M\tau_c\kappa$ with constant term $b_1 = \Big(\ln\rho + [1-\rho+\rho\beta]\ln\beta + \rho[1-\beta]\ln[1-\beta] + \rho\mathrm{E}_{\omega_{jc}}\left[\ln\omega_{jc}\right]\Big)\Big/\Big(1-\rho\Big) + \ln Q - \ln C - \ln\pi^F$, where we define the average firm value across locations defined as $\pi^F = \frac{1}{C}\sum_{k=1}^{C}\exp\left(V_k^F/\sigma^F\right)$. The labor demand elasticity is defined as:

$$\frac{\ln N_c^D}{\ln y_c^W} = \underbrace{-\frac{\beta}{\sigma^F}}_{\text{Ext. margin}} \quad \underbrace{-1-\frac{\beta\rho}{1-\rho}}_{\text{Int. margin}} = \epsilon^{\mathrm{ND}} < 0. \tag{A.18}$$

Labor demand increases in local productivity B_c (i.e., $\epsilon^{\mathrm{B}} > 0$) and decreases in the (gross) factor price of commercial floor space defined by $r_c^M\tau_c\kappa$ (i.e., $1+\epsilon^{\mathrm{MD}} < 0$).

Floor Space Demand. Analogous to labor demand, we can also derive firms' demand for commercial floor space using the intensive margin commercial floor space demand from equation (A.14) and the location choice of firms from equation (A.16):

$$\begin{aligned}
\ln M_c^D &= \ln F_c + \mathrm{E}_{\omega_{jc}}\left[\ln M_{jc}^*\right] \\
&= \frac{1}{\sigma^F}\ln B_c - \frac{\beta}{\sigma^F}\ln y_c^W - \frac{1-\beta}{\sigma^F}\ln r_c^M - \frac{1-\beta}{\sigma^F}\ln(\tau_c\kappa) - \ln\left(C\pi^F\right) \\
&\quad + \frac{\rho}{1-\rho}\ln B_c - \frac{\rho\beta}{1-\rho}\ln y_c^W - \frac{1-\rho\beta}{1-\rho}\ln r_c^M - \frac{1-\rho\beta}{1-\rho}\ln(\tau_c\kappa) \\
&\quad + \frac{1}{1-\rho}\ln\rho + \frac{\rho\beta}{1-\rho}\ln\beta + \frac{1-\rho\beta}{1-\rho}\ln(1-\beta) + \ln Q + \frac{\rho}{1-\rho}\mathrm{E}_{\omega_{jc}}\left[\ln\omega_{jc}\right] \\
\ln M_c^D &= \underbrace{\left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right)}_{=\epsilon^{\mathrm{B}}}\ln B_c \underbrace{-\beta\left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right)}_{=1+\epsilon^{\mathrm{ND}}}\ln y_c^W \underbrace{-\left(1+[1-\beta]\left[\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right]\right)}_{=\epsilon^{\mathrm{MD}}}\ln r_c^M
\end{aligned}$$

$$\underbrace{-\left(1+[1-\beta]\left[\frac{1}{\sigma^F}+\frac{\rho}{1-\rho}\right]\right)}_{=\epsilon^{\mathrm{MD}}}\ln(\tau_c\kappa)+b_2 \tag{A.19}$$

with constant $b_2 = \Big(\ln\rho+\rho\beta\ln\beta+[1-\rho\beta]\ln[1-\beta]+\rho\mathrm{E}_{\omega_{jc}}\left[\ln\omega_{jc}\right]\Big)\Big/\Big(1-\rho\Big)+\ln Q-\ln C-\ln\pi^F$. The commercial floor space demand elasticity is defined as:

$$\frac{\partial\ln M_c^D}{\partial\ln r_c^M}=-\frac{1-\beta}{\sigma^F}-1-\frac{\rho(1-\beta)}{1-\rho}=\epsilon^{\mathrm{MD}}<0.$$

A.1.3 Construction Sector

We assume that a competitive, local construction sector provides both residential and commercial floor space. For positive supply on the two markets, there must be a no-arbitrage condition between both construction types. Following Ahlfeldt et al. (2015), we assume that the residential share μ of total floor space is determined by the prices of residential housing, r_c, and commercial floor space, r_c^M:

$$\begin{aligned}&\mu=1, && \text{for } r_c^M<\phi r_c\\ &\mu\in(0,1), && \text{for } r_c^M=\phi r_c\\ &\mu=0, && \text{for } r_c^M>\phi r_c\end{aligned} \tag{A.20}$$

with $\phi\geq 1$ denoting additional regulatory costs of commercial land use compared to residential housing.[20] In equilibrium, the no-arbitrage condition fixes the ratio between residential and commercial floor space prices and every municipality has positive supply of residential housing H_c and commercial floor space M_c. We can rewrite the two types of floor space in terms of total floor space, S_c, available in city c:

$$H_c=\mu S_c \qquad\qquad M_c=(1-\mu)S_c. \tag{A.21}$$

We follow the standard approach in urban economics and assume that the housing construction sector relies on a Cobb-Douglas technology with constant returns to scale using land ready for construction, L_c, and capital, K_c, to produce total floor space (see, e.g., Thorsnes, 1997, Epple et al., 2010, Combes et al., 2017):

$$S_c=H_c+M_c=L_c^{\gamma}K_c^{1-\gamma} \tag{A.22}$$

with γ being the output elasticity of land. In contrast to the capital tax literature, we assume global capital markets with unlimited supply at an exogenous rate s (Oates and Fischel, 2016). Consequently, the price for capital s is given and constant across municipalities. Profits in the

[20] We abstract from heterogeneity in the residential land use share, μ, and the regulatory markup, ϕ, for simplicity. This assumption does not influence our results qualitative.

construction industry are given by:

$$\Pi_c^C = r_c^M \underbrace{L_c^{\gamma} K_c^{1-\gamma}}_{=S_c} - l_c L_c - sK_c \tag{A.23}$$

with inputs and factor prices $L_c, K_c, l_c, s > 0$ and the output elasticity of land defined as $\gamma \in (0, 1)$. Profit maximizing behavior yields the following first-order conditions:

$$\frac{\partial \Pi_c^C}{\partial L_c} = \gamma r_c^M \frac{S_c}{L_c} - l_c \stackrel{!}{=} 0$$
$$\frac{\partial \Pi_c^C}{\partial K_c} = (1-\gamma) r_c^M \frac{S_c}{K_c} - s \stackrel{!}{=} 0.$$

Treating the supply of capital K_c as infinitely elastic and the price of capital s as exogenous, we can solve for land prices l_c as a function of the floor space price r_c^M. Taking logs of the second first-order condition we can derive the capital demand of the construction industry conditional on factor prices and land input:

$$\begin{aligned}
\ln s &= \ln(1-\gamma) + \ln r_c^M + \ln S_c - \ln K_c \\
\ln s &= \ln(1-\gamma) + \ln r_c^M + \gamma \ln L_c + (1-\gamma) \ln K_c - \ln K_c \\
\ln K_c &= \frac{1}{\gamma} \ln(1-\gamma) + \frac{1}{\gamma} \ln r_c^M + \ln L_c - \frac{1}{\gamma} \ln s.
\end{aligned}$$

Using the capital demand and the first-order condition with respect to land, we can solve for the price ratio of land to floor space in city c:

$$\begin{aligned}
\ln l_c &= \ln \gamma + \ln r_c^M + \ln S_c - \ln L_c \\
&= \ln \gamma + \ln r_c^M + \gamma \ln L_c + (1-\gamma) \ln K_c - \ln L_c \\
&= \ln \gamma + \ln r_c^M - (1-\gamma) \ln L_c + \frac{1-\gamma}{\gamma} \Big(\ln(1-\gamma) + \ln r_c^M + \gamma \ln L_c - \ln s \Big) \\
&= \underbrace{\ln \gamma + \frac{1-\gamma}{\gamma} \ln(1-\gamma)}_{=c_0} - \frac{1-\gamma}{\gamma} \ln s - \frac{1}{\gamma} \ln r_c^M \\
\ln l_c &= c_0 - \frac{1-\gamma}{\gamma} \ln s + \frac{1}{\gamma} \ln r_c^M
\end{aligned} \tag{A.24}$$

where we shorten notation by introducing the term c_0 that is constant across municipalities. Land prices increase in the floor space rent r_c^M (and equivalently in residential rents r_c).

A.1.4 Land Supply

While the total land area in each municipality is fixed and inelastic, the share of land ready for residential or commercial construction may be elastic. We model the supply of land ready for construction in city c according to the following log supply function:

$$\ln L_c = \theta \ln l_c \tag{A.25}$$

with land supply elasticity $\epsilon^{\text{LS}} = \theta > 0$. The preparation of new area includes, e.g., clearing and leveling the site, or building road access and connections to the electrical grid.

A.1.5 Local Governments

Local governments use share $\psi \in (0,1)$ of the property tax revenues to finance the local public good g_c. All remaining revenues are distributed lump-sum to all workers in the economy irrespective of location (share $1-\psi$). The government budget is defined as:

$$g_c = \psi \underbrace{\left(H_c r_c t_c + M_c r_c^M \left[\{1+t_c\} \kappa - 1 \right] \right)}_{\text{Total tax revenue}}$$

$$\ln g_c = \ln \psi + \ln \left(H_c r_c t_c + M_c r_c^M \left[\{1+t_c\} \kappa - 1 \right] \right), \tag{A.26}$$

where total tax revenue is the sum of residential property tax payments, $H_c r_c t_c$, and property taxes on rented commercial floor space, $M_c r_c^M$. Increases in city c's property tax rate t_c yield higher tax revenues and thereby a mechanical increase in local spending on the public good.

A.2 Equilibrium

The spatial equilibrium is determined by equalizing supply and demand on the markets for labor, residential housing, commercial floor space, and land in each city as well as the government budget constraint. Hence, we can summarize the equilibrium conditions using the following twelve equations:

$$\begin{aligned}
\ln N_c &= \frac{1-\delta}{\sigma^H} \ln y_c^W - \frac{\alpha(1-\delta)}{\sigma^H} \ln r_c - \frac{\alpha(1-\delta)}{\sigma^H} \ln \tau_c + \frac{1}{\sigma^H} \ln A_c + \frac{\delta}{\sigma^H} \ln g_c + a_1 \\
\ln N_c &= \left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho} \right) \ln B_c - \left(1 + \beta \left[\frac{1}{\sigma^F} + \frac{\rho}{1-\rho} \right] \right) \ln y_c^W - (1-\beta) \left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho} \right) \ln r_c^M \\
&\quad - (1-\beta) \left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho} \right) \ln(\tau_c \kappa) + b_1 \\
\ln H_c &= \ln N_c + \ln \alpha + \ln y_c^W - \ln r_c - \ln \tau_c \\
\ln H_c &= \ln \mu + \ln S_c \\
\ln M_c &= \left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho} \right) \ln B_c - \beta \left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho} \right) \ln y_c^W - \left(1 + [1-\beta] \left[\frac{1}{\sigma^F} + \frac{\rho}{1-\rho} \right] \right) \ln r_c^M \\
&\quad - \left(1 + [1-\beta] \left[\frac{1}{\sigma^F} + \frac{\rho}{1-\rho} \right] \right) \ln(\tau_c \kappa) + b_2 \\
\ln M_c &= \ln(1-\mu) + \ln S_c \\
\ln S_c &= (1-\gamma) \ln K_c + \gamma \ln L_c \\
\ln K_c &= \ln L_c + \frac{1}{\gamma} \ln r_c^M + \frac{1}{\gamma} \ln(1-\gamma) - \frac{1}{\gamma} \ln s \\
\ln L_c &= \theta \ln l_c \\
\ln l_c &= c_0 - \frac{1-\gamma}{\gamma} \ln s + \frac{1}{\gamma} \ln r_c^M
\end{aligned}$$

$$\ln r_c^M = \ln \phi + \ln r_c$$
$$\ln g_c = \ln \psi + \ln \Big(H_c r_c t_c + M_c r_c^M [\{1 + t_c\}\kappa - 1] \Big)$$

where we again use $\tau_c = 1 + t_c$ to simplify the notation in the following. We further simplify the equations using the key elasticities we defined above (see also Table A.1 for an overview):

$$\ln N_c = \epsilon^{\text{NS}} \ln y_c^W + (1 + \epsilon^{\text{HD}}) \ln r_c + (1 + \epsilon^{\text{HD}}) \ln \tau_c + \epsilon^{\text{A}} \ln A_c + \delta \epsilon^{\text{A}} \ln g_c + a_1 \tag{A.27a}$$
$$\ln N_c = \epsilon^{\text{B}} \ln B_c + \epsilon^{\text{ND}} \ln y_c^W + (1 + \epsilon^{\text{MD}}) \ln r_c^M + (1 + \epsilon^{\text{MD}}) \ln(\tau_c \kappa) + b_1 \tag{A.27b}$$
$$\ln H_c = \ln N_c + \ln \alpha + \ln y_c^W - \ln r_c - \ln \tau_c \tag{A.27c}$$
$$\ln H_c = \ln \mu + \ln S_c \tag{A.27d}$$
$$\ln M_c = \epsilon^{\text{B}} \ln B_c + (1 + \epsilon^{\text{ND}}) \ln y_c^W + \epsilon^{\text{MD}} \ln r_c^M + \epsilon^{\text{MD}} \ln(\tau_c \kappa) + b_2 \tag{A.27e}$$
$$\ln M_c = \ln(1 - \mu) + \ln S_c \tag{A.27f}$$
$$\ln S_c = (1 - \gamma) \ln K_c + \gamma \ln L_c \tag{A.27g}$$
$$\ln K_c = \ln L_c + \frac{1}{\gamma} \ln r_c^M + \frac{1}{\gamma} \ln(1 - \gamma) - \frac{1}{\gamma} \ln s \tag{A.27h}$$
$$\ln L_c = \theta \ln l_c \tag{A.27i}$$
$$\ln l_c = c_0 - \frac{1 - \gamma}{\gamma} \ln s + \frac{1}{\gamma} \ln r_c^M \tag{A.27j}$$
$$\ln r_c^M = \ln \phi + \ln r_c \tag{A.27k}$$
$$\ln g_c = \ln \psi + \ln \Big(H_c r_c t_c + M_c r_c^M [\{1 + t_c\}\kappa - 1] \Big) \tag{A.27l}$$

We can solve this system of equations for the equilibrium quantities in terms of population, residential housing, commercial floor space, use of capital, developed land, equilibrium prices for labor, residential housing, commercial floor space, and land as well as public good provision in equilibrium.

The derivation proceeds in four steps: First, we derive effective housing demand as a function of exogenous parameters and endogenous public goods (Section A.2.1). Second, we similarly solve for effective housing supply (Section A.2.2). Combining both we, third, derive equilibrium prices and quantities conditional on local public good provision (Section A.2.3). In Section A.2.4 we also solve for public good provision in equilibrium. Section A.2.5 provides a summary of the equilibrium prices and quantities.

A.2.1 Step 1 – Effective Housing Demand

To solve the model, we first derive the effective residential housing demand function, taking into account the extensive margin of people moving across locations. By combining equations (A.27a) and (A.27c), we get the following expression:

$$\ln H_c^D = a_1 + \ln \alpha + \epsilon^{\text{A}} \ln A_c + \delta \epsilon^{\text{A}} \ln g_c + \epsilon^{\text{HD}} \ln r_c + \epsilon^{\text{HD}} \ln \tau_c + \Big(1 + \epsilon^{\text{NS}}\Big) \ln y_c^W.$$

Table A.1: Key Elasticities of the Spatial Equilibrium Model

Key Elasticity	Definition
Panel A – Labor Market	
Labor Supply w.r.t.	
Wages	$\epsilon^{\text{NS}} = \frac{\partial \ln N_c}{\partial \ln y_c^W} = \frac{1-\delta}{\sigma^H}$
Exogenous Amenities	$\epsilon^{\text{A}} = \frac{\partial \ln N_c}{\partial \ln A_c} = \frac{1}{\sigma^H}$
Local Public Goods	$\delta\epsilon^{\text{A}} = \frac{\partial \ln N_c}{\partial \ln g_c} = \frac{\delta}{\sigma^H}$
Labor Demand w.r.t.	
Wages	$\epsilon^{\text{ND}} = \frac{\partial \ln N_c}{\partial \ln y_c^W} = -\left(1+\beta\left[\frac{1}{\sigma^F}+\frac{\rho}{1-\rho}\right]\right)$
Productive Amenities	$\epsilon^{\text{B}} = \frac{\partial \ln N_c}{\partial \ln B_c} = \frac{1}{\sigma^F}+\frac{\rho}{1-\rho}$
Panel B – Construction Sector and Land Market	
Residential Housing Demand w.r.t. Rents	$\epsilon^{\text{HD}} = \frac{\partial \ln H_c}{\partial \ln r_c} = -\frac{\alpha(1-\delta)+\sigma^H}{\sigma^H}$
Commercial Floor Space Demand w.r.t. Rents	$\epsilon^{\text{MD}} = \frac{\partial \ln M_c}{\partial \ln r_c^M} = -\left(1+[1-\beta]\left[\frac{1}{\sigma^F}+\frac{\rho}{1-\rho}\right]\right)$
Panel C – Land Market	
Land Supply w.r.t. Land Prices	$\frac{\partial \ln L_c}{\partial \ln l_c} = \theta$

Notes: This table summarizes the key supply and demand elasticities of the structural spatial equilibrium model.

By clearing the labor market, i.e., equating expressions (A.27a) and (A.27b), we can derive wages as a function of amenities, public goods, and floor space prices:

$$\begin{aligned}\ln y_c^W = \Big(& b_1 - a_1 - \epsilon^{\text{A}} \ln A_c - \delta\epsilon^{\text{A}} \ln g_c + \epsilon^{\text{B}} \ln B_c - \left[1+\epsilon^{\text{HD}}\right] \ln \tau_c + \left[1+\epsilon^{\text{MD}}\right] \ln\left[\tau_c\kappa\right] \\ & - \left[1+\epsilon^{\text{HD}}\right] \ln r_c + \left[1+\epsilon^{\text{MD}}\right] \ln r_c^M\Big) \Big/ \left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right). \end{aligned} \tag{A.28}$$

As the partial derivative of log wages with respect to residential housing costs is positive ($-\left[1+\epsilon^{\text{HD}}\right] / \left[\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right] > 0$), wages (partly) compensate for higher rents and/or higher residential property taxes *ceteris paribus*. Using this intermediate wage equation, we can rewrite residential housing demand as a function of housing costs, exogenous amenities, and local public goods:

$$\begin{aligned}\ln H_c^D = \Big(& \left[1+\epsilon^{\text{NS}}\right] b_1 - \left[1+\epsilon^{\text{ND}}\right] a_1 - \epsilon^{\text{A}}\left[1+\epsilon^{\text{ND}}\right]\left[\ln A_c + \delta \ln g_c\right] + \epsilon^{\text{B}}\left[1+\epsilon^{\text{NS}}\right] \ln B_c \\ & - \left[1+\epsilon^{\text{NS}} + \epsilon^{\text{HD}}\left\{1+\epsilon^{\text{ND}}\right\}\right] \ln r_c - \left[1+\epsilon^{\text{NS}} + \epsilon^{\text{HD}}\left\{1+\epsilon^{\text{ND}}\right\}\right] \ln \tau_c \\ & + \left[1+\epsilon^{\text{MD}}\right]\left[1+\epsilon^{\text{NS}}\right] \ln r_c^M + \left[1+\epsilon^{\text{MD}}\right]\left[1+\epsilon^{\text{NS}}\right] \ln[\tau_c\kappa]\Big) \Big/ \left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right) + \ln\alpha \end{aligned}$$

and use the no-arbitrage condition in equation (A.27k) to rewrite residential housing demand in terms of residential rents:

$$\begin{aligned}\ln H_c^D = \Big(& \left[1+\epsilon^{\text{NS}}\right] b_1 - \left[1+\epsilon^{\text{ND}}\right] a_1 + \left[1+\epsilon^{\text{MD}}\right]\left[1+\epsilon^{\text{NS}}\right] \ln\phi + \epsilon^{\text{B}}\left[1+\epsilon^{\text{NS}}\right] \ln B_c \\ & - \epsilon^{\text{A}}\left[1+\epsilon^{\text{ND}}\right]\left[\ln A_c + \delta \ln g_c\right] - \left[\epsilon^{\text{HD}}\left\{1+\epsilon^{\text{ND}}\right\} - \epsilon^{\text{MD}}\left\{1+\epsilon^{\text{NS}}\right\}\right] \ln r_c \\ & - \left[1+\epsilon^{\text{NS}} + \epsilon^{\text{HD}}\left\{1+\epsilon^{\text{ND}}\right\}\right] \ln \tau_c \end{aligned}$$

$$+\left[1+\epsilon^{\mathrm{MD}}\right]\left[1+\epsilon^{\mathrm{NS}}\right]\ln[\tau_c\kappa]\Big)\Big/\Big(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\Big)+\ln\alpha.$$

Residential housing demand is now a function of exogenous parameters and two endogenous measures, residential rents r_c and public good levels g_c.

Definition A.1 (Effective Housing Demand)**.** *The effective residential housing demand elasticity $\tilde{\epsilon}^{\mathrm{HD}}$ captures the response of residential housing demand to changes in residential rents holding public good levels constant but taking into account equilibrium effects on the labor market and the commercial floor space market. We define the effective residential housing demand elasticity as:*

$$\tilde{\epsilon}^{\mathrm{HD}}=-\frac{\epsilon^{\mathrm{HD}}[1+\epsilon^{\mathrm{ND}}]-\epsilon^{\mathrm{MD}}[1+\epsilon^{\mathrm{NS}}]}{\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}}<0.$$

Given that $\epsilon^{\mathrm{HD}}<0$, $\epsilon^{\mathrm{MD}}<0$, $\epsilon^{\mathrm{ND}}<0$, and $\epsilon^{\mathrm{NS}}>0$, it follows that $\epsilon^{\mathrm{HD}}<0$.

We can rewrite residential housing demand accordingly using this definition:

$$\begin{aligned}\ln H_c^D=&\Big(\left[1+\epsilon^{\mathrm{NS}}\right]b_1-\left[1+\epsilon^{\mathrm{ND}}\right]a_1+\left[1+\epsilon^{\mathrm{MD}}\right]\left[1+\epsilon^{\mathrm{NS}}\right]\ln\phi+\epsilon^{\mathrm{B}}\left[1+\epsilon^{\mathrm{NS}}\right]\ln B_c\\&-\epsilon^{\mathrm{A}}\left[1+\epsilon^{\mathrm{ND}}\right][\ln A_c+\delta\ln g_c]+\left[1+\epsilon^{\mathrm{MD}}\right]\left[1+\epsilon^{\mathrm{NS}}\right]\ln\kappa\Big)\Big/\Big(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\Big)\\&+\ln\alpha+\tilde{\epsilon}^{\mathrm{HD}}\ln r_c+\tilde{\epsilon}^{\mathrm{HD}}\ln\tau_c.\end{aligned}\tag{A.29}$$

A.2.2 Step 2 – Effective Housing Supply

To clear the residential housing market, demand needs to equal floor space supply, which we can rewrite as a function of capital costs and residential rents by combining equation (A.27d) and equations (A.27g)–(A.27k):

$$\begin{aligned}\ln H_c^S&=\ln S_c+\ln\mu\\&=\underbrace{(1-\gamma)\ln K_c+\gamma\ln L_c}_{=\ln S_c}+\ln\mu\\&=\underbrace{(1-\gamma)\ln L_c+\frac{1-\gamma}{\gamma}\ln r_c^M+\frac{1-\gamma}{\gamma}\ln(1-\gamma)-\frac{1-\gamma}{\gamma}\ln s}_{=(1-\gamma)\ln K_c}+\gamma\ln L_c+\ln\mu\\&=\underbrace{\theta\ln l_c}_{=\ln L_c}+\frac{1-\gamma}{\gamma}\ln r_c^M+\frac{1-\gamma}{\gamma}\ln(1-\gamma)-\frac{1-\gamma}{\gamma}\ln s+\ln\mu\\&=\underbrace{\frac{\theta}{\gamma}\ln r_c^M-\frac{\theta(1-\gamma)}{\gamma}\ln s+\theta c_0}_{=\theta\ln l_c}+\frac{1-\gamma}{\gamma}\ln r_c^M+\frac{1-\gamma}{\gamma}\ln(1-\gamma)-\frac{1-\gamma}{\gamma}\ln s+\ln\mu\\&=\frac{1-\gamma+\theta}{\gamma}\ln r_c^M-\frac{(1+\theta)(1-\gamma)}{\gamma}\ln s+\frac{1-\gamma}{\gamma}\ln(1-\gamma)+\theta c_0+\ln\mu\\\ln H_c^S&=\frac{1-\gamma+\theta}{\gamma}\underbrace{(\ln r_c+\ln\phi)}_{=\ln r_c^M}-\frac{(1+\theta)(1-\gamma)}{\gamma}\ln s+\frac{1-\gamma}{\gamma}\ln(1-\gamma)+\theta c_0+\ln\mu.\end{aligned}$$

Using these intermediate steps, we can also derive the effective housing supply elasticity.

Definition A.2 (Effective Housing Supply). *The effective residential housing supply elasticity $\tilde{\epsilon}^{\text{HS}}$ captures the response of residential housing supply to changes in residential rents taking into account both the factor substitution in the construction industry and the elasticity of land supply. We define the effective residential housing supply elasticity as:*

$$\tilde{\epsilon}^{\text{HS}} = \frac{1-\gamma+\theta}{\gamma} > 0.$$

Given that $\gamma \in (0,1)$ and $\theta > 0$ it follows that $\tilde{\epsilon}^{\text{HS}} > 0$.

By rewriting residential housing supply, we get:

$$\ln H_c^S = \tilde{\epsilon}^{\text{HS}} \ln r_c + \tilde{\epsilon}^{\text{HS}} \ln \phi - \frac{(1+\theta)(1-\gamma)}{\gamma} \ln s + \frac{1-\gamma}{\gamma} \ln(1-\gamma) + \theta c_0 + \ln \mu. \tag{A.30}$$

A.2.3 Step 3 – Equilibrium Conditional on Public Good Provision

Net Rents. Using equations (A.29) and (A.30) we can clear the residential housing market and solve for equilibrium net rents for residential floor space in city c as a function of equilibrium public good provision g_c^* and exogenous parameters:

$$\begin{aligned}
\ln r_c^* = & \Bigg(\left[\ln \alpha - \ln \mu - \theta c_0 - \frac{1-\gamma}{\gamma} \ln\{1-\gamma\} + \frac{\{1+\theta\}\{1-\gamma\}}{\gamma} \ln s \right] \left[\epsilon^{\text{NS}} - \epsilon^{\text{ND}} \right] \\
& + \left[1+\epsilon^{\text{NS}} \right] b_1 - \left[1+\epsilon^{\text{ND}} \right] a_1 + \left[\left\{ 1+\epsilon^{\text{MD}} \right\} \left\{ 1+\epsilon^{\text{NS}} \right\} - \tilde{\epsilon}^{\text{HS}} \left\{ \epsilon^{\text{NS}} - \epsilon^{\text{ND}} \right\} \right] \ln \phi \\
& - \epsilon^{\text{A}} \left[1+\epsilon^{\text{ND}} \right] [\ln A_c + \delta \ln g_c^*] + \epsilon^{\text{B}} \left[1+\epsilon^{\text{NS}} \right] \ln B_c + \tilde{\epsilon}^{\text{HD}} \left[\epsilon^{\text{NS}} - \epsilon^{\text{ND}} \right] \ln \tau_c \\
& + \left[1+\epsilon^{\text{MD}} \right] \left[1+\epsilon^{\text{NS}} \right] \ln \kappa \Bigg) \Bigg/ \Bigg(\left[\tilde{\epsilon}^{\text{HS}} - \tilde{\epsilon}^{\text{HD}} \right] \left[\epsilon^{\text{NS}} - \epsilon^{\text{ND}} \right] \Bigg) \\
\ln r_c^* = & \frac{\tilde{\epsilon}^{\text{HD}}}{d_0} \ln \tau_c - \frac{\delta \epsilon^{\text{A}} \left(1+\epsilon^{\text{ND}}\right)}{d_0 \left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)} \ln g_c^* - \frac{\epsilon^{\text{A}} \left(1+\epsilon^{\text{ND}}\right)}{d_0 \left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)} \ln A_c \\
& + \frac{\epsilon^{\text{B}} \left(1+\epsilon^{\text{NS}}\right)}{d_0 \left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)} \ln B_c + \frac{\left(1+\epsilon^{\text{MD}}\right) \left(1+\epsilon^{\text{NS}}\right)}{d_0 \left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)} \ln \kappa + \frac{d_{r^H}}{d_0}
\end{aligned} \tag{A.31}$$

with

$$d_0 = \tilde{\epsilon}^{\text{HS}} - \tilde{\epsilon}^{\text{HD}} > 0 \tag{A.32}$$

$$\begin{aligned}
d_{r^H} = & \ln \alpha - \ln \mu - \theta c_0 - \frac{1-\gamma}{\gamma} \ln(1-\gamma) + \frac{(1+\theta)(1-\gamma)}{\gamma} \ln s + \frac{1+\epsilon^{\text{NS}}}{\epsilon^{\text{NS}} - \epsilon^{\text{ND}}} b_1 \\
& - \frac{1+\epsilon^{\text{ND}}}{\epsilon^{\text{NS}} - \epsilon^{\text{ND}}} a_1 + \left(\frac{\left[1+\epsilon^{\text{MD}}\right] \left[1+\epsilon^{\text{NS}}\right]}{\epsilon^{\text{NS}} - \epsilon^{\text{ND}}} - \tilde{\epsilon}^{\text{HS}} \right) \ln \phi.
\end{aligned}$$

Using the no-arbitrage condition in equation (A.27k) we can solve for the equilibrium net-of-tax price of commercial floor space, again as a function of equilibrium local public goods:

$$\begin{aligned}
\ln r_c^{M*} = & \frac{\tilde{\epsilon}^{\text{HD}}}{d_0} \ln \tau_c - \frac{\delta \epsilon^{\text{A}} \left(1+\epsilon^{\text{ND}}\right)}{d_0 \left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)} \ln g_c^* - \frac{\epsilon^{\text{A}} \left(1+\epsilon^{\text{ND}}\right)}{d_0 \left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)} \ln A_c \\
& + \frac{\epsilon^{\text{B}} \left(1+\epsilon^{\text{NS}}\right)}{d_0 \left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)} \ln B_c + \frac{\left(1+\epsilon^{\text{MD}}\right) \left(1+\epsilon^{\text{NS}}\right)}{d_0 \left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)} \ln \kappa + \frac{d_{r^M}}{d_0}
\end{aligned} \tag{A.33}$$

with

$$d_{r^M} = \ln\alpha - \ln\mu - \theta c_0 - \frac{1-\gamma}{\gamma}\ln(1-\gamma) + \frac{(1+\theta)(1-\gamma)}{\gamma}\ln s + \frac{1+\epsilon^{\text{NS}}}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}b_1 - \frac{1+\epsilon^{\text{ND}}}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}a_1 + \left(\frac{\left[1+\epsilon^{\text{NS}}\right]\left[1+\epsilon^{\text{MD}}\right]}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}} - \tilde{\epsilon}^{\text{HD}}\right)\ln\phi.$$

Wages. Having solved for the price of residential and commercial floor space, we can derive equilibrium wages in city c by exploiting the intermediate wage equation (A.28):

$$\ln y_c^{W*} = -\frac{\tilde{\epsilon}^{\text{HS}}\left(\epsilon^{\text{HD}}-\epsilon^{\text{MD}}\right)}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln\tau_c - \frac{\delta\epsilon^{\text{A}}\left(\tilde{\epsilon}^{\text{HS}}-\epsilon^{\text{MD}}\right)}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln g_c^* - \frac{\epsilon^{\text{A}}\left(\tilde{\epsilon}^{\text{HS}}-\epsilon^{\text{MD}}\right)}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln A_c + \frac{\epsilon^{\text{B}}\left(\tilde{\epsilon}^{\text{HS}}-\epsilon^{\text{HD}}\right)}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln B_c + \frac{\left(1+\epsilon^{\text{MD}}\right)\left(\tilde{\epsilon}^{\text{HS}}-\epsilon^{\text{HD}}\right)}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln\kappa + \frac{d_w}{d_0} \tag{A.34}$$

with

$$d_w = \left(\theta c_0 - \ln\alpha + \frac{1-\gamma}{\gamma}\ln[1-\gamma] + \ln\mu - \frac{[1-\gamma][1+\theta]}{\gamma}\ln s\right)\frac{\epsilon^{\text{HD}}-\epsilon^{\text{MD}}}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}} + \frac{\tilde{\epsilon}^{\text{HS}}\left(1+\epsilon^{\text{HD}}\right)-\epsilon^{\text{HD}}\left(1+\epsilon^{\text{MD}}\right)}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}\ln\phi - \frac{\tilde{\epsilon}^{\text{HS}}-\epsilon^{\text{MD}}}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}a_1 + \frac{\tilde{\epsilon}^{\text{HS}}-\epsilon^{\text{HD}}}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}b_1.$$

Land Prices. The construction problem yields the relation between commercial floor space prices and land prices in equation (A.27j). Solving for land prices yields:

$$\ln l_c^* = \frac{\tilde{\epsilon}^{\text{HD}}}{\gamma d_0}\ln\tau_c - \frac{\delta\epsilon^{\text{A}}\left(1+\epsilon^{\text{ND}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln g_c^* - \frac{\epsilon^{\text{A}}\left(1+\epsilon^{\text{ND}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln A_c + \frac{\epsilon^{\text{B}}\left(1+\epsilon^{\text{NS}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln B_c + \frac{\left(1+\epsilon^{\text{MD}}\right)\left(1+\epsilon^{\text{NS}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln\kappa + \frac{d_l}{\gamma d_0} \tag{A.35}$$

with

$$d_l = \ln\alpha - \ln\mu - \frac{1-\gamma}{\gamma}\ln(1-\gamma) - \frac{1+\epsilon^{\text{ND}}}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}a_1 + \frac{1+\epsilon^{\text{NS}}}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}b_1 + \left(\gamma d_0 - \theta\right)c_0 + \frac{(1-\gamma)(1+\theta-\gamma d_0)}{\gamma}\ln s + \frac{1+\epsilon^{\text{NS}}+\epsilon^{\text{HD}}\left(1+\epsilon^{\text{ND}}\right)}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}\ln\phi.$$

Developed Land. Using equilibrium land prices and the land supply function allows to solve for equilibrium land use in city c:

$$\ln L_c^* = \frac{\tilde{\epsilon}^{\text{HD}}\theta}{\gamma d_0}\ln\tau_c - \frac{\delta\theta\epsilon^{\text{A}}\left(1+\epsilon^{\text{ND}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln g_c^* - \frac{\theta\epsilon^{\text{A}}\left(1+\epsilon^{\text{ND}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln A_c + \frac{\theta\epsilon^{\text{B}}\left(1+\epsilon^{\text{NS}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln B_c + \frac{\theta\left(1+\epsilon^{\text{MD}}\right)\left(1+\epsilon^{\text{NS}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln\kappa + \frac{\theta d_l}{\gamma d_0}. \tag{A.36}$$

Capital Stock. Equilibrium land use and equilibrium floor space prices also determine the equilibrium capital stock in equation (A.27h):

$$\begin{aligned}\ln K_c^* =& \frac{\tilde{\epsilon}^{\mathrm{HD}}(1+\theta)}{\gamma d_0} \ln \tau_c - \frac{\delta \epsilon^{\mathrm{A}}(1+\theta)\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln g_c^* - \frac{\epsilon^{\mathrm{A}}(1+\theta)\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln A_c \\ &+ \frac{\epsilon^{\mathrm{B}}(1+\theta)\left(1+\epsilon^{\mathrm{NS}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln B_c + \frac{(1+\theta)\left(1+\epsilon^{\mathrm{MD}}\right)\left(1+\epsilon^{\mathrm{NS}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln \kappa + \frac{d_K}{\gamma d_0}\end{aligned} \tag{A.37}$$

with

$$\begin{aligned}d_K =& (1+\theta)\left([\ln\alpha - \ln\mu]\left[\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right] - \left[1+\epsilon^{\mathrm{ND}}\right]a_1 + \left[1+\epsilon^{\mathrm{NS}}\right]b_1\right) \\ &- \theta\left(1+\theta\gamma d_0\right)c_0 - \frac{(1-\gamma)(1+\theta)-\gamma d_0}{\gamma}\ln(1-\gamma) \\ &+ \frac{(1-\gamma)(1+\theta)^2 - \gamma(1+\theta[1-\gamma])d_0}{\gamma}\ln s \\ &+ \frac{(1+\theta)\left(1+\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{HD}}\left[1+\epsilon^{\mathrm{ND}}\right]\right)}{\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}}\ln\phi.\end{aligned}$$

Floor Space. Land use and the capital stock in equilibrium also determine total floor space production. Using the production function of the construction sector we can solve for the equilibrium floor space quantity in city c:

$$\begin{aligned}\ln S_c^* =& \frac{\tilde{\epsilon}^{\mathrm{HS}}\tilde{\epsilon}^{\mathrm{HD}}}{d_0} \ln \tau_c - \frac{\tilde{\epsilon}^{\mathrm{HS}}\delta \epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln g_c^* - \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln A_c \\ &+ \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln B_c + \frac{\tilde{\epsilon}^{\mathrm{HS}}\left(1+\epsilon^{\mathrm{MD}}\right)\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln \kappa + \frac{d_S}{\gamma d_0}\end{aligned} \tag{A.38}$$

with

$$\begin{aligned}d_S =& \frac{1-\gamma+\theta}{\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}}\Big([\ln\alpha-\ln\mu]\left[\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right] - \left[1+\epsilon^{\mathrm{ND}}\right]a_1 + \left[1+\epsilon^{\mathrm{NS}}\right]b_1 \\ &\qquad + \left[1+\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{HD}}\left\{1+\epsilon^{\mathrm{ND}}\right\}\right]\ln\phi\Big) \\ &+ (1-\gamma+\theta-\gamma d_0)\left(\frac{[1-\gamma][1+\theta]}{\gamma}\ln s - \theta c_0 - \frac{1-\gamma}{\gamma}\ln[1-\gamma]\right).\end{aligned}$$

Using the residential share μ of total floor space we can solve for residential housing in equilibrium:

$$\begin{aligned}\ln H_c^* =& \frac{\tilde{\epsilon}^{\mathrm{HS}}\tilde{\epsilon}^{\mathrm{HD}}}{d_0} \ln \tau_c - \frac{\tilde{\epsilon}^{\mathrm{HS}}\delta \epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln g_c^* - \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln A_c \\ &+ \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln B_c + \frac{\tilde{\epsilon}^{\mathrm{HS}}\left(1+\epsilon^{\mathrm{MD}}\right)\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln \kappa + \frac{d_H}{\gamma d_0}\end{aligned} \tag{A.39}$$

with

$$d_H = d_S + \gamma d_0 \ln\mu.$$

Similarly, we can solve for equilibrium commercial floor space production:

$$\ln M_c^* = \frac{\tilde{\epsilon}^{\text{HS}}\tilde{\epsilon}^{\text{HD}}}{d_0}\ln\tau_c - \frac{\tilde{\epsilon}^{\text{HS}}\delta\epsilon^{\text{A}}(1+\epsilon^{\text{ND}})}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln g_c^* - \frac{\tilde{\epsilon}^{\text{HS}}\epsilon^{\text{A}}(1+\epsilon^{\text{ND}})}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln A_c$$
$$+\frac{\tilde{\epsilon}^{\text{HS}}\epsilon^{\text{B}}\left(1+\epsilon^{\text{NS}}\right)}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln B_c + \frac{\tilde{\epsilon}^{\text{HS}}\left(1+\epsilon^{\text{MD}}\right)\left(1+\epsilon^{\text{NS}}\right)}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln\kappa + \frac{d_M}{\gamma d_0} \tag{A.40}$$

with

$$d_M = d_S + \gamma d_0 \ln(1-\mu).$$

Population. By exploiting the labor supply to city c as a function of rents and wages, we can also solve for equilibrium population:

$$\ln N_c^* = -\frac{\tilde{\epsilon}^{\text{HS}}\left(\epsilon^{\text{ND}}\left[1+\epsilon^{\text{HD}}\right]-\epsilon^{\text{NS}}\left[1+\epsilon^{\text{MD}}\right]\right)}{d_0\left(\epsilon^{\text{NS}}+\epsilon^{\text{ND}}\right)}\ln\tau_c - \frac{\delta\epsilon^{\text{A}}\left(1+\epsilon^{\text{MD}}+\epsilon^{\text{ND}}\left[1+\tilde{\epsilon}^{\text{HS}}\right]\right)}{d_0\left(\epsilon^{\text{NS}}+\epsilon^{\text{ND}}\right)}\ln g_c^*$$
$$-\frac{\epsilon^{\text{A}}\left(1+\epsilon^{\text{MD}}+\epsilon^{\text{ND}}\left[1+\tilde{\epsilon}^{\text{HS}}\right]\right)}{d_0\left(\epsilon^{\text{NS}}+\epsilon^{\text{ND}}\right)}\ln A_c + \frac{\epsilon^{\text{B}}\left(1+\epsilon^{\text{HD}}+\epsilon^{\text{NS}}\left[1+\tilde{\epsilon}^{\text{HS}}\right]\right)}{d_0\left(\epsilon^{\text{NS}}+\epsilon^{\text{ND}}\right)}\ln B_c$$
$$+\frac{\left(1+\epsilon^{\text{MD}}\right)\left(1+\epsilon^{\text{HD}}+\epsilon^{\text{NS}}\left[1+\tilde{\epsilon}^{\text{HS}}\right]\right)}{d_0\left(\epsilon^{\text{NS}}+\epsilon^{\text{ND}}\right)}\ln\kappa + \frac{d_N}{d_0} \tag{A.41}$$

with

$$d_N = -\frac{1+\epsilon^{\text{MD}}+\epsilon^{\text{ND}}\left(1+\tilde{\epsilon}^{\text{HS}}\right)}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}a_1 + \frac{1+\epsilon^{\text{HD}}+\epsilon^{\text{NS}}\left(1+\tilde{\epsilon}^{\text{HS}}\right)}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}b_1$$
$$+\left(\ln\mu - \ln\alpha + \theta c_0 + \frac{1-\gamma}{\gamma}\ln[1-\gamma] - \frac{[1-\gamma][1+\theta]}{\gamma}\ln s\right)$$
$$\times\left(\frac{\epsilon^{\text{ND}}\left[1+\epsilon^{\text{HD}}\right]-\epsilon^{\text{NS}}\left[1+\epsilon^{\text{MD}}\right]}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}\right)$$
$$+\frac{\tilde{\epsilon}^{\text{HS}}\epsilon^{\text{ND}}\left(1+\epsilon^{\text{HD}}\right)+\left(1+\epsilon^{\text{MD}}\right)\left(1+\epsilon^{\text{HD}}+\epsilon^{\text{NS}}\right)}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}\ln\phi.$$

A.2.4 Step 4 – Equilibrium Public Good Provision

So far, we solved the equilibrium conditional on equilibrium public good levels g_c^* in order to differentiate between the direct effects of taxes on equilibrium outcomes and the indirect effects operating through increases in local public goods financed via property taxes.

We can now also derive equilibrium public good provision g_c^* as a function of exogenous parameters. To simplify exposition and keep the model analytically tractable, we assume that rents for residential housing equal the prices for commercial floor space ($\phi = 1$), which implies that both types of land use are subject to the same regulations (Ahlfeldt et al., 2015). Moreover, we assume that residential and commercial floor space are taxed at the same rate, i.e., $\kappa = 1$.

Using the no-arbitrage condition from equation (A.27k), the supply functions for residential and commercial floor space from equations (A.27d) and (A.27f), effective housing supply from equation (A.30), and equilibrium rents for residential housing in equation (A.43), we can solve for equilibrium public good provision:

$$\begin{aligned}
\ln g_c &= \ln \psi + \ln \left(H_c r_c t_c + M_c r_c^M \underbrace{\left[\{1+t_c\} \overbrace{\kappa}^{=1} - 1 \right]}_{=t_c} \right) \\
&= \ln \psi + \ln \left(H_c r_c t_c + M_c \underbrace{\overbrace{\phi}^{=1} r_c}_{=r_c^M} t_c \right) \\
&= \ln \psi + \ln \left(\mu S_c r_c t_c + (1-\mu) S_c r_c t_c \right) \\
&= \ln \psi + \ln S_c + \ln r_c + \ln t_c \\
&= \ln \psi + \underbrace{\ln H_c - \ln \mu}_{=\ln S_c} + \ln r_c + \ln t_c \\
&= \underbrace{\tilde{\epsilon}^{\mathrm{HS}} \ln r_c + \tilde{\epsilon}^{\mathrm{HS}} \ln \phi - \frac{(1+\theta)(1-\gamma)}{\gamma} \ln s + \frac{1-\gamma}{\gamma} \ln(1-\gamma) + \theta c_0 + \ln \mu}_{=\ln H_c} \\
&\quad + \ln \psi - \ln \mu + \ln r_c + \ln t_c \\
&= \left(1 + \tilde{\epsilon}^{\mathrm{HS}}\right) \ln r_c + \ln t_c + \underbrace{\tilde{\epsilon}^{\mathrm{HS}} \ln \phi}_{=0} - \frac{(1+\theta)(1-\gamma)}{\gamma} \ln s + \frac{1-\gamma}{\gamma} \ln(1-\gamma) + \theta c_0 + \ln \psi \\
&= \left(1 + \tilde{\epsilon}^{\mathrm{HS}}\right) \left(\frac{\tilde{\epsilon}^{\mathrm{HD}}}{d_0} \ln \tau_c - \frac{\delta \epsilon^{\mathrm{A}} \left[1+\epsilon^{\mathrm{ND}}\right]}{d_0 \left[\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right]} \ln g_c - \frac{\epsilon^{\mathrm{A}} \left[1+\epsilon^{\mathrm{ND}}\right]}{d_0 \left[\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right]} \ln A_c \right. \\
&\qquad \left. + \frac{\epsilon^{\mathrm{B}} \left[1+\epsilon^{\mathrm{NS}}\right]}{d_0 \left[\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right]} \ln B_c + \underbrace{\frac{\left[1+\epsilon^{\mathrm{MD}}\right] \left[1+\epsilon^{\mathrm{NS}}\right]}{d_0 \left[\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right]} \ln \kappa}_{=0} + \frac{d_{rH}}{d_0} \right) \\
&\quad + \ln t_c - \frac{(1+\theta)(1-\gamma)}{\gamma} \ln s + \frac{1-\gamma}{\gamma} \ln(1-\gamma) + \theta c_0 + \ln \psi
\end{aligned}$$

$$\begin{aligned}
\ln g_c^* = &\left(\frac{\tilde{\epsilon}^{\mathrm{HD}} \left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]}{d_0} \ln \tau_c + \ln t_c - \frac{\epsilon^{\mathrm{A}} \left[1+\tilde{\epsilon}^{\mathrm{HS}}\right] \left[1+\epsilon^{\mathrm{ND}}\right]}{d_0 \left[\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right]} \ln A_c + \frac{d_{rH} \left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]}{d_0} + d_G \right. \\
&\left. + \frac{\epsilon^{\mathrm{B}} \left[1+\tilde{\epsilon}^{\mathrm{HS}}\right] \left[1+\epsilon^{\mathrm{NS}}\right]}{d_0 \left[\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right]} \ln B_c \right) \Bigg/ \left(\frac{\delta \epsilon^{\mathrm{A}} \left[1+\epsilon^{\mathrm{ND}}\right] \left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]}{d_0 \left[\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right]} + 1 \right) \qquad \text{(A.42)}
\end{aligned}$$

with

$$d_G = -\frac{(1+\theta)(1-\gamma)}{\gamma} \ln s + \frac{1-\gamma}{\gamma} \ln(1-\gamma) + \theta c_0 + \ln \psi.$$

A.2.5 Summary

Hence, we arrive at the following spatial equilibrium prices and quantities for city c (conditional on equilibrium public good levels g_c^* and assuming equal tax rates and equal prices for residential and commercial floor space, i.e., $\kappa = \phi = 1$):

$$\begin{aligned}
\ln r_c^* &= \frac{\tilde{\epsilon}^{\mathrm{HD}}}{d_0}\ln\tau_c - \frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln g_c^* - \frac{\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c \\
&\quad + \frac{\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{d_{rH}}{d_0} \\
\ln r_c^{M*} &= \frac{\tilde{\epsilon}^{\mathrm{HD}}}{d_0}\ln\tau_c - \frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln g_c^* - \frac{\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c \\
&\quad + \frac{\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{d_{rM}}{d_0} \\
\ln l_c^* &= \frac{\tilde{\epsilon}^{\mathrm{HD}}}{\gamma d_0}\ln\tau_c - \frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln g_c^* - \frac{\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c \\
&\quad + \frac{\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{d_l}{\gamma d_0} \\
\ln y_c^{W*} &= -\frac{\tilde{\epsilon}^{\mathrm{HS}}\left(\epsilon^{\mathrm{HD}}-\epsilon^{\mathrm{MD}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln\tau_c - \frac{\delta\epsilon^{\mathrm{A}}\left(\tilde{\epsilon}^{\mathrm{HS}}-\epsilon^{\mathrm{MD}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln g_c^* - \frac{\epsilon^{\mathrm{A}}\left(\tilde{\epsilon}^{\mathrm{HS}}-\epsilon^{\mathrm{MD}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c \\
&\quad + \frac{\epsilon^{\mathrm{B}}\left(\tilde{\epsilon}^{\mathrm{HS}}-\epsilon^{\mathrm{HD}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{d_w}{d_0} \\
\ln S_c^* &= \frac{\tilde{\epsilon}^{\mathrm{HS}}\tilde{\epsilon}^{\mathrm{HD}}}{d_0}\ln\tau_c - \frac{\tilde{\epsilon}^{\mathrm{HS}}\delta\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln g_c^* - \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c \\
&\quad + \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{d_S}{\gamma d_0} \\
\ln H_c^* &= \frac{\tilde{\epsilon}^{\mathrm{HS}}\tilde{\epsilon}^{\mathrm{HD}}}{d_0}\ln\tau_c - \frac{\tilde{\epsilon}^{\mathrm{HS}}\delta\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln g_c^* - \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c \\
&\quad + \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{d_H}{\gamma d_0} \\
\ln M_c^* &= \frac{\tilde{\epsilon}^{\mathrm{HS}}\tilde{\epsilon}^{\mathrm{HD}}}{d_0}\ln\tau_c - \frac{\tilde{\epsilon}^{\mathrm{HS}}\delta\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln g_c^* - \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c \\
&\quad + \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{d_M}{\gamma d_0} \\
\ln L_c^* &= \frac{\tilde{\epsilon}^{\mathrm{HD}}\theta}{\gamma d_0}\ln\tau_c - \frac{\delta\theta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln g_c^* - \frac{\theta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c \\
&\quad + \frac{\theta\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{\theta d_l}{\gamma d_0} \\
\ln N_c^* &= -\frac{\tilde{\epsilon}^{\mathrm{HS}}\left(\epsilon^{\mathrm{ND}}\left[1+\epsilon^{\mathrm{HD}}\right]-\epsilon^{\mathrm{NS}}\left[1+\epsilon^{\mathrm{MD}}\right]\right)}{d_0\left(\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{ND}}\right)}\ln\tau_c - \frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{MD}}+\epsilon^{\mathrm{ND}}\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]\right)}{d_0\left(\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{ND}}\right)}\ln g_c^* \\
&\quad - \frac{\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{MD}}+\epsilon^{\mathrm{ND}}\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]\right)}{d_0\left(\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{ND}}\right)}\ln A_c + \frac{\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{HD}}+\epsilon^{\mathrm{NS}}\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]\right)}{d_0\left(\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{d_N}{d_0} \\
\ln K_c^* &= \frac{\tilde{\epsilon}^{\mathrm{HD}}(1+\theta)}{\gamma d_0}\ln\tau_c - \frac{\delta\epsilon^{\mathrm{A}}(1+\theta)\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln g_c^* - \frac{\epsilon^{\mathrm{A}}(1+\theta)\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c \\
&\quad + \frac{\epsilon^{\mathrm{B}}(1+\theta)\left(1+\epsilon^{\mathrm{NS}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{d_K}{\gamma d_0}
\end{aligned}$$

$$\ln g_c^* = \left(\frac{\tilde{\epsilon}^{\mathrm{HD}} \left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]}{d_0} \ln \tau_c + \ln t_c - \frac{\epsilon^{\mathrm{A}} \left[1+\tilde{\epsilon}^{\mathrm{HS}}\right] \left[1+\epsilon^{\mathrm{ND}}\right]}{d_0 \left[\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right]} \ln A_c + \frac{d_{r^H} \left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]}{d_0} + d_G \right.$$
$$\left. + \frac{\epsilon^{\mathrm{B}} \left[1+\tilde{\epsilon}^{\mathrm{HS}}\right] \left[1+\epsilon^{\mathrm{NS}}\right]}{d_0 \left[\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right]} \ln B_c \right) \Bigg/ \left(\frac{\delta \epsilon^{\mathrm{A}} \left[1+\epsilon^{\mathrm{ND}}\right] \left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]}{d_0 \left[\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right]} + 1 \right)$$

with d_0, d_{r^H}, d_{r^M}, d_l, d_w, d_S, d_H, d_M, d_N, and d_G being constant terms.

Gross Rents. Based on these derivations, we can also solve for the gross rent in city c, which is one of the key parameters in the sufficient statistics approach in Section 2:

$$\ln r_c^{C*} = \ln r_c^* \tau_c = \frac{\tilde{\epsilon}^{\mathrm{HS}}}{d_0} \ln \tau_c - \frac{\delta \epsilon^{\mathrm{A}} \left(1+\epsilon^{\mathrm{ND}}\right)}{d_0 \left(\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right)} \ln g_c^* - \frac{\epsilon^{\mathrm{A}} \left(1+\epsilon^{\mathrm{ND}}\right)}{d_0 \left(\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right)} \ln A_c$$
$$+ \frac{\epsilon^{\mathrm{B}} \left(1+\epsilon^{\mathrm{NS}}\right)}{d_0 \left(\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right)} \ln B_c + \frac{d_{r^H}}{d_0} \tag{A.43}$$

Real Wages. Combining the previous results, we can also derive the real wage in city c, i.e., local wages adjusted for local costs of living—a measure that has been frequently used in the previous literature (see, e.g., Kline and Moretti, 2014). Using the equilibrium wage y_c^{W*} and the equilibrium gross rent for residential housing, r_c^{C*}, we derive the real wage as (again conditional on equilibrium public good levels and assuming $\kappa = \phi = 1$):

$$\ln \frac{y_c^{W*}}{r_c^* \tau_c} = - \frac{\tilde{\epsilon}^{\mathrm{HS}} \left(\epsilon^{\mathrm{HD}} - \epsilon^{\mathrm{MD}} + \epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right)}{d_0 \left(\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right)} \ln \tau_c - \frac{\delta \epsilon^{\mathrm{A}} \left(\tilde{\epsilon}^{\mathrm{HS}} - \epsilon^{\mathrm{MD}} - \epsilon^{\mathrm{ND}} - 1\right)}{d_0 \left(\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right)} \ln g_c^*$$
$$- \frac{\epsilon^{\mathrm{A}} \left(\tilde{\epsilon}^{\mathrm{HS}} - \epsilon^{\mathrm{MD}} - \epsilon^{\mathrm{ND}} - 1\right)}{d_0 \left(\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right)} \ln A_c + \frac{\epsilon^{\mathrm{B}} \left(\tilde{\epsilon}^{\mathrm{HS}} - \epsilon^{\mathrm{HD}} - \epsilon^{\mathrm{NS}} - 1\right)}{d_0 \left(\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right)} \ln B_c$$
$$+ \frac{d_w - d_{r^H}}{d_0}. \tag{A.44}$$

A.3 Welfare Analysis

Following the standard approach in the spatial equilibrium literature, we assume a utilitarian welfare function that aggregates the utility of all agents—workers, firm owners, construction company owners, and landlords—in the economy:

$$W = W^H + W^F + \underbrace{W^C}_{=0} + W^L.$$

We measure worker welfare, W^H, by workers' utility and the welfare of firms owners, W^F, by the firm values defined above. The welfare of construction firm owners, W^C, and landlords' welfare, W^L, are measured by their profits. The construction sector is assumed to operate under perfect competition and makes zero profits, thus, welfare of construction firms is zero. We assume that the economy is large and a change in city c's property tax rate does not affect the utility of workers, firms or landlords in other locations.

Worker Welfare. Following the setup in Kline and Moretti (2014), we define workers' aggregate welfare as the inclusive value of equation (A.6). Welfare is then given by (with the number of workers still being normalized to one):

$$W^H = \sigma^H \ln \left(\sum_{c=1}^{C} \exp \left[\frac{V_c^H}{\sigma^H} \right] \right).$$

We are interested in the change in welfare if city c increases its property tax rate by a small amount:

$$\begin{aligned}
\frac{\mathrm{d}W^H}{\mathrm{d}\ln\tau_c} &= \frac{\sigma^H}{\sum_{k=1}^{C} \exp\left(V_k^H/\sigma^H\right)} \sum_{k=1}^{C} \frac{\mathrm{d}\exp\left(V_k^H/\sigma^H\right)}{\mathrm{d}\ln\tau_c} \\
&= \frac{\sigma^H}{\sum_{k=1}^{C} \exp\left(V_k^H/\sigma^H\right)} \sum_{k=1}^{C} \exp\left(\frac{V_k^H}{\sigma^H}\right) \frac{1}{\sigma^H} \frac{\mathrm{d}V_k^H}{\mathrm{d}\ln\tau_c} \\
&= \sum_{k=1}^{C} \frac{\exp\left(V_k^H/\sigma^H\right)}{\sum_{m=1}^{C} \exp\left(V_m^H/\sigma^H\right)} \frac{\mathrm{d}V_k^H}{\mathrm{d}\ln\tau_c} \\
&= \sum_{k=1}^{C} N_k \frac{\mathrm{d}V_k^H}{\mathrm{d}\ln\tau_c} \\
\frac{\mathrm{d}W^H}{\mathrm{d}\ln\tau_c} &= N_c \frac{\mathrm{d}V_c^H}{\mathrm{d}\ln\tau_c} = -N_c \left([1-\delta] \left[\alpha \frac{\mathrm{d}\ln r_c^{C*}}{\mathrm{d}\ln\tau_c} - \frac{\mathrm{d}\ln y_c^{W*}}{\mathrm{d}\ln\tau_c} \right] - \delta \frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln\tau_c} \right).
\end{aligned}$$

To first order, an increase in city c's property tax affects workers' welfare via the pass-through of property taxes on tax-inclusive gross rents $r_c^{C*} = \tau_c r_c^* = (1+t_c) r_c^*$, its effect on wages y_c^{W*}, and the transmission into local public goods g_c^*. Following the envelope conditions, behavioral responses will have no first-order impact on household utility. The sign and the magnitude of the welfare consequences for residents in city c depend (i) on the extent to which wages and net rents compensate for the utility loss due to higher tax payments, and (ii) on the responsiveness of equilibrium public good spending to changes in the tax rate. The lower the preferences for public goods, δ (relative to the preferences for private goods, $1-\delta$,) the more important the former effect. The higher public good preferences, the more important the latter effect.

Welfare of Firm Owners. We derive firm values accordingly and again use the inclusive value from equation (A.15) to measure the welfare of firm owners (Suárez Serrato and Zidar, 2016):

$$W^F = \sigma^F \ln \left(\sum_{c=1}^{C} \exp \left[\frac{V_c^F}{\sigma^F} \right] \right).$$

Looking at the change in firm owners' welfare in response to marginal increases in city c's tax rate yields the following result:

$$\frac{\mathrm{d}W^F}{\mathrm{d}\ln\tau_c} = F_c \frac{\mathrm{d}V_c^F}{\mathrm{d}\ln\tau_c} = -F_c \left([1-\beta] + [1-\beta] \frac{\mathrm{d}\ln r_c^{M*}}{\mathrm{d}\ln\tau_c} + \beta \frac{\mathrm{d}\ln y_c^{W*}}{\mathrm{d}\ln\tau_c} \right).$$

A change in the property tax rate thus operates via (i) the impact on local wages y_c^{W*}, and (ii) the impact on the gross price of commercial floor space $\kappa(1+t_c)r_c^{M*} = \kappa\tau_c r_c^{M*}$. The change in the welfare of firm owners thus depends on the share of the tax burden that can be passed on to landlords in terms of lower net prices for commercial floor space and the share that can be shifted to workers via lower wages. Both effects are weighted according to their importance in the production function governed by the Cobb-Douglas parameter β.

Welfare of Construction Company Owners. The welfare of firm owners in the construction industry is given by their profits based on equation (A.23):

$$W^C = \sum_{c=1}^{C} \Pi_c^C = \sum_{c=1}^{C} \left(r_c^{M*} S_c^* - sK_c^* - l_c^* L_c^* \right) = 0.$$

Property tax increases yield lower sales in the construction industry because workers and firms demand less floor space S_c^* and every unit is sold at a lower price r_c^{M*}. Construction firms react by decreasing their demand for land, L_c^*, and capital, K_c^*, and thus the price of land, l_c^*, will decrease as well. With some algebra, one can show that W^C evaluates to zero in equilibrium and construction firms still make zero profits irrespective of the tax as long as we assume price-taking behavior and constant returns to scale (see, e.g., Thorsnes, 1997, Epple et al., 2010, Combes et al., 2017).

Welfare of Land Owners. Since construction companies operate in a perfectly competitive market, landlord welfare will be determined by the impact on land owners. We denote land owners' profits by producer surplus as in Kline and Moretti (2014), i.e., the area between land prices and the inverse land supply function defined in equation (A.25). We normalize this number with the size of the nationwide land market denoted by Λ:

$$W^L = \frac{1}{\Lambda} \sum_{c=1}^{C} \int_0^{L_c^*} \left(l_c^* - u^{\frac{1}{\theta}} \right) \mathrm{d}u = \frac{1}{\Lambda} \sum_{c=1}^{C} \left(l_c^* L_c^* - \frac{L_c^{*1+\frac{1}{\theta}}}{1+\frac{1}{\theta}} \right) = \frac{1}{\Lambda} \sum_{c=1}^{C} \left(l_c^* L_c^* - \frac{\theta L_c^* \overbrace{L_c^{*\frac{1}{\theta}}}^{=l_c^*}}{1+\theta} \right)$$

$$W^L = \frac{1}{\Lambda} \sum_{c=1}^{C} \frac{l_c^* L_c^*}{1+\theta}.$$

Tax increases in city c reduce the welfare of land owners according to the following expression:

$$\begin{aligned}
\frac{\mathrm{d}W^L}{\mathrm{d}\ln\tau_c} &= \frac{1}{(1+\theta)\Lambda} \left(l_c^* \frac{\mathrm{d}L_c^*}{\mathrm{d}\ln\tau_c} + L_c^* \frac{\mathrm{d}l_c^*}{\mathrm{d}\ln\tau_c} \right) \\
&= \frac{1}{(1+\theta)\Lambda} \left(l_c^* \frac{\mathrm{d}\exp\left[\ln L_c^*\right]}{\mathrm{d}\ln\tau_c} + L_c^* \frac{\mathrm{d}\exp\left[\ln l_c^*\right]}{\mathrm{d}\ln\tau_c} \right) \\
&= \frac{1}{(1+\theta)\Lambda} \left(l_c^* \frac{\mathrm{d}\exp\left[\ln L_c^*\right]}{\mathrm{d}\ln L_c^*} \frac{\mathrm{d}\ln L_c^*}{\mathrm{d}\ln\tau_c} + L_c^* \frac{\mathrm{d}\exp\left[\ln l_c^*\right]}{\mathrm{d}\ln l_c^*} \frac{\mathrm{d}\ln l_c^*}{\mathrm{d}\ln\tau_c} \right) \\
&= \frac{1}{(1+\theta)\Lambda} \left(l_c^* L_c^* \frac{\mathrm{d}\ln L_c^*}{\mathrm{d}\ln\tau_c} + L_c^* l_c^* \frac{\mathrm{d}\ln l_c^*}{\mathrm{d}\ln\tau_c} \right)
\end{aligned}$$

$$
\begin{aligned}
&= \frac{l_c^* L_c^*}{(1+\theta)\Lambda}\left(\frac{\mathrm{d}\ln L_c^*}{\mathrm{d}\ln \tau_c} + \frac{\mathrm{d}\ln l_c^*}{\mathrm{d}\ln \tau_c}\right) \\
\frac{\mathrm{d}W^L}{\mathrm{d}\ln \tau_c} &= \frac{l_c^* L_c^*}{\gamma\Lambda}\frac{\mathrm{d}\ln r_c}{\mathrm{d}\ln \tau_c} = \frac{l_c^* L_c^*}{\Lambda}\frac{\mathrm{d}\ln l_c^*}{\mathrm{d}\ln \tau_c} = \Lambda_c \frac{\mathrm{d}\ln l_c^*}{\mathrm{d}\ln \tau_c},
\end{aligned}
$$

where Λ_c denotes the share of local land sales $l_c^* L_c^*$ relative to the nationwide land market Λ. The stronger the impact of property taxes on land prices and the more severe the reduction in land demand due to higher taxes, the bigger the welfare loss for land owners. As their welfare is decreasing in the land supply elasticity (see denominator), landlords will only bear part of the tax burden as long as the supply of land ready for construction is not perfectly elastic. Otherwise landlords make zero profits and won't bear any tax burden.

Summary. After deriving the welfare impact of property tax increases for all four groups of agents, we summarize the welfare consequences in the following Proposition A.1:

Proposition A.1 (Welfare Effects in the Structural Model)**.** *Let W^H, W^F, W^C, and W^L denote the welfare of workers, firm owners, constructors, and land owners in the spatial equilibrium, respectively. The welfare changes of a marginal increase in city c's property tax rate t_c are determined by:*

(i) the elasticities of equilibrium rents, land prices, and wages with respect to the property tax rate,

(ii) the responsiveness of the local public good provision in equilibrium with respect to the tax,

(iii) three exogenous model parameters, namely the housing share in consumption, α, the labor share in the tradable good production, β, and the preferences for local public goods, δ.

This result is based on the four welfare predictions (each evaluated for a single household):

$$
\frac{\mathrm{d}W^H}{\mathrm{d}\ln \tau_c} = -\left([1-\delta]\left[\alpha\frac{\mathrm{d}\ln r_c^{C*}}{\mathrm{d}\ln \tau_c} - \frac{\mathrm{d}\ln y_c^{W*}}{\mathrm{d}\ln \tau_c}\right] - \delta\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln \tau_c}\right) \tag{A.45}
$$

$$
\frac{\mathrm{d}W^F}{\mathrm{d}\ln \tau_c} = -\left([1-\beta] + [1-\beta]\frac{\mathrm{d}\ln r_c^{M*}}{\mathrm{d}\ln \tau_c} + \beta\frac{\mathrm{d}\ln y_c^{W*}}{\mathrm{d}\ln \tau_c}\right) \tag{A.46}
$$

$$
\frac{\mathrm{d}W^C}{\mathrm{d}\ln \tau_c} = 0 \tag{A.47}
$$

$$
\frac{\mathrm{d}W^L}{\mathrm{d}\ln \tau_c} = \frac{\mathrm{d}\ln l_c^*}{\mathrm{d}\ln \tau_c}. \tag{A.48}
$$

The analysis shows that workers' marginal welfare loss from tax hikes decreases in the preference for the local public good, δ. Hence, the stronger the preferences for public goods and the stronger the transmission of taxes into public good spending, the smaller the welfare loss as workers are compensated for rising costs of living. Proposition A.1 implies that the rent, land price, wage, and public good elasticities with respect to the property tax are sufficient to infer the welfare effects of the tax in a local labor market model (given the housing share in consumption, the labor share in production, and the preferences for public goods). In the following, we discuss the comparative statics behind these elasticities.

A.4 Comparing Welfare Predictions

In this section we compare the welfare predictions that arise from the sufficient statistics approach in Proposition 1 to those from the structural representation of the spatial equilibrium model derived in Proposition A.1. To illustrate differences and similarities between these results, we elaborate on the welfare effects separately for each group of agents putting the equations from both propositions side-by-side.

Workers. We start the discussion by comparing the impact of small property tax increases on household utility in both approaches. The first of the following two equations illustrates the results for workers' welfare from Proposition A.1, the second equation restates the corresponding result from the sufficient statistics approach:

$$\frac{\mathrm{d}W^H}{\mathrm{d}\ln\tau_c} = -\left([1-\delta]\left[\alpha\frac{\mathrm{d}\ln r_c^{C*}}{\mathrm{d}\ln\tau_c} - \frac{\mathrm{d}\ln y_c^{W*}}{\mathrm{d}\ln\tau_c}\right] - \delta\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln\tau_c}\right) \tag{A.49a}$$

$$\Delta W_i\frac{\partial v_i}{\partial y} = -\left(\frac{\partial v_i}{\partial y}\left[h_i^*\frac{\mathrm{d}r_c^{C*}}{\mathrm{d}t_c} - \underbrace{\frac{\mathrm{d}y_i^*}{\mathrm{d}t_c}}_{=\frac{\mathrm{d}y_i^{W*}}{\mathrm{d}t_c}}\right] - \frac{\partial v_i}{\partial g}\frac{\mathrm{d}g_c^*}{\mathrm{d}t_c}\right), \tag{A.49b}$$

where we multiply the latter equation by the marginal utility from income for better comparability across equations.

Both results lead to the same prediction regarding the impact on household utility, consisting of three components. First, household utility decreases in the pass-through of taxes into tax-inclusive gross rents ($\mathrm{d}\ln r_c^{C*}/\mathrm{d}\ln\tau_c$ in the structural model, $\mathrm{d}r_c^{C*}/\mathrm{d}t_c$ in the sufficient statistics approach). This effect is scaled by the importance of housing expenditures in overall consumption (via the housing expenditure share α in the structural model and the size of the dwelling h_i^* in the sufficient statistics approach) and the preferences for private good consumption (denoted by $1-\delta$ in the structural model and $\partial v_i/\partial y$ in the sufficient statistics approach).

Second, household utility increases in the responsiveness of local wages to property tax increases ($\mathrm{d}\ln y_c^{W*}/\mathrm{d}\ln\tau_c$ in the structural model, $\mathrm{d}y_i^*/\mathrm{d}t_c$ in the sufficient statistics approach), again weighted by households' marginal utility from income. In the structural model, we assumed that renter households only receive income from wage earnings, excluding other income channels by assumption.

Third, household utility increases when additional tax revenues are used for higher public good provision ($\mathrm{d}\ln g_c^*/\mathrm{d}\ln\tau_c$ in the structural model, $\mathrm{d}g_c^*/\mathrm{d}t_c$ in the sufficient statistics approach). In contrast to rents and wages, this effect is weighted by households' preferences for public goods (denoted by δ in the structural model and $\partial v_i/\partial g$ in the sufficient statistics approach).

Firm Owners. When comparing the implications on household utility for firm owners in both approaches, we arrive at the following two results:

$$\frac{\mathrm{d}W^F}{\mathrm{d}\ln\tau_c} = -\left([1-\beta] + [1-\beta]\frac{\mathrm{d}\ln r_c^{M*}}{\mathrm{d}\ln\tau_c} + \beta\frac{\mathrm{d}\ln y_c^{W*}}{\mathrm{d}\ln\tau_c}\right) \tag{A.50a}$$

$$\Delta W_i \frac{\partial v_i}{\partial y} = -\left(\frac{\partial v_i}{\partial y}\left[\underbrace{h_i^*\frac{\mathrm{d}r_c^{C*}}{\mathrm{d}t_c}}_{=0} - \underbrace{\frac{\mathrm{d}y_i^*}{\mathrm{d}t_c}}_{=\frac{\mathrm{d}y_i^{F*}}{\mathrm{d}t_c}}\right] - \underbrace{\frac{\partial v_i}{\partial g}\frac{\mathrm{d}g_c^*}{\mathrm{d}t_c}}_{=0}\right), \tag{A.50b}$$

where we again multiply the result from Proposition 1 with the marginal utility from income for better comparability. Since the structural approach relied on the assumption that firm owners are absent from the city and thus not affected by rent changes or additional public good provision, utility changes in equation (A.50a) are solely determined by the impact on firm profits. Translated to the sufficient statistics prediction, this closes down the first and the third term on the right-hand side of equation (A.50b) by assumption. Only the impact on household income—reflected in the second term on the right-hand side ($\mathrm{d}y_i^*/\mathrm{d}t_c$)—remains in the equation, reflecting the change in business profits just as in the structural model.

Landlords. Finally, we compare the impact of property tax increases on landlords' utility:

$$\frac{\mathrm{d}W^L}{\mathrm{d}\ln\tau_c} = \frac{\mathrm{d}\ln l_c^*}{\mathrm{d}\ln\tau_c} \tag{A.51a}$$

$$\Delta W_i \frac{\partial v_i}{\partial y} = -\left(\frac{\partial v_i}{\partial y}\left[\underbrace{h_i^*\frac{\mathrm{d}r_c^{C*}}{\mathrm{d}t_c}}_{=0} - \underbrace{\frac{\mathrm{d}y_i^*}{\mathrm{d}t_c}}_{=\frac{\mathrm{d}y_i^{L*}}{\mathrm{d}t_c}}\right] - \underbrace{\frac{\partial v_i}{\partial g}\frac{\mathrm{d}g_c^*}{\mathrm{d}t_c}}_{=0}\right). \tag{A.51b}$$

In the structural model, we equalized landlord utility with consumer surplus on the land market, which decreases in proportion to decreases in the land price for small tax changes. As for firm owners, we followed the standard assumption in the spatial equilibrium literature and assumed landlords to live abroad and thus be unaffected by changes other than those reflecting income from the housing market. When applying this assumption to the sufficient statistics approach, equation (A.51b) simplifies to the impact of property taxes on landlord income, $\mathrm{d}y_i^{L*}/\mathrm{d}t_c$.

Summary. The welfare predictions for the three groups of agents yield very similar results regarding the impact of small property tax increases on household utility. This similarity reflects the virtue of sufficient statistics approaches: they allow to abstract from deep structural modeling assumptions while still offering clear-cut results on the welfare effects of policy changes.

A.5 Comparative Statics

Using the equilibrium outcomes derived in Section A.2 we can take a closer look at the comparative statics in the model. In Section A.5.1, we first analyze the effects of tax increases on the key determinants for welfare effects laid out in the previous section. In a second step, we derive comparative statics of other equilibrium prices in Section A.5.2. Finally, in Section A.5.3 we discuss comparative statics for equilibrium quantities.

A.5.1 Key Determinants for Welfare Effects

As stated in Proposition A.1 on the welfare effects in our structural equilibrium model, we are particularly interested in four elasticities: the elasticity of gross rents with respect to property tax changes, the elasticity of local wages with respect to property tax changes, the elasticity of land prices with respect to property tax changes, and the elasticity of local public good provision with respect to property tax changes. In the following, we discuss the comparative statics for each of these four elasticities.

Local Public Goods. We start by studying the impact of property tax increases on local public goods, which is given by the following formula:

$$\frac{\mathrm{d}\ln g_c^*\left(t_c, r_c^*\left[\tau_c, g_c^*\left\{\tau_c\right\}\right]\right)}{\ln\tau_c} = \underbrace{\frac{\partial \ln g_c^*}{\partial \ln t_c}}_{>0}\underbrace{\frac{\partial \ln t_c}{\partial \ln \tau_c}}_{>0} + \underbrace{\frac{\partial \ln g_c^*}{\partial \ln r_c^*}}_{>0}\left(\underbrace{\frac{\partial \ln r_c^*}{\partial \ln \tau_c}}_{<0} + \underbrace{\frac{\partial \ln r_c^*}{\partial \ln g_c^*}}_{<0}\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln \tau_c}\right)$$

$$\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln \tau_c} = \frac{\left(1+t_c\right)/t_c}{\frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}+1} + \frac{\tilde{\epsilon}^{\mathrm{HD}}\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)/\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)}{\frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}+1}. \quad \text{(A.52)}$$

This effect on equilibrium public good provision in city c can thus be decomposed in (i) a positive mechanical effect through higher revenues from taxing the existing housing stock at current prices, and (ii) a countervailing behavioral effect on the tax base reflecting that higher taxes decrease prices and quantities traded on both floor space markets.

Just as in the standard Laffer curve argument, the higher the property tax rate t_c, the more important the second, behavioral channel distorting the tax base relative to the mechanical revenue effect. The total effect of tax increases on public good spending will be positive as long as the tax rate is sufficiently small:

$$\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln \tau_c} > 0 \quad \Leftrightarrow \quad t_c < -\frac{\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}}{\tilde{\epsilon}^{\mathrm{HS}}\left(1+\tilde{\epsilon}^{\mathrm{HD}}\right)}.$$

In the following, we turn to the elasticities of gross rents, wages, and land prices with respect to property tax increases making use of this intermediate result to disentangle the different driving forces underlying the model.

Gross Rents. The effect of property tax increases on equilibrium tax-inclusive gross rents for residential and commercial floor space in city c is given by the following formula:

$$
\begin{aligned}
\frac{\mathrm{d}\ln r_c^{C*}\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln\tau_c} &= \frac{\mathrm{d}\ln\tau_c r_c^*\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln\tau_c} = \frac{\mathrm{d}\ln\tau_c r_c^{M*}\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln\tau_c} \\
&= \frac{\partial\ln r_c^{C*}}{\partial\ln\tau_c} + \frac{\partial\ln r_c^{C*}}{\partial\ln g_c^*}\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln\tau_c} \\
&= \underbrace{\frac{\tilde{\epsilon}^{\mathrm{HS}}}{\tilde{\epsilon}^{\mathrm{HS}} - \tilde{\epsilon}^{\mathrm{HD}}}}_{>0} - \underbrace{\frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{\left(\tilde{\epsilon}^{\mathrm{HS}} - \tilde{\epsilon}^{\mathrm{HD}}\right)\left(\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right)}}_{>0} \underbrace{\frac{\frac{\tilde{\epsilon}^{\mathrm{HD}}\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}} + \frac{1+t_c}{t_c}}{\frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} + 1}}_{\lesseqgtr 0}.
\end{aligned} \tag{A.53}
$$

The impact of tax increases on consumer price rents ($\mathrm{d}\ln r_c^{C*}/\mathrm{d}\ln\tau_c$) can be decomposed into two effects: (i) a direct effect reflecting the pass-through of tax increases in consumer price rents that depends on the relative elasticities of (effective) housing supply and housing demand as in the standard textbook incidence model, and (ii) an indirect effect operating through the transmission of tax revenue into local public goods and the capitalization of public good provision in local prices. Figure A.1 illustrates these two effects. Panel A shows the partial, direct effect reflecting the standard tax incidence mechanism. The more mobile households are and the more elastic housing demand, the lower (higher) will be the direct pass-through of tax increases in consumer (producer) price rents. Panel B depicts the indirect effect and shows how the analysis changes when higher taxes lead to additional local public good provision, which is capitalized in rents and increases local cost-of-living. The indirect effect countervails the decrease in housing demand triggered by the tax increase—thereby raising consumer price rents even further and alleviating the reduction in producer price rents. This latter effect will be positive as long as public good spending increases in the tax rate.

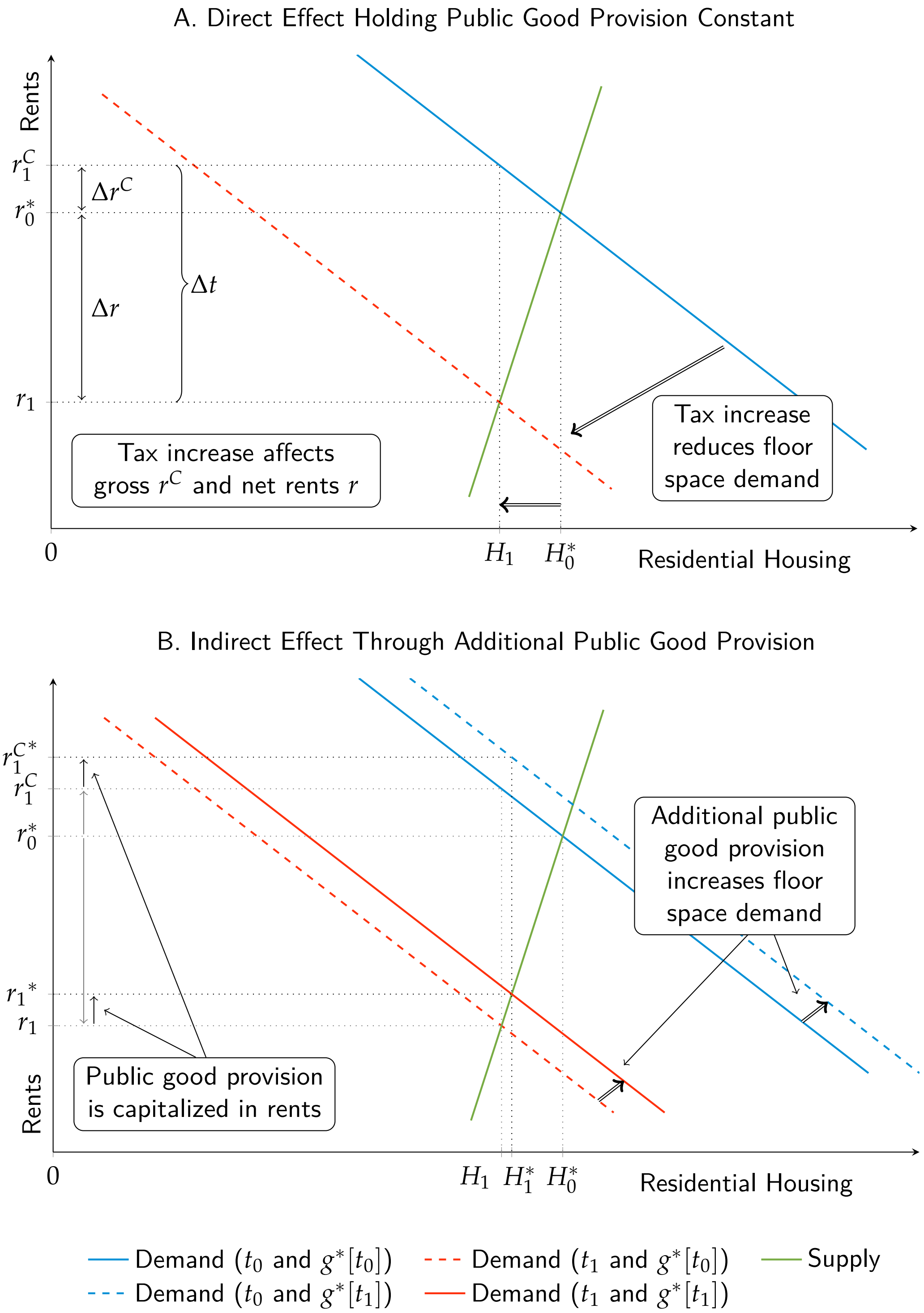
Wages. Third, the effect of property tax increases on equilibrium wages is given by:

$$
\begin{aligned}
\frac{\mathrm{d}\ln y_c^{W*}\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln\tau_c} &= \frac{\partial\ln y_c^{W*}}{\partial\ln\tau_c} + \frac{\partial\ln y_c^{W*}}{\partial\ln g_c^*}\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln\tau_c} \\
&= \underbrace{-\frac{\tilde{\epsilon}^{\mathrm{HS}}\left(\epsilon^{\mathrm{HD}} - \epsilon^{\mathrm{MD}}\right)}{d_0\left(\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right)}}_{\lesseqgtr 0} \underbrace{-\frac{\delta\epsilon^{\mathrm{A}}\left(\tilde{\epsilon}^{\mathrm{HS}} - \epsilon^{\mathrm{MD}}\right)}{d_0\left(\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right)}}_{<0} \underbrace{\frac{\frac{\tilde{\epsilon}^{\mathrm{HD}}\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}} + \frac{1+t_c}{t_c}}{\frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} + 1}}_{\lesseqgtr 0}.
\end{aligned} \tag{A.54}
$$

The total effect of property tax increases on equilibrium wages in city c can be decomposed in (i) a direct effect that is potentially compensating for higher costs of living due to the tax increase, and (ii) an indirect effect operating through higher local public good provision. Both effects may potentially be smaller or larger than zero, the sign being theoretically undetermined in both cases.

Tax increases trigger two opposing effects for profit maximizing firms in the city. On the one hand, higher property tax payments raise the factor price of commercial floor space and

Figure A.1: Comparative Statics of Tax Increases on the Housing Market



Notes: This figure illustrates the comparative statics of property tax increases on equilibrium gross and net rents, r^C and r, respectively. Panel A shows the partial, direct effect conditional on local public good provision g_c. Panel B shows the additional indirect effect coming through changes in public goods. Subscripts 0 and 1 refer to the situation before and after the tax change, respectively.

firms thus try to re-optimize by using less floor space relative to labor. On the other hand, property taxes make it more costly for workers to live in city c and residents demand higher wages to compensate for increased costs of living. Without compensating wage increases, inframarginal workers will move to other places. The sign and the magnitude of the two direct effects of tax increases on wages are determined by the relative strength of the residential and the commercial floor space demand elasticity, ϵ^{HD} and ϵ^{MD}, respectively.

The indirect effect again operates through the capitalization of public goods into wages and depends on the extent to which tax increases yield additional public good spending at the local level. As long as higher taxes raise the level of public good provision, the indirect channel will lead to lower wages, since workers are compensated via additional amenities.

Figure A.2 illustrates both the direct and the indirect effect for the impact of tax increases on wage earnings ($\mathrm{d}\ln y^{W*}/\mathrm{d}\ln\tau_c$). Tax increases lead to rising consumer price rents, which reduces the attractiveness of the city for workers; their labor supply to the city decreases (see Panel A). Taxes also increase the factor price of commercial floor space and reduce firms' floor space demand, which lowers the marginal product of labor and thus decreases labor demand. Panel A illustrates the case where workers are more responsive and wages increase in response to the tax. The indirect effect through additional public good spending operates in the opposite direction and makes the city more attractive for both workers and firms (see Panel B).

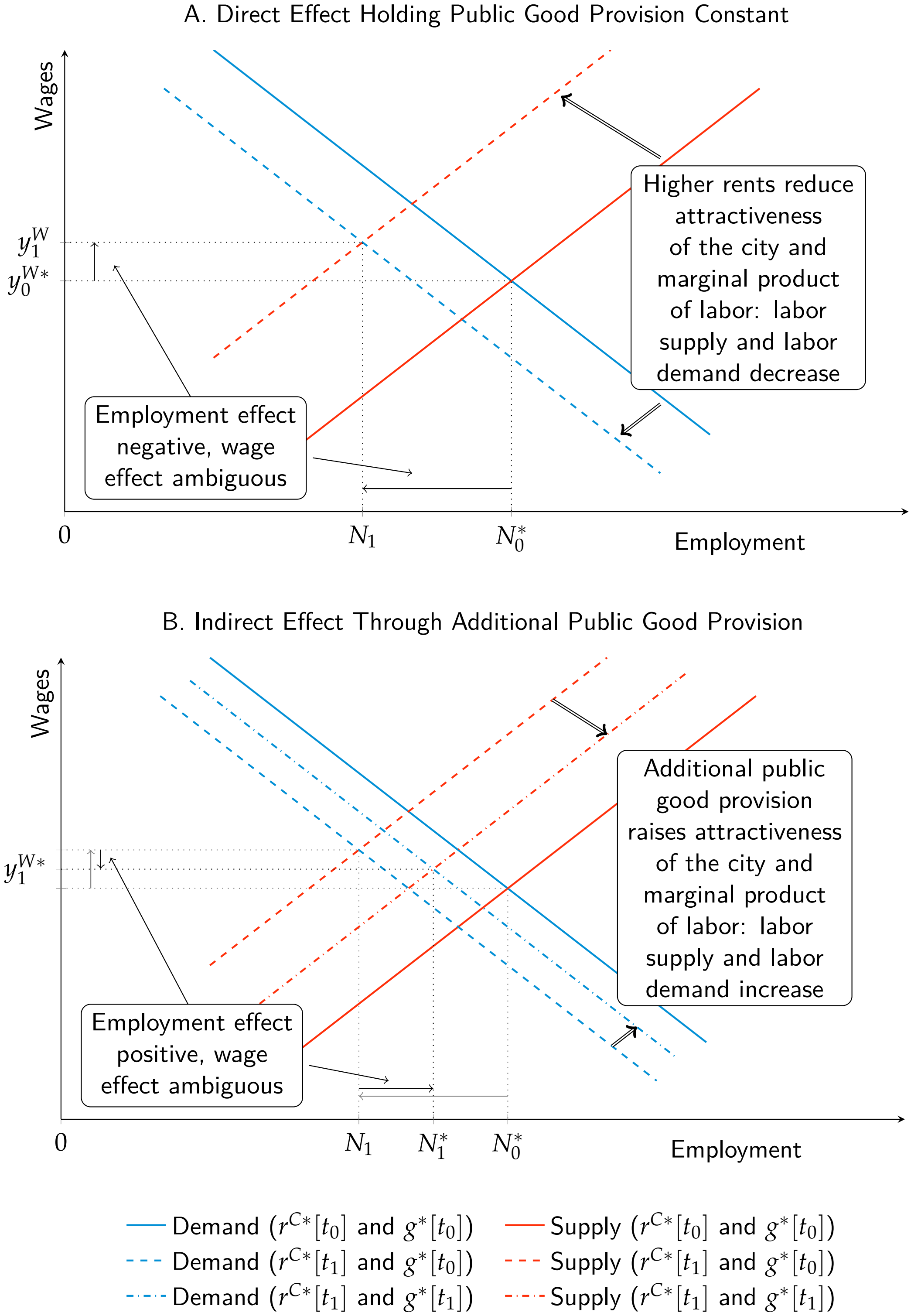
Land Prices. Finally, we derive the effect of property tax increases on equilibrium land prices:

$$\begin{aligned}\frac{\mathrm{d}\ln l_c^*\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln\tau_c} &= \frac{\partial\ln l_c^*}{\partial\ln\tau_c} + \frac{\partial\ln l_c^*}{\partial\ln g_c^*}\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln\tau_c} \\ &= \underbrace{\frac{\tilde{\epsilon}^{\text{HD}}}{\gamma\left(\tilde{\epsilon}^{\text{HS}} - \tilde{\epsilon}^{\text{HD}}\right)}}_{<0} \underbrace{- \frac{\delta\epsilon^{\text{A}}\left(1+\epsilon^{\text{ND}}\right)}{\gamma\left(\tilde{\epsilon}^{\text{HS}} - \tilde{\epsilon}^{\text{HD}}\right)\left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)}}_{>0} \underbrace{\frac{\frac{\tilde{\epsilon}^{\text{HD}}\left(1+\tilde{\epsilon}^{\text{HS}}\right)}{\tilde{\epsilon}^{\text{HS}}-\tilde{\epsilon}^{\text{HD}}} + \frac{1+t_c}{t_c}}{\frac{\delta\epsilon^{\text{A}}\left(1+\epsilon^{\text{ND}}\right)\left(1+\tilde{\epsilon}^{\text{HS}}\right)}{\left(\tilde{\epsilon}^{\text{HS}}-\tilde{\epsilon}^{\text{HD}}\right)\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)} + 1}}_{\lesseqgtr 0}.\end{aligned} \tag{A.55}$$

The total effect of property tax increases on equilibrium land prices in city c ($\mathrm{d}\ln l_c^*/\mathrm{d}\ln\tau_c$) can again be decomposed in (i) a direct, negative effect that reflects lower construction activity and reduced land use in the construction sector due to the tax increase, and (ii) an indirect effect operating through higher local public good provision, where the sign is again theoretically undetermined. This indirect effect depends on the impact of public goods on land prices (second term in the last equation) and the degree to which tax increases raise the public good provision (last term in the equation). This latter effect will be positive as long as public good spending increases in the tax rate.

The reasoning behind the negative direct effect is that less land is needed for construction if population levels, floor space demand, and the housing stock decrease. As a result, land prices decrease as well to balance supply and demand, and to reach a new equilibrium on the market for land ready for development. This direct effect is again potentially diminished by an indirect effect operating through increases in local public goods, which would make city c

Figure A.2: Comparative Statics of Tax Increases on the Labor Market



Notes: This figure illustrates the comparative statics of property tax increases on equilibrium wages y^W. Panel A shows the direct effect conditional on local public good provision g. Panel B shows the additional indirect effect coming through changes in public goods. Subscripts 0 and 1 refer to the situation before and after the tax change, respectively.

more attractive due to increased non-pecuniary amenities in the city.

A.5.2 Additional Results for Equilibrium Prices

In the following, we derive how other equilibrium prices in the structural model respond to changes in property taxes. In particular, we study the impact on net rents and real wages, i.e., wages relative to gross local housing costs, which has been a key parameter in previous studies. We derive the following theoretical predictions:

Net Rents. The total effect of property tax increases on equilibrium net rents for residential and commercial floor space in city c can be decomposed in (i) a direct, negative effect that is compensating for higher costs of living due to the tax increase, and (ii) an indirect effect operating through higher local public good provision with an ambiguous sign:

$$\begin{aligned}\frac{\mathrm{d}\ln r_c^*\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln\tau_c} &= \frac{\mathrm{d}\ln r_c^{M*}\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln\tau_c}\\ &= \frac{\partial\ln r_c^*}{\partial\ln\tau_c} + \frac{\partial\ln r_c^*}{\partial\ln g_c^*}\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln\tau_c}\\ &= \underbrace{\frac{\tilde{\epsilon}^{\mathrm{HD}}}{\tilde{\epsilon}^{\mathrm{HS}} - \tilde{\epsilon}^{\mathrm{HD}}}}_{<0} \underbrace{-\frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{\left(\tilde{\epsilon}^{\mathrm{HS}} - \tilde{\epsilon}^{\mathrm{HD}}\right)\left(\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right)}}_{>0} \underbrace{\frac{\frac{\tilde{\epsilon}^{\mathrm{HD}}\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}} + \frac{1+t_c}{t_c}}{\frac{\delta\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})(1+\tilde{\epsilon}^{\mathrm{HS}})}{(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}})(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}})} + 1}}_{\lesseqgtr 0},\end{aligned} \tag{A.56}$$

where the first fraction reflects the direct, negative effect, the second fraction reflects the capitalization of public goods into rents, and the third fraction denotes the translation of property taxes into public good spending. The indirect effect depends on the capitalization of public goods in rental prices and the degree to which tax increases raise the public good provision. It will be positive as long as public good spending increases in the tax rate.

The statutory incidence of property taxes in our model is on the user of the housing services. Workers and firms thus have to finance the additional burden of higher property taxes. However, we assume that both groups of agents are at least somewhat mobile across jurisdictions and housing demand is thus at least somewhat elastic. As a result, renters are able to shift part of the additional tax burden onto landlords, leading to a decrease in net rents for residential and commercial floor space when holding public good levels constant, i.e., a direct, negative effect. As in the case of the direct effect on gross rents, the first term again resembles very closely the standard textbook result on tax incidence: The direct effect on renters and landlords is solely determined by the supply and demand elasticities on the housing market.

At the same time, tax increases impact the provision of local public goods in equilibrium. Higher property taxes will increase tax revenues holding prices and quantities on the housing market fixed and thus increase the spending on public goods. Capitalization of public goods would thus reduce the downward pressure on net rents. However, there is a countervailing effect of property taxes on housing prices and quantities, which potentially lowers tax revenues and thereby public good spending. As discussed above, the combined effect is theoretically undetermined, as is thus the indirect effect of property taxes on housing costs.

Real Wages. The total effect of property tax increases on equilibrium real wages in city c, i.e., the wage adjusted for local costs of living, can also be decomposed in (i) a direct, negative effect that reflects higher costs of living due to the tax increase even after accounting for potentially compensating rent decreases, and (ii) an indirect effect operating through higher local public good provision:

$$\begin{aligned}\frac{\mathrm{d}\frac{y_c^{W*}}{r_c^*\tau_c}}{\mathrm{d}\ln\tau_c} &= \frac{\partial\ln y_c^{W*}}{\partial\ln\tau_c} + \frac{\partial\ln y_c^{W*}}{\partial\ln g_c^*}\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln\tau_c} \\ &= \underbrace{-\frac{\tilde{\epsilon}^{\mathrm{HS}}\left(\epsilon^{\mathrm{HD}}-\epsilon^{\mathrm{MD}}+\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}}_{<0}\underbrace{-\frac{\delta\epsilon^{\mathrm{A}}\left(\tilde{\epsilon}^{\mathrm{HS}}-\epsilon^{\mathrm{MD}}-\epsilon^{\mathrm{ND}}-1\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}}_{<0}\underbrace{\frac{\frac{\tilde{\epsilon}^{\mathrm{HD}}\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}}+\frac{1+t_c}{t_c}}{\frac{\delta\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})(1+\tilde{\epsilon}^{\mathrm{HS}})}{(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}})(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}})}+1}}_{\lesseqgtr 0},\end{aligned} \tag{A.57}$$

where the first fraction reflects the direct effect, the second fraction reflects the capitalization of public goods into wages and rents, and the third fraction denotes the translation of property taxes into public good spending. The indirect effect depends on the capitalization of public goods in wages and rents, and the degree to which tax increases raise the public good provision.

As seen before, net rents for residential housing may decrease in reaction to higher taxes thereby partly compensating for tax increases. The additional property tax burden would thus be shared between renters and landlords. Similarly, firms may compensate for higher costs of living in the municipality by paying higher wages. However, even taking together lower net rents and potentially higher wages does not fully balance the additional property tax burden. Real incomes in the jurisdiction thus decrease in response to tax increases (direct effect).

For the case of real wages, the indirect effect operating through higher public good provision does not alleviate the direct effect, but yields additional downward pressure on real wages as long as the effect of property taxes on public good spending is positive. This mirrors the fact that workers' compensation for higher costs of living may also come through increases in local public goods instead of higher real wages.

A.5.3 Results for Equilibrium Quantities

In the following, we derive how equilibrium quantities in the structural model respond to changes in property taxes. We derive the following theoretical predictions:

Population. The total effect of property tax increases on equilibrium population levels in city c can be decomposed in (i) a direct, negative effect that is due to lower real wages, and (ii) an indirect effect operating through higher local public good provision:

$$\frac{\mathrm{d}\ln N_c^*\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln\tau_c} = \frac{\partial\ln N_c^*}{\partial\ln\tau_c} + \frac{\partial\ln N_c^*}{\partial\ln g_c^*}\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln\tau_c}$$

$$= \underbrace{-\frac{\tilde{\epsilon}^{\mathrm{HS}}\left(\epsilon^{\mathrm{ND}}\left[1+\epsilon^{\mathrm{HD}}\right]-\epsilon^{\mathrm{NS}}\left[1+\epsilon^{\mathrm{MD}}\right]\right)}{d_0\left(\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{ND}}\right)}}_{<0}$$

$$\underbrace{-\frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{MD}}+\epsilon^{\mathrm{ND}}\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]\right)}{d_0\left(\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{ND}}\right)}}_{>0}\underbrace{\frac{\frac{\tilde{\epsilon}^{\mathrm{HD}}\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}}+\frac{1+t_c}{t_c}}{\frac{\delta\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})(1+\tilde{\epsilon}^{\mathrm{HS}})}{(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}})(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}})}+1}}_{\lesseqqgtr 0}, \tag{A.58}$$

where the first fraction reflects the direct, negative effect, the second fraction reflects workers' valuation of public goods when choosing their location, and the third fraction denotes the translation of property taxes into public good spending. The indirect effect depends on workers' (positive) valuation of public goods when choosing locations and the degree to which tax increases raise the public good provision. This indirect effect will be positive as long as public good spending increases in the tax rate.

When property taxes in city c increase, it becomes more expensive to live there—even after considering compensating effects though lower net rents and potentially higher wages. With constant local public goods and lower real incomes after the tax reform, the city becomes less attractive to live in (direct effect). As we assume that workers are at least somewhat mobile across jurisdictions, inframarginal workers will leave the municipality after the tax increase. The indirect effect through increases in local public goods works in the opposite direction and thus reduces the outflow of workers as long as public good levels increase in the tax rate.

Housing Stock The total effect of property tax increases on the residential, commercial, and total housing stock in equilibrium in city c can be decomposed in (i) a direct, negative effect that reflects lower rents and lower demand due to the tax increase, and (ii) an indirect effect operating through higher local public good provision:

$$\frac{\mathrm{d}\ln H_c^*\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln\tau_c}=\frac{\mathrm{d}\ln M_c^*\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln\tau_c}=\frac{\mathrm{d}\ln S_c^*\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln\tau_c}$$

$$=\frac{\partial\ln H_c^*}{\partial\ln\tau_c}+\frac{\partial\ln H_c^*}{\partial\ln g_c^*}\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln\tau_c}$$

$$=\underbrace{\frac{\tilde{\epsilon}^{\mathrm{HS}}\tilde{\epsilon}^{\mathrm{HD}}}{\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}}}_{<0}\underbrace{-\frac{\tilde{\epsilon}^{\mathrm{HS}}\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}}_{>0}\underbrace{\frac{\frac{\tilde{\epsilon}^{\mathrm{HD}}\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}}+\frac{1+t_c}{t_c}}{\frac{\delta\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})(1+\tilde{\epsilon}^{\mathrm{HS}})}{(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}})(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}})}+1}}_{\lesseqqgtr 0}, \tag{A.59}$$

where the first fraction reflects the direct, negative effect, the second fraction reflects the impact of public goods on the housing stock, and the third fraction denotes the translation of property taxes into public good spending. The indirect effect depends on the impact of public goods on the local housing stock (positive) and the degree to which tax increases raise the public good provision, which can be positive or negative. It will be positive as long as public good spending increases in the tax rate.

With constant public goods and lower real wages, the jurisdiction becomes less attractive to live in. Population levels decline in response to property tax increases. If less people are willing to locate in city c, the demand for residential housing declines. A similar mechanism is at work for firms' location choice and their demand for commercial floor space. Eventually, both the residential housing stock and the amount of commercial floor space will be lower compared to the pre-reform equilibrium. This direct effect is in line with the prediction of the new view on the property tax. When accounting for endogenous local public goods, this prediction becomes less clear-cut due to the indirect effect. As long as public good spending increases in the tax rate, the public good provision alleviates the negative effect on the housing stock as higher public good levels increase the demand for city c despite the loss in real wages.

Land Use. The total effect of property tax increases on the equilibrium quantity of land used for residential or commercial construction activity in city c can also be decomposed in (i) a direct, negative effect that reflects lower activity in the construction sector due to the tax increase, and (ii) an indirect effect operating through higher local public good provision:

$$\begin{aligned}\frac{\mathrm{d}\ln L_c^*\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln \tau_c} &= \frac{\partial \ln L_c^*}{\partial \ln \tau_c} + \frac{\partial \ln L_c^*}{\partial \ln g_c^*}\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln \tau_c} \\ &= \underbrace{\frac{\tilde{\epsilon}^{\mathrm{HD}}\theta}{\gamma\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)}}_{<0} - \underbrace{\frac{\theta\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}}_{>0} \underbrace{\frac{\frac{\tilde{\epsilon}^{\mathrm{HD}}\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}} + \frac{1+t_c}{t_c}}{\frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}+1}}_{\lesseqgtr 0},\end{aligned} \tag{A.60}$$

where the first fraction reflects the direct, negative effect, the second fraction reflects the impact of public goods on land use, and the third fraction denotes the transmission of property taxes into public good spending. The indirect effect depends on the impact of public goods on land use and the degree to which tax increases raise the public good provision. It will be positive as long as public good spending increases in the tax rate.

With decreasing housing demand and lower levels of floor space provision after an increase in the property tax, the demand of the construction sector for land ready for building decreases as well. This mechanism is reflected in the direct effect. As before, the indirect effect works in the opposite direction and mitigates the direct effect as long as public good spending increases in the tax rate.

Capital Stock. Finally, the total effect of property tax increases on the equilibrium capital stock in city c can again be decomposed in (i) a direct, negative effect that reflects lower construction activity due to the tax increase, and (ii) an indirect effect operating through higher local public good provision:

$$\frac{\mathrm{d}\ln K_c^*\left(\tau_c, g_c^*\left[\tau_c\right]\right)}{\mathrm{d}\ln \tau_c} = \frac{\partial \ln K_c^*}{\partial \ln \tau_c} + \frac{\partial \ln K_c^*}{\partial \ln g_c^*}\frac{\mathrm{d}\ln g_c^*}{\mathrm{d}\ln \tau_c}$$

$$= \underbrace{\frac{\tilde{\epsilon}^{\mathrm{HD}}(1+\theta)}{\gamma\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)}}_{<0} - \underbrace{\frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)(1+\theta)}{\gamma\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}}_{>0} \underbrace{\frac{\frac{\tilde{\epsilon}^{\mathrm{HD}}\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}} + \frac{1+t_c}{t_c}}{\frac{\delta\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})(1+\tilde{\epsilon}^{\mathrm{HS}})}{(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}})(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}})} + 1}}_{\lesseqgtr 0}, \tag{A.61}$$

where the first fraction reflects the direct, negative effect, the second fraction reflects the impact of public goods on the equilibrium capital stock, and the third fraction denotes the translation of property taxes into public good spending, where the sign of the latter term is again theoretically undetermined. The indirect effect depends on the impact of public goods on the capital stock and the degree to which tax increases raise the public good provision. It will be positive as long as public good spending increases in the tax rate.

Lower population levels, lower housing demand, and a smaller housing stock reduce the need for additional construction. Analogous to the demand for developed land, the capital demand of the construction sector declines, too. Again, this is in line with the capital tax view and reflects the direct effect holding public good provision constant. The indirect effect operates through the impact of public goods on the capital stock and will alleviate the direct negative effect as long as tax increases yield additional tax revenues that are spent on increases in local public good provision.

B Data Appendix

Table B.1: Definition of Variables and Data Sources

Variable	Years	Source
Business Tax Rates	2001–2018	Annual reports on the business tax scaling factors of German municipalities are published by the Statistical Offices (publication *Hebesätze der Realsteuern*). We calculate the local business tax rate as the product of local business tax scaling factors and a federal tax rate of 5% (before 2008) and 3.5% (since 2008).
Business Profits	2008–2015	Annual statistics on total business profits in a municipality are provided by the Federal Statistical Office and the Statistical Offices of the Länder (publication *Realsteuervergleich*). We calculate business profits as total business tax revenues divided by the local business tax rate.
Housing Prices	2008–2015	We calculate municipality-year averages in per square meter consumer and producer price rents (*Bruttowarmmiete* and *Kaltmiete*, respectively) as well as offered sales prices per square meter (*Kaufpreise*) based on the dataset RWI-GEO-RED v3 provided by the research data center FDZ Ruhr. This dataset includes all real-estate advertisements published on the platform *ImmobilienScout24* (Boelmann and Schaffner, 2019). We combine four scientific use files which are differentiated by ad types: houses offered for rent (DOI: 10.7807/immo:red:hm:suf:v3, apartments offered for rent (DOI: 10.7807/immo:red:wm:suf:v3), houses offered for sale (DOI: 10.7807/immo:red:hk:suf:v3), and apartments offered for sale (DOI: 10.7807/immo:red:wk:suf:v3). We only include apartments with a living space between 40 and 100 square meters and houses with a living space of 100 to 200 square meters (roughly the 10th and 90th percentiles for both dwelling types). We drop properties with unrealistic prices per square meter (net rents below three or above 20 EUR per square meter, sales prices below 200 or above 8,000 EUR per square meter, roughly corresponding to the bottom and top 0.5 percent) and unrealistic reported ancillary cost to net rent ratio (below 4% or above 30% for houses, below 10% or above 40% for apartments). We further exclude rental ads (offered sales) that are posted more than six (twelve) months.
Housing Stock Ownership	2011	Census data on the ownership of the local housing stock is provided by the Federal Statistical Office. We classify municipalities as having either (i) more public landlords or (ii) more private landlords. The first category includes municipalities with a "typical" ownership mix of as well as those municipalities with a rather large public or non-profit housing ownership share of at least 10% (classifications: *Kommune oder kommunales Wohnungsunternehmen*, *Bund oder Land*, or *Organisation ohne Erwerbszweck*). The second category consists of municipalities with a commercial share of at least 10% (classifications: *Privatwirtschaftliches Wohnungsunternehmen* or *Anderes privatwirtschaftliches Unternehmen*) or an extremely large private owner share above 95% (classifications: *Privatperson/-en*, *Gemeinschaft von Wohnungseigentümern/-innen*, or *Wohnungsgenossenschaft*).

continued

Table B.1 continued

Variable	Years	Source
Land Use	2007	Data on land use in German municipalities is provided in the database *Statistik Lokal* by the Federal Statistical Office and the Statistical Offices of the Länder. We construct two measures of housing supply constraints based on this data. First, we classify municipalities according to the share of undevelopable land (wetlands, water bodies, mining areas, and wasteland) over the total surface of the municipality. Second, we calculate the share of already developed land (residential, commercial, industrial land use as well as streets) over the potentially developable area in a municipality.
Local GDP	2008–2015 (counties)	Data on the gross domestic product per capita in German counties is provided by the Working Group Regional Accounts (*Volkswirtschaftliche Gesamtrechnung der Länder, Revision 2014*).
Population	2008–2015	Annual data on municipal population are provided by the Federal Statistical Office and the Statistical Offices of the Länder (*Gemeindeverzeichnis*). We adjust population levels before 2011 using the Census shock to smoothen breaks in municipal time series due to different reporting methods.
Property Tax Rates	2001–2018	Annual reports on the property tax scaling factors of German municipalities are published by the Statistical Offices (publication *Hebesätze der Realsteuern*). We calculate the local property tax rate as the product of local property tax scaling factors and an average federal tax rate of 0.32%.
Revenues	2008–2015	Data on municipal revenues are provided by the Federal Statistical Office and the Statistical Offices of the Länder in the online database *Regionalstatistik*. Property tax revenues come from the publication *Realsteuervergleich*. Revenues are based on quarterly financial statements of German municipalities (*Vierteljährliche Kassenergebnisse*) using accrual accounting (*Doppelte Buchführung, Doppik*).
Spending	2009–2015	Data on municipal expenditures are provided by the Federal Statistical Office and the Statistical Offices of the Länder (*Koordinierung länderübergreifende Datenanfrage*). Expenditures are based on annual financial statements of German municipalities (*Jahresrechnungsstatistik*) using accrual accounting (*Doppelte Buchführung, Doppik*).
Standard Tax Rates	2001–2018 (states)	We collect state-level standard scaling factors (known as *Fiktive Hebesätze*, *Nivellierungshebesätze*, or *Durchschnittshebesätze*) for the local property tax from state laws on fiscal equalization schemes and publications of the Statistical Offices of the Länder. We calculate standard tax rates by multiplying these state-wide scaling factors with the average federal tax rate of 0.32%.
Unemployment	2008–2015	Annual statistics on the number of unemployed individuals in each German municipality are provided in the publication *Arbeitsmarkt in Zahlen – Arbeitsmarktstatistik / Arbeitslose nach Gemeinden* by the Federal Employment Agency (*Bundesagentur für Arbeit*).
Wages	2008–2015	The Institute for Employment Research (IAB) provided us with annual data on municipality-level average daily wages of all employees subject to social security.

Notes: This table summarizes the definition of variables used in our empirical analysis and provides details on the data sources. See Table B.2 for descriptive statistics.

Table B.2: Descriptive Statistics

Variable	Mean	SD	P10	P25	P50	P75	P90
Panel A – Housing Prices							
Average Rent (in €/m²)	9.09	2.06	7.03	7.71	8.57	10.08	11.73
Panel B – Fiscal Variables							
Local Property Tax Rate (in %)	1.30	0.30	0.96	1.09	1.28	1.48	1.71
Standard Tax Rate (in %)	0.97	0.28	0.59	0.70	0.99	1.22	1.32
Local Business Tax Rate (in %)	13.85	1.89	11.55	12.25	13.82	15.40	16.62
Expenditures per Capita (in €)	2,519.20	1,212.27	1,488.05	1,773.01	2,263.85	3,047.11	3,799.63
Revenues per Capita (in €)	2,621.72	1,351.18	1,518.37	1,817.87	2,345.59	3,188.67	3,930.63
Property Taxes per Capita (in €)	155.11	48.96	94.80	119.89	150.23	183.73	221.41
Panel C – Economic Indicators							
Average Daily Wages (in €)	71.67	14.83	53.67	61.94	70.62	80.53	91.35
Business Profits per Capita (in €)	4,215.87	5,390.21	1,362.86	2,118.60	3,256.91	5,072.34	7,454.63
Local Population Levels	153,801	283,491	5,428	11,960	32,030	124,577	548,547
Local GDP per Capita (in €)	37,753	16,385	24,088	27,247	32,599	41,573	59,925
Local Unemployment Rate (in %)	7.03	2.92	3.70	4.74	6.55	8.66	11.25

Notes: This table provides descriptive statistics for the baseline estimation sample. Means are weighted by average population levels over the sample period. See Table B.1 for detailed information on all variables.

C Supplementary Results

C.1 Proof of Proposition 1 (Household Welfare)

Proof. We start the derivation assuming that (i) households maximized utility and (ii) the economy is in equilibrium: $u_i = u_i(h_i^*, x_i^*, g_c^*)$ with prices r_c^{C*}, taxes t_c, and incomes y_i^*. We are interested in the utility consequences of a small increase in the property tax t_c:

$$\frac{\mathrm{d}u_i}{\mathrm{d}t_c} = \frac{\mathrm{d}u_i(h_i^*, x_i^*, g_c^*)}{\mathrm{d}t_c} = \frac{\mathrm{d}v_i(r_c^{C*}, y_i^*, g_c^*)}{\mathrm{d}t_c}. \tag{C.1}$$

For the latter term we make use of the indirect utility function $v_i(\cdot)$, which we assume to be differentiable at equilibrium prices, incomes, and public good provision. We can rewrite this expression in terms of a set of partial derivatives using the chain rule:

$$\frac{\mathrm{d}v_i}{\mathrm{d}t_c} = \frac{\partial v_i}{\partial r}\frac{\mathrm{d}r_c^{C*}}{\mathrm{d}t_c} + \frac{\partial v_i}{\partial y}\frac{\mathrm{d}y_i^*}{\mathrm{d}t_c} + \frac{\partial v_i}{\partial g}\frac{\mathrm{d}g_c^*}{\mathrm{d}t_c} \tag{C.2}$$

Employing the envelope theorem and Roy's identity allows to simplify the first term on the right-hand side measuring the utility consequences of rent increases:

$$\frac{\mathrm{d}v_i}{\mathrm{d}t_c} = \underbrace{-h_i^*\frac{\partial v_i}{\partial y}}_{=\partial v_i/\partial r}\frac{\mathrm{d}r_c^{C*}}{\mathrm{d}t_c} + \frac{\partial v_i}{\partial y}\frac{\mathrm{d}y_i^*}{\mathrm{d}t_c} + \frac{\partial v_i}{\partial g}\frac{\mathrm{d}g_c^*}{\mathrm{d}t_c}. \tag{C.3}$$

The intuition is that the marginal utility loss from rising rents per m^2 increases in proportion to the (i) amount of floor space consumed and (ii) marginal utility from income. It also implies that quantity responses to small tax reforms have no first-order impact on welfare.

In the final step, we divide the resulting expression by the marginal utility from income. We can thus denote the money-metric effect of a small increase in city c's property tax on household i's welfare as:

$$\Delta W_i = \frac{\mathrm{d}v_i/\mathrm{d}t_c}{\mathrm{d}v_i/\mathrm{d}y} = -h_i^*\frac{\mathrm{d}r_c^{C*}}{\mathrm{d}t_c} + \frac{\mathrm{d}y_i^*}{\mathrm{d}t_c} + \delta_i^g\frac{\mathrm{d}g_c^*}{\mathrm{d}t_c} \qquad \text{with } \delta_i^g = \frac{\partial v_i/\partial g}{\partial v_i/\partial y}, \tag{C.4}$$

which is the result presented in Proposition 1. □

C.2 A Model of the German Fiscal Equalization Scheme

In this appendix, we formally model the incentives that arise in the municipal equalization schemes at the state level in Germany once a federal state increases its standard tax rate. The following discussion builds on the model of Egger et al. (2010). Municipalities raise revenues R from property taxes and received transfers T via the state-level equalization scheme. Transfers are determined by the difference between fiscal needs N and fiscal capacity C:

$$T = \alpha(N - C), \tag{C.5}$$

where α is the exogenous share of the net fiscal need—i.e., the difference between fiscal need and fiscal capacity—that is to be covered by equalization transfers. Fiscal needs are a function of population size of the municipality. To illustrate the immediate mechanics behind the equalization scheme, we abstract from population changes and assume that fiscal needs are exogenously given. Fiscal capacity is a function of the municipality's local tax base, denoted by B, and the state-level standard tax rate s. In line with the state laws on fiscal equalization, we model fiscal capacity as $C = sB$. The tax base $B(t)$ itself is a function of the tax rate t and we assume that the tax base is decreasing and concave in the tax rate, i.e., $B'_t < 0, B''_t < 0$.

We assume that the municipality chooses its tax rate in order to maximize revenues from taxes and transfers received via the equalization scheme:

$$\max_t R = \max_t tB(t) + T = \max_t tB + \alpha(N - sB). \tag{C.6}$$

The first-order condition for the revenue-maximizing tax rate is given by:

$$\begin{aligned} \frac{\mathrm{d}R}{\mathrm{d}t} &= B + tB'_t - \alpha s B'_t = 0 \\ B &= -B'_t(t - \alpha s), \end{aligned} \tag{C.7}$$

The municipality faces the typical Laffer curve trade-off when setting the tax rate. While a higher tax rate mechanically leads to more revenues, it also creates distortions thereby diminishing the tax base and thus tax revenues. The latter negative effect on the tax base is mitigated to some extent by equalization transfers, which compensate for a lower tax base independent of the chosen tax rate. The case with $\alpha = 0$ describes a world without equalization schemes. Rewriting the first-order condition, we characterize the optimal tax rate t^* as:

$$t^* = \frac{B}{-B'_t} + \alpha s. \tag{C.8}$$

Based on this setup, we can derive the first of the two theoretical predictions regarding the effect of increases in the state-level standard tax rate on local tax rates.

Proposition C.1 (Effects of Standard Tax Rate Increases I)**.** *If the state government increases the state-level standard tax rate s, this creates an incentive for municipalities to raise their local tax rate t.*

Proof. To derive this prediction, we start out with the characterization from equation (C.8) and take the total derivative with respect to the standard tax rate s:

$$
\begin{aligned}
\frac{\mathrm{d}t}{\mathrm{d}s} &= -\frac{B_t'B_t'\frac{\mathrm{d}t}{\mathrm{d}s} - BB_t''\frac{\mathrm{d}t}{\mathrm{d}s}}{B_t'^2} + \alpha \\
B_t'^2\frac{\mathrm{d}t}{\mathrm{d}s} &= -B_t'B_t'\frac{\mathrm{d}t}{\mathrm{d}s} + BB_t''\frac{\mathrm{d}t}{\mathrm{d}s} + \alpha B_t'^2 \\
2B_t'^2\frac{\mathrm{d}t}{\mathrm{d}s} - BB_t''\frac{\mathrm{d}t}{\mathrm{d}s} &= \alpha B_t'^2 \\
\frac{\mathrm{d}t}{\mathrm{d}s} &= \frac{\alpha B_t'^2}{2B_t'^2 - BB_t''} > 0. \qquad \text{(C.9)}
\end{aligned}
$$

Since the tax base B is a decreasing and concave function in the local tax rate t, the derivate will be positive. □

The previous literature has also confirmed this prediction empirically exploiting quasi-experimental equalization scheme reforms in the states Lower Saxony (Egger et al., 2010) and North Rhine-Westphalia (Baskaran, 2014, Rauch and Hummel, 2016). The prediction in Proposition C.1 could thus be used to construct an instrumental variables strategy exploiting only variation from state-level reforms. However, our identification approach introduced in Section 4 exploits only within-state variation in local tax rates and housing market trends. We account for geographically fine region-by-year fixed effects at the sub-state level throughout our analysis and also show that it is important to take out different trends within federal states (see the discussion in Section 5.2). This makes it impossible to use an instrument that relies only on variation at the level of the federal states.

Nevertheless, we can exploit the institutional setting of fiscal equalization schemes and exploit municipality-level variation in the incentives to adjust property tax rates as a response to state-level standard tax rate changes. This yields our second theoretical prediction on the effects of increases in state-level standard tax rates.

Proposition C.2 (Effects of Standard Tax Rate Increases II)**.** *The incentive to raise the municipal tax rate t following from an increase in the state-level standard tax rate s is larger the lower the local tax rate t compared to the standard tax rate s as long as the tax base $B(t)$ is sufficiently concave in t.*

Proof. To prove this prediction, we start with the result from equation (C.9) and take the total derivative with respect to the local tax rate t:

$$
\begin{aligned}
\frac{\mathrm{d}^2t}{\mathrm{d}s\mathrm{d}t} &= \frac{\left(2B_t'^2 - BB_t''\right)\alpha 2B_t'B_t'' - \alpha B_t'^2\left(4B_t'B_t'' - BB_t''' - B_t'B_t''\right)}{\left(2B_t'^2 - BB_t''\right)^2} \\
&= \alpha\frac{2B_t'B_t''\left(2B_t'^2 - BB_t''\right) - B_t'^2\left(3B_t'B_t'' - BB_t'''\right)}{\left(2B_t'^2 - BB_t''\right)^2}. \qquad \text{(C.10)}
\end{aligned}
$$

Using the first-order condition $B = -B_t'(t - \alpha s)$, we can rewrite this expression as:

$$
\frac{\mathrm{d}^2t}{\mathrm{d}s\mathrm{d}t} = \alpha\frac{2B_t'B_t''\left[2B_t'^2 + B_t'(t-\alpha s)B_t''\right] - B_t'^2\left[3B_t'B_t'' + B_t'(t-\alpha s)B_t'''\right]}{\left(2B_t'^2 - BB_t''\right)^2}
$$

$$
\begin{aligned}
&= \alpha B_t'^2 \frac{2B_t'' \left[2B_t' + (t-\alpha s)B_t''\right] - \left[3B_t'B_t'' + B_t'(t-\alpha s)B_t'''\right]}{\left(2B_t'^2 - BB_t''\right)^2} \\
&= \alpha B_t'^2 \frac{4B_t'B_t'' + 2(t-\alpha s)B_t''^2 - 3B_t'B_t'' - (t-\alpha s)B_t'B_t'''}{\left(2B_t'^2 - BB_t''\right)^2} \\
&= \alpha B_t'^2 \frac{B_t'B_t'' + (t-\alpha s)\left[2B_t''^2 - B_t'B_t'''\right]}{\left(2B_t'^2 - BB_t''\right)^2}
\end{aligned}
$$

$$
\frac{\mathrm{d}^2 t}{\mathrm{d}s\mathrm{d}t} = \underbrace{\alpha B_t'^2}_{>0} \cdot \underbrace{\left[B_t'B_t'' + (t-\alpha s)\left(2B_t''^2 - B_t'B_t'''\right)\right]}_{\lesseqgtr 0} \Big/ \underbrace{\left(2B_t'^2 - BB_t''\right)^2}_{>0}. \tag{C.11}
$$

The second derivative will thus be negative as long as the following condition holds:

$$
\begin{aligned}
B_t'B_t'' + (t-\alpha s)\left(2B_t''^2 - B_t'B_t'''\right) &< 0 \\
B_t'B_t'' &< -(t-\alpha s)\left(2B_t''^2 - B_t'B_t'''\right) \\
\frac{B_t'B_t''}{t-\alpha s} &< B_t'B_t''' - 2B_t''^2 \\
2B_t''^2 - \frac{B_t'^2 B_t''}{B} &< B_t'B_t''' \\
B_t''\left(2B_t'' - \frac{B_t'^2}{B}\right) &< B_t'B_t''' \\
B_t''\left(\frac{2B_t''}{B_t'} - \frac{B_t'}{B}\right) &> B_t''' \\
B_t''\left(\frac{2B_t''}{B_t'} + \frac{1}{t-\alpha s}\right) &> B_t'''.
\end{aligned} \tag{C.12}
$$

The latter inequality holds as long as the tax base $B(t)$ is sufficiently concave in t. It follows that $\mathrm{d}^2 t/\mathrm{d}s\mathrm{d}t < 0$ in this case and the incentive to raise the local tax rate thus increases the smaller the local tax rate t relative to the standard tax rate s. □

Example. In the remainder of this section, we illustrate that the general condition in equation (C.12) is likely to be fulfilled in practice. To this end, let us assume a more specific tax base function $B(t) = \Lambda - \gamma t^k$, where Λ is the total tax base absent any property tax, i.e., for $t = 0$. The tax base is a decreasing and concave function in the tax rate of the order k.

Using this functional form for the tax base, verify that $\mathrm{d}^2 t/\mathrm{d}s\mathrm{d}t < 0$ if $\alpha k/(1+k) > t/s$:

$$
\begin{aligned}
-k(k-1)\gamma t^{k-2}\left(\frac{-2k(k-1)\gamma t^{k-2}}{-k\gamma t^{k-2}} + \frac{1}{t-\alpha s}\right) &> -k(k-1)(k-2)\gamma t^{k-3} \\
-t\left(\frac{2(k-1)}{t} + \frac{1}{t-\alpha s}\right) &> -(k-2) \\
-2(k-1) - \frac{t}{t-\alpha s} &> -k+2 \\
-\frac{t}{t-\alpha s} &> k \\
-t &> kt - k\alpha s
\end{aligned}
$$

$$k\alpha s > (1+k)t$$
$$\frac{\alpha k}{1+k} > \frac{t}{s}. \tag{C.13}$$

Equation C.13 shows a relationship between the degree of concavity (the higher k, the more concave the tax base in t), the relative difference between the municipalities tax rate t and the standard tax rate s, and the share of net fiscal need that is compensated, α. For given tax rates, the inequality will hold for more concave tax base function. For the local property tax, with a quite inelastic tax base, it seems likely that the function is somewhat concave, with k substantially higher than in the linear or the quadratic case.[21] For given concavity, the inequality will hold for lower own tax rates relative to standard tax rates. In other words, municipalities with a relatively lower property tax rate t will have a stronger incentive to increase t after an increase in the standard tax rate s.

We exploit this relationship to build our instrumental variable. Reprinting IV equation (5) from Section 4.2, we interact a dummy variable indicating an increase in state s's standard tax rate in year t ($StandardTaxRateIncrease_{s,t}$) with a measure capturing the relative difference between the new standard tax rate and the old local tax rate in municipality m in year $t-1$:

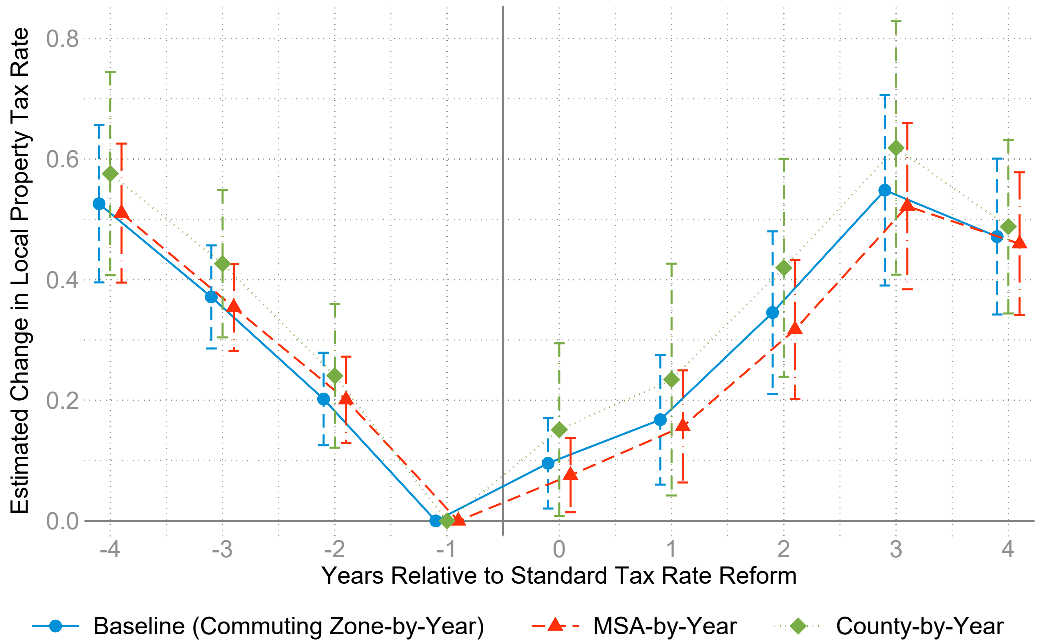
$$IV_{m,t} = StandardTaxRateIncrease_{s,t} \cdot \frac{StandardTaxRate_{s,t} - PropertyTaxRate_{m,t-1}}{PropertyTaxRate_{m,t-1}}$$

As shown in Appendix Figure C.1, we document a very strong first stage relationship.

[21] In the German context, we can fix $\alpha = 0.9$ (Baskaran, 2014). For $k = 4$ ($k = 5$), the inequality becomes $0.72 > t/s$ ($0.75 > t/s$). Hence municipalities whose tax rate t is around 25% below the standard tax rate have a stronger incentive to increase their tax rate the lower t compared to s.

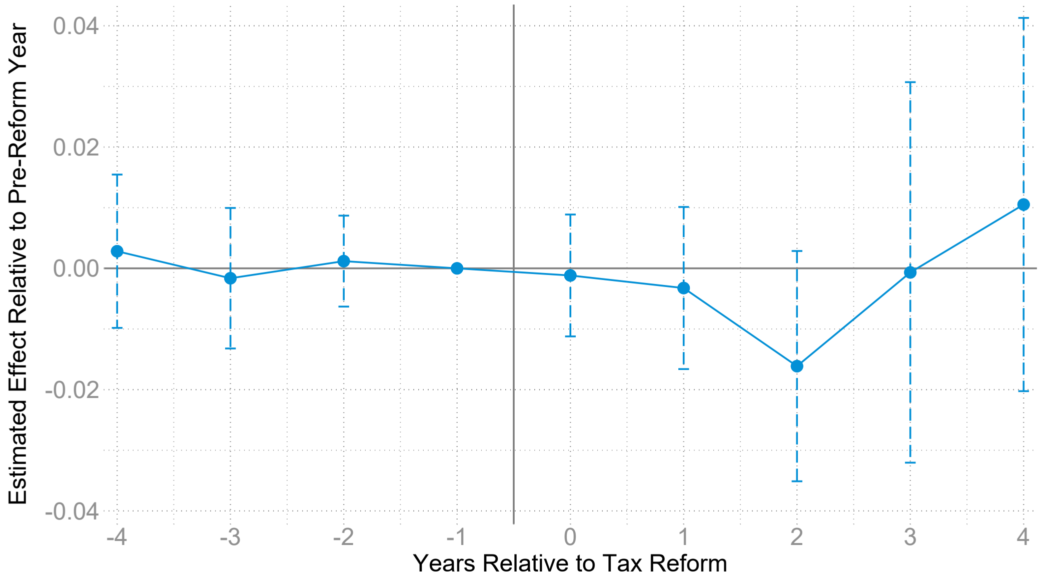
C.3 Additional Figures

Figure C.1: Robustness of First Stage Using Standard Tax Rate Increases



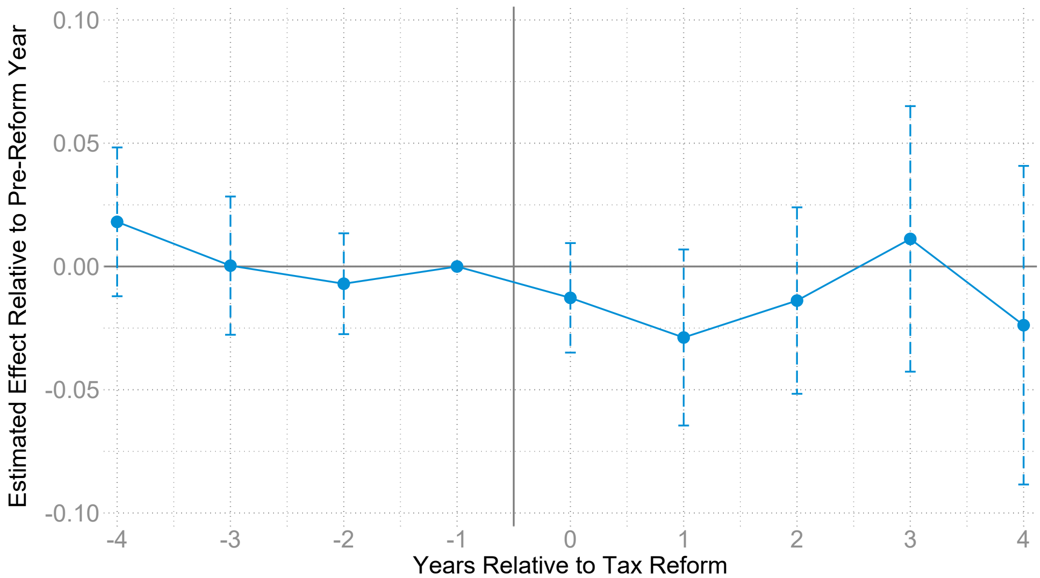
Notes: This figure shows the estimated treatment effects of state-level reforms in the standard tax rate on local property tax rates using alternative specifications to account for regional confounders. Formally, we regress year-to-year changes in municipalities' property tax rates on leads and lags of the instrumental variable from equation (5), absorbing different region-by-year fixed effects (cf. first-stage regression model in equation (6)). Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.2: Effect of Property Taxes on Net Rents



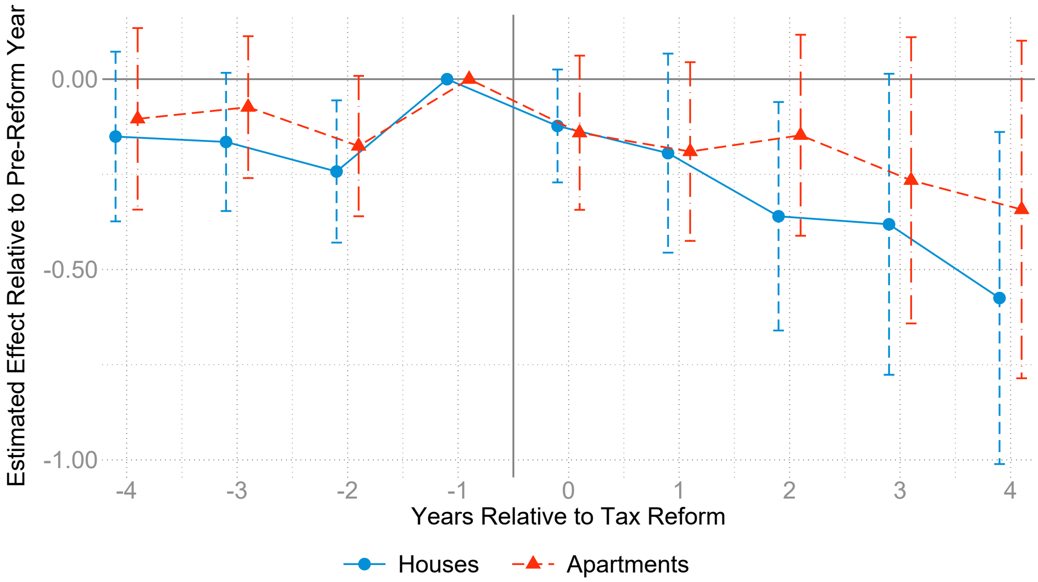
Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on net rents (in logs) relative to the pre-reform year. The underlying econometric model is described in equations (3) and (4). The specification also accounts for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.3: Effect of Property Taxes on Offered Sales Prices



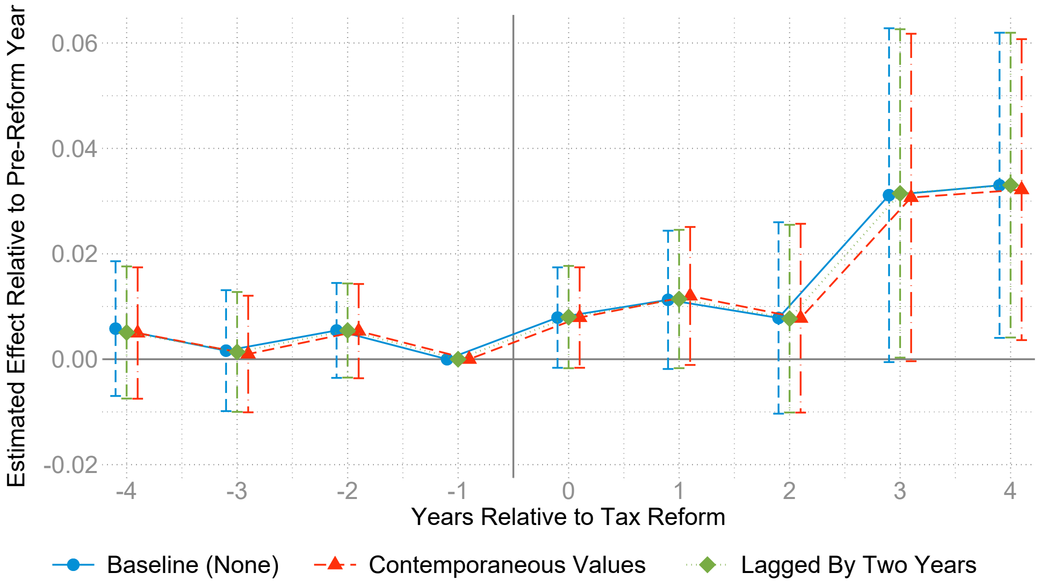
Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on offered sales prices (in logs) relative to the pre-reform year. The underlying econometric model is described in equations (3) and (4). The specification also accounts for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.4: Effect of Property Taxes on Building Permits



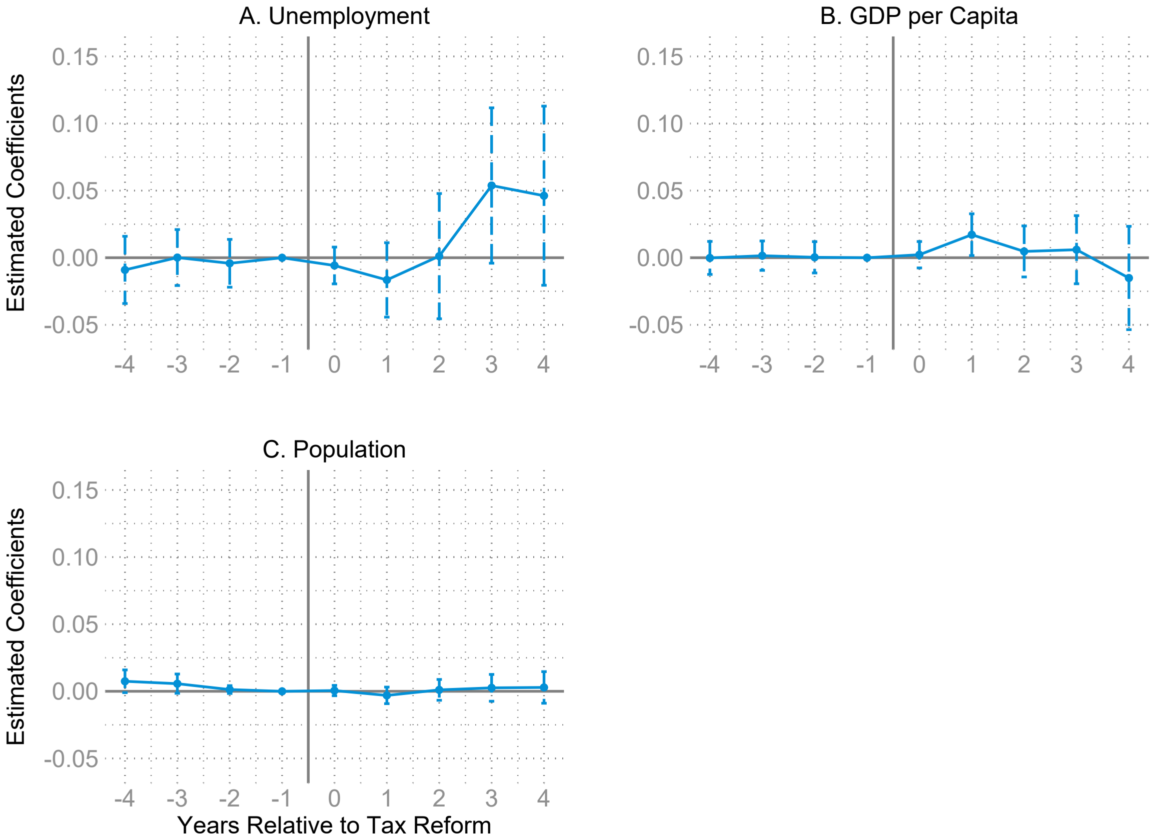
Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on building permits for apartments and houses (in logs) relative to the pre-reform year. The underlying econometric model is described in equations (3) and (4). The specification also accounts for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.5: Accounting for Local Business Cycle Confounders



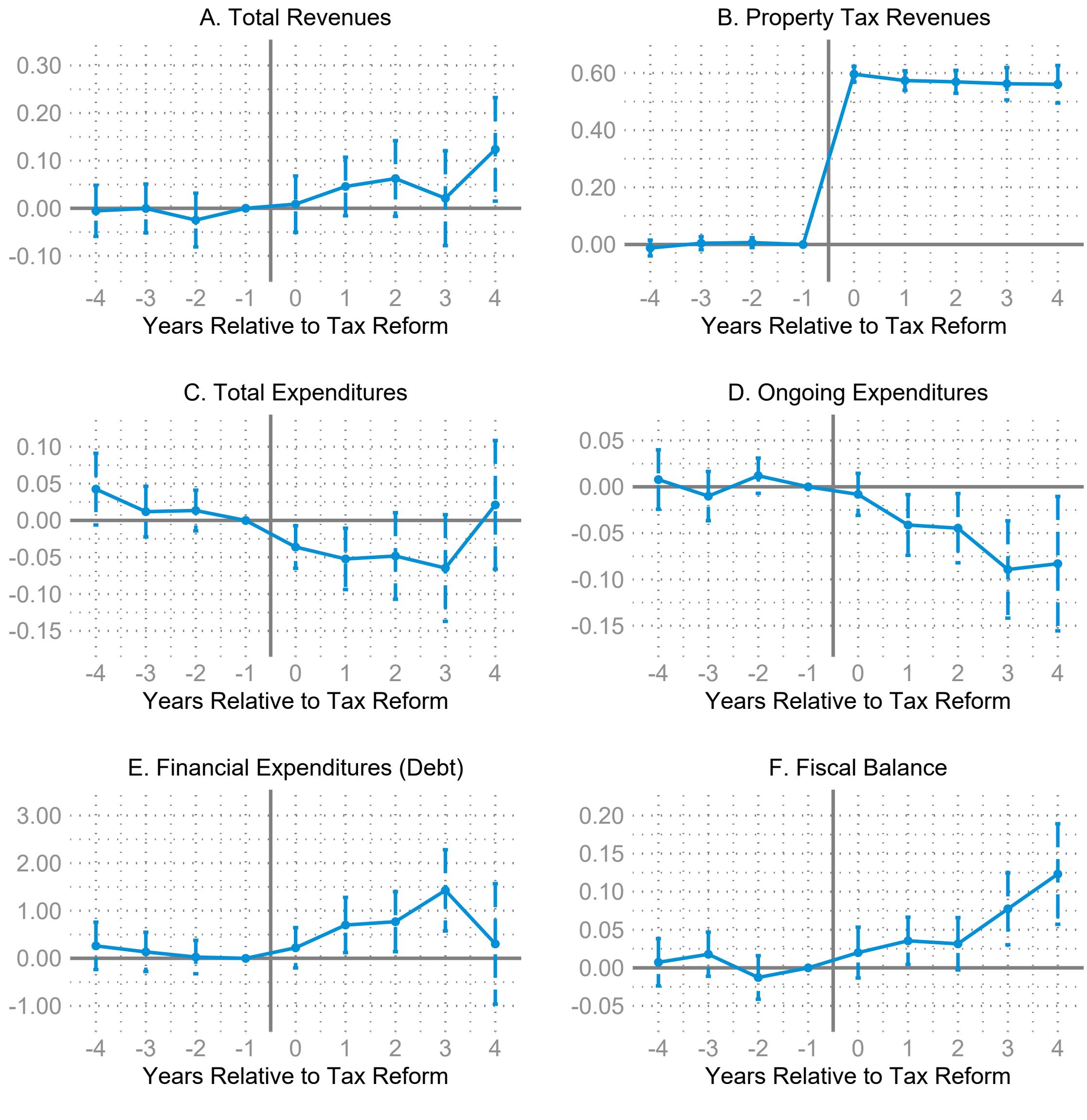
Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year using different sets of control variables for local business cycles. The underlying econometric model is described in equations (3) and (4). All specifications also account for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.6: Effect of Property Taxes on Local Business Cycle Outcomes



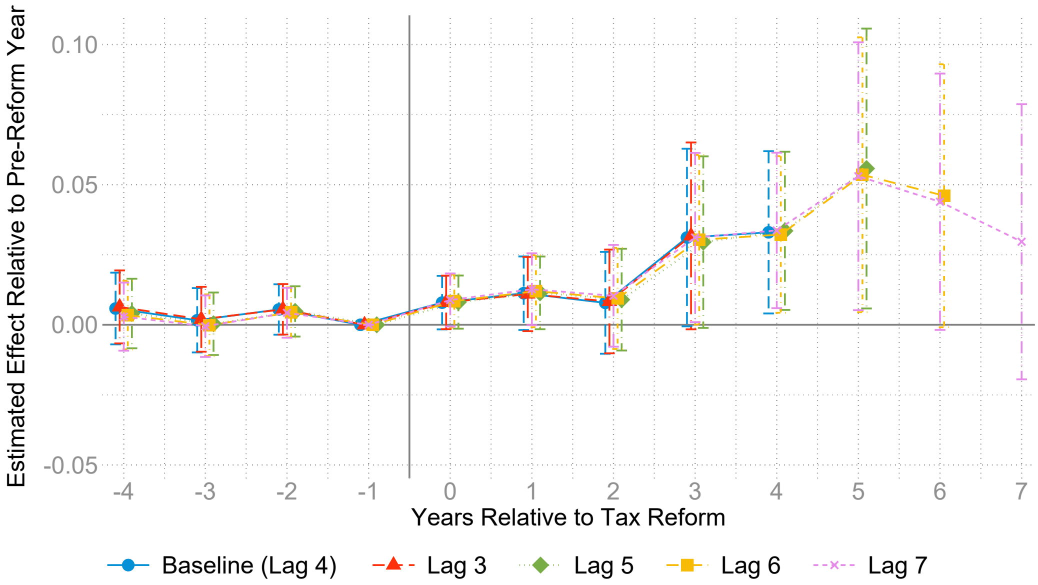
Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on local business cycle measures relative to the pre-reform year. The underlying econometric model is described in equations (3) and (4). All specifications also account for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.7: Effect of Property Taxes on Municipal Finances



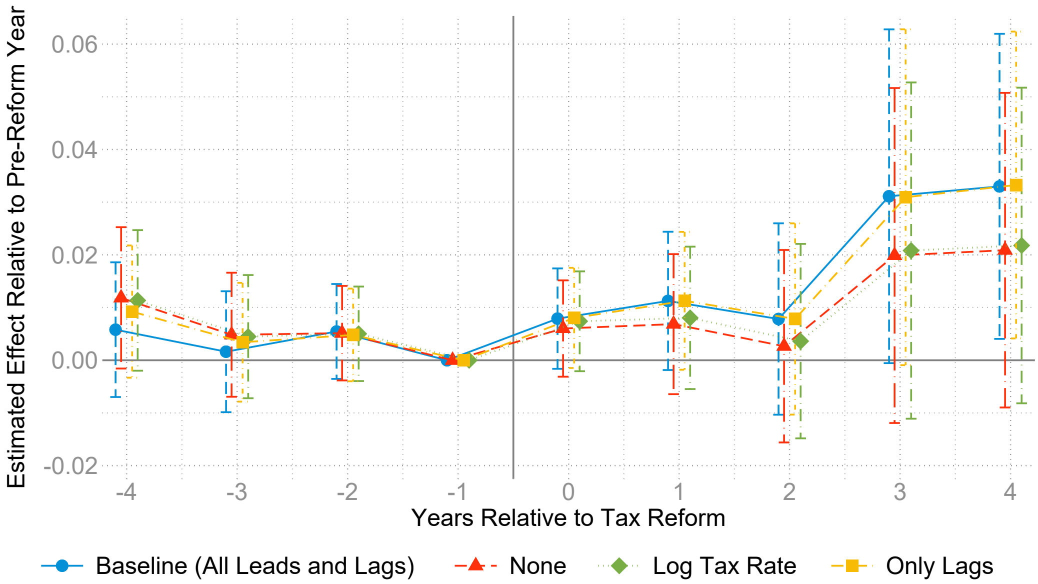
Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on municipal revenues and expenditures relative to the pre-reform year. The underlying econometric model is described in equations (3) and (4). All specifications also account for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.8: Robustness Regarding Lead and Lag Specification



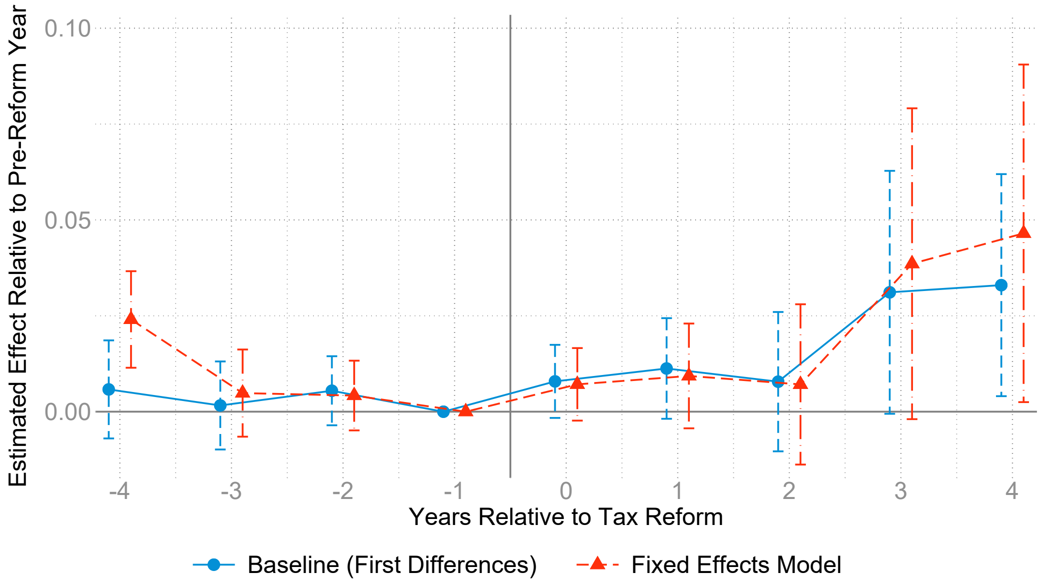
Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year using alternative specifications regarding the lag length. The underlying econometric model is described in equations (3) and (4). All specifications also account for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.9: Robustness Regarding Local Business Tax Specification



Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year using alternative control sets for changes in local business tax rates. The underlying econometric model is described in equations (3) and (4). All specifications also account for CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.10: Robustness Regarding Estimation Model Specification

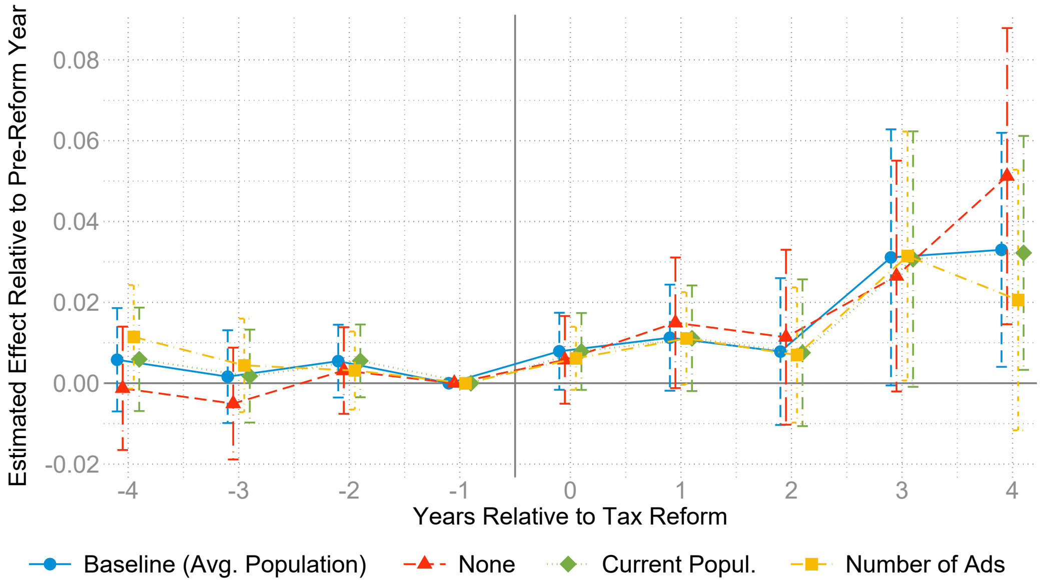


Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year comparing first differences results and estimates from a model with municipality fixed effects. The underlying econometric model is described in equations (3) and (4). All specifications also account for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.11: Robustness Regarding Sample Composition

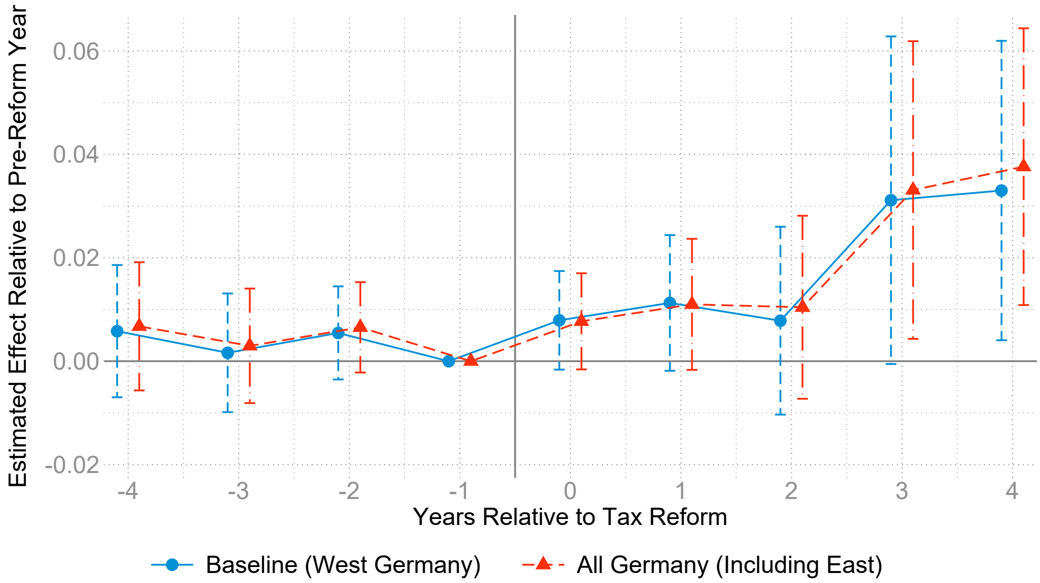
Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year using different requirements regarding the minimum number of ads per municipality-year observation. The underlying econometric model is described in equations (3) and (4). All specifications also account for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.12: Robustness Regarding Weighting Procedure



Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year using different weighting procedures. The underlying econometric model is described in equations (3) and (4). All specifications also account for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.13: Robustness Regarding Geographical Coverage

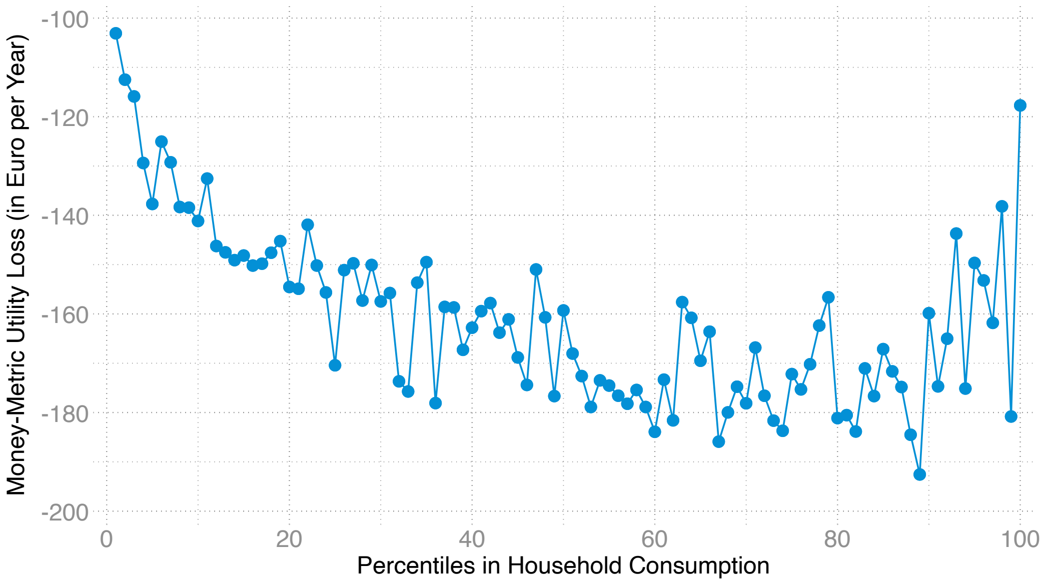


Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year for West Germany only and all Germany including the East. The underlying econometric model is described in equations (3) and (4). All specifications also account for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.14: Reduced-Form Effects on Other Welfare-Relevant Outcomes

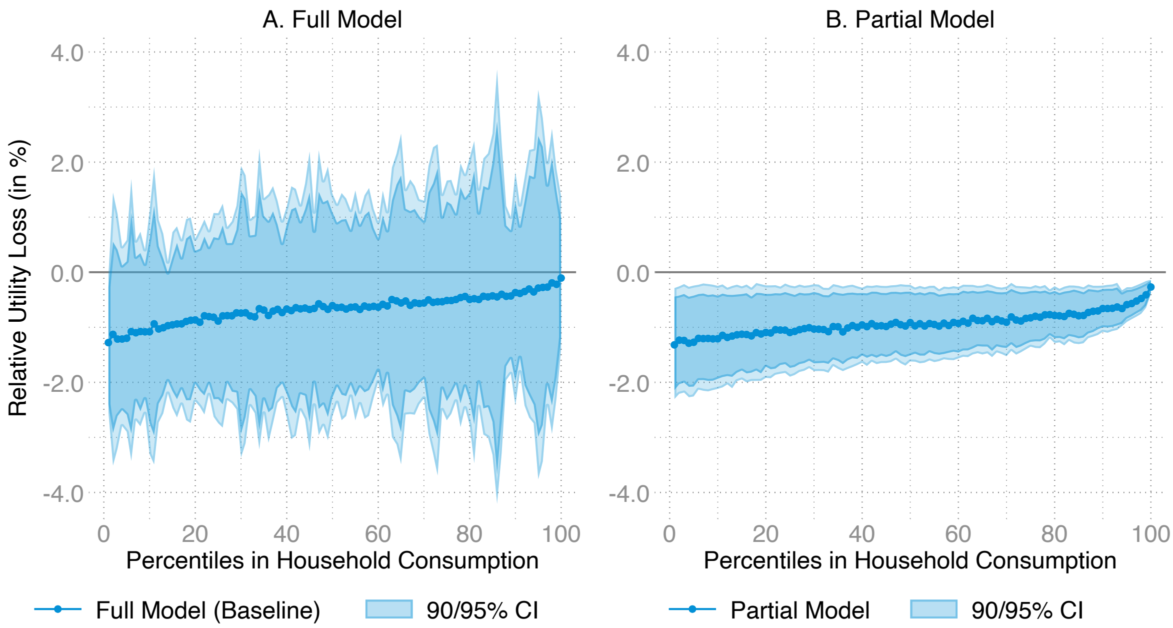
Notes: This figure illustrates the estimated treatment effect of a one percentage point increase in the property tax rate on average municipal wages and business incomes relative to the pre-reform year. The underlying econometric model is described in equations (3) and (4). All specifications also account for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Vertical bars indicate 95% confidence intervals. Standard errors are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

Figure C.15: Property Tax Increases and Absolute Utility Changes



Notes: This figure illustrates the money-metric utility consequences of a one percentage point increase in the local property tax over the distribution of household consumption (in euro per year). We simulate money-metric utility changes as presented in equation (7) and Table 1 for each household in the German Income and Expenditure Survey (EVS, 2013). The depicted curves are based on average changes within percentiles of the consumption distribution across households using sampling weights and the OECD-modified equivalence scale. See Appendix B for detailed information on all variables.

Figure C.16: Property Tax Increases and Household Utility – Inference



Notes: This figure illustrates the relative utility consequences of a one percentage point increase in the local property tax over the household consumption distribution (in percent) showing 90% and 95% confidence intervals. Panel A shows the results for the full model including housing market and general equilibrium responses. Panel B illustrates the welfare effects of housing market responses only. We calculate relative utility losses as money-metric utility changes in euro per year divided by total household consumption. We simulate money-metric utility changes as presented in equation (7) and Table 1 for each household in the German Income and Expenditure Survey (EVS, 2013). The depicted curves are based on average changes within percentiles of the consumption distribution across households using sampling weights and the OECD-modified equivalence scale. Confidence intervals are based on 1,000 bootstrap replications of the respective simulation. In each bootstrap run, we sample independently from the EVS survey and the coefficient distributions of medium-run estimates. See Appendix B for detailed information on all variables.

C.4 Additional Tables

Table C.1: Bounded Estimates Following Oster (2019)

	(1) Uncontrolled Estimate	(2) Controlled Estimate	(3) Bounded Estimate
Panel A – Using Contemporaneous Controls			
Medium-Run Effect	0.032**	0.031**	0.031
	(0.014)	(0.014)	
Number of Observations	10,628	10,628	
Adjusted R-squared	0.004	0.005	
Panel B – Using Lagged Control Variables			
Medium-Run Effect	0.032**	0.032**	0.033
	(0.014)	(0.014)	
Number of Observations	10,628	10,628	
Adjusted R-squared	0.004	0.005	

Notes: This table illustrates the bounded estimates for the treatment effect of a one percentage point increase in the property tax rate on gross rents (in logs) relative to the pre-reform year. Bounds have been obtained using the approximation in Oster (2019) and calibrating $\delta = 1$ and $R^2_{max} = 1.3 \cdot R^2_{controlled}$. Panel A presents bounds using contemporaneous business cycle control variables (population, unemployment, county-level GDP) for the controlled model. Panel B relies on the same control variables lagged by two years. The underlying econometric model is described in equations (3) and (4). The specification also accounts for leads and lags in the local business tax rate and CZ-by-year fixed effects. Observations are weighted by average population levels over the sample period. Standard errors (in parentheses) are robust to clustering at the municipality level. See Appendix B for detailed information on all variables.

C.5 Sensitivity of Simulated Welfare Effects

In this section we test the robustness of our simulation result to various modeling assumptions. Appendix Figure C.17 illustrates the results, always contrasting the baseline model from the main text (in blue) to an alternative simulation (in red).

In Panel A we test whether our method to calculate the additional tax burden for house owners and landlords drives our findings. Our baseline simulation relies on imputed rents (for owner-occupied housing) and the average property tax-to-rent ratio (for landlords) in order to predict additional tax payments, which may potentially underestimate the actual tax bill. We compare this prediction to an alternative simulation where we use the reported property tax base instead to calculate the increase in tax payments resulting from a one percentage point increase in the property tax. Results turn out to be quite similar for both implementations. The latter method yields somewhat lower utility losses for households in the upper half of the distribution and thus if anything a more regressive pattern compared to the baseline.

In Panel B we check whether results are sensitive to the assignment to different percentiles. In the baseline we group households based on private consumption expenditures. An alternative way to calculate population percentiles is to use total household income on the horizontal axis and also scale relative utility losses using income instead of consumption. We find very similar effects of around -1.1 percent relative utility loss at the bottom of the income distribution, but lower relative utility losses for households above the first decile. Overall, grouping and scaling over household income yields a more regressive pattern with approximately zero losses at the top of the distribution. The intuition behind this pattern is that total income is more unequally distributed across households compared to consumption expenditures.

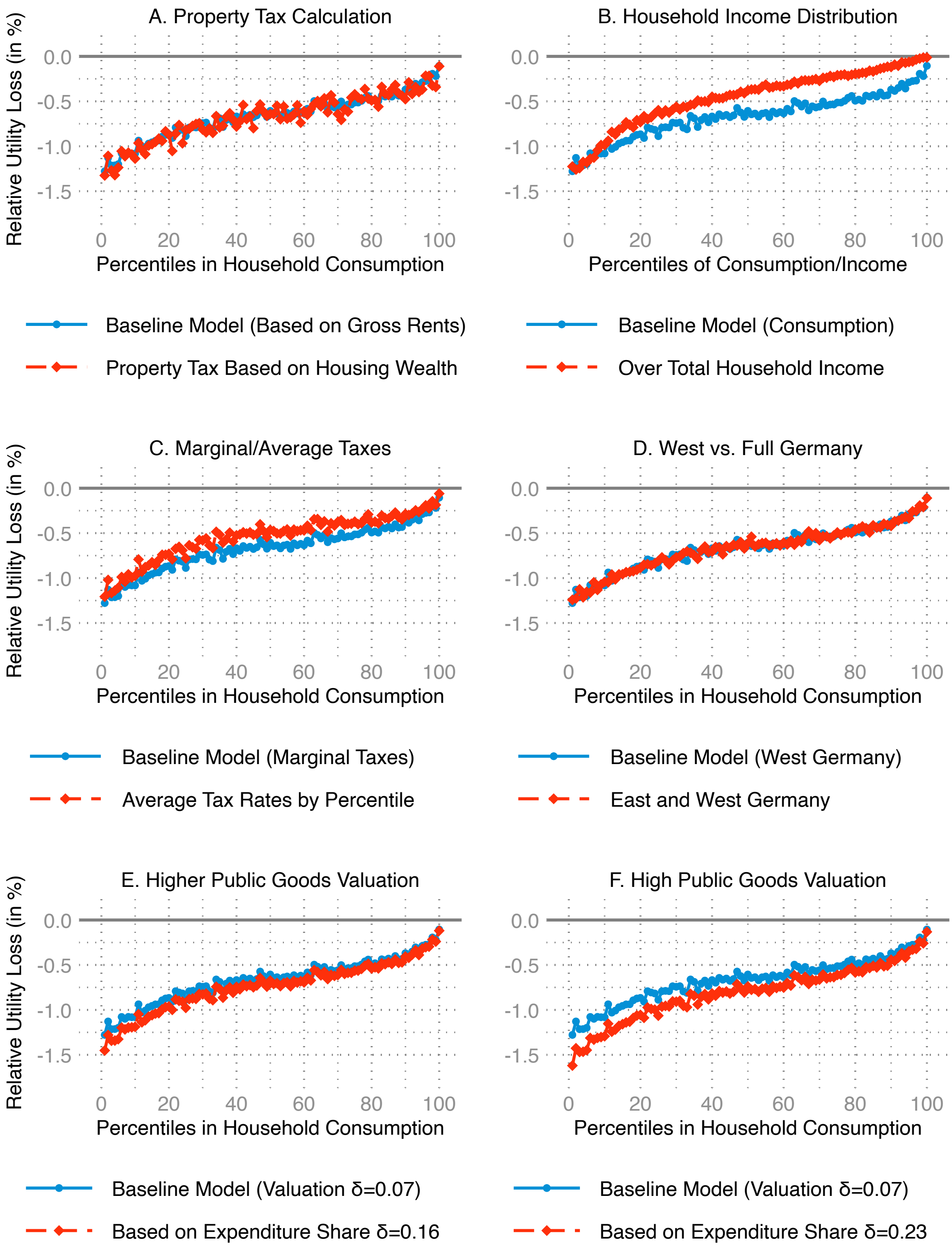
Next we assess the impact of our tax simulation in Panel C. In the baseline simulation, we impute marginal tax rates based on the statutory schedules in the personal income tax system, social security contributions, and transfer withdrawal (assuming a marginal rate of 80%). Since the EVS survey includes little information on the tax unit, these statutory rates may be at odds with the actual rates. Alternatively we calculate average income tax rates and average rates for social security contributions within population percentiles and use these imputed average tax wedges to transform gross income effects into net income changes.[22] Results are rather similar across the distribution with somewhat lower relative utility losses for medium incomes and very similar results at both ends of the consumption distribution.

In Panel D we further assess whether results are different for West Germany compared to all German states. Our baseline estimate on the pass-through of taxes into gross rents and also the baseline simulation are based on West Germany only. In Appendix Figure C.13 we showed that pass-through results are very similar when including East Germany as well. Similarly, we find that simulation results are very stable whether we simulate household utility changes for West Germany only or for East and West Germany combined using all 42,792 households from the EVS survey.

[22] We impute the following sets of tax rates: $\left\{\tau_p^I = \frac{1}{|\mathcal{H}_p|}\sum_{i\in\mathcal{H}_p}\frac{T_i^I}{Y_i}\right\}_{p=1}^{100}$ for the pure income tax wedge (applying to landlord and business incomes), and $\left\{\tau_p^W = \frac{1}{|\mathcal{H}_p|}\sum_{i\in\mathcal{H}_p}\frac{T_i^I}{Y_i}+\frac{T_i^S}{y_i^W}\right\}_{p=1}^{100}$ for the tax wedge on wage earnings.

Finally, we turn to the importance of local public goods (bottom row of Appendix Figure C.17). In the baseline simulation we used a revealed preferences approach to calibrate individuals' preferences for public vs. private goods based on the observed ratio of local government expenditures relative to local GDP, $\delta = 0.073$ (resulting in $\delta_i^g = 0.079$). In Panel E of Appendix Figure C.17, we replicate this simulation while assuming a higher valuation of public goods, namely the baseline estimate $\delta = 0.16$ from Fajgelbaum et al. (2019). In Panel F, we further increase the calibrated valuation for public goods using their upper bound estimate of $\delta = 0.23$ from Fajgelbaum et al. (2019). In line with the negative semi-elasticity of municipal expenditures with respect to the property tax rate shown in Appendix Figure C.7, we find that the utility losses increase the higher the relative valuation for public vs. private goods. This effect is most pronounced for households at the lower end of the distribution and less relevant for high-consumption households, enforcing the regressive nature of the property tax.

Figure C.17: Robustness of Simulation Results



Notes: This figure illustrates the robustness of our simulation results. See Appendix B for detailed information on all variables.

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