Property Taxation, Housing, and Local Labor Markets: Evidence from German Municipalities*

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Abstract. We analyze the incidence and the welfare implications of property taxation. We suggest a novel theoretical perspective by introducing property taxes in a spatial equilibrium model, where workers and firms are mobile but have location-specific preferences, and where tax revenues finance local public goods. The model predicts that the welfare effects of property taxes depend on four reduced-form elasticities. We estimate these elasticities using an event study design and exploiting the institutional setting of municipal property taxation in Germany with more than 31,000 tax reforms in the years between 1992–2017. Our results imply that renters bear one fifth, firm owners bear about one third, and land owners bear more than 40 percent of the welfare loss of property tax increases.

Keywords: property taxation, tax incidence, local labor markets, rental housing

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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). A major reason is that the institutional setting and data availability oftentimes make identification challenging. This is particularly true in the context of the U.S. where long (and wide) panels of local property tax rates are relatively scarce, assessments of property tax values happen frequently and non-randomly and assessment practices differ markedly across jurisdictions.

In this paper, we study the effects property taxes on local land, housing, and labor markets using Germany as a laboratory. German municipalities may autonomously adjust local property tax rates (*Grundsteuer*) via municipality-specific scaling factors to a federal tax rate. Important for identification, this is the only channel through which municipalities can influence the tax burden. All legal rules determining the tax base are set at the federal level, and property values are assessed by the tax offices of the states and remain fixed over time. Each year, more than ten percent of the 8,481 West German municipality change their local property tax rate, resulting in a maximum of 31,862 tax reforms over 26 years that we can exploit for identification.

Our paper consists of two parts. In the first, theoretical part, we analyze the incidence of property taxation through the lens of a spatial equilibrium model with local labor markets (Moretti, 2011). In our model, mobile individuals and mobile firms pay property taxes and respond to local prices and amenities as assumed in Tiebout sorting models. At the same time, workers have location-specific preferences and firms are differently productive across places, limiting their regional mobility. We introduce a construction sector, which produces residential and commercial floor space following Ahlfeldt et al. (2015) and endogenize the supply of developed land. Importantly, we allow local governments to use tax revenues to finance endogenous local public goods. We show that the property tax incidence can be decomposed into a direct effect, conditional on public good provision, and an indirect effect, which describes the capitalization of increases in local amenities due to the tax increase.[1] While the direct effect is negative for housing and land prices, it is ambiguous for wages as property taxes increase the price of floor space decreasing the marginal productivity of labor, but at the same time local wages increase to compensate workers for increased costs of living. If property tax rates are not too high, i.e., if local public goods are not over-provided, the indirect effect alleviates the negative direct effect on net rents as individuals benefit from the increase in public goods. In a last step, we show that the marginal welfare effects of property tax changes are governed by the three price elasticities on the housing, land, and labor market as well as the responsiveness of the local public good provision to changes in the tax rate.

In the second part of the paper, we test the theoretical predictions exploiting the quasi-

[1] We use the term incidence in the strict sense describing the effect of taxes on prices. We use the term pass-through as a synonym. We use our incidence estimates as sufficient statistics to simulate marginal welfare effects of the tax, which measure the share of the welfare loss borne by the respective agents.

experimental setting of property taxation in Germany. We combine administrative data on the universe of municipalities and their local property tax rates from 1992–2017 with various commercial and administrative data sources on housing, land, and labor prices and quantities.[2] 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 land prices, the housing stock, population levels, land use, and wages. Our empirical model enables us to assess the dynamics of the treatment effect in the short and medium run (up to five periods after the tax reform). In addition, we can test the exogeneity of tax reforms by investigating pre-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 by flexibly controlling for shocks at the commuting-zone level and find that estimates are robust.

The empirical results confirm our theoretical priors. We show that real net rents decrease in the short run – implying that part of the tax burden is on the landlord – but start to revert back to the pre-reform level three years after a tax increase. This suggests that both the statutory and the economic incidence of the tax are on the tenant in the long run. As predicted by the model, both municipal population and the housing stock respond negatively to higher local property taxes, reflecting the fact that higher costs of living make a city less attractive. The same pattern holds for land sales and land prices. However, we do not find significant effects on local wages. We also show that house prices, land prices, wages, population levels, the housing stock, and land sales do not change systematically prior to a tax change, which suggests that reverse causality is not an issue.

Linking the empirical results to the theoretical model, we calculate marginal welfare effects of property tax increases borne by tenants, firm owners, and land owners, respectively. Our simulation results show that workers bear one fifth and firm owners bear one third of the welfare loss. The remaining half of the burden is borne by land owners, who thereby face the largest loss in welfare. Importantly, the welfare implications hardly depend on whether or not and to which degree property tax increases are mirrored by rising local public good levels. These results also highlight the importance of going beyond the pure economic tax incidence and studying the welfare implications of property tax increases.

Related Literature. Our paper speaks to three different strands of the literature. Looking through the lens of a local labor market model, we provide a new perspective on the incidence of property taxation. These models, which have become the "workhorse of the urban growth literature" (Glaeser, 2009, p. 25) extend the traditional 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). We further add to the literature by endogenizing the supply of developed land, and incorporating a construction sector as in Ahlfeldt et al. (2015). Moreover, we introduce endogenous amenities by allowing local governments to spend

[2] We only observe house prices for 436 (mostly urban) municipalities, accounting for 40 % of the population.

the property tax revenue on local public goods. In this respect, our paper is related to the work of Diamond (2016), who studied a different, non-fiscal type of endogenous local amenity due to geographic skill sorting.

Our model encompasses elements of both the *capital tax (or new) view* and *benefit view*, which have been the two standard frameworks to analyze the effects of property taxes. On the one hand, the capital tax view adopts a general equilibrium perspective and argues that the national average burden of the property tax is borne by capital owners, i.e., landlords (Mieszkowski, 1972, Mieszkowski and Zodrow, 1989). Only local deviations from the national average are passed on to renters. On the other hand, 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). In the benefit view, the tax is equivalent to a user fee for local public services, whereas the tax is progressive, falling mainly on richer landlords in the capital tax view. Our framework allows for capitalization into local prices while workers' utility might still differ across places in equilibrium, other than in Brueckner (1981). While our model is close to a capital tax world with endogenous amenities, we deviate from the assumption of a fixed capital stock in the economy. In contrast, we assume global capital markets and perfect mobility of capital. As a consequence, higher property taxes reduce the overall capital stock in the society, a channel that has been neglected in the previous literature (Oates and Fischel, 2016). Our models implies a second type of capital, namely floor space, which is consumed by workers and used as input in firms' production. The housing stock is provided by a perfectly competitive construction sector (see Thorsnes, 1997, Epple et al., 2010, Combes et al., 2016). As in classical property tax studies, our model predicts that land owners will bear a substantial share of the tax burden via lower prices and reduced demand for developed land.

Empirically, we provide clean evidence on the effects of the property tax on housing, land, and labor market prices and quantities using administrative data from German municipalities. In particular, we add to the existing empirical literature on the property tax incidence on rents, which has predominantly focused on the US. Using Germany as a case study is particularly interesting in this context, as it has one of the largest private rental markets among Western countries. The previous literature has offered a wide range of estimates of the property tax incidence 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 burden is shifted onto renters. Our results also show the dynamics of the property tax incidence in the short and medium run, an important but often issue (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). Our findings of a negative effect on municipal population levels are in line with evidence provided by Ferreira (2010) and Shan (2010), who show that property taxes affect mobility rates of the elderly. Last, our study offers evidence that property tax increases reduce housing investment, a mechanism that Lyytikäinen (2009) shows for the case of Finnish municipalities. In a similar vein, Lutz (2015) finds that property taxes reduce building permits and capital investment in rural areas;

in contrast, property taxes are capitalized into land prices in urban areas.

Last, we contribute to the empirical literature by studying the value and (optimal) provision of local public goods (Samuelson, 1954). In the United States, the most important local public good financed through property taxes are expenditures on public schools and there is a large literature studying the valuation of local school quality by residents (see, e.g., Bradbury et al., 2001, Bayer et al., 2007, Cellini et al., 2010, Boustan, 2013). A recent paper by Schönholzer and Zhang, 2017 shows that residents also value other types of local amenities, such as expenditures on public security. While both schools and police are predominantly financed at the state level in Germany, German municipalities do spend part of their tax revenues within their local jurisdictions, improving the quality of streets, parks, or cultural amenities such as theaters. What is more, cities finance local transportation agencies or garbage companies, which are usually owned by the municipality. We provide new evidence on how changes in property tax rates affect these kinds of local amenities and also test whether municipalities extract part of the tax revenues as rents (Diamond, 2017). **[TO COME: New data just arrived]**

The remainder of this paper is organized as follows. In Section 2 we set up our theoretical model. Section 3 presents the institutional framework of property taxation in Germany. Section 4 provides information on the used data. We set up our empirical model in Section 5. In Section 6, we present our reduced-form results. Section 7 discusses welfare effects of the tax, Section 8 concludes.

2 Theoretical Model

We introduce local property taxation into a Rosen-Roback type general equilibrium model of local labor markets (Moretti, 2011, Kline and Moretti, 2014, 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 Sections 2.1–2.5. Second, we solve for the spatial equilibrium and 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 2.6). In Section 2.7, we derive the welfare effects of tax changes and show how marginal welfare effects relate to the key elasticities of the model. Appendix B provides a more comprehensive description of the model including all derivations.

2.1 Workers

There is a continuum of $N = 1$ workers indexed by i. Labor is homogeneous and each worker provides inelastically one unit of labor, earns a wage w_c, and pays rent r_c^H for residential floor space. In the theoretical model, we assume that there is only one homogeneous housing good and do not differentiate between owner-occupied and rental housing. In equilibrium, the implicit price of rental and owner occupied housing has to be the same (Poterba, 1984).[3]

[3] Empirically, we will look separately at the effects of rents and house sales price.

Workers maximize utility over floor space consumption h_i, a composite good bundle x_i of non-housing goods, whose aggregate price is normalized to one, and locations c. Workers are mobile across municipalities, but individuals have idiosyncratic location preferences e_{ic}, so that local labor supply is not necessarily infinitely elastic. In addition, there is an exogenous city-specific consumption amenity A_c, related to climate and geography, for instance. Each city c levies a municipal property tax denoted by t_c, with the statutory incidence on the user of the housing service.[4] Local governments spend (part of) the tax revenue on (improvements) of local public goods G_c.

Workers maximize utility $U_{ic} = A_c G_c^{\delta} \left(h_i^{\alpha} x_i^{1-\alpha}\right)^{1-\delta} e_{ic}$, subject to the budget constraint $r_c^H(1+t_c)h_i + px_i = w_c$, which yields indirect utility:

$$V_{ic}^H = a_0 + \underbrace{(1-\delta)\left(\ln w_c - \alpha \ln r_c^H - \alpha \ln[1+t_c]\right) + \delta \ln G_c + \ln A_c}_{=V_c^H} + \ln e_{ic}.$$

where α denotes the housing share in consumption, individuals have preferences $\delta \in (0,1)$ for the public vs. private goods, and a_0 is a constant. Indirect utility can be rewritten as sum of a city-specific part V_c^H and a worker-location-specific component e_{ic}. In line with the literature on local labor markets, we assume that the logarithm of e_{ic} is independent and identically extreme value type I distributed with scale parameter $\sigma^H > 0$. Hence, the greater σ^H, the stronger workers' preference for given locations and the lower their mobility. The distributional assumption regarding e_{ic} gives rise to McFadden's conditional logit model.

Given that the total number of workers is normalized to one and the number of cities C is large, log labor supply in municipality c is given by:

$$\ln N_c^S = \underbrace{\frac{1-\delta}{\sigma^H}}_{=\epsilon^{\text{NS}}} \ln w_c - \underbrace{\frac{\alpha(1-\delta)}{\sigma^H}}_{=1+\epsilon^{\text{HD}}} \ln r_c^H - \underbrace{\frac{\alpha(1-\delta)}{\sigma^H}}_{=1+\epsilon^{\text{HD}}} \ln \tau_c + \underbrace{\frac{\delta}{\sigma^H}}_{=\delta\epsilon^{\text{A}}} \ln G_c + \underbrace{\frac{1}{\sigma^H}}_{=\epsilon^{\text{A}}} \ln A_c + a_1 \tag{1}$$

where a_1 is a constant and we redefine the property tax rate as $\tau_c = 1 + t_c$. Equation (1) also defines various key elasticities of our model, such as the labor supply elasticity $\epsilon^{\text{NS}} = \frac{1-\delta}{\sigma^H}$.

Demand for residential housing in city c is determined by the number of workers in city c and their individual housing demand:

$$\ln H_c = \ln N_c + \ln \alpha + \ln w_c - \ln r_c^H - \ln \tau_c. \tag{2}$$

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:

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

[4] 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 (see Appendix B.9).

2.2 Firms

There are F firms indexed by j that operate under monopolistic competition and produce a tradable output good Y_{jc}, using labor N_{jc} and commercial floor space M_{jc}. Similar to the worker problem there is an exogenous local production amenity B_c and idiosyncratic firm-location-specific productivity shifters ω_{jc}. The price of the output good is denoted by p_{jc}. Following Melitz (2003), we can use total product demand Q to write firms profits as:

$$\Pi_{jc}^F = Q^{1-\rho} \underbrace{\left(B_c \omega_{jc} N_{jc}^{\beta} M_{jc}^{1-\beta}\right)^{\rho}}_{=Y_{jc}} - w_c N_{jc} - r_c^M \tau_c \kappa M_{jc}$$

where β denotes the labor share in production, r_c^M is the factor price of commercial floor space, $\kappa > 0$ is a scale parameter that allows property taxes on commercial rents to differ from residential property taxes, and the constant product demand elasticity is given by $\epsilon^{\text{PD}} = -\frac{1}{1-\rho}$.

Profit maximization yields optimal factor demands, N_{jc}^{D*}, M_{jc}^{D*}, conditional on local productivity and factor prices. Using the profit function from above, the value of firm j in city c in terms of factor costs and local productivity is then given by (Suárez Serrato and Zidar, 2016):

$$V_{jc}^F = \frac{1-\rho}{\rho} \ln \Pi_{jc}^F \left(N_{jc}^{D*}, M_{jc}^{D*}\right) = b_0 + \underbrace{\ln B_c - \beta \ln w_c - (1-\beta) \ln r_c^M - (1-\beta) \ln(\tau_c \kappa)}_{=V_c^F} + \ln \omega_{jc}$$

where b_0 is a constant. Assuming again that idiosyncratic productivity shifters $\ln \omega_{jc}$ are drawn i.i.d. from an extreme value type I distribution with scale parameter σ^F, we can derive the number of firms in city c, normalizing the total number of firms to $F = 1$. Using the number of firms in a given city, which defines the extensive margin of labor demand, and optimal labor demand conditional on location at the intensive margin (N_{jc}^{D*}), aggregate labor demand in city c is given by:

$$\begin{aligned} \ln N_c^D = & \underbrace{\left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right)}_{=\epsilon^{\text{B}}} \ln B_c \underbrace{- \left(1 + \beta \left[\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right]\right)}_{=\epsilon^{\text{ND}}} \ln w_c \underbrace{-(1-\beta) \left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right)}_{=1+\epsilon^{\text{MD}}} \ln r_c^M \\ & \underbrace{-(1-\beta) \left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right)}_{=1+\epsilon^{\text{MD}}} \ln(\tau_c \kappa) + b_1 \end{aligned} \quad (3)$$

where b_1 is a constant. The labor demand elasticity is defined as:

$$\frac{\partial \ln N_c^D}{\partial \ln w_c} = \underbrace{-\frac{\beta}{\sigma^F}}_{\text{Ext. margin}} \underbrace{-1 - \frac{\beta\rho}{1-\rho}}_{\text{Int. margin}} = \epsilon^{\text{ND}} < 0.$$

Analogously, we can derive the demand for commercial floor space using the intensive margin demand, M_{jc}^{D*}, and the location choice of firms:

$$\ln M_c^D = \underbrace{\left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right)}_{=\epsilon^{\mathrm{B}}} \ln B_c \underbrace{-\beta\left(\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right)}_{=1+\epsilon^{\mathrm{ND}}} \ln w_c \underbrace{-\left(1 + [1-\beta]\left[\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right]\right)}_{=\epsilon^{\mathrm{MD}}} \ln r_c^M$$
$$\underbrace{-\left(1 + [1-\beta]\left[\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right]\right)}_{=\epsilon^{\mathrm{MD}}} \ln(\tau_c \kappa) + b_2 \tag{4}$$

with constant b_2. The commercial floor space demand elasticity is defined as:

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

2.3 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 price of residential housing, r_c^H, and commercial floor space, r_c^M:

$$\begin{aligned} &\mu = 1, && \text{for } r_c^M < \phi r_c^H \\ &\mu \in (0,1), && \text{for } r_c^M = \phi r_c^H \\ &\mu = 0, && \text{for } r_c^M > \phi r_c^H \end{aligned} \tag{5}$$

with $\phi \geq 1$ denoting additional regulatory costs of commercial land use compared to residential housing.[5] 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:

$$H_c = \mu S_c \qquad\qquad M_c = (1-\mu)S_c. \tag{6}$$

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., 2016):

$$S_c = H_c + M_c = L_c^\gamma K_c^{1-\gamma} \tag{7}$$

with γ being the output elasticity of land. We assume global capital markets with unlimited supply at an exogenous rate s. Profits in the construction industry are given by $\Pi_c^C =$

[5] 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.

$r_c^M S_c - l_c L_c - sK_c$, where l_c denotes the price of land. Capital demand is then given by:

$$\ln K_c = \frac{1}{\gamma}\ln(1-\gamma) + \frac{1}{\gamma}\ln r_c^M + \ln L_c - \frac{1}{\gamma}\ln s \tag{8}$$

which can be used to solve for the price ratio of land to floor space in city c:

$$\ln l_c = c_0 - \frac{1-\gamma}{\gamma}\ln s + \frac{1}{\gamma}\ln r_c^M \tag{9}$$

with c_0 being a constant. Land prices increase in the commercial floor space rent r_c^M (and equivalently in residential rents r_c^H).

2.4 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 land supply in city c as:

$$\ln L_c = \theta \ln l_c \tag{10}$$

with the supply elasticity of land ready for building defined as $\epsilon^{\text{LS}} = \theta > 0$. We model the land supply elasticity as constant across places for simplicity. In the empirical part of the paper we test for heterogeneous effects by geographical supply determinants. In line with the literature, we assume that landowners are absent (see, e.g., Kline and Moretti, 2014, Ahlfeldt et al., 2015, Diamond, 2016).

2.5 Local Governments

Local governments use share $\psi \in (0,1)$ of the property tax revenue 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:

$$G_c = \psi \underbrace{\left(H_c r_c^H t_c + M_c r_c^M \left[\{1+t_c\}\kappa - 1\right]\right)}_{\text{Total tax revenue}}, \tag{11}$$

where total tax revenue is the sum of residential property taxes, $H_c r_c^H t_c$, 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, leading to a mechanical increase in local spending on the public good.

2.6 Equilibrium and Comparative Statics

The spatial equilibrium is described by equations (1) through (11). It is determined by equalizing supply and demand on the markets for labor, residential housing, commercial floor space, and land in each city, accounting for the government budget constraint. The solution to this system of equations yields equilibrium quantities in terms of population, residential housing, commercial floor space, use of capital, and developed land as well as equilibrium prices for labor, residential housing, commercial floor space, and land, which are derived in Appendix B.6.

In the following, we show how equilibrium outcomes respond to changes in property taxes. The comparative statics of our model yield theoretical predictions on the impact of property taxes on equilibrium quantities and prices that eventually govern the welfare effects (see Section 2.7). We estimate and test quantity and price responses against the theoretical priors using the institutional setting in Germany in Section 6. Proposition 1 summarizes the price effects of property tax increases in our model.

Proposition 1 (Price Effects). *Let r_c^{H*}, r_c^{M*}, l_c^*, and w_c^*, respectively, denote the equilibrium net rent for residential housing, the net rent for commercial floor space, the land price, and the wage level in municipality c, each as a function of the local property tax rate τ_c and equilibrium public good provision $G_c^*(\tau_c)$. An increase in city c's tax rate triggers two effects on equilibrium prices:*

(i) A direct, negative effect on residential and commercial rents as well as the land price, and a direct effect on the local wage level that is theoretically ambiguous and may be positive or negative.

(ii) An indirect effect operating through the capitalization of public goods, which moderates the negative effect on housing and land prices as long as tax increases raise the public good supply.

$$\frac{d\ln r_c^{H*}\left(\tau_c, G_c^*[\tau_c]\right)}{d\ln\tau_c} = \underbrace{\frac{\partial\ln r_c^{H*}}{\partial\ln\tau_c}}_{<0} + \underbrace{\frac{\partial\ln r_c^{H*}}{\partial\ln G_c^*}}_{>0}\frac{\partial\ln G_c^*}{\partial\ln\tau_c} = \frac{d\ln r_c^{M*}\left(\tau_c, G_c^*[\tau_c]\right)}{d\ln\tau_c} \tag{12a}$$

$$\frac{d\ln l_c^*\left(\tau_c, G_c^*[\tau_c]\right)}{d\ln\tau_c} = \underbrace{\frac{\partial\ln l_c^*}{\partial\ln\tau_c}}_{<0} + \underbrace{\frac{\partial\ln l_c^*}{\partial\ln G_c^*}}_{>0}\frac{\partial\ln G_c^*}{\partial\ln\tau_c} \tag{12b}$$

$$\frac{d\ln w_c^*\left(\tau_c, G_c^*[\tau_c]\right)}{d\ln\tau_c} = \underbrace{\frac{\partial\ln w_c^*}{\partial\ln\tau_c}}_{\lesseqgtr 0} + \underbrace{\frac{\partial\ln w_c^*}{\partial\ln G_c^*}}_{<0}\frac{\partial\ln G_c^*}{\partial\ln\tau_c}. \tag{12c}$$

Proof. See Section B.7 in the Appendix. □

The direct effect decreases equilibrium rental prices for residential and commercial floor space and thereby compensates for rising taxes. The equilibrium price of land, being the inelastic input factor in the floor space production, also decreases in response to tax increases while holding public goods constant. As shown in the Appendix, the model intuitively fixes the ratio of these direct marginal effects to be equal to the land share in the floor space production, $\frac{\partial\ln r_c^{H*}}{\partial\ln\tau_c}\Big/\frac{\partial\ln l_c^*}{\partial\ln\tau_c} = \gamma$. The direct effect on rents closely mirrors the tax incidence in a standard partial equilibrium model.

Corollary 1. *The direct rent response to property tax increases in the spatial equilibrium is determined by the effective housing supply and demand elasticities, which account also for equilibrium responses on the land and the labor market as well as the market for commercial floor space:*

$$\frac{\partial\ln r_c^{H*}}{\partial\ln\tau_c} = \frac{\tilde{\epsilon}^{\mathrm{HD}}}{\tilde{\epsilon}^{\mathrm{HS}} - \tilde{\epsilon}^{\mathrm{HD}}} < 0 \tag{13}$$

where $\tilde{\varepsilon}^{\mathrm{HS}}$ *and* $\tilde{\varepsilon}^{\mathrm{HD}}$ *denote the effective housing supply and demand elasticities, respectively.*

Proof. See Lemma B.2 in Appendix B.7. □

The more elastic the effective housing supply, the lower the tax burden for the supply side, i.e., landlords and constructors. The more elastic effective housing demand, the larger the compensating effects on net rents and wages, and the lower the tax burden on renters.

The direct effect on wages is ambiguous. On the one hand, higher property tax payments raise the factor price of commercial floor space and reduce firms' floor space demand, which decreases the marginal product of labor. On the other hand, property taxes increase worker's costs of living, which – given worker mobility – induces a demand for higher wages as a compensating differential. Hence, the sign of the direct wage effect is determined by the relative sizes of the commercial and residential floor space demand. The direct effect of property taxes on the local real wage, defined as the wage over costs of living in city c, is unambiguously negative as shown in Lemma B.4 in the Appendix.

The total effects on equilibrium prices differs from the direct effects because tax increases raise additional revenues that the local government (partly) spends for additional supply of local public goods. Public goods are one of the determinants of workers' location choice and thus labor supply and residential housing demand. If higher taxes increase the local level of public goods, which is the case if initial tax rates are not too high, there is an indirect effect that alleviates the direct, compensating effect on rents, land price, and wages if the direct wage effect is positive. The magnitudes and the signs of the total effects depend on the relative importance of direct and indirect effects.

Quantity effects of property tax increases follow immediately from the model outline above.

Lemma 1 (Quantity Effects)**.** *Let* H_c^* *and* M_c^* *denote the residential housing stock and the commercial floor space in equilibrium, respectively, let* L_c^* *be the equilibrium land area used for development and let* N_c^* *be the equilibrium population level in municipality c, each as a function of the property tax rate* τ_c *and equilibrium public good provision* $G_c^*(\tau_c)$*. An increase in city c's property tax rate* t_c *triggers (i) a direct, negative, and (ii) an indirect, potentially moderating effect on equilibrium quantities:*

$$\frac{d\ln H_c^*\left(\tau_c, G_c^*[\tau_c]\right)}{d\ln\tau_c} = \underbrace{\frac{\partial\ln H_c^*}{\partial\ln\tau_c}}_{<0} + \underbrace{\frac{\partial\ln H_c^*}{\partial\ln G_c^*}}_{>0}\frac{\partial\ln G_c^*}{\partial\ln\tau_c} = \frac{d\ln M_c^*\left(\tau_c, G_c^*[\tau_c]\right)}{d\ln\tau_c} \tag{14a}$$

$$\frac{d\ln L_c^*\left(\tau_c, G_c^*[\tau_c]\right)}{d\ln\tau_c} = \underbrace{\frac{\partial\ln L_c^*}{\partial\ln\tau_c}}_{<0} + \underbrace{\frac{\partial\ln L_c^*}{\partial\ln G_c^*}}_{>0}\frac{\partial\ln G_c^*}{\partial\ln\tau_c} \tag{14b}$$

$$\frac{d\ln N_c^*\left(\tau_c, G_c^*[\tau_c]\right)}{d\ln\tau_c} = \underbrace{\frac{\partial\ln N_c^*}{\partial\ln\tau_c}}_{<0} + \underbrace{\frac{\partial\ln N_c^*}{\partial\ln G_c^*}}_{>0}\frac{\partial\ln G_c^*}{\partial\ln\tau_c}. \tag{14c}$$

Proof. See Section B.7 in the Appendix. □

Again, looking first at the direct effects, the model predicts the quantities on the floor space, land, and labor market to decrease in response to an increase in the property tax given the real-wage loss in city c. Workers will thus leave the city, employment levels are lower, construction and land use decrease.

The magnitude and the sign of the total effects of tax increases on equilibrium quantities again depend on the relative importance of the direct vs. the indirect effect, that operates through increases in local public good supply and moderates the direct effects as long as property tax increases lead to higher spending on local public goods.

2.7 Welfare Effects

In this section, we derive the marginal welfare effects of property tax changes for the different agents in the model. We present the results for representative agents in city c, implicitly assuming that the distribution of agents across municipalities is homogeneous (Suárez Serrato and Zidar, 2016). Proposition 2 summarizes the welfare effects based on price responses.

Proposition 2 (Welfare Effects)**.** *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. A marginal increase in city c's property tax rate t_c leads to welfare changes that 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

$$\frac{dW^H}{d\ln\tau_c} = -\left([1-\delta]\left[\alpha + \alpha\frac{d\ln r_c^{H*}}{d\ln\tau_c} - \frac{d\ln w_c^*}{d\ln\tau_c}\right] - \delta\frac{d\ln G_c^*}{d\ln\tau_c}\right) \tag{15a}$$

$$\frac{dW^F}{d\ln\tau_c} = -\left([1-\beta] + [1-\beta]\frac{d\ln r_c^{M*}}{d\ln\tau_c} + \beta\frac{d\ln w_c^*}{d\ln\tau_c}\right) \tag{15b}$$

$$\frac{dW^C}{d\ln\tau_c} = 0 \tag{15c}$$

$$\frac{dW^L}{d\ln\tau_c} = \frac{d\ln l_c^*}{d\ln\tau_c}. \tag{15d}$$

Proof. See Section B.8 in the Appendix. □

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 2 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, which can be calibrated according to official statistics. In the following sections, we estimate the behavioral responses to changes in property taxes using the German institutional framework. In Section 7, we use the behavioral elasticities and the respective welfare formulas to assess the marginal welfare effects of the property tax.

3 Institutional Background

We test the theoretical predictions of our model using administrative data from German municipalities. In this section, we provide a short overview on the institutional setting of property taxation in Germany (see Spahn, 2004, for more details).

Property taxes are one of the oldest forms of taxation that is still used today. The current German property tax regulations are based on a law from 1936.[6] Besides local business taxes and municipal shares on federal income and sales taxes, the property tax is one of the three most important income sources for the German municipalities. Property taxes account for around 15 percent of municipal revenues, amounting to a total of 12 billion EUR for all municipalities in 2013. All legal regulations of the German 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 rarely been changed over the past decades.

The property tax liability is calculated according to the following formula, that we discuss in more detail below:

$$\textit{Tax Liability} = \textit{Assessed Value} \times \underbrace{\textit{Federal Tax Rate} \times \textit{Municipal Scaling Factors}}_{\text{Local Property Tax Rate}}. \qquad (16)$$

Assessed Values. The house value (*Einheitswert*) is assessed by the tax offices of the federal state (not by the municipality) when the property is built and, importantly, remains fixed over time. There is no regular reassessment of properties to adjust the assessed value to the market value of the property or to inflation rates. Even when being sold, the assessed value does not change. Reassessments only occur if the owner creates a new building or substantially improves an existing structure on her land.[7] The last general assessment of property values in West Germany took place in 1964. In order to make the assessment comparable for buildings that have been constructed after that date, property values of new structures are evaluated based on market rents as of 1964 using historical rent indices. So even new buildings are assessed as if they had been built several decades ago. As a consequence, assessed values differ substantially from current market values. Assessment notices do not provide any details 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. The average assessed value for West German homes was 48,900 EUR in 2013, roughly a fifth of the reported current market value (according to the German Income and Expenditure Survey, EVS).

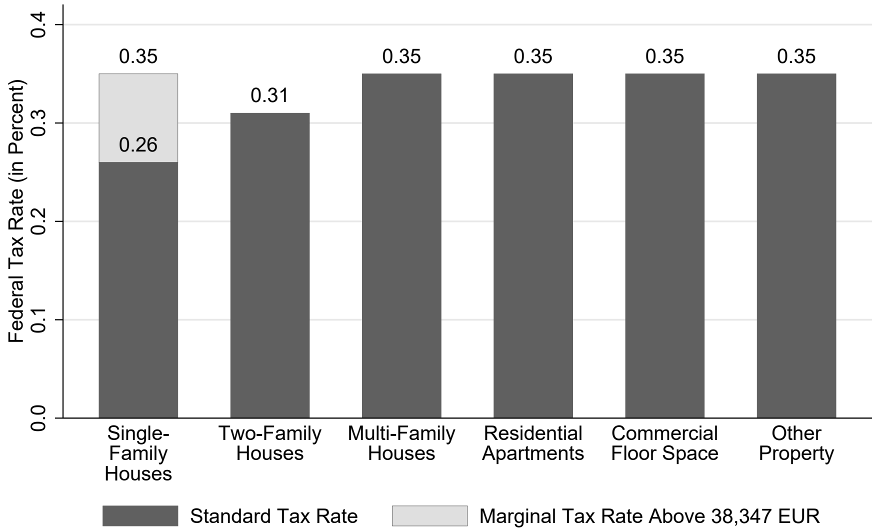
Federal Tax Rates. The federal tax rate (*Grundsteuermesszahl*) is set at 0.35 percent for all property types in West Germany with two exceptions (see Figure 1). First, consider a single-

[6] The law distinguishes between taxes on agricultural land (*Grundsteuer A*) and taxes on residential and commercial land as well as improvements (*Grundsteuer B*). We focus solely on the latter one in this paper as only this type of the tax is relevant for residential housing markets and commercial floor space.

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

family house in West Germany. The first 38,347 EUR are taxed at 0.26 percent while every Euro above that threshold is taxed at the standard marginal tax rate of 0.35 percent. Second, two-family houses are taxed at 0.31 percent. All other property types are taxed at 0.35 percent. The federal tax schedule is thus progressive for single-family houses and otherwise flat. Once the property type has been determined by the state tax offices, land and structures are taxed at the same rate.[8] The average federal property tax rate in our sample is 0.32 percent.

Figure 1: Federal Tax Rates in West Germany (in Percent)



Notes: This graph shows the federal tax rates for different property types in West Germany. Federal tax rates are flat except for single-family houses, which are taxed at 0.26 percent up to an assessed value of 38,347 EUR and with a marginal tax rate of 0.35 percent above that threshold. All tax rates are in percent. The average federal tax rate in our sample is 0.32 percent. *Source:* § 15 *Grundsteuergesetz*.

Municipal Scaling Factors. While the assessment of property values is done on the state level and federal tax rates are set at the federal level, the municipal councils decide yearly on the local scaling factor (*Hebesatz*). The decision is usually made in the last months of the preceding year, and most tax changes become effective on January 1st.

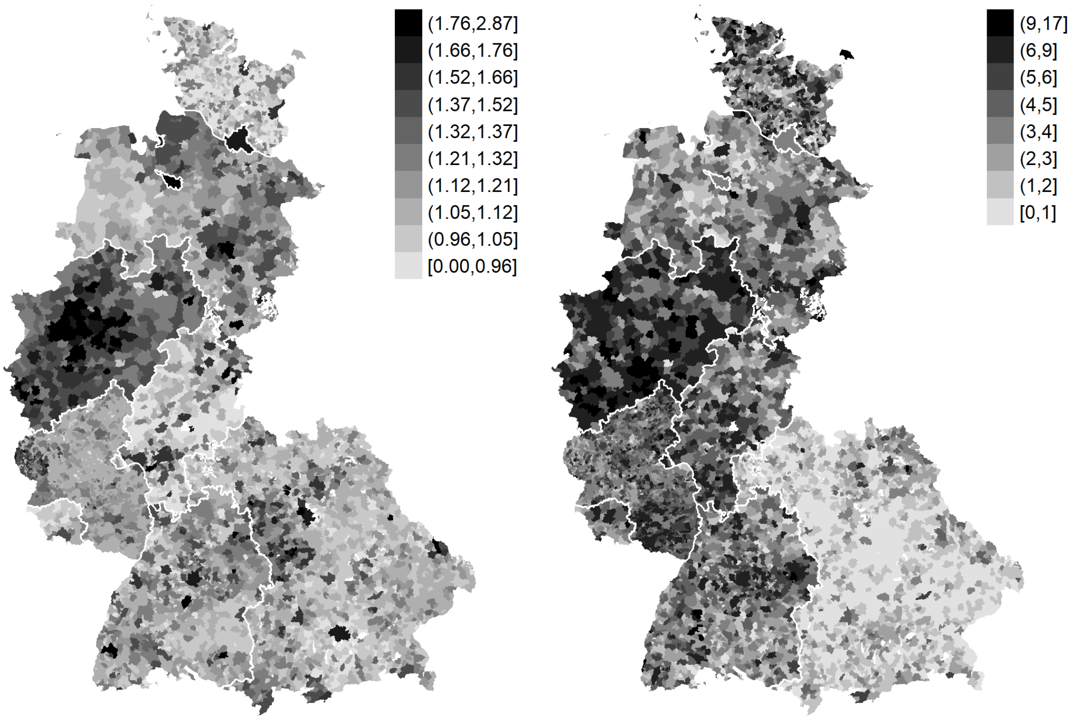
For a given housing stock and thus a fixed federal rate, local property tax rates only vary due to changes in local scaling factors. Figure 2 demonstrates the substantial cross-sectional and time variation in tax rates induced by changes in scaling factors. The left panel of the figure shows the local tax rates for all West German municipalities in 2017, assuming a federal tax rate of 0.32 percent. Local property tax rates vary between 0.73 and 1.71 percent (bottom and top one percent). Annual mean and median tax rates increased steadily from around 0.86 in 1992 to 1.17 percent in 2017. The average tax per square meter was 0.20 EUR for rental apartments, which corresponds to 3.29 percent on top of the average net rent in our sample.[9]

[8] As tax rates for developed properties and undeveloped land are also similar, the German system is thus essentially a one-rate property tax (see the discussion in Plassmann and Tideman, 2000, and Lyytikäinen, 2009, for the differences between one-rate and multi-rate tax systems and their effect on housing construction).

[9] The average tax burden for rental apartments in West Germany is published annually by the German Tenants'

Figure 2: Variation in Local Property Tax Rates in West Germany

A. Local Property Tax Rates in 2013 (in Percent) B. Number of Property Tax Changes 1992–2017



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 1992–2017. Jurisdictional boundaries are as of December 31, 2010. White lines indicate federal state borders. *Source:* Federal Statistical Office and Statistical Offices of the federal states. *Maps:* © GeoBasis-DE / BKG 2015.

The right panel of Figure 2 demonstrates the number of municipal scaling factor changes in the period from 1992 to 2017. Over this period, more than ninety percent of all municipalities changed their local tax rate at least once, while less than six percent of municipalities still have the same multiplier as in the beginning of the 1990s. On average, municipalities changed the factor four times during this period, i.e., every six years. Many municipalities experienced even more changes. One percent of municipalities changed their property tax multiplier more than ten times since 1992. Almost 97 percent of all tax changes during this period are tax increases.

Statutory Incidence. Property owners are liable for the tax payment irrespective of whether the property is owner-occupied, for rent or vacant. However, for rental housing, property taxes are part of the ancillary costs that renters have to pay on top of net rents to their landlords according to the legal regulations on operating costs (*Betriebskostenverordnung*). In this regulation, landlords are directed to include the tax payments in the ancillary bill the renters receives each year and it is a common practice to do so. As a consequence, the statutory incidence is on the user of the housing service for both owner-occupied and rental housing.

Association (*Deutscher Mieterbund*) based on a survey on operating costs (*Betriebskostenspiegel*).

Commercial Property Taxes. For German firms property tax liabilities are of second order. Municipalities tax revenues from local business taxes were 43 billion EUR as of 2013, tax revenues from property taxes amounted to 12 billion EUR. From these 12 billion EUR, the largest share came from residential buildings. A conservative estimate is that two thirds of a municipalities total area are for residential, one third for commercial use. Commercial property taxes thus make up less than ten percent of firms' total tax bill on average.

4 Data and Descriptive Statistics

This sections gives an overview on the data used for our empirical analysis. We combine administrative data on the fiscal and economic situation of German municipalities with housing market information, and administrative wage data from social security registers (Section 4.1). In Section 4.2 we define our baseline data set used in the empirical analysis. Appendix A provides more details on the definition and the sources of all variables.

4.1 Variables and Data Sources

German Municipality Data. We collected a comprehensive data set for all West German municipalities from the Federal Statistical Office and the Statistical Offices of the Länder, including data on the economic, fiscal and budgetary situation, most importantly local scaling factors, as well as population figures and information on the housing stock, land prices, land use, and local GDP. In addition we collect unemployment data from the Federal Employment Agency. 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*). Using these sources we construct a balanced panel for the universe of all 8,481 West German municipalities ranging from 1992 to 2017.[10] Table A.1 in the Appendix provides details on the definition and data sources of all variables as well as the years for which data is available, Appendix Table A.2 shows descriptive statistics.

Housing Price Data. We combine the municipality panel with housing market data provided by the German real estate association IVD (*Immobilienverband Deutschland*). This data set delivers eight distinct rent indices for standardized rental apartments with 70 square meter and three bedrooms, and seven house price indices for single-family buildings. These indices differ by construction year and apartment quality and thus allow us to study heterogeneous effects of property taxes. It is important to note, that this data only includes quoted net prices and quoted net rents (*Nettokaltmiete*) and does not contain information on operating costs, taxes, or actual transaction prices. Thus, we do not observe gross prices including property taxes.

We validate the house price and rent data against several other data sources: (i) official household survey data from the German micro census, which includes information on rents at the county level every four years, covering 89 large municipalities; (ii) housing market indicators

[10] We complement this panel with earlier data from the Statistical Offices of the federal states of Bavaria (since 1970), Lower Saxony (since 1981), and Northrhine-Westfalia (since 1977), three of the largest states in Germany.

provided by *Empirica*, an independent economic consultancy specialized in the real-estate sector, covering the same large municipalities over the period 2004–2013; (iii) data provided by *Bulwiengesa*, a different real-estate consultancy, whose data set includes 102 municipalities. Figure A.1 in the Appendix compares the different measures and shows that data quality of our IVD data set seems reasonable. In addition, Appendix Figure A.2 plots average reported rents in 2010 for all West German counties and the regional coverage of the IVD data.

Wage Data. We additionally use linked employer-employee data from the Institute for Employment Research (LIAB) to study the effect of property taxes on wages at the municipal level. The LIAB data is based on a one percent stratified random sample of all German establishments, covering about 15,000 plants. The firm data are linked to social security records, matching all employees working in these plants. Overall, the LIAB data covers between 1.6 and 2.0 million workers per year, which corresponds to about 6 percent of all German workers (see Alda et al., 2005, Fuest et al., 2018, for more information on the dataset). We link the municipal tax information to the LIAB via the plant location, and calculate the mean wage for all municipality-year cells.[11]

4.2 Sample Definition

While our municipality data set contains the universe of all West German municipalities, the housing data covers only 436 municipalities (five percent of all West German municipalities). Panel A of Figure A.3 in the Appendix shows that the housing data set accounts for roughly forty percent of the West German population. Panel B differentiates the sample by city size. The housing data set includes all large cities above 100,000 inhabitants and a substantial part of the medium-sized cities with a population above 20,000. Appendix Figure A.4 shows the size distribution of municipalities in the baseline sample and municipalities in the full sample. Despite the difference in population, both samples are rather comparable when looking at the number and the size of property tax changes, i.e., the source of identifying variation in our empirical analysis, as can be seen in Appendix Figure A.5.

In the empirical analysis below, we use the housing data sample as the baseline sample, also for results on other outcomes, in order to have a consistent sample definition.[12] Yet, if data is available we additionally present estimates on the full sample of all West German municipalities.

We exclude East German municipalities from our analysis for two reasons. First, and foremost, East German housing markets don't seem ideal testing grounds for our theoretical predictions given the tremendous population loss and the large inflow of public and private capital after reunification. In fact, East German municipalities on average lost more than 15 percent of their population since the fall of the Berlin Wall in 1989. As a consequence, housing markets in many East Germany regions have been subject to substantial excess supply

[11] About 10 percent of the wages in the LIAB are right censored at the social security contribution ceiling. We get similar results when using the median municipal wage, which should be hardly affected by wage censoring.

[12] Note that for some outcomes we have to restrict the estimation sample even further to only 89 city counties (*kreisfreie Städte*) if data is solely available at the county level.

during the past decades. Second, there were substantial mergers of East German municipalities after reunification, which complicates any longitudinal study at the municipal level. About 60 percent of the East German municipalities experienced at least one merger since 1990. Given that our data are based on municipal boundaries as of December 31, 2010, we cannot assign the correct tax rates.[13]

5 Empirical Model

We make use of an event study design to investigate the effects of property tax changes. As identified by our theoretical model, we are interested in the effects of property taxes on the following outcome variables: net rents, house prices, number of houses, number of apartments, wages, population, land sales, and land prices. Denoting an outcome in municipality c in year t as $y_{c,t}$, our regression model reads as follows:

$$\ln y_{c,t} = \sum_{k=-4}^{6} \beta_k D_{c,t}^{k} + \mu_c + \zeta_{c,t} + \varepsilon_{c,t}. \tag{17}$$

We regress logged outcomes on a set of event study indicators $D_{c,t}^{k}$ with the event window running from four years prior to a tax reform ($k = -4$) to six years after the event ($k = 6$).

We estimate two different variants, which differ in the way we define event indicators $D_{c,t}^{k}$. First, we implement the most intuitive and basic model, where $D_{c,t}^{k}$ is simply a dummy variable indicating a tax increase k years ago.[14] Second, we follow Simon (2016) and Fuest et al. (2018) in estimating a specification where the event indicator $D_{c,t}^{k}$ switches on only for large tax increases, i.e., increases being equal or greater than the median of the tax increase distribution. The reason is that tax reforms might only have real effects if tax changes are sizable for example due to adjustment costs.

Our baseline specification of the event study includes four leads and six lags, $k = -4, \ldots, 6$, which enables us to investigate the dynamics of the relation between property taxes and outcomes on the housing, land, and labor market, where (quantity) responses might take some time (England, 2016).[15] In both models, end points $D_{c,t}^{-4}$ and $D_{c,t}^{6}$ of the event study are adjusted to account for the fact that our panel is unbalanced in event time due to staggered tax reforms across municipalities (McCrary, 2007).[16] This adjustment makes the set of $4 + 6 + 1$

[13] A possible solution would be to use a (weighted) average of the municipalities which merged, but this would introduce considerable measurement error and several artificial tax changes. Moreover, using these municipalities in our analysis would require the strong assumption that the decision to merge is unrelated to the fiscal and economic situation in a municipality.

[14] Almost 97 percent of the property tax reforms between 1992–2017 are tax increases. Estimates are not sensitive to whether we keep municipalities with tax decreases in the control group or exclude them from the sample.

[15] Clearly, the choice of the event window is determined by data availability over time. The chosen baseline is a compromise between the length of the event window and statistical power. We experimented with other event window definitions, finding very similar results.

[16] Hence, the coefficient β_{-4} captures the effect of all tax changes occurring four or more years before the current reform. Likewise, the coefficient β_6 measures the effect of all tax changes that happened six or more years after a reform. Since endpoints are estimated on unbalanced data, we follow standard practice and do not plot them in the event study graphs (Smith et al., 2017, Fuest et al., 2018).

event indicators $D^k_{c,t}$ perfectly collinear and we thus normalize coefficients to the pre-reform year by omitting the respective event indicator $D^{-1}_{c,t}$ from the regression, i.e., $\beta_{-1} = 0$.

To control for time-invariant factors, we include municipality fixed effects μ_c.[17] The vector $\zeta_{c,t}$ controls for local shocks by including state $\times$ year fixed effects and linear county trends. Moreover, and importantly, we include event study coefficients indicating whether the local business tax, the other tax instrument at the disposal of municipalities, changed.[18] The error term is denoted by $\varepsilon_{c,t}$. We allow for clustering of standard errors at the municipal level to account for correlation in unobservable components over time and between the different building and construction types.[19]

Identification of the β_k coefficients comes from changes within a municipality relative to the pre-reform year and relative to the regional trend. The identifying assumption is that there are no other factors that simultaneously affect property taxes and the outcome variables. Using an event study design allows to directly test for reverse causality problems. In order to obtain causal estimates, we need pre-trends to be flat and insignificantly different from zero. While municipality fixed effects control for time-invariant confounders, our estimator will be biased if local shocks affect both municipal fiscal policies and housing as well as labor markets.

We test for confounding factors in two ways. First, we assess the sensitivity of our estimates with respect to the inclusion of a very rich set of time-varying control variables. In our baseline, we include state $\times$ year fixed effects and linear county trends. As a robustness check, we estimate one less demanding specification, dropping the linear county trends, and one more demanding one, including commuting zone $\times$ year fixed effects. Estimates prove to be robust (see Appendix C.1). Second, we directly test whether tax reforms are driven by the local business cycle by using municipal unemployment and GDP per capita at the county level as outcomes variables in the event study regression in equation (17).

6 Reduced Form Results

In this section, we present reduced-form results for the effects of property tax changes on prices and quantities on the housing, land, and labor market. First, we test the theoretical predictions derived from our spatial equilibrium model in Section 2. Second, we investigate heterogeneous effects with respect to city size, population density, the availability of developable land, and the housing quality to check whether the mechanisms implied by the theory are supported by the data.

[17] Our data contains several indices for each municipality differing by construction type and building quality. We include all indices and account for type-quality-specific municipality fixed effects in rent and price regressions.

[18] As it turns out, controlling for changes in the local business tax, does not affect our results on the housing or land market. But intuitively, and in line with the results in Fuest et al. (2018), we find differences in wage responses. Ignoring changes in business taxes would lead to more negative wage effects.

[19] The results are not sensitive to whether we cluster at the municipal level or the level of commuting zones.

6.1 Main Results

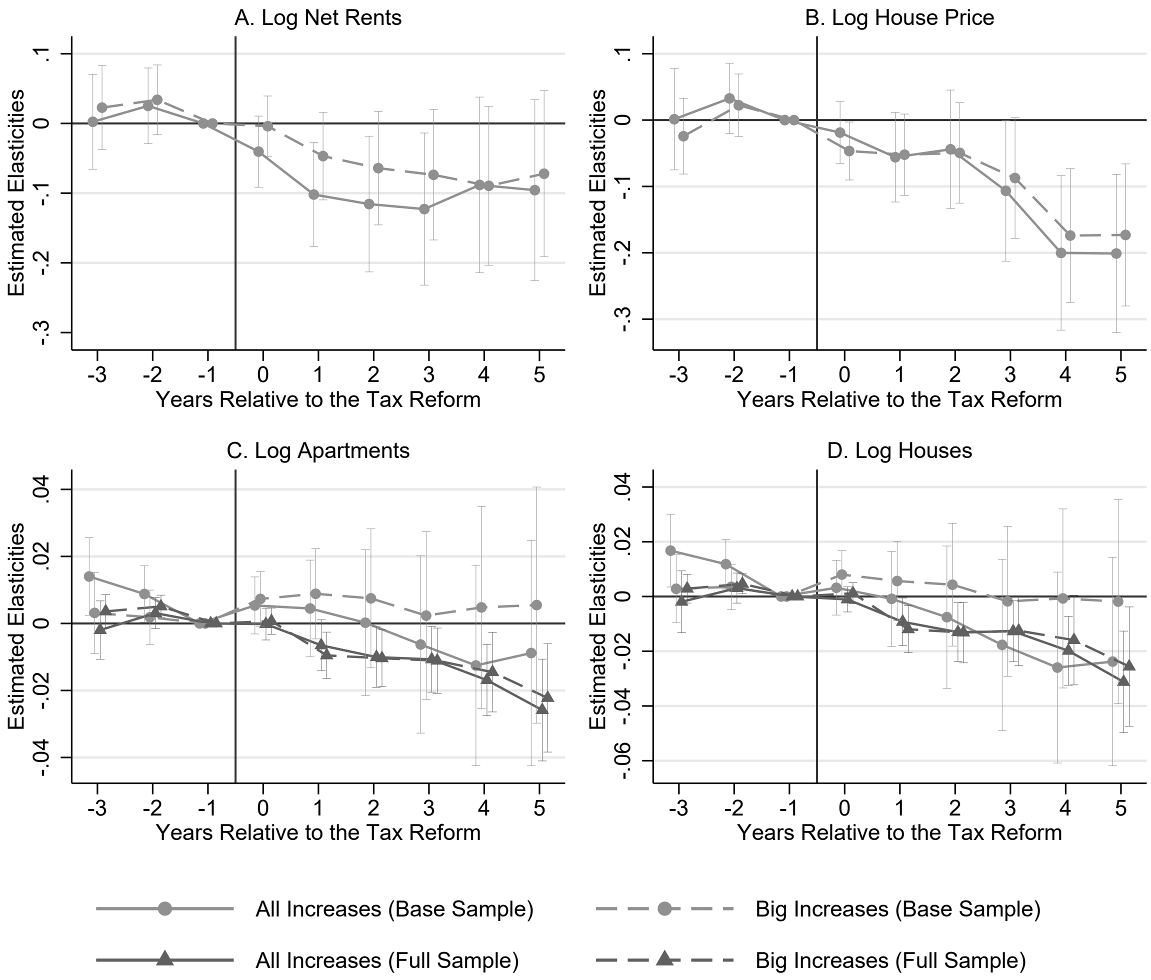
We report event study results for various outcomes on the housing, land, and labor market. For each outcome, we plot two event study specifications: the classic design where event study dummies indicate tax increases, and an alternative specification where event dummies are equal to one for large tax increases only. For both models, estimated treatment effects of (large) tax increases are rescaled such that plotted coefficients can be interpreted as average elasticities. Various sensitivity checks with respect to the length of the event window, and the way we account for local shocks are presented and discussed in Appendix C.1.

Housing Market. We start by analyzing the housing market effects, Figure 3 summarizes the results. Panel A reports the event study results using log quoted net rents as an outcome. While pre-reform trends are flat as required by our identifying assumption, we find that net rents for new contracts are about 0.1 percent lower in the three years after the reform for a tax increase of one percent. This short to medium-run effect is statistically different from zero at the 90 percent level. However, after three years, the negative effect on rents starts to revert slowly towards zero. This implies that in the medium run, more and more of the incidence is borne by the new renter. A likely explanation of this adjustment path lies in the supply of rental dwellings, which is inelastic in the short run but becomes more elastic over time.

Next, we look at the effects of property tax increases on net house prices, which are plotted in Panel B of Figure 3. We detect a gradual decrease in house prices after a property tax increase. The implied elasticity five years after the tax increase is about -0.2. Hence, and in line with the literature, we find clear evidence of property tax capitalization into house values. While buyers have to bear the full tax burden in the short run, they are able to shift part of the future tax liability onto the seller of the house, which is reflected in lower transaction prices.

Panels C and D show the quantity effects of rising property taxes on the housing market. While we find a gradually negative effect on the stock of apartments and residential buildings in a municipality, magnitudes are small and results are not statistically significant at conventional levels. The lower magnitudes of the quantity responses are intuitive as the housing stock cannot adjust as quickly as prices. This is also predicted by the theoretical model, where the tax elasticity of floor space equals the tax elasticity of rents multiplied by the effective housing supply elasticity. Because of this sluggish construction response, it is difficult to identify quantity effects that are statistically significantly different from zero. A potential way to overcome this problem is to increase the number of observations. As mentioned in Section 4.2, our baseline sample is restricted to municipalities for which we have housing price data. Yet for some variables, we have data from the universe of West German municipalities. While effects might be different across samples due to heterogeneous treatment effects, we can increase statistical power by testing quantity responses in the full sample. For this reason, we plot two additional sets of event studies estimates for the full municipality sample in Panels C and D. We find that the effect on the number of residential houses is very similar across samples, but highly significant in the full sample with an elasticity of around -0.03 six years after a tax increase (Panel D). Moreover, we find an effect of similar magnitude on the

Figure 3: The Effects of Property Taxes on the Housing Market

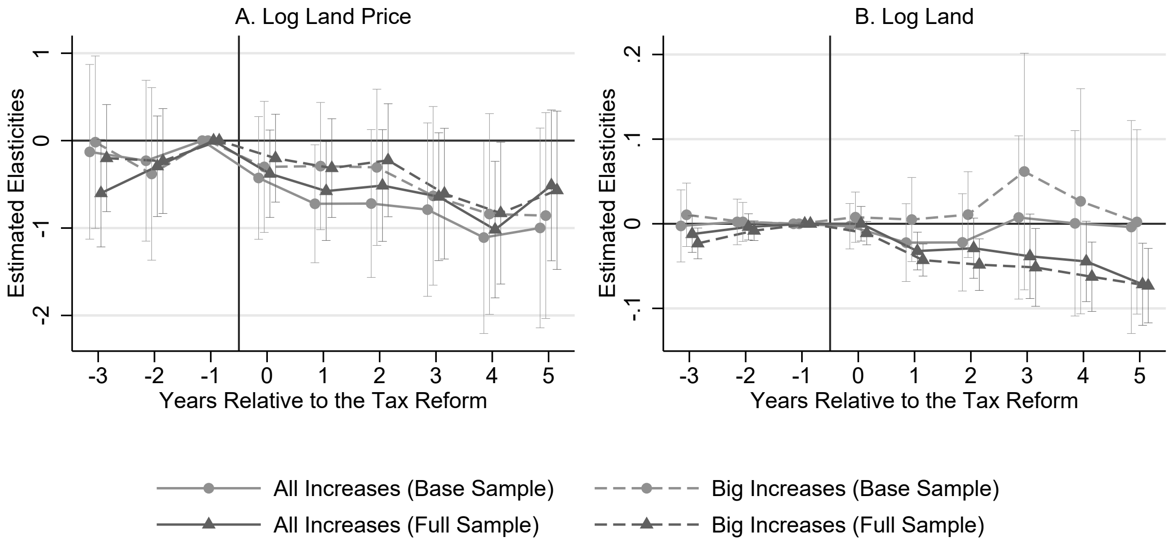


Notes: This figure shows the effects of property taxes on the housing market using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases), or as an increase that is greater than or equal to the median of the tax change distribution (big increases). The base sample includes all municipalities from our housing data set (see Section 4.2 for details), the full sample includes all municipalities for which we have data on the respective outcome. Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

number of apartments in the full sample, while effects in the base sample, which covers larger, more urban areas, is closer to zero (Panel C). These findings are in line with evidence from Lutz (2015) who reports capitalization effects in more urban areas, while property taxes reduce residential construction in rural communities. The results again highlight the importance of treatment effect dynamics as the quantity effects take time to evolve, which is again in line with the idea that housing supply is rather inelastic in the short run.

Land Market. Next we turn to the land market. Figure 4 summarizes the results. Panel A shows that the land price strongly decreases in response to a tax increase and only gradually starts to recover five years after the tax reform. This is in line with the theoretical prediction from our spatial equilibrium model. Notably, the magnitude of the effect is larger compared to the effects on rents, which suggests that the land supply is relatively inelastic in German municipalities (cf. Section 2.6). As above, effects on the quantity of residential land use are not conclusive within the house price sample and we cannot reject the null hypotheses of no effect. However, we find negative and statistically significant effects on the land area used for residential housing in the full sample of municipalities: five years after a tax change, the land use is reduced by 0.07 percent for a one percent tax increase (see Panel B of Figure 4).

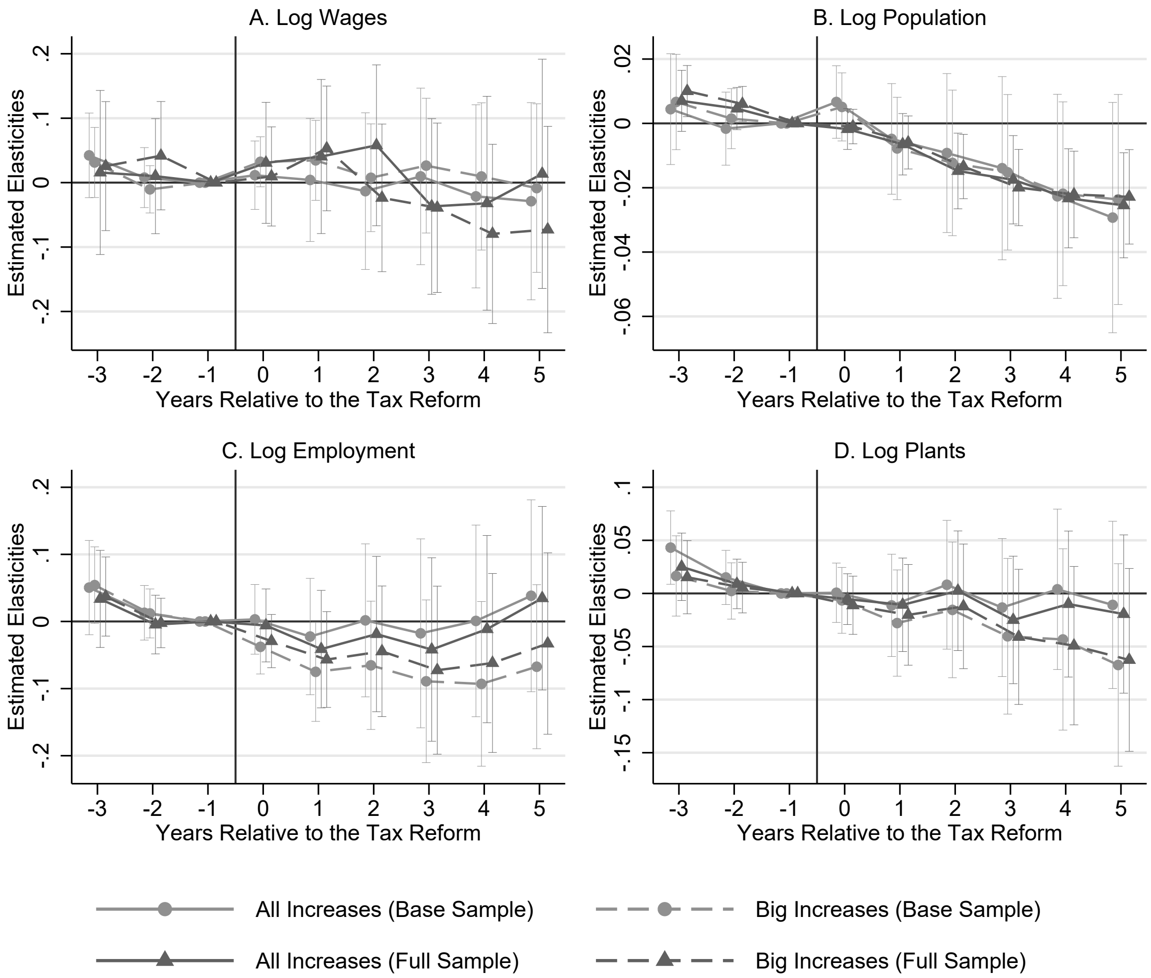
Figure 4: The Effects of Property Taxes on the Land Market



Notes: This figure shows the effects of property taxes on the land market using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases), or as an increase that is greater than or equal to the median of the tax change distribution (big increases). The base sample includes all municipalities from our housing data set (see Section 4.2 for details), the full sample includes all municipalities for which we have data on the respective outcome. Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Labor Market. Last, we turn to local labor market outcomes. Panel A of Figure 5 shows that wages are largely unaffected by tax increase. In light of our theoretical predictions derived from the spatial equilibrium model this implies that the rent elasticities of commercial and residential floor space are roughly of similar size. As for the housing stock, we see a gradual decline of around 0.02-0.03 percent in municipal population in response to a one percent tax increase (see Panel B). Effects are again similar in magnitude for the baseline and the full sample, but we again lack statistical power in the house price sample. Panels C and D show a insignificant but visible decline of roughly equal size in local employment and the number of plants in a municipality when we focus on large tax increases, which is in line with the mechanisms predicted by the theoretical model.

Figure 5: The Effects of Property Taxes on the Labor Market



Notes: This figure shows the effects of property taxes on the labor market using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases), or as an increase that is greater than or equal to the median of the tax change distribution (big increases). The base sample includes all municipalities from our housing data set (see Section 4.2 for details), the full sample includes all municipalities for which we have data on the respective outcome. Panels C and D are based on a subsample of large municipalities ("urban counties") as data on employment and plants are only observed at the county level. Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Sensitivity Checks. We conduct a wide range of of robustness checks. First we can directly test the identifying assumption that tax reforms are not driven by local business cycles by putting log GDP and log unemployment on the left-hand side of our estimation equation (17). As shown in Appendix Figure C.1, pre-trends are very flat for GDP, while we detect a small pre-trend for local unemployment. In terms of post-treatment effects, the figure suggests no effect in local GDP due to the property tax increase. Local unemployment is increasing after tax reforms, in particular in the baseline house price sample. While most effects are not statistically significant, the results suggest that an increase in local property taxes tends to hurt the overall local economy.

Moreover, and in a similar vain, we test the sensitivity of our estimates with respect to confounders. In our baseline specification we include state times year fixed effects and linear county trends. This rich set of non-parametric controls is likely to account for various potentially confounding shocks at the local level. As a sensitivity check, we estimate one more parsimonious specification including only state times year fixed effects but excluding county trends, and one even richer specification, where we control for commuting-zone times year fixed effects. There are 204 commuting zones which delineate local labor markets based on commuting flows. Including commuting zone times year fixed effects thus absorbs any common shocks within labor market regions.[20] Figures C.2–C.4 in Appendix C.1 show the results. If anything, pre-trends become flatter in the more involved baseline specification. In terms of post-treatment effect, the general pattern is confirmed for most outcomes.

6.2 Heterogeneous Effects

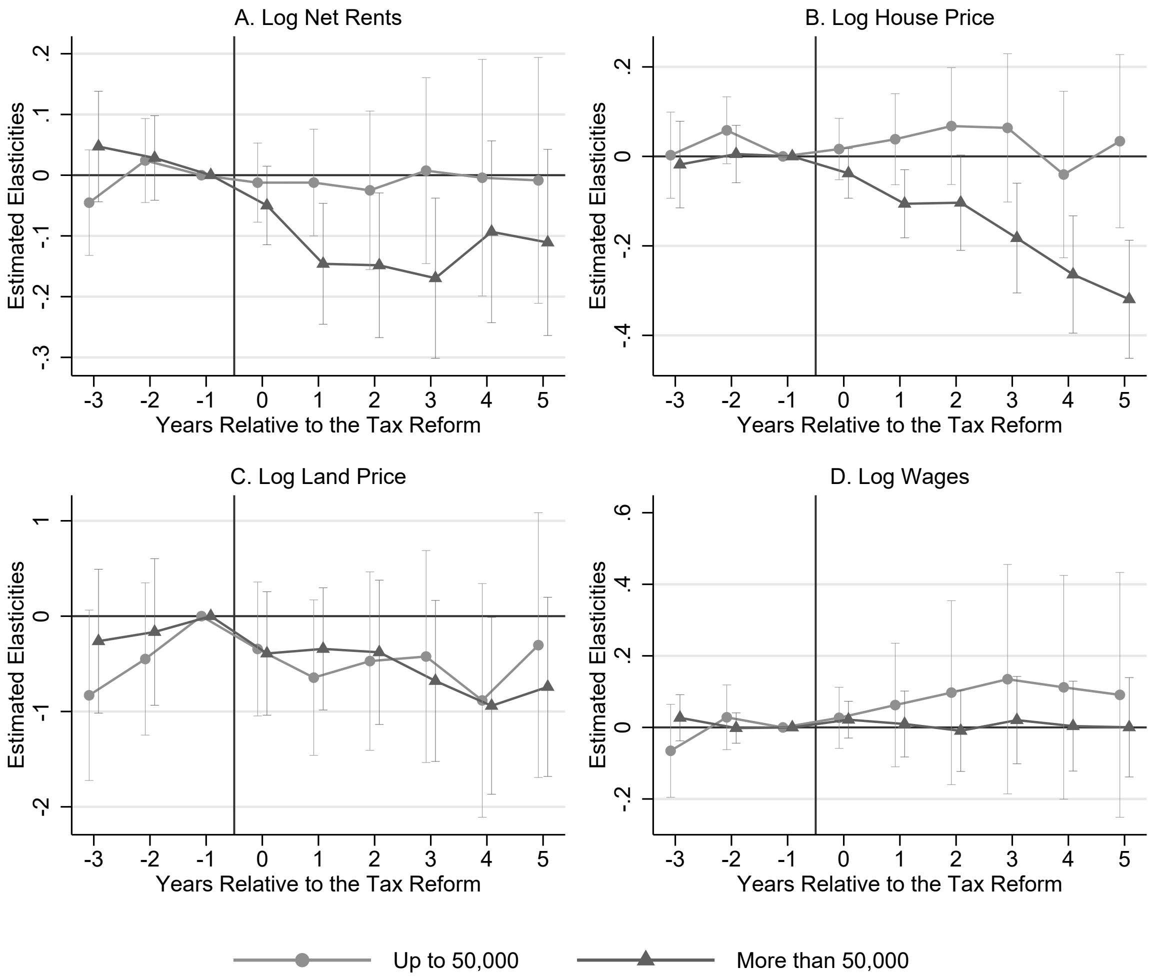
We can further test the underlying mechanisms of the theoretical model by estimating heterogeneous effects for certain municipality types. For instance, the theoretical model assumes that the negative effect of property taxes on rents is higher, the less elastic the supply of rental housing. While the adjustment pattern shown Panel A of Figure 3 has provided a first indication for this mechanism with net rents decreasing in the short run, but reverting to pre-reform levels in the longer run. We can exploit cross-sectional differences in the housing supply elasticity by differentiating between municipalities with below and above 50,000 inhabitants. With strong urbanization trends and growing cities, housing and land supply in cities is rather inelastic. Hence, we would expect to see stronger price reactions in larger municipalities. This is confirmed by Figure 6, which shows that rents, house prices and land prices decrease more strongly in larger cities. Conversely, Figure C.10 in Appendix C.2 demonstrates stronger quantity responses in smaller, more rural municipalities.[21] In light of the theoretical predictions, these results suggest that housing and land supply are indeed more elastic in rural areas than in cities.

A different way to investigate heterogeneous effects is to distinguish municipalities by the share of undevelopable land (Hilber and Vermeulen, 2016). Following the rationale of Saiz (2010), municipalities with a high share of undevelopable land are assumed to have less elastic land and housing supply and should see stronger price effects. Figure C.13 in the Appendix confirms this prediction – at least for house and land prices. While the municipalities with a more elastic housing supply hardly face any price changes, they experience stronger quantity responses instead (see Appendix Figure C.14).

[20] The rich specification is only meaningful for outcomes measures at the municipal level. We are forced to focus on a subset of 88 municipalities (city counties) for the few outcomes that we observe at the county level only, i.e., land prices, employment, number of plants. There are 88 municipalities and 73 commuting zones in this sample, which makes commuting zone $\times$ year fixed effects highly collinear with the identifying variation, which is at the municipality-year level.

[21] We find similar results when interacting tax hikes with population density indicators (see Figures C.11 and C.12 in Appendix C.2). The heterogeneous responses by city size or density already became apparent when looking at the main results in Section 6.1, where quantity responses become stronger and more significant when switching from the mostly urban baseline to the full sample, which also includes smaller and more rural municipalities.

Figure 6: The Effects of Property Taxes on Prices by City Size



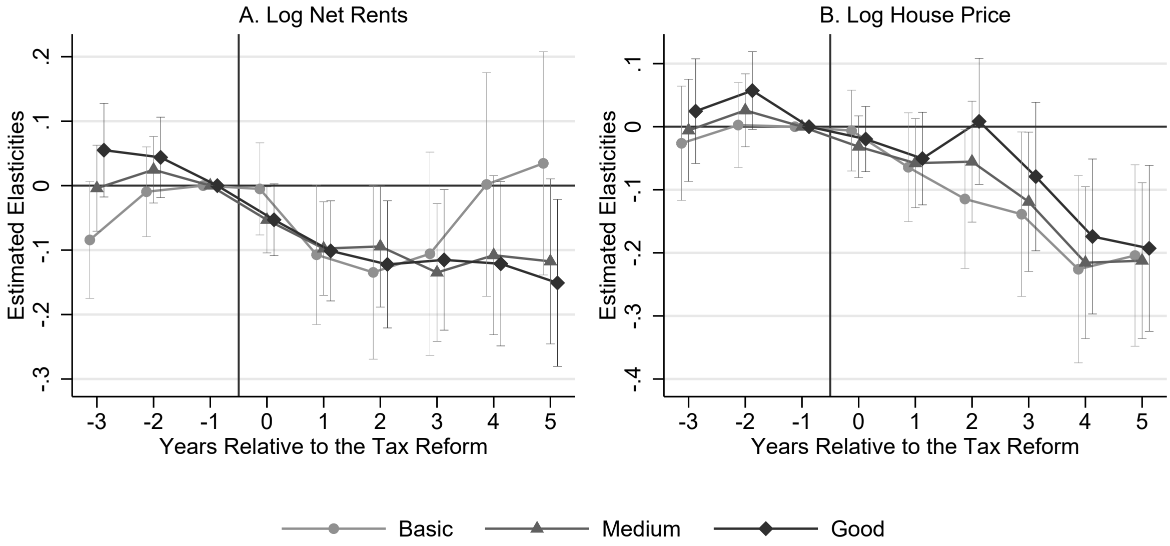
Notes: This figure shows the effects of property taxes on prices by city size using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Last, we check for differential responses by construction quality, Figure 7 shows the results. We find that net rents in apartments of the lowest quality revert back more quickly to the pre-reform level than net rents of higher quality housing (see Panel A). This implies that the pass-through of the tax burden on renters in lower quality housing is higher and faster *ceteris paribus*. Looking at sales prices of houses, Panel B suggests that the tax shifting from buyers to sellers is slightly lower for high quality housing, yet estimates are not statistically different from each other.

7 Combining Theory and Empirics

In the following section, we combine the reduced form estimates presented in Section 6.1 with the theoretical model set up in Section 2. First, we calculate marginal welfare effects of property

Figure 7: The Effects of Property Taxes on Prices by House Quality



Notes: This figure shows the effects of property taxes on prices by house quality using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

tax increases using the reduced form results and the welfare formulas from Section 2.7. Second, we assess the role of endogenous amenities in shaping the welfare effects of the property tax by running counterfactual simulations.

7.1 Welfare Effects of Property Tax Increases

Ignoring public goods, Proposition 2 shows that the marginal welfare effects of property tax increases are governed by four key elasticities and three additional model parameters, which we calibrate using estimates from the literature and external data sources. In Table 1, we summarize the key medium-run elasticities after five years for both the house price sample and the full sample.[22] All elasticities are negative and have the predicted sign. As already discussed above, price effects are larger in magnitude than quantity effects.

Calibrating the housing share in consumption α and the labor share in production β, we can derive the welfare losses of property tax increases for workers, firm owners, and land owners, calculated as respective shares of the marginal welfare effects over the total welfare loss. Figure 8 visualizes the results for different assumptions on the calibrated parameters α

[22] The presented elasticities are the coefficients of the conventional event study design using all tax increases after five years. As noted above, we scale the coefficients such that they represent elasticities, i.e., they measure the effect of the outcome in percent in response to a one percent increase in the local property tax rate. For the simulation, we are interested in the medium to long-run effect of property taxes. The traditional difference-in-difference estimate would provide us with average treatment effect relative to the pre-treatment period. As shown above, most of the effects materialize gradually rather than sharply after treatment, which would mean that the DiD estimate is lower than the medium-term effect. We nevertheless present DiD estimates in Appendix Table C.1 and confirm this pattern empirically. The event study results provides unbiased estimates for medium-run effects in case of flat pre-trends, which is the case for our outcomes.

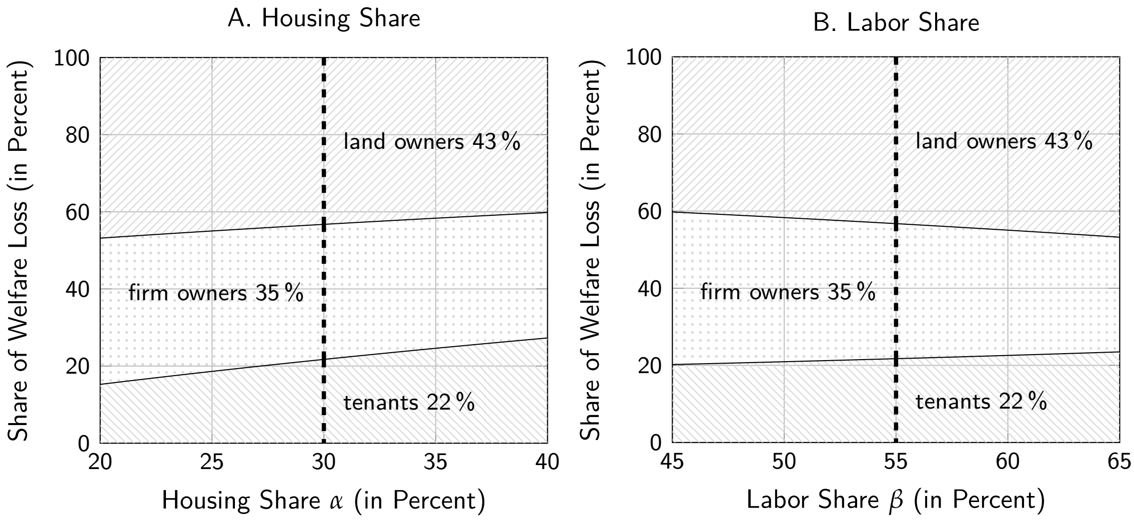
Table 1: Reduced Form Elasticities

	Base Sample			Full Sample		
Outcome	Elasticity	S.E.	Obs.	Elasticity	S.E.	Obs.
Log Net Rent	-0.096	(0.079)	37,672	-0.096	(0.079)	37,672
Log House Price	-0.201	(0.072)***	33,767	-0.201	(0.072)***	33,767
Log Apartments	-0.009	(0.020)	2,780	-0.026	(0.009)***	93,212
Log Houses	-0.024	(0.023)	2,780	-0.031	(0.011)***	93,212
Log Land Price	-0.999	(0.687)	1,205	-0.512	(0.524)	6,987
Log Land	-0.004	(0.076)	1,712	-0.072	(0.030)**	50,843
Log Wage	-0.029	(0.092)	973	0.014	(0.108)	8,067
Log Population	-0.029	(0.022)	5,050	-0.025	(0.010)**	189,535

Notes: This table summarizes the reduced-form results for the key medium-run elasticities of our model for both the house price sample and the full sample. For detailed information on all variables, see Appendix Table A.1.

and β (see Table C.2 in Appendix C.3 for the corresponding numbers). For our preferred baseline values of the housing and labor share, $\alpha = 0.3$ and $\beta = 0.55$, we find that workers bear 22 percent of the welfare loss of property tax increases, firm owners bear 35 percent, and land owners 43 percent.

Figure 8: Welfare Effects Without Endogenous Local Public Goods



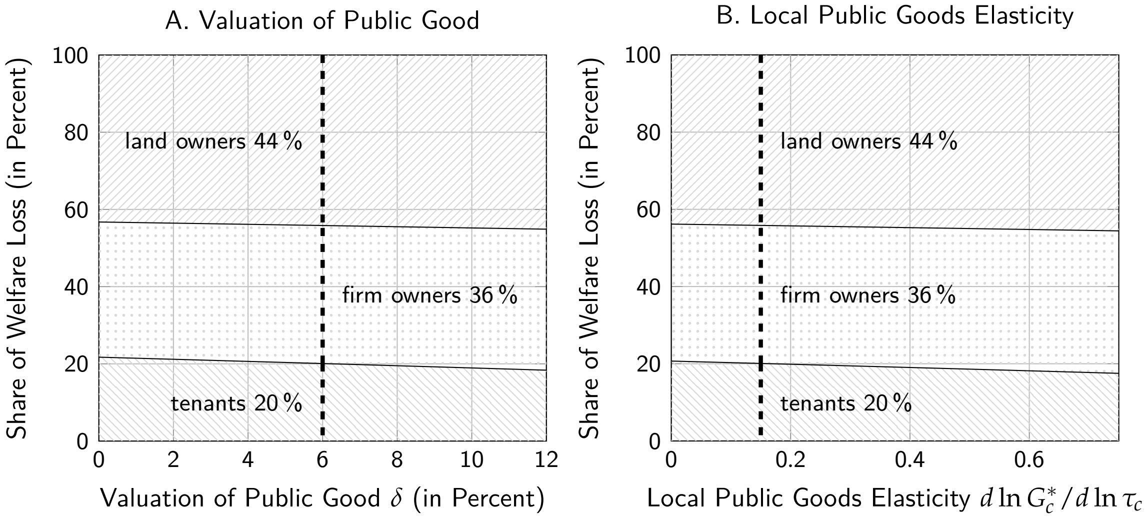
Notes: This figure presents welfare effects arising in a model where property tax revenues are not spent on local amenities. The marginal welfare effects are shown for different values of the housing share in consumption (α) in Panel A (assuming parameter $\beta = 0.55$), and the labor share in the production of the tradable good (β) in Panel B (assuming $\alpha = 0.3$). Marginal welfare effects are based on Proposition 2 in Section 2.6 and the following three reduced-form elasticities: $d \ln r_c^{H*} / d \ln \tau_c = -0.096$, $d \ln l_c^* / d \ln \tau_c = -0.512$, and $d \ln w_c^* / d \ln \tau_c = 0.014$ (see full sample results in Table 1). The dashed vertical lines mark the baseline specification with parameters calibrated at $\alpha = 0.3$ and $\beta = 0.55$.

7.2 The Relevance of Local Public Goods

Next, we assess the empirical relevance of endogenous local public goods. Public goods affect marginal welfare effects in two ways: (i) through the valuation of public relative to private goods, and (ii) via the transmission of property tax increases into additional public good spending. While we do not know the average individual valuation of the public goods, δ, we can calibrate the parameter to the average share of local public expenditures relative to local GDP (Fajgelbaum et al., 2016, Michaillat and Saez, 2017), which yields an average of $\delta = 0.06$. The importance of local public goods for marginal welfare effects also depends on how responsive public good spending is to changes in property taxation. As explained in Section 2.6, the direct, negative effects of tax increases on equilibrium prices are alleviated if the tax revenue is spent on local public goods valued by the population (see Proposition 1).

[Disclaimer: We just obtained detailed administrative data on municipal expenditure types and should be able to show the effects of tax increases on different type of local expenditures. Hence, we could directly estimates $\frac{d \ln G_c^*}{d \ln \tau_c}$ (for different types of G) and would not need to simulate it as done below]

Figure 9: Welfare Effects With Endogenous Local Public Goods



Notes: This figure presents welfare effects arising in a model where property tax revenues are partly spent on local amenities. The marginal welfare effects are shown for different assumptions on the valuation of the local public good (δ) in Panel A (assuming parameters $d \ln G_c^* / d \ln \tau_c = 0.15$), and the local public goods elasticity with respect to tax changes ($d \ln G_c^* / d \ln \tau_c$) in Panel B (assuming $\delta = 0.06$). Marginal welfare effects are based on Proposition 2 in Section 2.7 and the following three reduced-form elasticities: $d \ln r_c^{H*} / d \ln \tau_c = -0.096$, $d \ln l_c^* / d \ln \tau_c = -0.512$, $d \ln w_c^* / d \ln \tau_c = 0.014$, and parameters $\alpha = 0.3$ and $\beta = 0.55$. The dashed vertical lines mark the baseline specification with parameters calibrated at $\delta = 0.06$ and $d \ln G_c^* / d \ln \tau_c = 0.15$.

Using the reduced form price elasticities and the calibrated parameters α, β, and δ, we can simulate marginal welfare effects over a range of potential elasticities $\frac{d \ln G_c^*}{d \ln \tau_c}$, i.e., different assumptions on the transmission of property tax increase in government spending. Figure 9 shows the welfare losses for workers, firm owners, and land owners. Panel A shows the simulated welfare effects for different assumptions on the valuation of public goods δ. Panel B illustrates the marginal welfare impact of property tax increases for different values of the public goods elasticity. Accounting for endogenous local public goods changes the results from Section 7.1 only marginally. Even large public good elasticities with respect to tax increases hardly lower the welfare loss for tenants within a reasonable range of assumptions for the valuation of public goods. When considering that taxes are used to finance local public goods, tenants bear around 20 percent of the welfare loss of higher taxes, firm owners bear roughly 36, and land owners 44 percent.

8 Conclusion

We propose a new theoretical angle to study the incidence and the welfare implications of property taxation by introducing property taxes into a local labor market in the spirit of Moretti (2011). Our spatial equilibrium models encompasses elements of both the capital and the benefit view of property taxation. It also nests simple partial-equilibrium analyses of the housing market. We show that rising local property taxes should lead to a decrease in housing and land prices, a decrease in the housing stock and the use of developed land, and a decrease in municipal population levels. Based on the price effects of property tax increases, the model also allows us to quantify marginal welfare effects.

In the second part of the paper, we empirically test the theoretical predictions of the model using rich administrative panel data and the institutional setting of German municipalities. An event study research design enables us to study treatment effect dynamics and to test for reverse causality in a straightforward manner. We confirm our theoretical predictions. In particular, we show that house prices, the housing and apartment stock as well as population levels decrease if property taxes increase in a municipality. We find no evidence of compensating wage increases following a tax hike.

The results for the net housing prices (rents and house price) inform about the incidence of the property tax. While we detect a short-run decrease of net rents following a tax increase, net rents start to revert back to the pre-reform level three years after the tax reform. This implies that in the medium-run the economic incidence of the property tax is largely on renters. House prices show a negative response, which is still visible after five years. Hence, house buyers are able to shift part of their future property tax burden on the sellers (which are either previous owners or construction companies for newly built houses). Using the reduced-form results we also quantify the welfare implications of property tax increases for the different agents in our model. Our simulations show that workers and tenants bear roughly 20 percent of the welfare loss, firm owners bear 36 percent, and land owners bear the largest share with 44 percent of the welfare loss. Importantly, the simulated welfare effects change only little when accounting for the fact that property taxes may be used to finance public goods and local public good provision may thus be endogenous.

References

Ahlfeldt, G. M., S. J. Redding, D. M. Sturm, and N. Wolf (2015). "The Economics of Density: Evidence From the Berlin Wall". *Econometrica* 83.6, pp. 2127–2189.

Alda, H., S. Bender, and H. Gartner (2005). "The Linked Employer-Employee Dataset Created From the IAB Establishment Panel and the Process-Produced Data of the IAB (LIAB)". *Schmollers Jahrbuch: Journal of Applied Social Science Studies* 125.2, pp. 327–336.

Bayer, P., F. Ferreira, and R. McMillan (2007). "A Unified Framework for Measuring Preferences for Schools and Neighborhoods". *Journal of Political Economy* 115.4, pp. 588–638.

Boustan, L. P. (2013). "Local public goods and the demand for high-income municipalities". *Journal of Urban Economics* 76.3, pp. 71–82.

Bradbury, K. L., C. J. Meyer, and K. E. Case (2001). "Property Tax Limits, Local Fiscal Behavior, and Property Values: Evidence from Massachusetts Under Proposition 2 1/2". *Journal of Public Economics* 80.2, pp. 287–311.

Bradley, S. (2017). "Inattention to Deferred Increases in Tax Bases: How Michigan Homebuyers are Paying for Assessment Limits". *Review of Economics and Statistics* 99.1, pp. 53–66.

Brueckner, J. K. (1981). "Labor Mobility and the Incidence of the Residential Property Tax". *Journal of Urban Economics* 10.2, pp. 173–182.

Carroll, R. J. and J. Yinger (1994). "Is The Property Tax a Benefit Tax? The Case of Rental Housing". *National Tax Journal* 47.2, pp. 295–316.

Cellini, S. R., F. Ferreira, and J. Rothstein (2010). "The Value of School Facility Investments: Evidence from a Dynamic Regression Discontinuity Design". *The Quarterly Journal of Economics* 125.1, pp. 215–261.

Combes, P.-P., G. Duranton, and L. Gobillon (2016). "The Production Function For Housing: Evidence From France". *CEPR Discussion Paper* 11669.

de Bartolomé, C. A. M. and S. S. Rosenthal (1999). "Property Tax Capitalization in a Model with Tax-Deferred Assets, Standard Deductions, and the Taxation of Nominal Interest". *Review of Economics and Statistics* 81.1, pp. 85–95.

Diamond, R. (2016). "The Determinants and Welfare Implications of US Workers' Diverging Location Choices by Skill: 1980–2000". *American Economic Review* 106.3, pp. 479–524.

– (2017). "Housing Supply Elasticity and Rent Extraction by State and Local Governments". *American Economic Journal: Economic Policy* 9.1, pp. 74–111.

Dixit, A. K. and J. E. Stiglitz (1977). "Monopolistic Competition and Optimum Product Diversity". *American Economic Review* 67.3, pp. 297–308.

Dusansky, R., M. Ingber, and N. Karatjas (1981). "The Impact of Property Taxation on Housing Values and Rents". *Journal of Urban Economics* 10.2, pp. 240–255.

England, R. W. (2016). "Tax Incidence and Rental Housing: A Survey and Critique of Research". *National Tax Journal* 69.2, pp. 435–460.

Epple, D., B. Gordon, and H. Sieg (2010). "A New Approach to Estimating the Production Function for Housing". *American Economic Review* 100.3, pp. 905–924.

Fajgelbaum, P., E. Morales, J. C. Suárez Serrato, and O. Zidar (2016). "State Taxes and Spatial Misallocation". Mimeo.

Ferreira, F. (2010). “You Can Take It With You: Proposition 13 Tax Benefits, Residential Mobility, and Willingness to Pay for Housing Amenities”. *Journal of Public Economics* 94.9–10, pp. 661–673.

Fuest, C., A. Peichl, and S. Siegloch (2018). “Do Higher Corporate Taxes Reduce Wages? Micro Evidence from Germany”. *American Economic Review* 108.2, pp. 393–418.

Glaeser, E. L. (2009). “The Death and Life of Cities”. In: *Making Cities Work: Prospects and Policies for Urban America*. Ed. by R. P. Inman. Princeton University Press, pp. 22–62.

Gyourko, J. and J. Tracy (1991). “The Structure of Local Public Finance and the Quality of Life”. *Journal of Political Economy* 99.4, pp. 774–806.

Hamilton, B. W. (1975). “Zoning and Property Taxation in a System of Local Governments”. *Urban Studies* 12.2, pp. 205–211.

– (1976). “Capitalization of Intrajurisdictional Differences in Local Tax Prices”. *American Economic Review* 66.5, pp. 743–753.

Heinberg, J. D. and W. E. Oates (1970). “The Incidence of Differential Property Taxes on Urban Housing: A Comment and Some Further Evidence”. *National Tax Journal* 23.1, pp. 92–98.

Hilber, C. A. L. and W. Vermeulen (2016). “The Impact of Supply Constraints on House Prices in England”. *Economic Journal* 126.591, pp. 358–405.

Hyman, D. N. and E. C. J. Pasour (1973). “Property Tax Differentials and Residential Rents in North Carolina”. *National Tax Journal* 26.2, pp. 303–307.

Kline, P. and E. Moretti (2014). “People, Places, and Public Policy: Some Simple Welfare Economics of Local Economic Development Programs”. *Annual Review of Economics* 6.1, pp. 629–662.

Lutz, B. (2015). “Quasi-Experimental Evidence on the Connection between Property Taxes and Residential Capital Investment”. *American Economic Journal: Economic Policy* 7.1, pp. 300–330.

Lyytikäinen, T. (2009). “Three-Rate Property Taxation and Housing Construction”. *Journal of Urban Economics* 65.3, pp. 305–313.

McCrary, J. (2007). “The Effect of Court-Ordered Hiring Quotas on the Composition and Quality of Police”. *American Economic Review* 97.1, pp. 318–353.

Melitz, M. J. (2003). “The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity”. *Econometrica* 71.6, pp. 1695–1725.

Michaillat, P. and E. Saez (2017). “Optimal Public Expenditure with Inefficient Unemployment”. Mimeo.

Mieszkowski, P. (1972). “The Property Tax: An Excise Tax Or a Profits Tax?” *Journal of Public Economics* 1.1, pp. 73–96.

Mieszkowski, P. and G. R. Zodrow (1989). “Taxation and The Tiebout Model: The Differential Effects of Head Taxes, Taxes on Land Rents, and Property Taxes”. *Journal of Economic Literature* 27.3, pp. 1098–1146.

Moretti, E. (2011). “Local Labor Markets”. In: *Handbook of Labor Economics*. Ed. by O. Ashenfelter and D. Card. Vol. 4B. North-Holland, pp. 1237–1313.

Oates, W. E. and W. A. Fischel (2016). “Are Local Property Taxes Regressive, Progressive, Or What?” *National Tax Journal* 69.2, pp. 415–434.

Orr, L. L. (1968). “The Incidence of Differential Property Taxes on Urban Housing”. *National Tax Journal* 21.3, pp. 253–262.

– (1970). “The Incidence of Differential Property Taxes: A Response”. *National Tax Journal* 23.1, pp. 99–101.

– (1972). “The Incidence of Differential Property Taxes on Urban Housing: Reply”. *National Tax Journal* 25.2, pp. 217–220.

Palmon, O. and B. A. Smith (1998). “New Evidence on Property Tax Capitalization”. *Journal of Political Economy* 106.5, pp. 1099–1111.

Plassmann, F. and T. N. Tideman (2000). “A Markov Chain Monte Carlo Analysis of the Effect of Two-Rate Property Taxes on Construction”. *Journal of Urban Economics* 47.2, pp. 216–247.

Poterba, J. M. (1984). “Tax Subsidies to Owner-Occupied Housing: An Asset-Market Approach”. *Quarterly Journal of Economics* 99.4, pp. 729–752.

Roback, J. (1982). “Wages, Rents, and the Quality of Life”. *Journal of Political Economy* 90.6, pp. 1257–1278.

Rosen, S. (1979). “Wage-Based Indexes of Urban Quality of Life”. In: *Current Issues in Urban Economics*. Ed. by P. Mieszkowski and M. Straszheim. Baltimore: Johns Hopkins University Press, pp. 74–104.

Saiz, A. (2010). “The Geographic Determinants of Housing Supply”. *Quarterly Journal of Economics* 125.3, pp. 1253–1296.

Samuelson, P. A. (1954). “The Pure Theory of Public Expenditure”. *Review of Economics and Statistics* 36.4, pp. 387–389.

Schönholzer, D. and C. Zhang (2017). “Valueing Local Public Goods using Municipal Annexations”. *mimeo*.

Shan, H. (2010). “Property Taxes and Elderly Mobility”. *Journal of Urban Economics* 67.6, pp. 194–205.

Simon, D. (2016). “Does Early Life Exposure to Cigarette Smoke Permanently Harm Childhood Welfare? Evidence from Cigarette Tax Hikes”. *American Economic Journal: Applied Economics* 8.4, pp. 128–159.

Smith, M., D. Yagan, O. Zidar, and E. Zwick (2017). “Capitalists in the Twenty-First Century”. Mimeo.

Spahn, P. B. (2004). “Land Taxation in Germany”. In: *International Handbook of Land and Property Taxation*. Ed. by R. M. Bird and N. E. Slack. Edward Elgar Publishing, pp. 98–106.

Suárez Serrato, J. C. and O. Zidar (2016). “Who Benefits from State Corporate Tax Cuts? A Local Labor Market Approach with Heterogeneous Firms”. *American Economic Review* 106.9, pp. 2582–2624.

Thorsnes, P. (1997). “Consistent Estimates of the Elasticity of Substitution between Land and Non-Land Inputs in the Production of Housing”. *Journal of Urban Economics* 42.1, pp. 98–108.

Tiebout, C. M. (1956). “A Pure Theory of Local Expenditures”. *Journal of Political Economy* 64.5, pp. 416–424.

Zodrow, G. R. (2001). “The Property Tax as a Capital Tax: A Room with Three Views”. *National Tax Journal* 54.1, pp. 139–156.

Zucman, G. (2015). “Taxing across Borders: Tracking Personal Wealth and Corporate Profits”. *Journal of Economic Perspectives* 28.4, pp. 121–148.

A Data Appendix

Table A.1: Definition of Variables and Data Sources

Variable	Years	Source
Property Tax Rates	1970–2017	The local property tax rate is calculated as the product of local property tax multipliers and an average federal tax rate of 0.32 percent. Data on property tax multipliers is provided by the Federal Statistical Office and the Statistical Offices of the federal states. Data for the period 1998–2017 are published by the Statistical Offices (*Hebesätze der Realsteuern*), data prior to 1998 were provided by the Statistical Offices of the federal states and are partly available online.
Net Rents	1972–2013	Data on quoted net rents are provided as indices for different market segments in the *IVD-Wohn-Preisspiegel* by the German real estate association IVD (*Immobilienverband Deutschland*). We validate these indices against county-level data from *empirica Preisdatenbank* for 2004–2013, *bulwiengesa AG (RIWIS)* for 1990–2013, and the German micro census provided by the RDC of the Federal Statistical Office and Statistical Offices of the Länder (1998, 2002, 2004, 2010, 2014).
House Prices	1972–2013	Data on quoted house prices are provided by the German real estate association IVD in the *IVD-Wohn-Preisspiegel* in addition to data on net rents.
Housing Stock	2001–2015	Data on the number of apartments (*Wohnungen in Wohn- und Nichtwohngebäuden*) and the number of residential buildings (*Wohngebäude*) in a municipality are provided by the Federal Statistical Office and the Statistical Offices of the federal states. Data for the years 2001–2007 stem from the database *Statistik lokal*, data for later years are published online in the database *Regionalstatistik*.
Wages	1999–2008	Data on wages as of June 30 are available in the linked employer-employee data of the Institute for Employment Research (LIAB, see Alda et al., 2005). The data set is based on a 1 % stratified random sample of all German establishments and contains information on all employees working in these plants. Sampling is based on the location of the establishment not the residence of the worker. Social security data covers more than 80 percent of the work force in Germany but excludes civil servants and self-employed individuals.
	1996–2009 (counties)	Data on yearly wages in German counties are provided by the Working Group Regional Accounts (*Volkswirtschaftliche Gesamtrechnung der Länder, Revision 2005*). We restrict the sample to city counties (*kreisfreie Städte*) and discard rural counties that contain more than one municipality to avoid measurement error.
Population	1970–2017	Data on municipal population are provided by the Federal Statistical Office and the Statistical Offices of the federal states combined with local property tax multipliers.
Employment	1996–2009 (counties)	Data on the average number of employed individuals in a county come from the official employment statistics of the Federal Statistical Office and the Statistical Offices of the federal states. We restrict the sample to city counties (*kreisfreie Städte*) and discard rural counties that contain more than one municipality to avoid measurement error.
Plants	1999–2012 (counties)	Yearly data on the number of establishments in a county come from the Federal Employment Agency (*Bundesagentur für Arbeit*). We restrict the sample to city counties (*kreisfreie Städte*) and discard rural counties that contain more than one municipality to avoid measurement error.

continued

Table A.1 continued

Variable	Years	Source
Land Prices	1995–2013 (counties)	Data on land transaction prices are provided online in the database *Regionalstatistik* for all German counties by the Federal Statistical Office and the Statistical Offices of the federal states. We restrict the sample to city counties (*kreisfreie Städte*) and discard rural counties that contain more than one municipality to avoid measurement error.
Land Use	2008–2015	Data on land use in German municipalities is provided online in the database *Regionalstatistik* by the Federal Statistical Office and the Statistical Offices of the federal states. We use the area covered by buildings and the surrounding land assigned to residential or commercial use (*Gebäude- und Freifläche*, measured in hectare) as our indicator of land used for construction.
Spending/Revenues	1998–2008	Data on municipal revenues and municipal spending are provided by the Federal Statistical Office and the Statistical Offices of the federal states. Data for the years 2001–2008 stem from the database *Statistik lokal*, data prior to 2001 come from the Statistical Offices of the federal states.
Local GDP	1992–2009 (counties)	Data on the gross domestic product in a German county is provided by the Working Group Regional Accounts (*Volkswirtschaftliche Gesamtrechnung der Länder, Revision 2005*). We restrict the sample to city counties (*kreisfreie Städte*) and discard rural counties that contain more than one municipality to avoid measurement error.
Unemployment	1998–2013	The number of unemployed individuals in a municipality is published by the Federal Employment Agency (*Bundesagentur für Arbeit, Arbeitslose nach Gemeinden*).

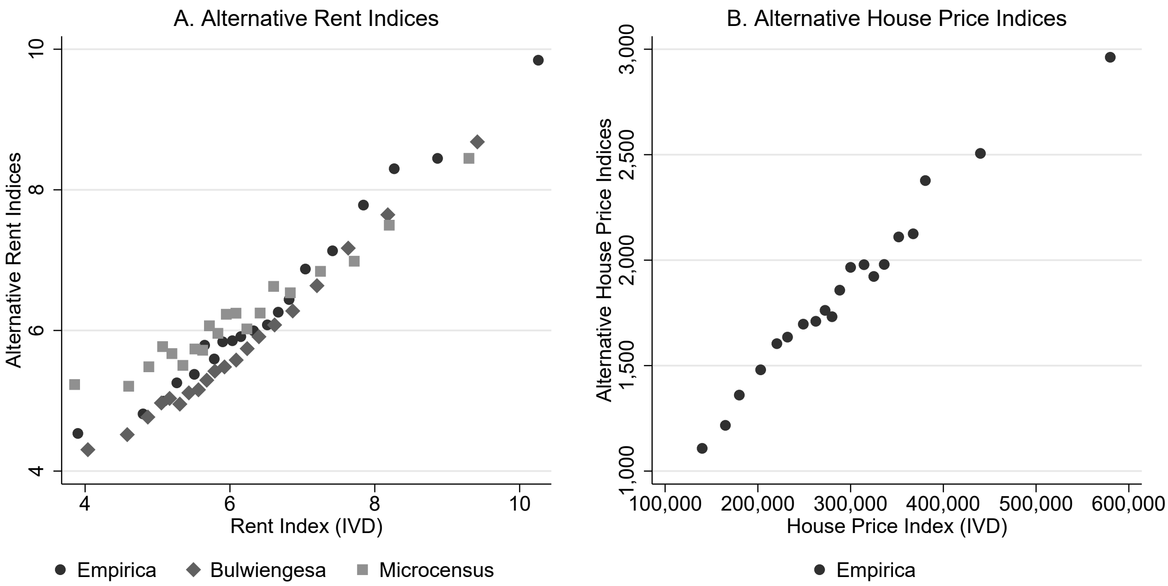
Notes: This table summarizes the definition of variables used in our empirical analysis and provides details on the data sources.

Table A.2: Descriptive Statistics

	Mean	SD	P25	P50	P75	Min	Max	N
Panel A – Price Data Sample								
Local Property Tax Rate	1.20	0.22	1.04	1.18	1.33	0.26	2.49	5,593
Number of Tax Changes 1992–2017	5.88	2.49	4.00	6.00	8.00	0.00	15.00	5,593
Change in Property Tax Rate	0.02	0.06	0.00	0.00	0.00	-0.51	0.94	5,531
Log Population	11.06	1.17	10.34	10.98	11.74	6.25	14.41	5,593
Log Houses	9.34	0.93	8.85	9.36	9.85	6.54	12.40	2,840
Log Apartments	10.18	1.12	9.47	10.12	10.87	7.20	13.72	2,840
Log Wage	3.11	0.08	3.05	3.10	3.14	2.93	3.48	840
Log Land Price	5.11	0.70	4.65	5.15	5.60	1.53	7.29	1,296
Log Land Sales	3.62	1.19	2.89	3.74	4.43	0.00	6.93	1,391
Log District Plants	8.36	0.80	7.75	8.26	8.84	6.85	10.85	1,054
Log Employment	9.90	1.28	9.16	9.88	10.71	5.25	13.66	3,969
Log Net Rent	1.73	0.31	1.53	1.74	1.94	0.57	3.77	41,779
Log House Price	12.31	0.50	11.99	12.29	12.61	4.59	14.36	37,072
Log Flat Price	7.30	0.45	7.02	7.35	7.60	4.61	9.39	27,858
Panel B – Full Sample								
Local Property Tax Rate	0.98	0.19	0.86	0.96	1.08	0.00	3.06	277,182
Number of Tax Changes 1992–2017	5.03	2.55	3.00	5.00	6.00	0.00	19.00	277,182
Change in Property Tax Rate	0.01	0.05	0.00	0.00	0.00	-3.06	2.04	268,769
Log Population	7.64	1.40	6.75	7.60	8.60	1.10	14.40	277,182
Log Houses	6.32	1.32	5.45	6.31	7.27	0.00	11.37	90,383
Log Apartments	6.70	1.43	5.72	6.66	7.73	0.00	12.64	90,383

Notes: This table presents descriptive statistics on the variables used. For detailed information on all variables, see Appendix Table A.1.

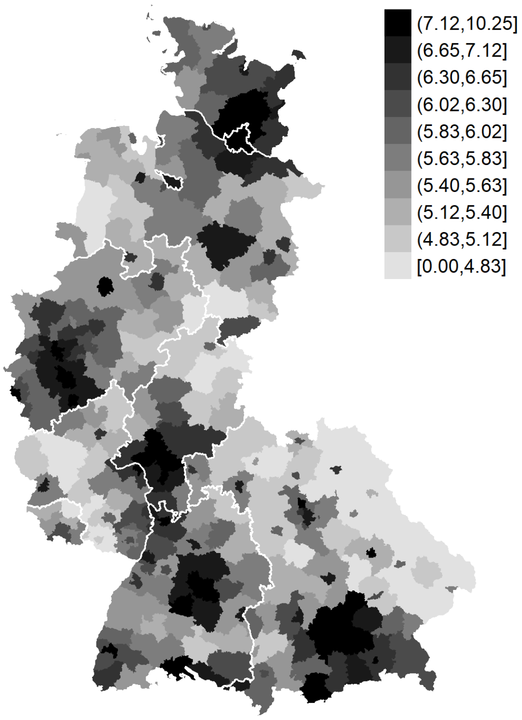
Figure A.1: Alternative Rent and House Price Measures



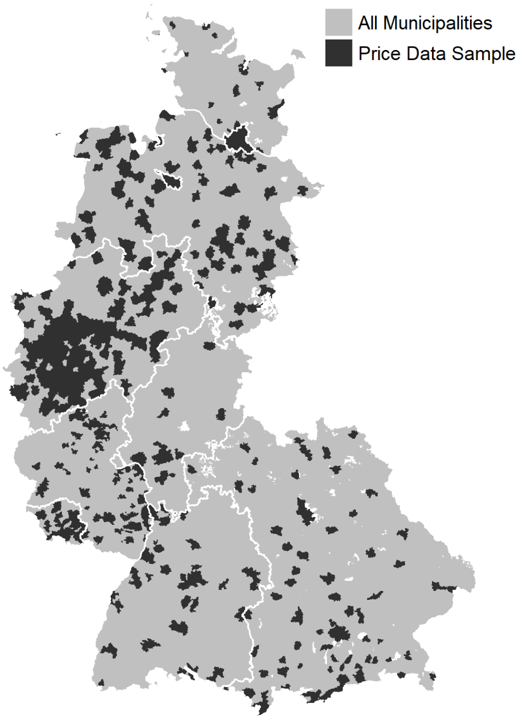
Notes: Panel A shows binned scatter plots for alternative rent price indices relative to our baseline IVD data. Panel B plots binned scatter plots for an alternative house price index, empirica prices are measured per square meter, IVD prices refer to total prices. Rents and prices measured in EUR. *Sources:* IVD-Wohn-Preisspiegel 1970–2013; empirica Preisdatenbank; bulwiengesa AG, RIWIS; RDC of the Federal Statistical Office and Statistical Offices of the Länder, Microcensus, 1998–2010, own calculations.

Figure A.2: Rents and Housing Price Data in West Germany

A. Average County-Level Rents in 2010 (in EUR)

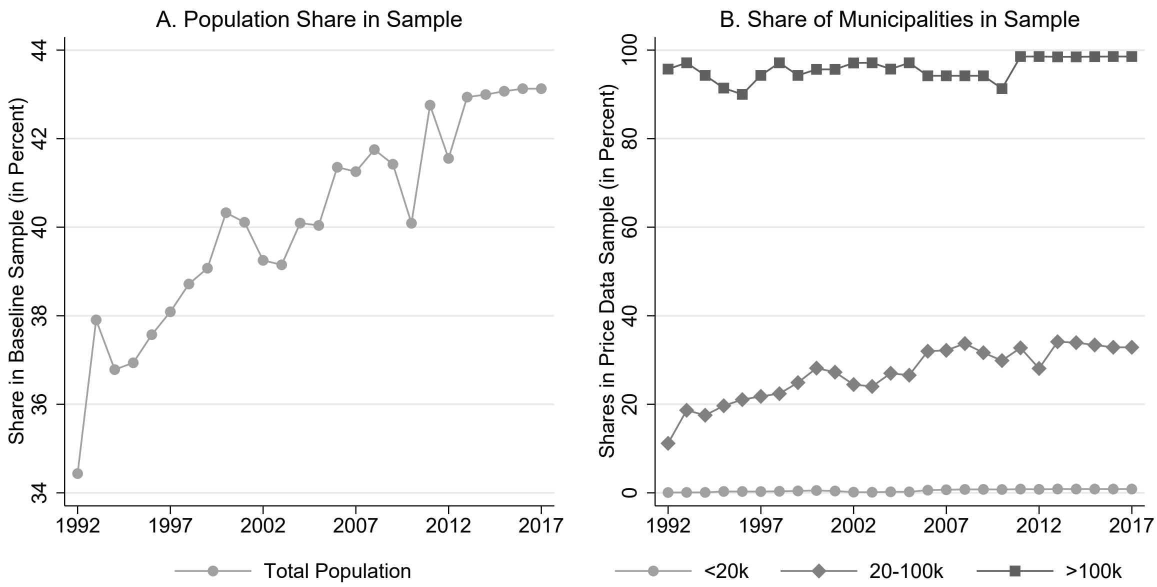


B. Regional Spread of Price Data Sample



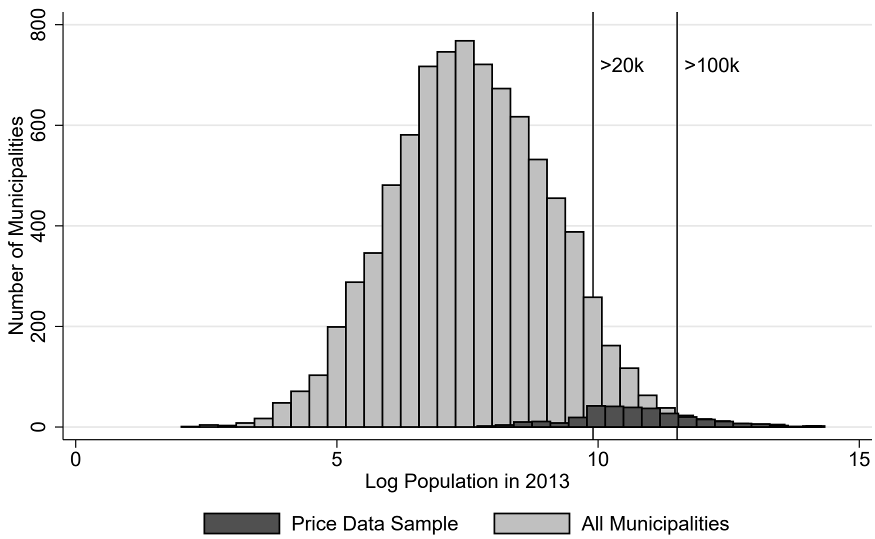
Notes: The left panel of this figure shows average residential rents in 2010 at the county level (measured in 2010 EUR). The right panel shows the geographical distribution of the base sample for which we have house price data. Jurisdictional boundaries are as of December 31, 2010. White lines indicate federal state borders. *Sources:* RDC of the Federal Statistical Office and Statistical Offices of the Länder, Microcensus, 2010, own calculations; IVD-Wohn-Preisspiegel 1970–2013. *Maps:* © GeoBasis-DE / BKG 2015.

Figure A.3: Share of Population and Municipalities in Price Data Sample (in Percent)



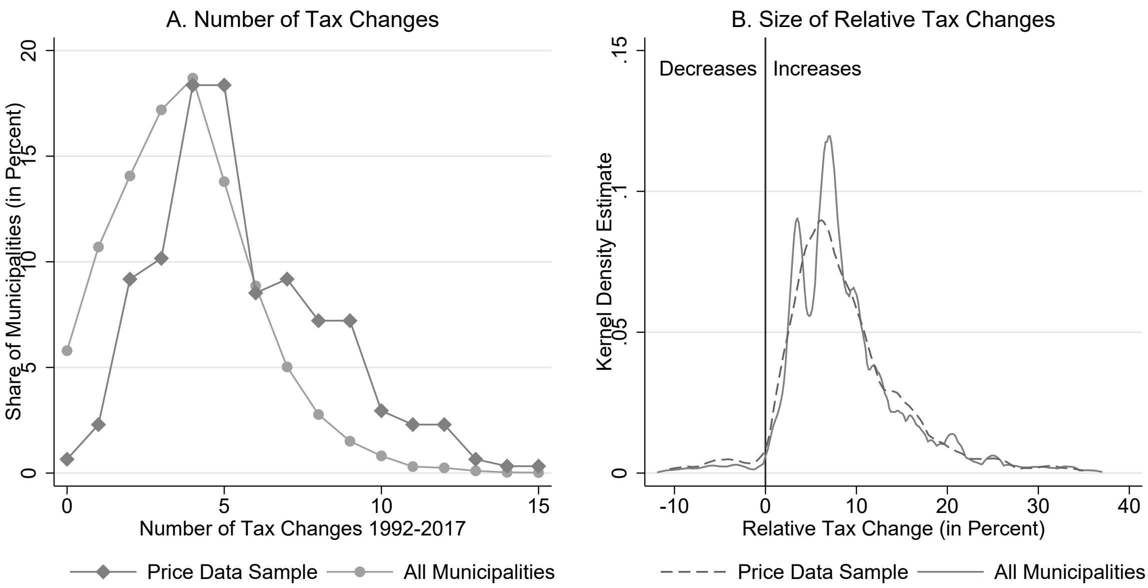
Notes: Panel A plots the share of the West German population that is included in our price data IVD estimation sample over time. Panel B shows the share of West German municipalities that is included in the price data estimation sample over time and by municipality size.

Figure A.4: Number of Municipalities by Size



Notes: This figure plots the size distribution of all municipalities in West Germany in light grey and the size distribution of municipalities in our price data estimation sample in dark grey. Size is measured as log population in 2013. Vertical lines indicate the population thresholds of 20,000 and 100,000 inhabitants. For details on all variables see Appendix Table A.1.

Figure A.5: Number and Size of Tax Changes



Notes: Panel A plots the distribution of the number of tax changes in the period 1992–2017 for all West German municipalities and for the municipalities in our price data sample. Panel B shows the kernel density estimate of the size distribution of relative tax changes for both groups of municipalities (excluding zeros and truncated at the bottom and top one percent). For details on all variables see Appendix Table A.1.

B Appendix: Theoretical Model

In this appendix, we provide an extended and more detailed description of our spatial equilibrium model outlined in Section 2 of the paper. Most importantly, it includes all derivations and intermediate steps needed to solve the model and analyze the equilibrium properties. The appendix is self-contained and consequently reiterates and replicates parts of Section 2 of the paper.

We introduce local property taxation into a Rosen-Roback type general equilibrium model of local labor markets (Moretti, 2011). There are $N = 1$ workers that locate in one out of C cities. The model consists of four groups of agents: workers, firms, construction companies and land owners. We solve for the spatial equilibrium and 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.

B.1 Workers

We assume that labor is homogeneous and each worker, i, provides inelastically one unit of labor. Each worker earns a wage w_c and pays rent r_c^H for residential floor space.[23] 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.[24] 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:

$$\max_{h_i, x_i} U_{ic} = A_c G_c^{\delta} \left(h_i^{\alpha} x_i^{1-\alpha} \right)^{1-\delta} e_{ic} \qquad \text{s.t. } r_c^H (1 + t_c) h_i + p x_i = w_c \tag{B.1}$$

with the bundle x_i of non-housing goods Z and the normalized aggregate price index p defined as in Melitz (2003):

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

and $h_i, x_{iz}, A_c, G_c, r_c^H, w_c, t_c, p_{iz}, e_{ic} > 0$ 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,

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

[24] 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 (see Appendix B.9).

1977). The Lagrangian reads:

$$\max_{h_i,x_i} \mathcal{L} = \ln A_c + \delta \ln G_c + \alpha(1-\delta)h_i + (1-\alpha)(1-\delta)\ln x_i + \ln e_{ic} + \lambda\left(w_c - r_c^H[1+t_c]h_i - x_i\right) \tag{B.3}$$

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

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

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

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

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

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

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 $x_{iz}^* = (1-\alpha)w_c p_{iz}^{-\frac{1}{1-\rho}}$. Using the optimal consumption quantities, log indirect utility is defined as:

$$\begin{aligned}
V_{ic}^H &= \ln U(h_i^*, x_i^*, A_c, G_c, e_{ic}) \\
&= \alpha(1-\delta)\ln h_i^* + (1-\alpha)(1-\delta)\ln x_i^* + \ln A_c + \delta \ln G_c + \ln e_{ic} \\
&= \alpha(1-\delta)\ln\left(\alpha\frac{w_c}{r_c^H(1+t_c)}\right) + (1-\alpha)(1-\delta)\ln\left([1-\alpha]w_c\right) + \ln A_c + \delta\ln G_c + \ln e_{ic}
\end{aligned}$$

$$
\begin{aligned}
&= \underbrace{(1-\delta)\left(\alpha \ln \alpha + [1-\alpha]\ln[1-\alpha]\right)}_{=a_0} + \ln A_c + \delta \ln G_c + \ln e_{ic} \\
&\quad + (1-\delta)(\alpha \ln w_c - \alpha \ln r_c^H - \alpha \ln[1+t_c] + (1-\alpha)\ln w_c) \\
V_{ic}^H &= a_0 + \underbrace{(1-\delta)(\ln w_c - \alpha \ln r_c^H - \alpha \ln[1+t_c]) + \ln A_c + \delta \ln G_c}_{=V_c^H} + \ln e_{ic}.
\end{aligned}
$$

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 $\frac{w_c}{r_c^H(1+t_c)}$ 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:

$$
\begin{aligned}
\ln N_c^S &= \frac{V_c^H}{\sigma^H} \underbrace{- \ln\left(C\pi^H\right)}_{=a_1} \\
\ln N_c^S &= \underbrace{\frac{1-\delta}{\sigma^H}}_{=\epsilon^{\text{NS}}} \ln w_c \underbrace{-\frac{\alpha(1-\delta)}{\sigma^H}}_{=1+\epsilon^{\text{HD}}} \ln r_c^H \underbrace{-\frac{\alpha(1-\delta)}{\sigma^H}}_{=1+\epsilon^{\text{HD}}} \ln \tau_c + \underbrace{\frac{1}{\sigma^H}}_{=\epsilon^{\text{A}}} \ln A_c + \frac{\delta}{\sigma^H} \ln G_c + a_1 \qquad \text{(B.6)}
\end{aligned}
$$

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:

$$\frac{\partial \ln N_c^S}{\partial \ln w_c} = \frac{1-\delta}{\sigma^H} = \epsilon^{\text{NS}} > 0. \tag{B.7}$$

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 (B.4):

$$\begin{aligned} H_c &= N_c h_i^* = N_c \alpha \frac{w_c}{r_c^H(1+t_c)} \\ \ln H_c &= \ln N_c + \ln \alpha + \ln w_c - \ln r_c^H - \ln \tau_c. \end{aligned} \tag{B.8}$$

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:

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

B.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:

$$\begin{aligned} \Pi_{jc}^F &= p_{jc}Y_{jc} - w_c N_{jc} - r_c^M(1+t_c)\kappa M_{jc} \\ Y_{jc} &= B_c \omega_{jc} N_{jc}^{\beta} M_{jc}^{1-\beta} \end{aligned} \tag{B.9}$$

with $Y_{jc}, N_{jc}, M_{jc}, p_{jc}, w_c, r_c^M > 0$. w_c 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:

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

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

$$\Pi^F_{jc} = Q^{1-\rho} \underbrace{\left(B_c \omega_{jc} N^{\beta}_{jc} M^{1-\beta}_{jc}\right)^{\rho}}_{=Y_{jc}} - w_c N_{jc} - r^M_c (1+t_c)\kappa M_{jc} \tag{B.10}$$

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:

$$\begin{aligned}
\frac{\partial \Pi^F_{jc}}{\partial N_{jc}} &= \rho\beta Q^{1-\rho} B^{\rho}_c \omega^{\rho}_{jc} N^{\rho\beta-1}_{jc} M^{\rho(1-\beta)}_{jc} - w_c \overset{!}{=} 0 \\
\frac{\partial \Pi^F_{jc}}{\partial M_{jc}} &= \rho(1-\beta) Q^{1-\rho} B^{\rho}_c \omega^{\rho}_{jc} N^{\rho\beta}_{jc} M^{\rho(1-\beta)-1}_{jc} - r^M_c (1+t_c)\kappa \overset{!}{=} 0.
\end{aligned}$$

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:

$$\begin{aligned}
\ln\left(r^M_c \tau_c \kappa\right) &= \ln\rho + \ln(1-\beta) + (1-\rho)\ln Q + \rho \ln B_c + \rho\ln\omega_{jc} + \rho\beta\ln N_{jc} \\
&\quad - (1-\rho[1-\beta])\ln M_{jc} \\
\ln M_{jc} &= \Big(\ln\rho + \ln[1-\beta] + [1-\rho]\ln Q + \rho\ln B_c + \rho\ln\omega_{jc} + \rho\beta\ln N_{jc} \\
&\quad - \ln r^M_c - \ln[\tau_c\kappa]\Big) \Big/ \Big(1-\rho[1-\beta]\Big).
\end{aligned} \tag{B.11}$$

We can derive log labor demand from the first first-order condition using the conditional factor demand for commercial floor space from equation (B.11):

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

Using equation (B.11) from above and firm j's labor demand in city c we can also solve for the commercial floor space demand of firm j:

$$\ln M_{jc}^* = \Big(\ln \rho + \rho\beta \ln \beta + [1-\rho\beta] \ln[1-\beta] + [1-\rho] \ln Q + \rho \ln B_c - \rho\beta \ln w_c \\ - [1-\rho\beta] \ln r_c^M - [1-\rho\beta] \ln[\tau_c \kappa] + \rho \ln \omega_{jc} \Big) \Big/ \Big(1-\rho\Big) \tag{B.13}$$

Equations (B.12) and (B.13) define the factor input demand conditional on local productivity and factor prices. We can now substitute the factor demand in the firm profit equation (B.10) and rewrite profits as a function of factor prices:

$$\Pi_{jc}^F = Q^{1-\rho} \underbrace{\Big(B_c \omega_{jc} N_{jc}^{\beta} M_{jc}^{1-\beta}\Big)^{\rho}}_{=Y_{jc}} - w_c N_{jc} - r_c^M \tau_c \kappa M_{jc}$$

$$\Pi_{jc}^F(N_{jc}^*, M_{jc}^*) = B_c^{\frac{\rho}{1-\rho}} \omega_{jc}^{\frac{\rho}{1-\rho}} w_c^{-\frac{\rho\beta}{1-\rho}} r_c^{M^{-\frac{\rho(1-\beta)}{1-\rho}}} (\tau_c\kappa)^{-\frac{\rho(1-\beta)}{1-\rho}} Q \rho^{\frac{\rho}{1-\rho}} \beta^{\frac{\rho\beta}{1-\rho}} (1-\beta)^{\frac{\rho(1-\beta)}{1-\rho}} (1-\rho)$$

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., $1-\rho = -1/\epsilon^{\text{PD}}$. The more elastic product demand ($\epsilon^{\text{PD}} \downarrow$), 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:

$$V_{jc}^F = \frac{1-\rho}{\rho} \ln \Pi_{jc}^F(N_{jc}^*, M_{jc}^*) = b_0 + \underbrace{\ln B_c - \beta \ln w_c - (1-\beta) \ln r_c^M - (1-\beta) \ln(\tau_c \kappa)}_{=V_c^F} + \ln \omega_{jc}$$

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:

$$F_c = \Pr\Big(V_{jc}^F \geq V_{jk}^F, \forall k \neq c\Big) = \frac{\exp\left(V_c^F/\sigma^F\right)}{\sum_{g=1}^{C} \exp\Big(V_g^F/\sigma^F\Big)}. \tag{B.14}$$

The number of firms in city c from equation (B.14) (extensive margin) and the firm-specific labor demand from equation (B.12) (intensive margin) define the aggregate log labor demand in city c:

$$\ln N_c^D = \ln F_c + \mathrm{E}_{\omega_{jc}}\Big[\ln N_{jc}^*\Big] \\ = \frac{1}{\sigma^F} \ln B_c - \frac{\beta}{\sigma^F} \ln w_c - \frac{1-\beta}{\sigma^F} \ln r_c^M - \frac{1-\beta}{\sigma^F} \ln(\tau_c\kappa) - \ln\Big(C\pi^F\Big) \\ + \frac{\rho}{1-\rho} \ln B_c - \frac{1-\rho+\rho\beta}{1-\rho} \ln w_c - \frac{\rho(1-\beta)}{1-\rho} \ln r_c^M - \frac{\rho(1-\beta)}{1-\rho} \ln(\tau_c\kappa)$$

$$+\frac{1}{1-\rho}\ln\rho+\frac{1-\rho+\rho\beta}{1-\rho}\ln\beta+\frac{\rho(1-\beta)}{1-\rho}\ln(1-\beta)+\ln Q+\frac{\rho}{1-\rho}\mathrm{E}_{\omega_{jc}}\left[\ln\omega_{jc}\right]$$

$$\ln N_c^D=\underbrace{\left(\frac{1}{\sigma^F}+\frac{\rho}{1-\rho}\right)}_{=\epsilon^{\mathrm{B}}}\ln B_c\underbrace{-\left(1+\beta\left[\frac{1}{\sigma^F}+\frac{\rho}{1-\rho}\right]\right)}_{=\epsilon^{\mathrm{ND}}}\ln w_c\underbrace{-(1-\beta)\left(\frac{1}{\sigma^F}+\frac{\rho}{1-\rho}\right)}_{=1+\epsilon^{\mathrm{MD}}}\ln r_c^M$$

$$\underbrace{-(1-\beta)\left(\frac{1}{\sigma^F}+\frac{\rho}{1-\rho}\right)}_{=1+\epsilon^{\mathrm{MD}}}\ln(\tau_c\kappa)+b_1 \tag{B.15}$$

as a function of local productivity B_c, wages w_c 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:

$$\frac{\ln N_c^D}{\ln w_c}=\underbrace{-\frac{\beta}{\sigma^F}}_{\text{Ext. margin}}\underbrace{-1-\frac{\beta\rho}{1-\rho}}_{\text{Int. margin}}=\epsilon^{\mathrm{ND}}<0. \tag{B.16}$$

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 (B.13) and the location choice of firms from equation (B.14):

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

$$\ln M_c^D=\underbrace{\left(\frac{1}{\sigma^F}+\frac{\rho}{1-\rho}\right)}_{=\epsilon^{\mathrm{B}}}\ln B_c\underbrace{-\beta\left(\frac{1}{\sigma^F}+\frac{\rho}{1-\rho}\right)}_{=1+\epsilon^{\mathrm{ND}}}\ln w_c\underbrace{-\left(1+[1-\beta]\left[\frac{1}{\sigma^F}+\frac{\rho}{1-\rho}\right]\right)}_{=\epsilon^{\mathrm{MD}}}\ln r_c^M$$

$$\underbrace{-\left(1+[1-\beta]\left[\frac{1}{\sigma^F}+\frac{\rho}{1-\rho}\right]\right)}_{=\epsilon^{\mathrm{MD}}}\ln(\tau_c\kappa)+b_2 \tag{B.17}$$

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:

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

B.3 Construction Sector

We assume that a competitive, local construction sector provides both types of housing, residential and commercial floor space. Every municipality has positive supply of residential housing H_c and commercial floor space M_c. Following Ahlfeldt et al. (2015), we define the two types of floor space in terms of total floor space S_c available in city c:

$$H_c = \mu S_c \qquad\qquad M_c = (1-\mu)S_c \tag{B.18}$$

with residential share $\mu \in [0,1]$. This share is exogeneously given, and determined by the additional regulatory costs of commercial land, denoted $\phi \geq 1$. In equlibrium there must be a no-arbitrage condition between residential and commericial floor space:

$$r_c^M = \phi r_c^H \tag{B.19}$$

In line with Ahlfeldt et al. (2015), we assume that the observed floor price in the data is the maximum of residential and commercial rents, r_c^M. This implies that (i) observed residential rents are higher due existing regulatory costs, and (ii) both types of floor space are offered, $0 < \mu < 1$.

The 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 $S_c = H_c + M_c$ (Epple et al., 2010). In contrast to the capital tax literature, we assume global capital markets with unlimited supply at an exogenous rate (Oates and Fischel, 2016). Consequently, the price for capital s is given and constant across municipalities. Profits in the construction industry are given by:

$$\Pi_c^C = r_c^M \underbrace{L_c^\gamma K_c^{1-\gamma}}_{=S_c} - l_c L_c - sK_c \tag{B.20}$$

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:

$$\ln s = \ln(1-\gamma) + \ln r_c^M + \ln S_c - \ln K_c$$
$$\ln s = \ln(1-\gamma) + \ln r_c^M + \gamma \ln L_c + (1-\gamma) \ln K_c - \ln K_c$$

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

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:

$$\begin{aligned}
\ln l_c &= \ln\gamma + \ln r_c^M + \ln S_c - \ln L_c \\
&= \ln\gamma + \ln r_c^M + \gamma\ln L_c + (1-\gamma)\ln K_c - \ln L_c \\
&= \ln\gamma + \ln r_c^M - (1-\gamma)\ln L_c + \frac{1-\gamma}{\gamma}\Big(\ln(1-\gamma) + \ln r_c^M + \gamma\ln L_c - \ln s\Big) \\
&= \underbrace{\ln\gamma + \frac{1-\gamma}{\gamma}\ln(1-\gamma)}_{=c_0} - \frac{1-\gamma}{\gamma}\ln s - \frac{1}{\gamma}\ln r_c^M \\
\ln l_c &= c_0 - \frac{1-\gamma}{\gamma}\ln s + \frac{1}{\gamma}\ln r_c^M
\end{aligned} \tag{B.21}$$

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^H).

B.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:

$$\ln L_c = \theta \ln l_c \tag{B.22}$$

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

B.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:

$$\begin{aligned}
G_c &= \psi \underbrace{\Big(H_c r_c^H t_c + M_c r_c^M \left[\{1+t_c\}\kappa - 1\right]\Big)}_{\text{Total tax revenue}} \\
\ln G_c &= \ln\psi + \ln\Big(H_c r_c^H t_c + M_c r_c^M \left[\{1+t_c\}\kappa - 1\right]\Big),
\end{aligned} \tag{B.23}$$

where total tax revenue is the sum of residential property taxes, $H_c r_c^H t_c$, 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 an mechanical increase in local spending on the public good.

B.6 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:

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

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

$$\ln N_c = \epsilon^{\text{NS}}\ln w_c + (1+\epsilon^{\text{HD}})\ln r_c^H + (1+\epsilon^{\text{HD}})\ln\tau_c + \epsilon^{\text{A}}\ln A_c + \delta\epsilon^{\text{A}}\ln G_c + a_1 \tag{B.24}$$

$$\ln N_c = \epsilon^{\text{B}}\ln B_c + \epsilon^{\text{ND}}\ln w_c + (1+\epsilon^{\text{MD}})\ln r_c^M + (1+\epsilon^{\text{MD}})\ln(\tau_c\kappa) + b_1 \tag{B.25}$$

$$\ln H_c = \ln N_c + \ln\alpha + \ln w_c - \ln r_c^H - \ln\tau_c \tag{B.26}$$

$$\ln H_c = \ln\mu + \ln S_c \tag{B.27}$$

$$\ln M_c = \epsilon^{\text{B}}\ln B_c + (1+\epsilon^{\text{ND}})\ln w_c + \epsilon^{\text{MD}}\ln r_c^M + \epsilon^{\text{MD}}\ln(\tau_c\kappa) + b_2 \tag{B.28}$$

$$\ln M_c = \ln(1-\mu) + \ln S_c \tag{B.29}$$

$$\ln S_c = (1-\gamma)\ln K_c + \gamma\ln L_c \tag{B.30}$$

$$\ln K_c = \ln L_c + \frac{1}{\gamma}\ln r_c^M + \frac{1}{\gamma}\ln(1-\gamma) - \frac{1}{\gamma}\ln s \tag{B.31}$$

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

Key Elasticity	Definition
Panel A – Labor Market	
Labor Supply	
Wages	$\epsilon^{\text{NS}} = \frac{\partial \ln N_c}{\partial \ln w_c} = \frac{1-\delta}{\sigma^H}$
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	
Wages	$\epsilon^{\text{ND}} = \frac{\partial \ln N_c}{\partial \ln w_c} = -\left(1 + \beta\left[\frac{1}{\sigma^F} + \frac{\rho}{1-\rho}\right]\right)$
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	$\epsilon^{\text{HD}} = \frac{\partial \ln H_c}{\partial \ln r_c^H} = -\frac{\alpha(1-\delta)+\sigma^H}{\sigma^H}$
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 spatial equilibrium model.

$$\ln L_c = \theta \ln l_c \tag{B.32}$$

$$\ln l_c = c_0 - \frac{1-\gamma}{\gamma}\ln s + \frac{1}{\gamma}\ln r_c^M \tag{B.33}$$

$$\ln r_c^M = \ln \phi + \ln r_c^H \tag{B.34}$$

$$\ln G_c = \ln \psi + \ln\left(H_c r_c^H t_c + M_c r_c^M[\{1+t_c\}\kappa - 1]\right) \tag{B.35}$$

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

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 (B.24) and (B.26), we get the following expression:

$$\ln H_c^D = a_1 + \ln\alpha + \epsilon^{\text{A}}\ln A_c + \delta\epsilon^{\text{A}}\ln G_c + \epsilon^{\text{HD}}\ln r_c^H + \epsilon^{\text{HD}}\ln\tau_c + \left(1+\epsilon^{\text{NS}}\right)\ln w.$$

By clearing the labor market, i.e., equating expressions (B.24) and (B.25), we can derive wages as a function of amenities, public goods, and floor space prices:

$$\begin{aligned}\ln w_c = \Big(&b_1 - a_1 - \epsilon^{\text{A}}\ln A_c - \delta\epsilon^{\text{A}}\ln G_c + \epsilon^{\text{B}}\ln B_c - \left[1+\epsilon^{\text{HD}}\right]\ln\tau_c + \left[1+\epsilon^{\text{MD}}\right]\ln[\tau_c\kappa] \\ &- \left[1+\epsilon^{\text{HD}}\right]\ln r_c^H + \left[1+\epsilon^{\text{MD}}\right]\ln r_c^M\Big)\Big/\left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right).\end{aligned} \tag{B.36}$$

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:

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

and use the no-arbitrage condition in equation (B.34) to rewrite residential housing demand in terms of residential rents:

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

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

Definition B.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:

$$\begin{aligned}\ln H_c^D = \Big(& \left[1+\epsilon^{\mathrm{NS}}\right] b_1 - \left[1+\epsilon^{\mathrm{ND}}\right] a_1 + \left[1+\epsilon^{\mathrm{MD}}\right] \left[1+\epsilon^{\mathrm{NS}}\right] \ln \phi + \epsilon^{\mathrm{B}} \left[1+\epsilon^{\mathrm{NS}}\right] \ln B_c \\ & - \epsilon^{\mathrm{A}} \left[1+\epsilon^{\mathrm{ND}}\right] [\ln A_c + \delta \ln G_c] + \left[1+\epsilon^{\mathrm{MD}}\right] \left[1+\epsilon^{\mathrm{NS}}\right] \ln \kappa \Big) \Big/ \left(\epsilon^{\mathrm{NS}} - \epsilon^{\mathrm{ND}}\right) \\ & + \ln \alpha + \tilde{\epsilon}^{\mathrm{HD}} \ln r_c^H + \tilde{\epsilon}^{\mathrm{HD}} \ln \tau_c. \end{aligned} \tag{B.37}$$

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 (B.27) and equations (B.30)–(B.34):

$$\begin{aligned}\ln H_c^S &= \ln S_c + \ln \mu \\ &= \underbrace{(1-\gamma) \ln K_c + \gamma \ln L_c}_{=\ln S_c} + \ln \mu\end{aligned}$$

$$= \underbrace{(1-\gamma)\ln L_c + \frac{1-\gamma}{\gamma}\ln r_c^M + \frac{1-\gamma}{\gamma}\ln(1-\gamma) - \frac{1-\gamma}{\gamma}\ln s}_{=(1-\gamma)\ln K_c} + \gamma \ln L_c + \ln \mu$$

$$= \underbrace{\theta \ln l_c}_{=\ln L_c} + \frac{1-\gamma}{\gamma}\ln r_c^M + \frac{1-\gamma}{\gamma}\ln(1-\gamma) - \frac{1-\gamma}{\gamma}\ln s + \ln \mu$$

$$= \underbrace{\frac{\theta}{\gamma}\ln r_c^M - \frac{\theta(1-\gamma)}{\gamma}\ln s + \theta c_0}_{=\theta \ln l_c} + \frac{1-\gamma}{\gamma}\ln r_c^M + \frac{1-\gamma}{\gamma}\ln(1-\gamma) - \frac{1-\gamma}{\gamma}\ln s + \ln \mu$$

$$= \frac{1-\gamma+\theta}{\gamma}\ln r_c^M - \frac{(1+\theta)(1-\gamma)}{\gamma}\ln s + \frac{1-\gamma}{\gamma}\ln(1-\gamma) + \theta c_0 + \ln \mu$$

$$\ln H_c^S = \frac{1-\gamma+\theta}{\gamma}\underbrace{\left(\ln r_c^H + \ln \phi\right)}_{=\ln r_c^M} - \frac{(1+\theta)(1-\gamma)}{\gamma}\ln s + \frac{1-\gamma}{\gamma}\ln(1-\gamma) + \theta c_0 + \ln \mu.$$

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

Definition B.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:

$$\ln H_c^S = \tilde{\epsilon}^{\text{HS}}\ln r_c^H + \tilde{\epsilon}^{\text{HS}}\ln \phi - \frac{(1+\theta)(1-\gamma)}{\gamma}\ln s + \frac{1-\gamma}{\gamma}\ln(1-\gamma) + \theta c_0 + \ln \mu. \tag{B.38}$$

Rents. Using equations (B.37) and (B.38) we can clear the residential housing market and solve for equilibrium rents for residential floor space in city c as a function of equilibrium public good provision G_c^* and exogenous parameters:

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

$$\begin{aligned}
\ln r_c^{H*} = & \frac{\tilde{\epsilon}^{\text{HD}}}{d_0}\ln\tau_c - \frac{\delta\epsilon^{\text{A}}\left(1+\epsilon^{\text{ND}}\right)}{d_0\left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)}\ln G_c^* - \frac{\epsilon^{\text{A}}\left(1+\epsilon^{\text{ND}}\right)}{d_0\left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)}\ln A_c \\
& + \frac{\epsilon^{\text{B}}\left(1+\epsilon^{\text{NS}}\right)}{d_0\left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)}\ln B_c + \frac{\left(1+\epsilon^{\text{MD}}\right)\left(1+\epsilon^{\text{NS}}\right)}{d_0\left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right)}\ln\kappa + \frac{d_{r^H}}{d_0}
\end{aligned} \tag{B.39}$$

with

$$d_0 = \tilde{\epsilon}^{\mathrm{HS}} - \tilde{\epsilon}^{\mathrm{HD}} > 0 \tag{B.40}$$

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

Using the no-arbitrage condition in equation (B.34) we can solve for the equilibrium price of commercial floor space, again as a function of equilibrium local public goods:

$$\begin{aligned} \ln r_c^{M*} = &\frac{\tilde{\epsilon}^{\mathrm{HD}}}{d_0}\ln\tau_c - \frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln G_c^* - \frac{\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c \\ &+ \frac{\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{\left(1+\epsilon^{\mathrm{MD}}\right)\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln\kappa + \frac{d_{r^M}}{d_0} \end{aligned} \tag{B.41}$$

with

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

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 (B.36):

$$\begin{aligned} \ln w_c^* = &-\frac{\tilde{\epsilon}^{\mathrm{HS}}\left(\epsilon^{\mathrm{HD}}-\epsilon^{\mathrm{MD}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln\tau_c - \frac{\delta\epsilon^{\mathrm{A}}\left(\tilde{\epsilon}^{\mathrm{HS}}-\epsilon^{\mathrm{MD}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln G_c^* - \frac{\epsilon^{\mathrm{A}}\left(\tilde{\epsilon}^{\mathrm{HS}}-\epsilon^{\mathrm{MD}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c \\ &+ \frac{\epsilon^{\mathrm{B}}\left(\tilde{\epsilon}^{\mathrm{HS}}-\epsilon^{\mathrm{HD}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{\left(1+\epsilon^{\mathrm{MD}}\right)\left(\tilde{\epsilon}^{\mathrm{HS}}-\epsilon^{\mathrm{HD}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln\kappa + \frac{d_w}{d_0} \end{aligned} \tag{B.42}$$

with

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

Land Prices. The construction problem yields the relation between commercial floor space prices and land prices in equation (B.33). Solving for land prices yields:

$$\begin{aligned} \ln l_c^* = &\frac{\tilde{\epsilon}^{\mathrm{HD}}}{\gamma d_0}\ln\tau_c - \frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln G_c^* - \frac{\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c \\ &+ \frac{\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{\left(1+\epsilon^{\mathrm{MD}}\right)\left(1+\epsilon^{\mathrm{NS}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln\kappa + \frac{d_l}{\gamma d_0} \end{aligned} \tag{B.43}$$

with

$$d_l = \ln\alpha - \ln\mu - \frac{1-\gamma}{\gamma}\ln(1-\gamma) - \frac{1+\epsilon^{\mathrm{ND}}}{\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}}a_1 + \frac{1+\epsilon^{\mathrm{NS}}}{\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}}b_1 + (\gamma d_0 - \theta)\,c_0$$

$$+\frac{(1-\gamma)(1+\theta-\gamma d_0)}{\gamma}\ln s+\frac{1+\epsilon^{\text{NS}}+\epsilon^{\text{HD}}\left(1+\epsilon^{\text{ND}}\right)}{\epsilon^{\text{NS}}-\epsilon^{\text{ND}}}\ln\phi.$$

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

$$\ln L_c^* = \frac{\tilde{\epsilon}^{\text{HD}}\theta}{\gamma d_0}\ln\tau_c - \frac{\delta\theta\epsilon^{\text{A}}\left(1+\epsilon^{\text{ND}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln G_c^* - \frac{\theta\epsilon^{\text{A}}\left(1+\epsilon^{\text{ND}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln A_c + \frac{\theta\epsilon^{\text{B}}\left(1+\epsilon^{\text{NS}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln B_c + \frac{\theta\left(1+\epsilon^{\text{MD}}\right)\left(1+\epsilon^{\text{NS}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln\kappa + \frac{\theta d_l}{\gamma d_0}. \tag{B.44}$$

Capital Stock. Equilibrium land use and equilibrium floor space prices also determine the equilibrium capital stock in equation (B.31):

$$\ln K_c^* = \frac{\tilde{\epsilon}^{\text{HD}}(1+\theta)}{\gamma d_0}\ln\tau_c - \frac{\delta\epsilon^{\text{A}}(1+\theta)\left(1+\epsilon^{\text{ND}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln G_c^* - \frac{\epsilon^{\text{A}}(1+\theta)\left(1+\epsilon^{\text{ND}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln A_c + \frac{\epsilon^{\text{B}}(1+\theta)\left(1+\epsilon^{\text{NS}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln B_c + \frac{(1+\theta)\left(1+\epsilon^{\text{MD}}\right)\left(1+\epsilon^{\text{NS}}\right)}{\gamma d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln\kappa + \frac{d_K}{\gamma d_0} \tag{B.45}$$

with

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

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:

$$\ln S_c^* = \frac{\tilde{\epsilon}^{\text{HS}}\tilde{\epsilon}^{\text{HD}}}{d_0}\ln\tau_c - \frac{\tilde{\epsilon}^{\text{HS}}\delta\epsilon^{\text{A}}(1+\epsilon^{\text{ND}})}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln G_c^* - \frac{\tilde{\epsilon}^{\text{HS}}\epsilon^{\text{A}}(1+\epsilon^{\text{ND}})}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln A_c + \frac{\tilde{\epsilon}^{\text{HS}}\epsilon^{\text{B}}\left(1+\epsilon^{\text{NS}}\right)}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln B_c + \frac{\tilde{\epsilon}^{\text{HS}}\left(1+\epsilon^{\text{MD}}\right)\left(1+\epsilon^{\text{NS}}\right)}{d_0\left(\epsilon^{\text{NS}}-\epsilon^{\text{ND}}\right)}\ln\kappa + \frac{d_S}{\gamma d_0} \tag{B.46}$$

with

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

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

$$\ln H_c^* = \frac{\tilde{\epsilon}^{\mathrm{HS}}\tilde{\epsilon}^{\mathrm{HD}}}{d_0}\ln\tau_c - \frac{\tilde{\epsilon}^{\mathrm{HS}}\delta\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln G_c^* - \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c + \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{\tilde{\epsilon}^{\mathrm{HS}}\left(1+\epsilon^{\mathrm{MD}}\right)\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln\kappa + \frac{d_H}{\gamma d_0} \tag{B.47}$$

with

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

Similarly we can solve for equilibrium commercial floor space production:

$$\ln M_c^* = \frac{\tilde{\epsilon}^{\mathrm{HS}}\tilde{\epsilon}^{\mathrm{HD}}}{d_0}\ln\tau_c - \frac{\tilde{\epsilon}^{\mathrm{HS}}\delta\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln G_c^* - \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{A}}(1+\epsilon^{\mathrm{ND}})}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln A_c + \frac{\tilde{\epsilon}^{\mathrm{HS}}\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln B_c + \frac{\tilde{\epsilon}^{\mathrm{HS}}\left(1+\epsilon^{\mathrm{MD}}\right)\left(1+\epsilon^{\mathrm{NS}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}\ln\kappa + \frac{d_M}{\gamma d_0} \tag{B.48}$$

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:

$$\begin{aligned}\ln N_c^* = &-\frac{\tilde{\epsilon}^{\mathrm{HS}}\left(\epsilon^{\mathrm{ND}}\left[1+\epsilon^{\mathrm{HD}}\right]-\epsilon^{\mathrm{NS}}\left[1+\epsilon^{\mathrm{MD}}\right]\right)}{d_0\left(\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{ND}}\right)}\ln\tau_c - \frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{MD}}+\epsilon^{\mathrm{ND}}\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]\right)}{d_0\left(\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{ND}}\right)}\ln G_c^* \\ &-\frac{\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{MD}}+\epsilon^{\mathrm{ND}}\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]\right)}{d_0\left(\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{ND}}\right)}\ln A_c + \frac{\epsilon^{\mathrm{B}}\left(1+\epsilon^{\mathrm{HD}}+\epsilon^{\mathrm{NS}}\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]\right)}{d_0\left(\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{ND}}\right)}\ln B_c \\ &+\frac{\left(1+\epsilon^{\mathrm{MD}}\right)\left(1+\epsilon^{\mathrm{HD}}+\epsilon^{\mathrm{NS}}\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]\right)}{d_0\left(\epsilon^{\mathrm{NS}}+\epsilon^{\mathrm{ND}}\right)}\ln\kappa + \frac{d_N}{d_0}\end{aligned} \tag{B.49}$$

with

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

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 for equilibrium public good provision G_c^*. 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 (B.34), the supply functions for residential and commercial floor space from equations (B.27) and (B.29), effective housing supply from equation (B.38), and equilibrium rents for residential housing in equation (B.51), we can solve for equilibrium public good provision:

$$\begin{aligned}
\ln G_c &= \ln \psi + \ln\left(H_c r_c^H 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^H t_c + M_c \underbrace{\overbrace{\phi}^{=1} r_c^H}_{=r_c^M} t_c \right) \\
&= \ln \psi + \ln\left(\mu S_c r_c^H t_c + (1-\mu) S_c r_c^H t_c \right) \\
&= \ln \psi + \ln S_c + \ln r_c^H + \ln t_c \\
&= \ln \psi + \underbrace{\ln H_c - \ln \mu}_{=\ln S_c} + \ln r_c^H + \ln t_c \\
&= \underbrace{\tilde{\epsilon}^{\text{HS}} \ln r_c^H + \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}_{=\ln H_c} \\
&\quad + \ln \psi - \ln \mu + \ln r_c^H + \ln t_c \\
&= \left(1 + \tilde{\epsilon}^{\text{HS}}\right) \ln r_c^H + \ln t_c + \underbrace{\tilde{\epsilon}^{\text{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}^{\text{HS}}\right) \left(\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 \right. \\
&\qquad\qquad \left. + \frac{\epsilon^{\text{B}} \left[1 + \epsilon^{\text{NS}}\right]}{d_0 \left[\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right]} \ln B_c + \underbrace{\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}_{=0} + \frac{d_{r^H}}{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 \\
\ln G_c^* &= \left(\frac{\tilde{\epsilon}^{\text{HD}} \left[1 + \tilde{\epsilon}^{\text{HS}}\right]}{d_0} \ln \tau_c + \ln t_c - \frac{\epsilon^{\text{A}} \left[1 + \tilde{\epsilon}^{\text{HS}}\right] \left[1 + \epsilon^{\text{ND}}\right]}{d_0 \left[\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right]} \ln A_c + \frac{d_r^H \left[1 + \tilde{\epsilon}^{\text{HS}}\right]}{d_0} + d_G \right. \\
&\quad \left. + \frac{\epsilon^{\text{B}} \left[1 + \tilde{\epsilon}^{\text{HS}}\right] \left[1 + \epsilon^{\text{NS}}\right]}{d_0 \left[\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right]} \ln B_c \right) \Bigg/ \left(\frac{\delta \epsilon^{\text{A}} \left[1 + \epsilon^{\text{ND}}\right] \left[1 + \tilde{\epsilon}^{\text{HS}}\right]}{d_0 \left[\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right]} + 1 \right) \qquad \text{(B.50)}
\end{aligned}$$

with

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

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 on residential and commercial floor space, i.e., $\kappa = 1$):

$$\begin{aligned}
\ln r_c^{H*} &= \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_{r^H}}{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_{r^M}}{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 w_c^* &= -\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}
\end{aligned}$$

$$
\begin{aligned}
\ln K_c^* = & \frac{\tilde{\epsilon}^{\mathrm{HD}}(1+\theta)}{\gamma d_0} \ln \tau_c - \frac{\delta \epsilon^{\mathrm{A}}(1+\theta)\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln G_c^* - \frac{\epsilon^{\mathrm{A}}(1+\theta)\left(1+\epsilon^{\mathrm{ND}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln A_c \\
& + \frac{\epsilon^{\mathrm{B}}(1+\theta)\left(1+\epsilon^{\mathrm{NS}}\right)}{\gamma d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln B_c + \frac{d_K}{\gamma d_0} \\
\ln G_c^* = & \left(\frac{\tilde{\epsilon}^{\mathrm{HD}}\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]}{d_0} \ln \tau_c + \ln t_c - \frac{\epsilon^{\mathrm{A}}\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]\left[1+\epsilon^{\mathrm{ND}}\right]}{d_0\left[\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right]} \ln A_c + \frac{d_r^H\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]}{d_0} + d_G\right. \\
& \left. + \frac{\epsilon^{\mathrm{B}}\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]\left[1+\epsilon^{\mathrm{NS}}\right]}{d_0\left[\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right]} \ln B_c\right) \Big/ \left(\frac{\delta \epsilon^{\mathrm{A}}\left[1+\epsilon^{\mathrm{ND}}\right]\left[1+\tilde{\epsilon}^{\mathrm{HS}}\right]}{d_0\left[\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right]}+1\right)
\end{aligned}
$$

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. From here, we can also derive the log real wage in city c using the equilibrium wage w_c^* and the equilibrium rent for residential housing r_c^{H*} (again conditional on equilibrium public good levels and assuming $\kappa = 1$):

$$
\begin{aligned}
\ln \frac{w_c^*}{r_c^{H*}\tau_c} = & -\frac{\tilde{\epsilon}^{\mathrm{HS}}\left(\epsilon^{\mathrm{HD}}-\epsilon^{\mathrm{MD}}+\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln \tau_c - \frac{\delta \epsilon^{\mathrm{A}}\left(\tilde{\epsilon}^{\mathrm{HS}}-\epsilon^{\mathrm{MD}}-\epsilon^{\mathrm{ND}}-1\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln G_c^* \\
& - \frac{\epsilon^{\mathrm{A}}\left(\tilde{\epsilon}^{\mathrm{HS}}-\epsilon^{\mathrm{MD}}-\epsilon^{\mathrm{ND}}-1\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln A_c + \frac{\epsilon^{\mathrm{B}}\left(\tilde{\epsilon}^{\mathrm{HS}}-\epsilon^{\mathrm{HD}}-\epsilon^{\mathrm{NS}}-1\right)}{d_0\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)} \ln B_c
\end{aligned}
\tag{B.51}
$$

B.7 Comparative Statics

Using the equilibrium outcomes derive above we can take a closer look at the comparative statics in the model. First we analyze the effects of tax increases on equilibrium prices and quantities. In a second step, we derive comparative statics with respect to the different amenities in the model.

Comparative Statics of Property Tax Increases. In the following, we derive how equilibrium outcomes respond to changes in property taxes. We derive the following theoretical predictions:

Lemma B.1 (Public Goods)**.** *The total effect of property tax increases on equilibrium public good provision in city c can be decomposed in (i) a direct, positive effect through higher revenues from taxing the existing housing stock at current prices, and (ii) an indirect, countervailing effect reflecting that higher taxes decrease prices and quantities traded on both floor space markets and thus the tax base.*

The higher the property tax rate t_c, the more important the second, indirect channel distorting the tax base relative to the direct revenue effect. The total effect of tax increases on public good spending will be positive as long as the tax rate is sufficiently small:

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

Proof. The effect of property tax increases on equilibrium public good levels is given by:

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

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

where the first fraction reflects the direct effect, the second fraction reflects the impact of property taxes on the housing market volume. While the numerator is positive for the direct and negative the indirect effect, respectively, the sign of the denominator and thus the sign of the total derivate depends on the model parameters. □

Lemma B.2 (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 that is theoretically undetermined. 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.*

Proof. The effect of property tax increases on equilibrium rents is given by:

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

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, which is theoretically undetermined. □

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, which leads to a decrease in net rents for residential and commercial floor space when holding public good levels constant, i.e., a direct, negative effect. 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 in Lemma B.1, the combined effect of is theoretically undetermined, as is thus the indirect effect of property taxes on housing costs.

Lemma B.3 (Wages)**.** *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 that is theoretically undetermined. The direct effect depends on the relative strength of residential and commercial housing demand, i.e., the relative mobility of workers and firms to avoid higher taxes. The indirect effect depends on the capitalization of public goods in wages and the degree to which tax increases raise the public good provision. Both the direct and the indirect effect are theoretically undetermined.*

Proof. The effect of property tax increases on equilibrium wages is given by:

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

where the first fraction reflects the direct effect, the second fraction reflects the capitalization of public goods into wages, and the third fraction denotes the translation of property taxes into public good spending. □

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 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.

Lemma B.4 (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 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 that is theoretically undetermined. 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, which is theoretically undetermined.*

Proof. The effect of property tax increases on equilibrium real wages is given by:

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

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. □

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 come through local public goods instead of higher real wages.

Lemma B.5 (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 that is theoretically undetermined. 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.*

Proof. The effect of property tax increases on equilibrium population levels is given by:

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

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, which is theoretically undetermined. □

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.

Lemma B.6 (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 that is theoretically undetermined. The indirect effect depends on the impact of public good supply on the local housing stock (positive) 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.*

Proof. The effect of property tax increases on the equilibrium housing stock is given by:

$$\begin{aligned}\frac{d\ln H_c^*\left(\tau_c, G_c^*\left[\tau_c\right]\right)}{d\ln\tau_c} &= \frac{d\ln M_c^*\left(\tau_c, G_c^*\left[\tau_c\right]\right)}{d\ln\tau_c} = \frac{d\ln S_c^*\left(\tau_c, G_c^*\left[\tau_c\right]\right)}{d\ln\tau_c} \\ &= \frac{\partial\ln H_c^*}{\partial\ln\tau_c} + \frac{\partial\ln H_c^*}{\partial\ln G_c^*}\frac{d\ln G_c^*}{d\ln\tau_c} \\ &= \underbrace{\frac{\tilde{\epsilon}^{\mathrm{HS}}\tilde{\epsilon}^{\mathrm{HD}}}{\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}}}_{<0} - \underbrace{\frac{\tilde{\epsilon}^{\mathrm{HS}}\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)}{\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}}_{>0} \underbrace{\frac{\frac{\tilde{\epsilon}^{\mathrm{HD}}\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}} + \frac{1+t_c}{t_c}}{\frac{\delta\epsilon^{\mathrm{A}}\left(1+\epsilon^{\mathrm{ND}}\right)\left(1+\tilde{\epsilon}^{\mathrm{HS}}\right)}{\left(\tilde{\epsilon}^{\mathrm{HS}}-\tilde{\epsilon}^{\mathrm{HD}}\right)\left(\epsilon^{\mathrm{NS}}-\epsilon^{\mathrm{ND}}\right)}+1}}_{\lesseqqgtr 0},\end{aligned}$$

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, which is theoretically undetermined. □

With constant public goods and lower real wages, the jurisdiction becomes less attractive to live in. Population levels decline in response to property tax increase. If less people are willing to locate in city c, the demand for residential housing declines. The same mechanism works 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 real wage loss.

Lemma B.7 (Land Use)**.** *The total effect of property tax increases on equilibrium land use in city c can 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 that is theoretically undetermined. 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.*

Proof. The effect of property tax increases on equilibrium land use is given by:

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

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 translation of property taxes into public good spending, which is theoretically undetermined. □

With decreasing housing demand and lower levels of floor space production after the tax reform, the demand of the construction sector for land ready for construction decreases as well. This reflects the direct effect. As before, the indirect effect works in the opposite direction as long as public good spending increases in the tax rate.

Lemma B.8 (Land Prices)**.** *The total effect of property tax increases on equilibrium land prices in city c can be decomposed in (i) a direct, negative effect that reflects lower construction activity and lower land use in the construction sector due to the tax increase, and (ii) an indirect effect operating through higher local public good provision that is theoretically undetermined. The indirect effect depends on the impact of public goods on land 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.*

Proof. The effect of property tax increases on equilibrium land prices is given by:

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

where the first fraction reflects the direct, negative effect, the second fraction reflects the impact of public goods on land prices, and the third fraction denotes the translation of property taxes into public good spending, which is theoretically undetermined. □

If population levels, floor space demand and the housing stock decrease, less land is needed for construction. 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.

Lemma B.9 (Capital Stock)**.** *The total effect of property tax increases on the equilibrium capital stock in city c can 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 that is 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.*

Proof. The effect of property tax increases on the equilibrium capital stock is given by:

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

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, which is theoretically undetermined. □

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 as well. 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 is spend on public goods.

B.8 Welfare Analysis

We assume a utilitarian welfare function that aggregates the utility of all agents 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. Following Kline and Moretti (2014) we define workers welfare as the inclusive value given by:

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

To first order, an increase in city c's property tax affects workers' welfare via the incidence of property taxes on gross rents $(1+t_c)r_c^{H*} = \tau_c r_c^{H*}$, its effect on wages w_c^*, and via the transmission into local public goods G_c^*:

$$\begin{aligned}
\frac{dW^H}{d\ln\tau_c} &= \frac{\sigma^H}{\sum_{k=1}^{C}\exp\left(V_k^H/\sigma^H\right)} \sum_{k=1}^{C} \frac{d\exp\left(V_k^H/\sigma^H\right)}{d\ln\tau_c} \\
&= \frac{\sigma^H}{\sum_{k=1}^{C}\exp\left(V_k^H/\sigma^H\right)} \sum_{k=1}^{C} \exp\left(\frac{V_k^H}{\sigma^H}\right) \frac{1}{\sigma^H} \frac{dV_k^H}{d\ln\tau_c} \\
&= \sum_{k=1}^{C} \frac{\exp\left(V_k^H/\sigma^H\right)}{\sum_{m=1}^{C}\exp\left(V_m^H/\sigma^H\right)} \frac{dV_k^H}{d\ln\tau_c} \\
&= \sum_{k=1}^{C} N_k \frac{dV_k^H}{d\ln\tau_c} \\
\frac{dW^H}{d\ln\tau_c} &= N_c \frac{dV_c^H}{d\ln\tau_c} = -N_c\left([1-\delta]\left[\alpha + \alpha\frac{d\ln r_c^{H*}}{d\ln\tau_c} - \frac{d\ln w_c^*}{d\ln\tau_c}\right] - \delta\frac{d\ln G_c^*}{d\ln\tau_c}\right).
\end{aligned}$$

The sign and the magnitude of this welfare effect for residents in city c depends (i) on the extent to which wages and net rents compensate for the real wage loss due to higher tax payments, and (ii) on the responsiveness of equilibrium public good spending to changes in the tax rate. The lower preferences for public goods, δ, the more important the former effect, the higher public good preferences, the more important the latter effect.

We derive firm values accordingly and again use the inclusive value to measure the welfare of firm owners (Suárez Serrato and Zidar, 2016):

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

A change in taxes in city c affects firm owners' welfare via the incidence on wages w_c^* and the impact on the gross price of commercial floor space $\kappa(1+t_c)r_c^{M*} = \kappa\tau_c r_c^{M*}$:

$$\frac{dW^F}{d\ln\tau_c} = F_c\frac{dV_c^F}{d\ln\tau_c} = -F_c\left([1-\beta] + [1-\beta]\frac{d\ln r_c^{M*}}{d\ln\tau_c} + \beta\frac{d\ln w_c^*}{d\ln\tau_c}\right).$$

The change in the welfare of firm owners 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 by lower wages.

The welfare of firm owners in the construction industry is given by their profits (see equation (B.20)):

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

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.

We summarize the welfare of landlords by their profits as in Kline and Moretti (2014), i.e., the area between land prices and the inverse of the land supply function defined in equation (B.22), and scale it 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 landlords according to the following expression:

$$\begin{aligned}
\frac{dW^L}{d\ln\tau_c} &= \frac{1}{(1+\theta)\Lambda} \left(l_c^* \frac{dL_c^*}{d\ln\tau_c} + L_c^* \frac{dl_c^*}{d\ln\tau_c} \right) \\
&= \frac{1}{(1+\theta)\Lambda} \left(l_c^* \frac{d\exp\left[\ln L_c^*\right]}{d\ln\tau_c} + L_c^* \frac{d\exp\left[\ln l_c^*\right]}{d\ln\tau_c} \right) \\
&= \frac{1}{(1+\theta)\Lambda} \left(l_c^* \frac{d\exp\left[\ln L_c^*\right]}{d\ln L_c^*} \frac{d\ln L_c^*}{d\ln\tau_c} + L_c^* \frac{d\exp\left[\ln l_c^*\right]}{d\ln l_c^*} \frac{d\ln l_c^*}{d\ln\tau_c} \right) \\
&= \frac{1}{(1+\theta)\Lambda} \left(l_c^* L_c^* \frac{d\ln L_c^*}{d\ln\tau_c} + L_c^* l_c^* \frac{d\ln l_c^*}{d\ln\tau_c} \right) \\
&= \frac{l_c^* L_c^*}{(1+\theta)\Lambda} \left(\frac{d\ln L_c^*}{d\ln\tau_c} + \frac{d\ln l_c^*}{d\ln\tau_c} \right) \\
\frac{dW^L}{d\ln\tau_c} &= \frac{l_c^* L_c^*}{\gamma\Lambda} \frac{d\ln r_c^H}{d\ln\tau_c} = \frac{l_c^* L_c^*}{\Lambda} \frac{d\ln l_c^*}{d\ln\tau_c} = \Lambda_c \frac{d\ln l_c^*}{d\ln\tau_c},
\end{aligned}$$

where Λ_c denotes the share of local land sales $l_c^* L_c^*$ relative to the nationwide land market Λ. The stronger the incidence 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 landlords. As landlords' 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.

B.9 The Property Tax as a Specific Tax

So far we assumed that property is taxed *ad valorem*, which allows us to derive an analytical solution for the spatial equilibrium. However, our central incidence prediction of a direct, negative effect of property taxes on net rents compensating for higher costs of living does not rely on this assumption but also goes through when we model property taxes as a specific tax. To see this, consider an alternative formulation of the households' budget constraint in equation (B.1):

$$(r_c^H + t_c)h_i + px_i = w_c$$

and an alternative profit specification for firms in the tradable good sector (see equation (B.9)):

$$\Pi_{jc}^F = p_{jc}Y_{jc} - w_c N_{jc} - (r_c^M + t_c\kappa)M_{jc}.$$

Using these assumptions, we can derive alternative functions for labor supply, residential housing demand, labor demand, and commercial floor space demand using the key elasticities defined above:

$$\ln N_c^S = \epsilon^{\text{NS}} \ln w_c + \left(1 + \epsilon^{\text{HD}}\right) \ln \left(r_c^H + t_c\right) + \epsilon^{\text{A}} \ln A_c + \delta\epsilon^{\text{A}} \ln G_c + a_1 \tag{B.52}$$

$$\ln H_c^D = \ln N_c + \ln \alpha + \ln w_c - \ln \left(r_c^H + t_c\right) \tag{B.53}$$

$$\ln N_c^D = \epsilon^{\text{B}} \ln B_c + \epsilon^{\text{ND}} \ln w_c + \left(1 + \epsilon^{\text{MD}}\right) \ln \left(r_c^M + t_c\kappa\right) + b_1 \tag{B.54}$$

$$\ln M_c^D = \epsilon^{\text{B}} \ln B_c + \left(1 + \epsilon^{\text{ND}}\right) \ln w_c + \epsilon^{\text{MD}} \ln \left(r_c^M + t_c\kappa\right) + b_2. \tag{B.55}$$

The equilibrium is now characterized by equations (B.27), (B.29)-(B.35) and (B.52)-(B.55). As in the case of an *ad valorem* tax, we also derive effective residential housing demand and effective residential housing supply as functions of residential rents and property taxes when modeling the property tax as a specific tax. Using the alternative expressions for labor demand and labor supply, we can derive new equilibrium wages conditional on taxes, floor space prices, and amenities:

$$\begin{aligned}\ln w_c = \Big(& b_1 - a_1 - \epsilon^{\text{A}} \ln A_c - \delta\epsilon^{\text{A}} \ln G_c + \epsilon^{\text{B}} \ln B_c - \left[1 + \epsilon^{\text{HD}}\right] \ln \left[r_c^H + t_c\right] \\ &+ \left[1 + \epsilon^{\text{MD}}\right] \ln \left[r_c^M + t_c\kappa\right] \Big) \Big/ \left(\epsilon^{\text{NS}} - \epsilon^{\text{ND}}\right).\end{aligned}$$

Using this intermediate step and the equilibrium conditions from above, we can solve for residential housing demand as a function of residential housing costs r_c^H, taxes, and amenities (note that we set $\phi = 1$ and $\kappa = 1$ again to keep the model analytically tractable):

$$\begin{aligned}\ln H_c^D &= \ln N_c + \ln \alpha + \ln w_c - \ln \left(r_c^H + t_c\right) \\ &= \overbrace{\epsilon^{\text{NS}} \ln w_c + \left(1 + \epsilon^{\text{HD}}\right) \ln \left(r_c^H + t_c\right) + \epsilon^{\text{A}} \ln A_c + \delta\epsilon^{\text{A}} \ln G_c + a_1}^{=\ln N_c^D}\end{aligned}$$

$$
\begin{aligned}
&\quad + \ln \alpha + \ln w_c - \ln \left(r_c^H + t_c\right) \\
&= \left(1+\epsilon^{\text{NS}}\right) \ln w_c + \epsilon^{\text{HD}} \ln \left(r_c^H + t_c\right) + \epsilon^{\text{A}} \ln A_c + \delta \epsilon^{\text{A}} \ln G_c + \ln \alpha + a_1
\end{aligned}
$$

$$
\begin{aligned}
\ln H_c^D = \ln \alpha + \frac{1+\epsilon^{\text{NS}}}{\epsilon^{\text{NS}} - \epsilon^{\text{ND}}} b_1 - \frac{1+\epsilon^{\text{ND}}}{\epsilon^{\text{NS}} - \epsilon^{\text{ND}}} a_1 & - \overbrace{\frac{\epsilon^{\text{HD}}\left(1+\epsilon^{\text{ND}}\right) - \epsilon^{\text{MD}}\left(1+\epsilon^{\text{NS}}\right)}{\epsilon^{\text{NS}} - \epsilon^{\text{ND}}}}^{=\tilde{\epsilon}^{\text{HD}}} \ln \left(r_c^H + t_c\right) \\
- \frac{1+\epsilon^{\text{ND}}}{\epsilon^{\text{NS}} - \epsilon^{\text{ND}}} \epsilon^{\text{A}} \ln A_c - \frac{1+\epsilon^{\text{ND}}}{\epsilon^{\text{NS}} - \epsilon^{\text{ND}}} \delta \epsilon^{\text{A}} \ln G_c + \frac{1+\epsilon^{\text{NS}}}{\epsilon^{\text{NS}} - \epsilon^{\text{ND}}} \epsilon^{\text{B}} \ln B_c.
\end{aligned}
$$

We can also write residential housing supply as a function of residential rents and exogenous model parameters only. It is still given by:

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

In the spatial equilibrium, demand and supply of residential housing must be equal. Using the above equations we can solve for equilibrium rents for residential floor space. Now consider the introduction of a property tax in city c and derive the tax incidence $\frac{dr_c^H}{dt_c}$ (ignoring the supply of public goods):

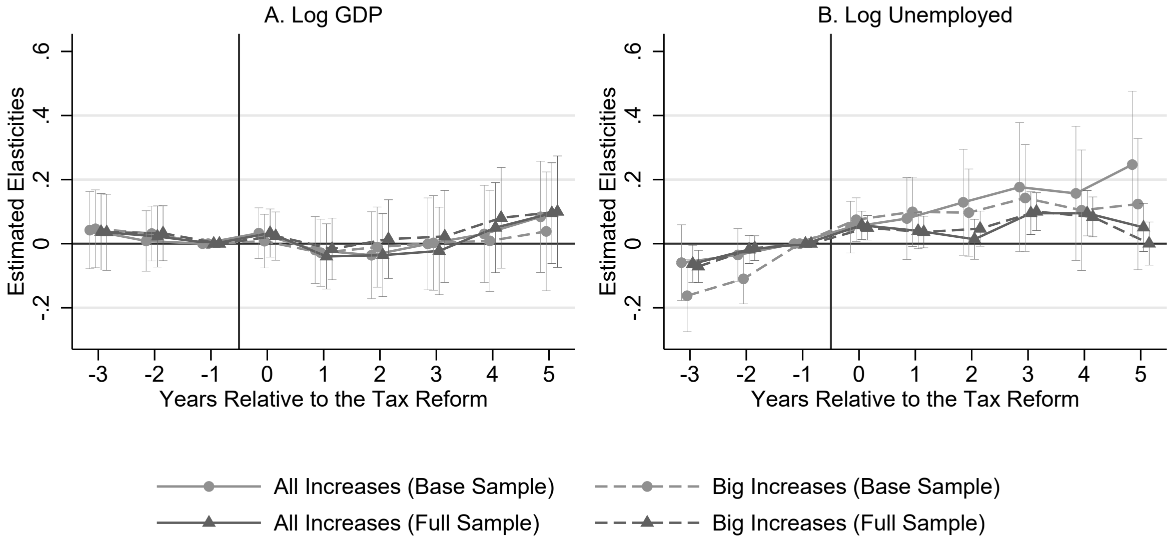
$$
\begin{aligned}
H_c^S\left(r_c^H\right) &= H_c^D\left(r_c^H + t_c\right) \\
\frac{dH_c^S\left(r_c^H\right)}{dt_c} &= \frac{dH_c^D\left(r_c^H + t_c\right)}{dt_c} \\
\frac{dH_c^S\left(r_c^H\right)}{dr_c^H} \frac{dr_c^H}{dt_c} &= \frac{dH_c^D\left(r_c^H + t_c\right)}{dr_c^H} \left(1 + \frac{dr_c^H}{dt_c}\right) \\
\frac{dr_c^H}{dt_c} \left(\frac{dH_c^S\left[r_c^H\right]}{dr_c^H} - \frac{dH_c^D\left[r_c^H + t_c\right]}{dr_c^H} \right) &= \frac{dH_c^D\left(r_c^H + t_c\right)}{dr_c^H} \\
\frac{dr_c^H}{dt_c} &= \frac{\frac{dH_c^D\left(r_c^H + t_c\right)}{dr_c^H}}{\frac{dH_c^S\left(r_c^H\right)}{dr_c^H} - \frac{dH_c^D\left(r_c^H + t_c\right)}{dr_c^H}} \\
&= \frac{\frac{dH_c^D}{dr_c^H}\frac{r_c^H}{H_c^D}}{\frac{dH_c^S}{dr_c^H}\frac{r_c^H}{H_c^S} - \frac{dH_c^D}{dr_c^H}\frac{r_c^H}{H_c^D}} \\
\frac{dr_c^H}{dt_c} &= \frac{\tilde{\epsilon}^{\text{HD}}}{\tilde{\epsilon}^{\text{HS}} - \tilde{\epsilon}^{\text{HD}}},
\end{aligned} \tag{B.56}
$$

which corresponds to the direct effect in the case of an *ad valorem* tax in Lemma B.2. In both cases – for specific taxes as well as *ad valorem* taxes – the incidence after introducing a new tax depends on the relative size of the effective housing supply and the effective housing demand elasticity with respect to the rental price.

C Appendix: Additional Results

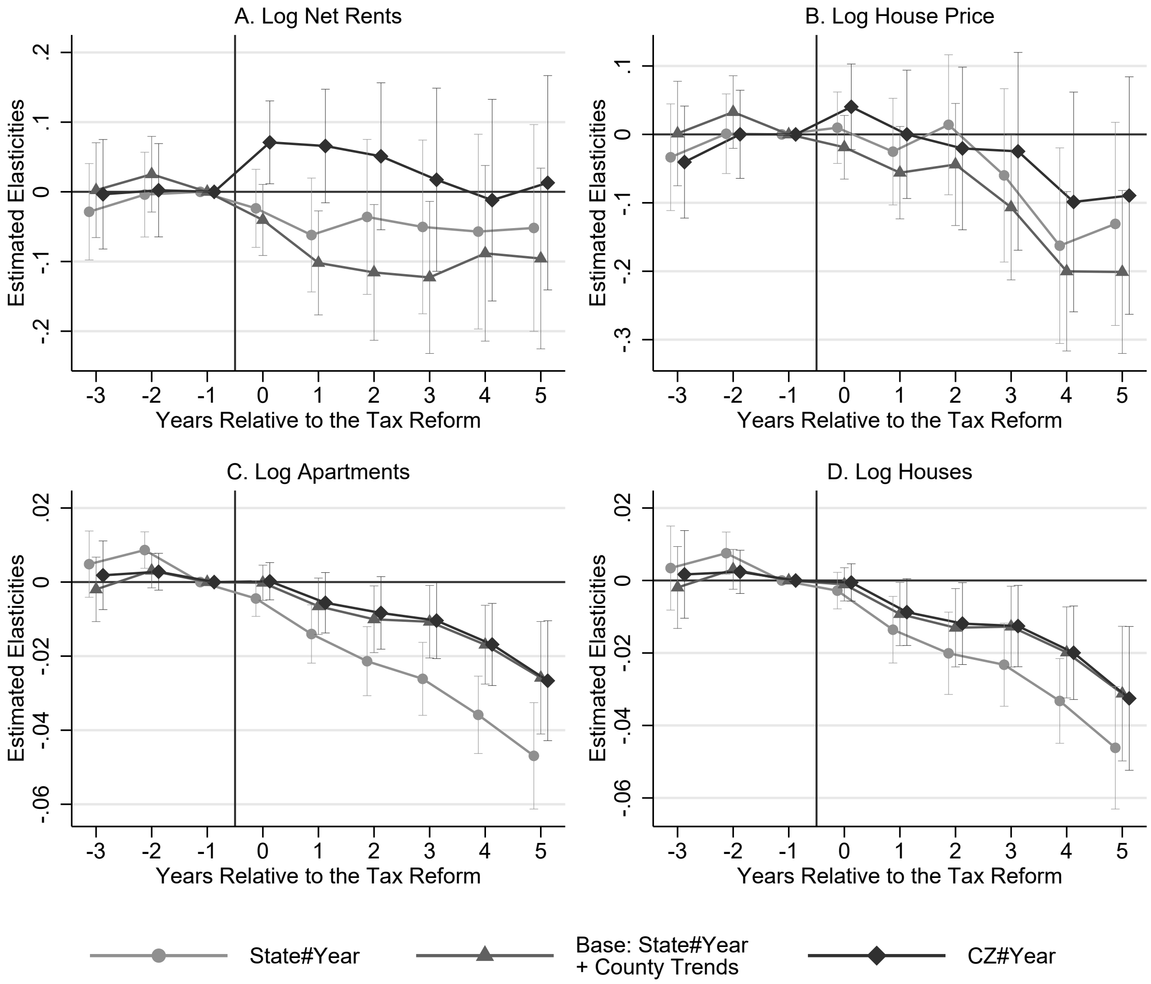
C.1 Robustness Checks

Figure C.1: The Effects of Property Taxes on the Business Cycle



Notes: This figure shows the effects of property taxes on the business cycle using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases), or as an increase that is greater than or equal to the median of the tax change distribution (big increases). The base sample includes all municipalities from our housing data set (see Section 4.2 for details), the full sample includes all municipalities for which we have data on the respective outcome. Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Figure C.2: The Effects of Property Taxes on the Housing Market By Regional Controls

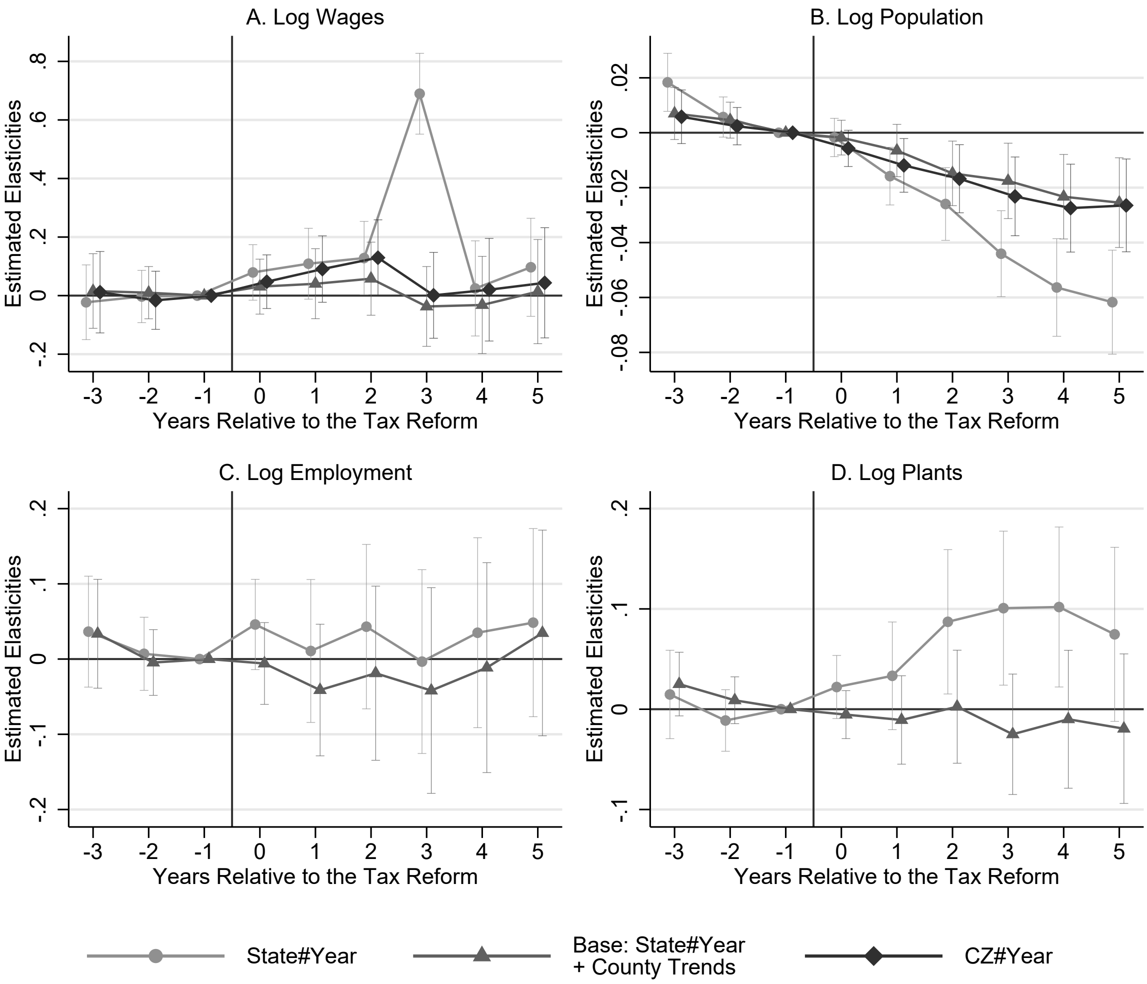


Notes: This figure shows the effects of property taxes on the housing market by regional controls using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Figure C.3: The Effects of Property Taxes on the Land Market By Regional Controls

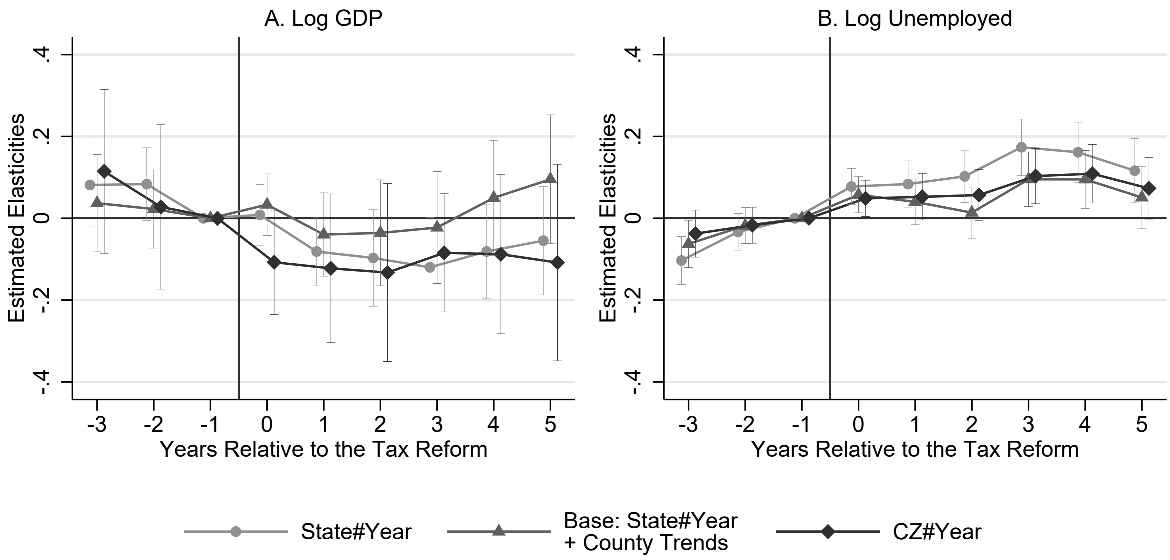
Notes: This figure shows the effects of property taxes on the land market by regional controls using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Figure C.4: The Effects of Property Taxes on the Labor Market By Regional Controls



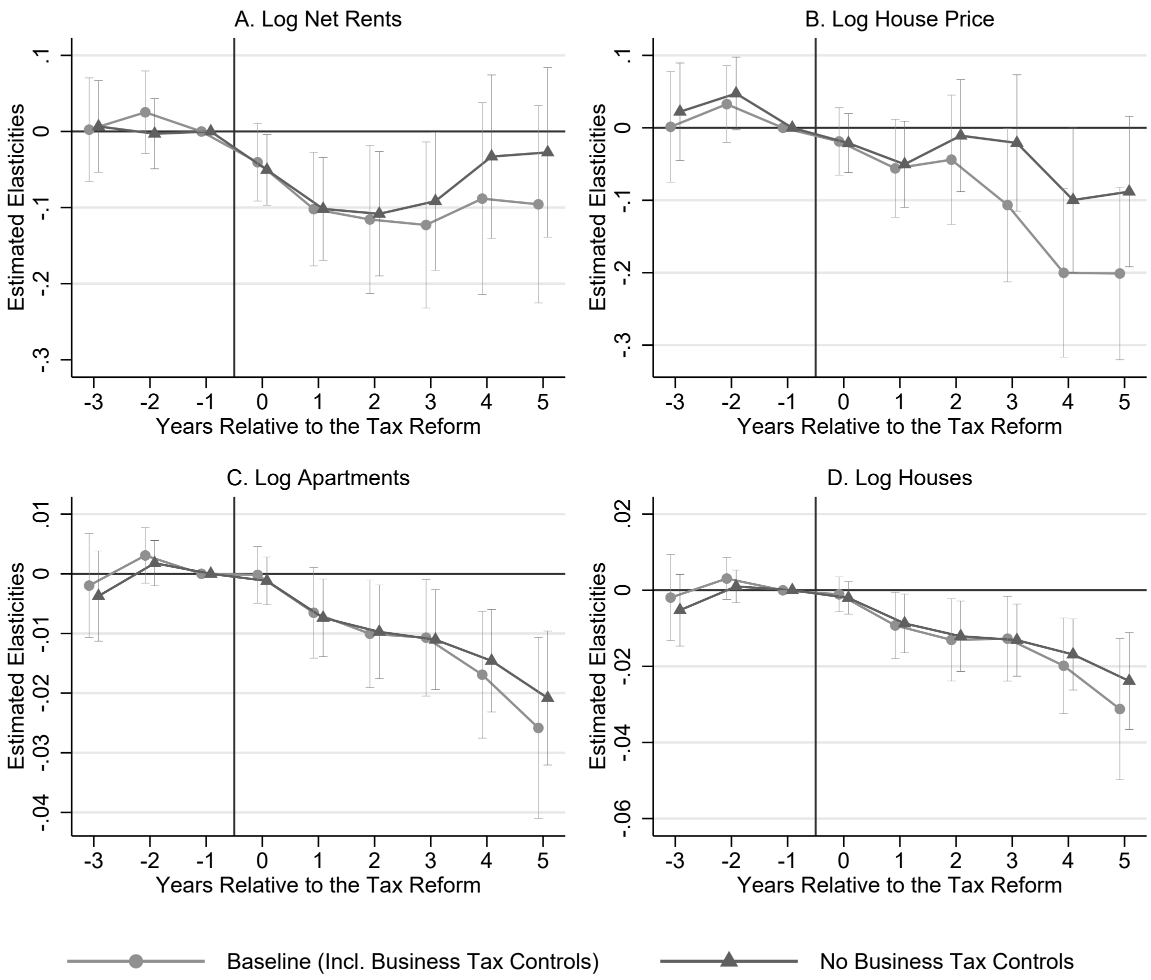
Notes: This figure shows the effects of property taxes on the labor market by regional controls using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Panels C and D are based on a subsample of large municipalities ("urban counties") as data on employment and plants are only observed at the county level. Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Figure C.5: The Effects of Property Taxes on the Business Cycle By Regional Controls



Notes: This figure shows the effects of property taxes on the business cycle by regional controls using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Figure C.6: The Effects of Property Taxes on the Housing Market By Business Tax Controls

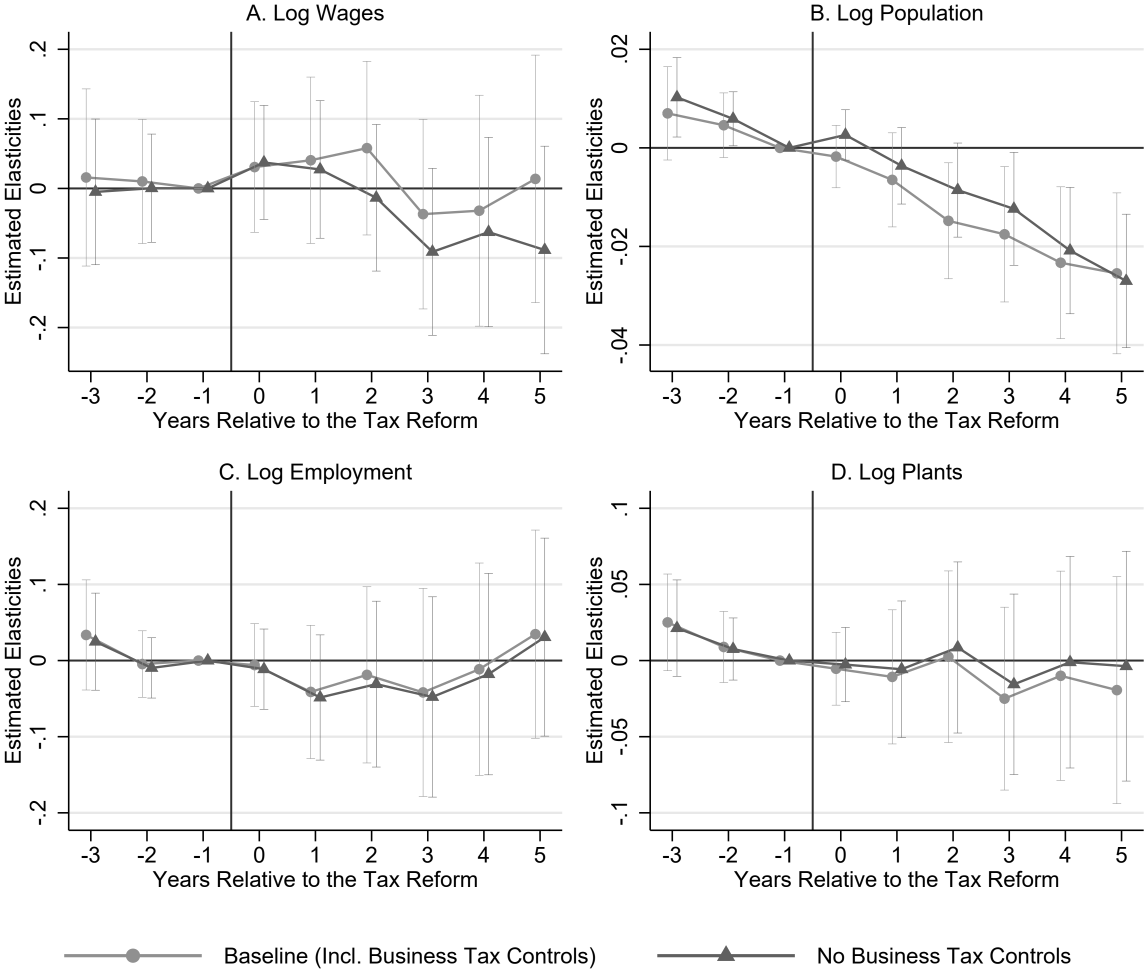


Notes: This figure shows the effects of property taxes on the housing market by business tax controls using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Figure C.7: The Effects of Property Taxes on the Land Market By Business Tax Controls

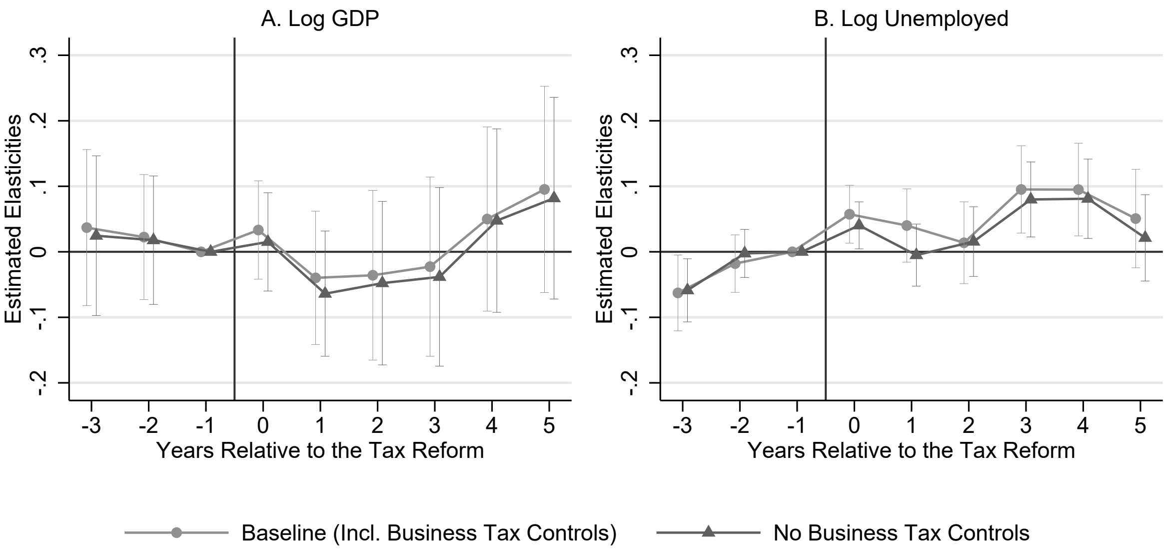
Notes: This figure shows the effects of property taxes on the land market by business tax controls using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Figure C.8: The Effects of Property Taxes on the Labor Market By Business Tax Controls



Notes: This figure shows the effects of property taxes on the labor market by business tax controls using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Panels C and D are based on a subsample of large municipalities ("urban counties") as data on employment and plants are only observed at the county level. Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

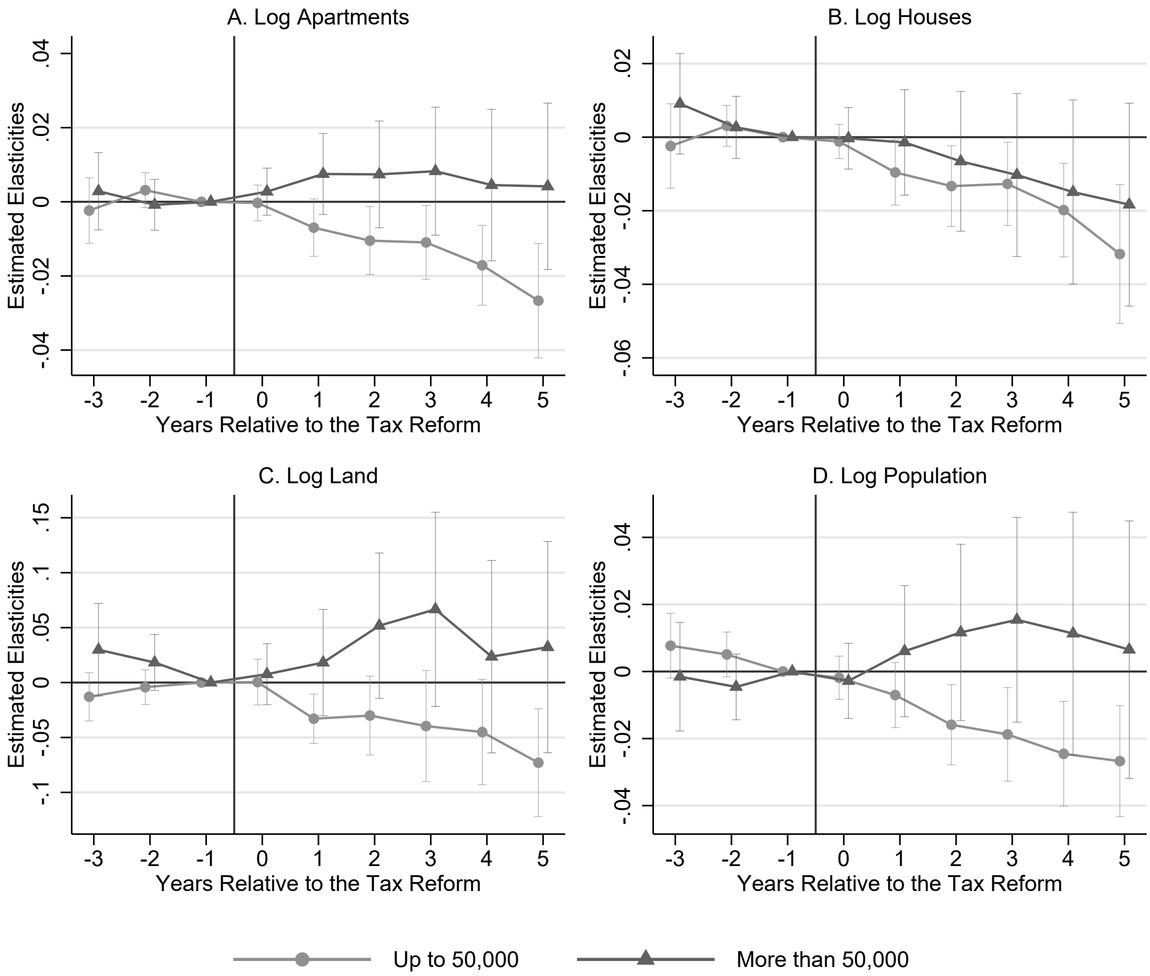
Figure C.9: The Effects of Property Taxes on the Business Cycle By Business Tax Controls



Notes: This figure shows the effects of property taxes on the business cycle by business tax controls using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

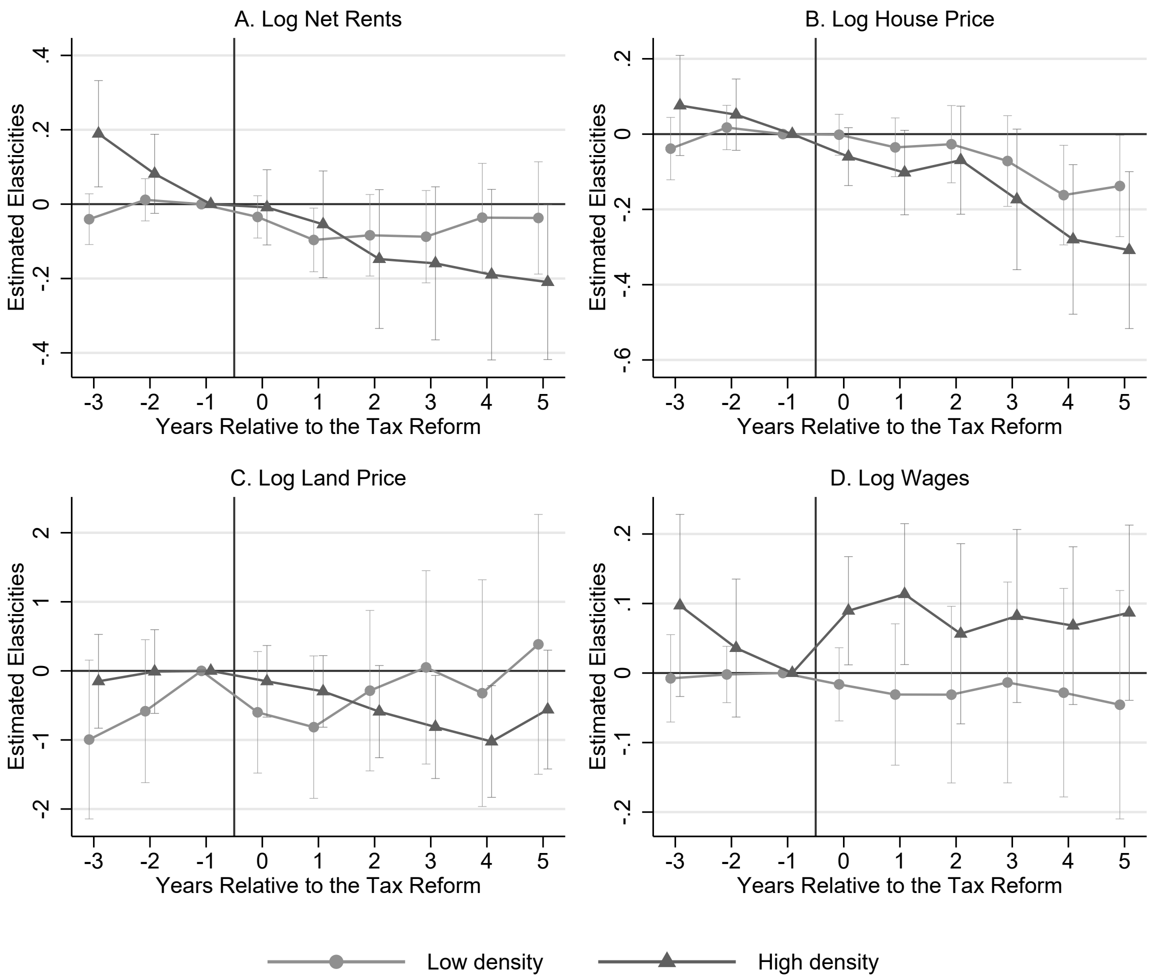
C.2 Heterogeneous Effects

Figure C.10: The Effects of Property Taxes on Quantities by City Size



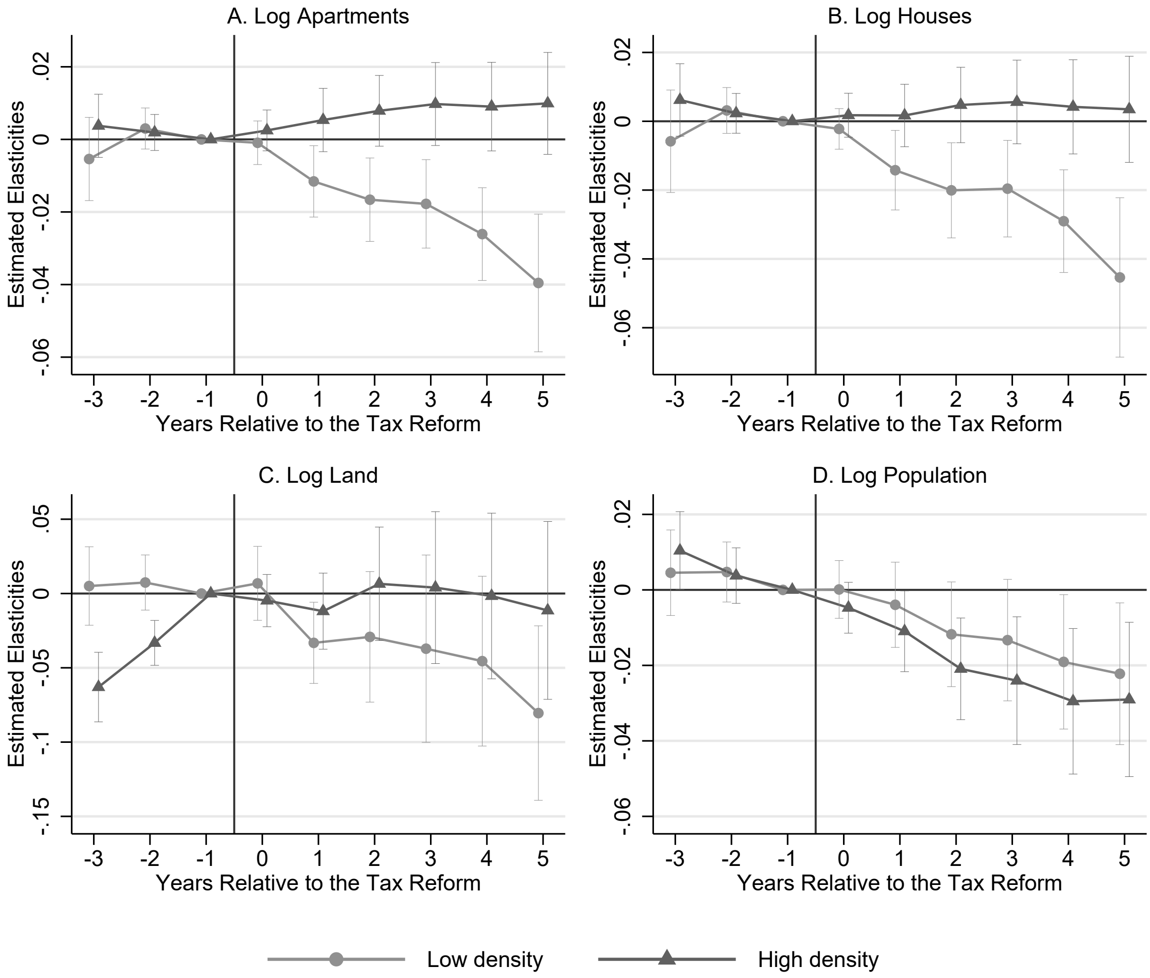
Notes: This figure shows the effects of property taxes on quantities by city size using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Figure C.11: The Effects of Property Taxes on Prices by Density



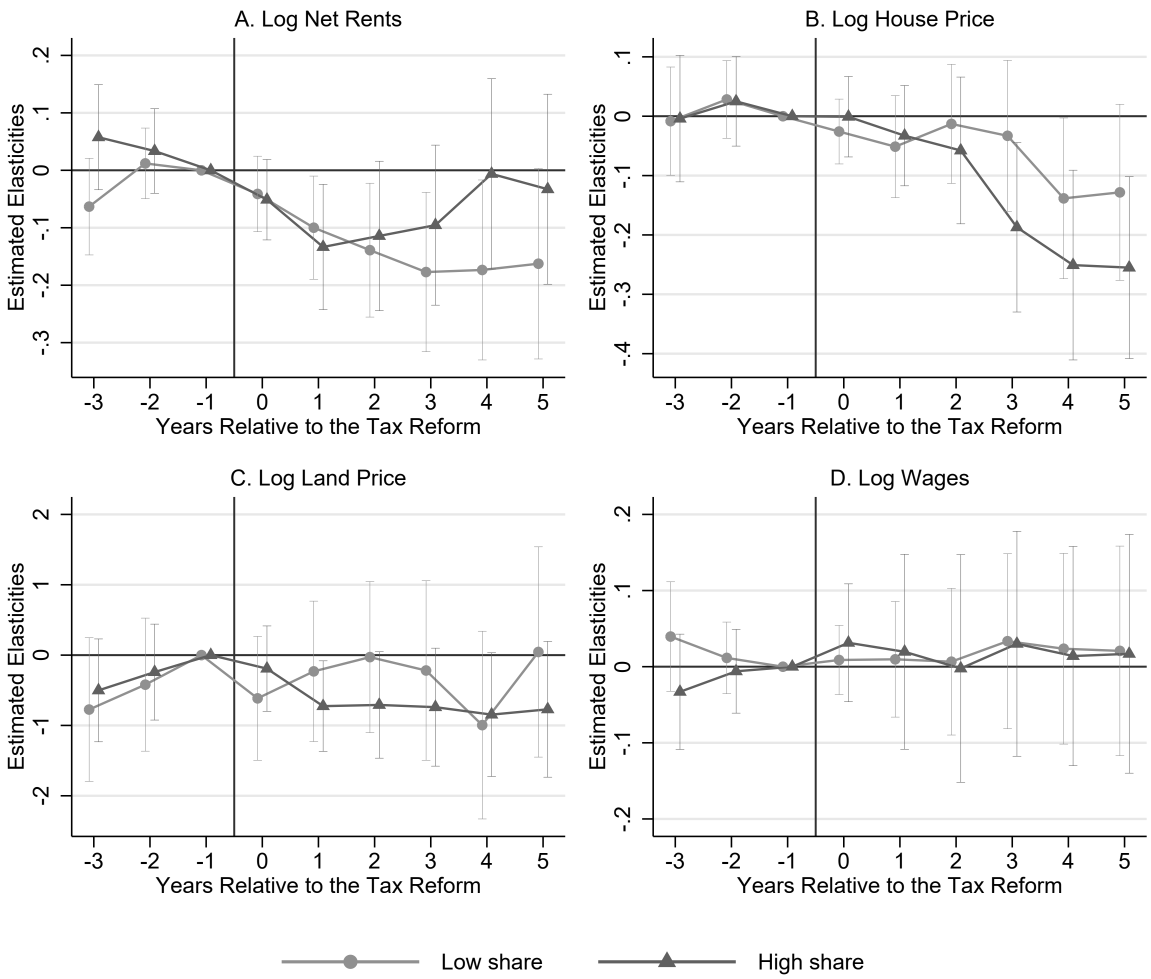
Notes: This figure shows the effects of property taxes on prices by density using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Figure C.12: The Effects of Property Taxes on Quantities by Density



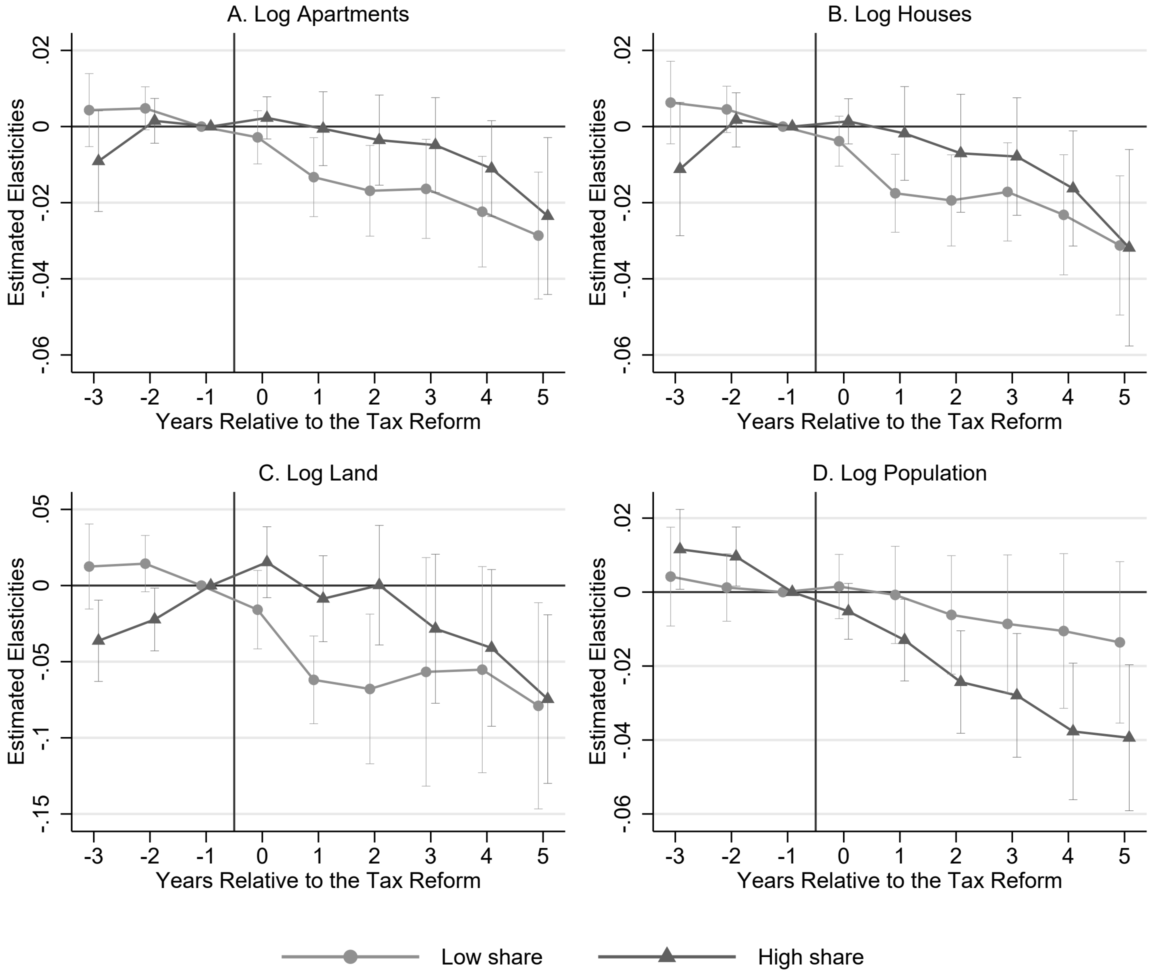
Notes: This figure shows the effects of property taxes on quantities by density using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Figure C.13: The Effects of Property Taxes on Prices by Undevelopable Land



Notes: This figure shows the effects of property taxes on prices by undevelopable land using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

Figure C.14: The Effects of Property Taxes on Quantities by Undevelopable Land



Notes: This figure shows the effects of property taxes on quantities by undevelopable land using the event study set-up from equation (17). The event is defined as an increase in the local property tax rate (all increases). Standard errors are clustered at the municipality level, vertical bars indicate 90 % confidence intervals. See Table A.1 in the Appendix for details on all variables.

C.3 Welfare Effects

Table C.1: Reduced Form Elasticities – Difference-in-Difference Estimates

	Base Sample			Full Sample		
Outcome	Elasticity	S.E.	Obs.	Elasticity	S.E.	Obs.
Log Net Rent	-0.018	(0.032)	37,672	-0.018	(0.032)	37,672
Log House Price	-0.038	(0.031)	33,767	-0.038	(0.031)	33,767
Log Apartments	0.010	(0.004)**	2,780	-0.004	(0.003)	93,192
Log Houses	0.011	(0.005)**	2,780	-0.003	(0.004)	93,192
Log Land Price	-0.070	(0.260)	1,205	0.007	(0.212)	6,987
Log Land	-0.025	(0.014)*	1,712	-0.011	(0.008)	50,825
Log Wage	0.006	(0.027)	973	-0.024	(0.040)	8,067
Log Population	0.000	(0.011)	5,050	-0.001	(0.008)	189,505

Notes: This table summarizes the reduced-form results for the key medium-run elasticities of our model for both the house price sample and the full sample. For detailed information on all variables, see Appendix Table A.1.

Table C.2: Welfare Effects of Property Tax Increases

Housing Share	$\alpha = 0.2$			$\alpha = 0.3$			$\alpha = 0.4$		
Labor Share β	0.45 (1)	0.55 (2)	0.65 (3)	0.45 (4)	0.55 (5)	0.65 (6)	0.45 (7)	0.55 (8)	0.65 (9)
Panel A – Marginal Welfare Effects									
Worker/Tenant	-0.167	-0.167	-0.167	-0.258	**-0.258**	-0.258	-0.348	-0.348	-0.348
Firm Owner	-0.504	-0.414	-0.325	-0.504	**-0.414**	-0.325	-0.504	-0.414	-0.325
Land Owner	-0.512	-0.512	-0.512	-0.512	**-0.512**	-0.512	-0.512	-0.512	-0.512
Total Welfare Effect	-1.183	-1.094	-1.005	-1.273	**-1.184**	-1.095	-1.364	-1.274	-1.185
Panel B – Welfare Loss Shares									
Worker/Tenant	0.141	0.153	0.166	0.202	**0.218**	0.235	0.255	0.273	0.294
Firm Owner	0.426	0.379	0.324	0.396	**0.350**	0.297	0.369	0.325	0.275
Land Owner	0.433	0.468	0.510	0.402	**0.432**	0.468	0.375	0.402	0.432

Notes: This table presents marginal welfare effects and welfare shares based on the following three reduced form elasticites $d\ln r_c^{H*}/d\ln\tau_c = -.096, d\ln l_c^{H*}/d\ln\tau_c = -.512, d\ln w_c^{H*}/d\ln\tau_c = .014$ and based on the calibrated housing share in consumption (α) and labor share in production (β) as indicated in the table head. Our preferred specification is given in column (5).