Policy Competition in a Spatial Economy

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Abstract

We incorporate policy competition among governments into a quantitative spatial model. The interdependence of policymaking among a network of counties in the U.S. is characterized by 3109×3109 endogenous bilateral linkages. These linkages are summarized by "policy impact"—the extent to which a jurisdiction changing its policy affects policy choices of others. Policy impact is heterogeneous across jurisdictions and the primary driver of the welfare effects of policy competition. Applying our model to local sales taxes in the U.S., we consider several centralized interventions to limit competition and document that (1) tax competition is harmful: federal interventions increase welfare, albeit heterogeneously across places; (2) ignoring endogenous policies from a quantitative spatial model underestimates welfare effects by 6%. To explore the underlying mechanisms, we rank counties by the magnitude of their policy impact. We show that interventions targeting high-policy impact jurisdictions raise welfare by six times more than targeting low-tax jurisdictions, as is commonly done through minimum tax rates. Although policy impact is endogenous, we document that jurisdiction size acts as a strong proxy.

Keywords: Quantitative spatial model; Tax competition; Tax havens; Trade; Commodity taxes; Public goods
JEL: H71; H72; R50; R51

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1. Introduction

What are the welfare effects of tax competition? Given trends in globalization, the relaxation of border controls, and technological change that enhance factor mobility, understanding the welfare effects of tax competition remains one of the most elusive topics in economics. Paramount to this difficulty is the fact that both government policies and the network of competitors are endogenous. Moreover, spillover effects across jurisdictions are highly heterogeneous, depending on several factors, including —but not restricted to— size or proximity. The theoretical tax competition literature (Wilson, 1986) has struggled to capture heterogeneous effects due its reliance on symmetric jurisdictions. Quantitative spatial models featuring a public sector and heterogeneity (Fajgelbaum et al., 2019) have yet to incorporate endogenous policy-making in a tractable way, especially for a large number of jurisdictions. The empirical literature (Agrawal et al., 2022) has been unable to cope with either problem. We propose a new approach by building a structural model of tax competition featuring thousands of heterogeneous jurisdictions, allowing us to quantify the welfare effects of strategic policy-making.

We focus local policy competition—where many jurisdictions have substantial autonomy over their tax policies, spatial linkages are critical, and taxes are set strategically to attract individuals and firms. Our quantitative spatial general equilibrium model combines elements of the recent trade (Allen et al., 2020) and public finance literature (Suárez Serrato and Zidar, 2016) with the major modification that local government policies are endogenous (Ferrari and Ossa, 2023). Residents decide where and how much to buy of differentiated products that are produced in each jurisdictions. Firms decide where and how much to produce depending on the aggregate demand. Local governments use tax and non-tax revenue to provide public services to their residents. They set their tax rates strategically (game-theoretically) maximizing the welfare of their residents but accounting for the decisions of firms and households and anticipating the changes in after-tax prices. Solving each government's optimization problem yields an elegant Ramsey rule that characterizes the equilibrium level of tax rate and how governments adjust their tax policy following changes in the rest of the economy. This rule helps fill the literature gap, noted in Caliendo and Parro (2022), that optimal policy needs to better match observed policy changes. The structure of our model can easily apply to study policy competition over commodity taxes, income taxation of commuters or teleworkers, and the current policy debate on U.S. tariffs and the resulting retaliatory trade policies.

We bring our model to the data to match sales tax rates for all U.S. counties, including those with zero tax rates. Using our Ramsey rule, we compute counterfactual general equilibrium effects of various tax coordination policies, allowing local governments to strategically respond

to these centralized interventions—an aspect absent prior literature. To assess its significance, we compare the welfare effects of centralized interventions with and without these responses, and find that they are economically important and highly heterogeneous across space.

Focusing on our baseline counterfactual that imposes a minimum sales tax rate of 2 percentage points, aggregate welfare increases by $21 per capita or 5% of the initial local sales tax burden. This effect is driven mainly by treated counties (counties with an initial rate lower than the minimum tax) that experience a welfare increase of $30 per capita (8% of their initial local tax burden) arising from both the direct effects of the intervention and any feedback from tax competition. On the other hand, non-treated counties affected only indirectly through economic and policy linkages, gain on average $3 per capita (0.5% of their initial local tax burden). The welfare effects are also heterogeneous across places, with 20% of the population losing from the introduction of a minimum tax.

Endogenizing local policy setting plays a significant role in the welfare results: 6% of the welfare effects of the minimum tax are due to endogenous tax setting. Allowing for strategic responses matters more for some jurisdictions than others, while also leading to detrimental effects for some jurisdictions as prices and taxes change simultaneously everywhere. We find that 55% of the population benefit from endogenous policy setting (8% higher welfare) and 45% losing from it (5% lower welfare). These results show the importance of accounting for strategic government responses when assessing the welfare effects of policies and interventions.

What would be the optimal intervention to mitigate policy competition? To advance this discussion, we focus on the essence of tax competition: the interdependence of tax setting among a network of local jurisdictions and introduce a new concept: the *Policy Network Matrix* (PNM), along with two measures that rank jurisdictions based on the degree of tax competition: Policy Responsiveness and Policy Impact. The PNM elegantly follows from our Ramsey rule, yielding all (endogenous) bilateral tax linkages at the general equilibrium of the economy. It quantifies strategic interactions (best responses) among heterogeneous jurisdictions that set policy under rich and realistic spatial/economic relationships that are not directly observed to the researcher.[1] The bilateral relationships are heterogeneous, with some jurisdictions raising their tax rates and others lowering their tax rates in response to a tax change elsewhere. In our setting, the policy network matrix contains 9 million elements, which are summarized into two measures.

The sum of each row of the PNM measures a county's Policy Responsiveness (PR) capturing

[1] While we derive our Policy Network Matrix for strategic interactions in the public sector, our methodology could be equally useful to other game-theoretic models of oligopolistic competition as in Caplin and Nalebuff (1991), and obviously, international trade with applications to tariffs and trade wars (Bagwell et al., 2021).

the effect of how that county responds to a coordinated tax rate increase of all its competitors. PR generalizes the scalar tax reaction slope coefficient estimated in prior empirical literature (Agrawal et al., 2022). In contrast, the sum of each column of the PNM, Policy Impact (PI), is our preferred measure of competition, characterizing the intensity of linkages among jurisdictions, and has not previously been characterized or used in the policy literature.[2] It measures the effect of an increase in the tax rate of that specific county on all the other county's tax rates—therefore identifying the key players in the tax competition game. These two measures are equal on average, but differ in their distribution: a county might not be influenced by neighboring counties but may trigger large responses in others. We also find that larger jurisdictions have larger policy impact while policy responsiveness is not correlated with size because all individual local jurisdictions are small relative to the entire USA.

We compare several counterfactual exercises targeting different sub-groups of jurisdictions based on the level of their tax rate and on their PI rank. We show that an intervention targeting high-policy impact jurisdictions lead to higher—six times larger—welfare effects than targeting low-tax jurisdictions. Our results suggest that optimal interventions should be designed to focus on key jurisdictions that have the largest effect on the economy as a whole rather than the current dominant approach of focusing on tax rates (through popular policy instruments such as minimum taxes and partial harmonization). Intuitively, targeting high-policy impact jurisdictions forces many other jurisdictions to change their tax rates, delivering the largest external welfare effects. While policy impact is a complex and endogenous metric, as practical matter, we show that it is highly correlated with jurisdiction size. As a result, even simple rules that force larger jurisdictions to raise their tax rates relative to smaller jurisdiction improves welfare substantially.

Our paper blends two strands of the literature focusing on public policies: tax competition and quantitative spatial models (Redding and Rossi-Hansberg, 2017). Although recent papers have use quantitative spatial models to determine the welfare effects of decentralization (Suárez Serrato and Zidar, 2016; Fajgelbaum et al., 2019), these models abstract from the fact that policies are chosen strategically in the first place by competing for mobile tax bases. While Ossa (2014), Bagwell et al. (2021) and Ferrari and Ossa (2023) make progress at endogenizing policies for a small number of competing jurisdictions (trade tariffs and subsidies), we advanced the literature by developing a tractable approach that allows researchers to study thousands of competing governments. We achieve this by borrowing tools from standard tax competition models that exploit governments' first order conditions and thus optimal policy rules (Zodrow

[2] Our Policy Impact measure relates to the number of out-degrees in a network as in, e.g., De Paula et al. (2024), to which we add an intensity measure of the strategic responses among competitors.

and Mieszkowski, 1986; Wilson, 1986). In addition, our approach allows us to match observed policy competition equilibrium, facilitating counterfactual analysis when local policies may endogenously respond to the counterfactual intervention. We do so by adding non-tax revenues (public finance amenities) that play an analogous role to urban amenities in quantitative urban economics models (Ahlfedlt et al., 2015).

To bring clarity on endogenous policy determination, it is essential to know the bilateral linkages among jurisdictions that determine the network of competitors. These linkages are highly asymmetric depending on both exogenous fundamentals as well as endogenous outcomes such as prices. Unlike standard quantitative spatial models, we provide the first explicit characterization and quantification of these linkages, introducing a novel method to rank jurisdictions based on their responses and impact along the network. We achieve this by leveraging the optimal policy rule for each jurisdiction as a first-order approximation of the nonlinear general equilibrium of the economy. This offers a structural identification of the network of competitors across thousands of jurisdictions that complements the reduced-form approach pioneered in De Paula et al. (2024) while adding a measure of the linkage intensity among competitors. Moreover, our endogenous determination of the network advances reduced-form empirical work on policy competition which relies on exogenous and sometimes ad hoc linkages across jurisdictions (Agrawal et al., 2022).

Unlike the literature characterizing the welfare effects of decentralization which compares the deviation between observed competitive equilibrium and the allocation by a social planner (Fajgelbaum and Gaubert, 2020 and Gaubert et al., 2024), our approach is relevant for considering small (marginal) changes in decentralization. Policies such as minimum tax rates, partial harmonization and other forms of policy coordination—including tariff treaties and environmental regulations—are widely used in practice. These interventions are most relevant for study optimal policy design by a federal government or international agencies.

The existing tax competition literature has extensively studied the effect of the level of the tax rate elsewhere in the economy on the tax setting of a given jurisdiction (Brueckner, 2003). We challenge the conventional wisdom in the literature, including our own work (Agrawal, 2016; Parchet, 2019), that this metric quantifies the intensity of tax competition. Rather our metric of Policy Impact is the relevant measure to determine the welfare effects of endogenous policies. We document how this metric can be practically implemented by targeting key players in the policy competition game and provide a tractable approach to do so.

2. Model

The purpose of this paper is to evaluate the welfare effects of interjurisdictional competition in spatial general equilibrium. To this aim, we build a spatial general equilibrium model using the example of commodity tax competition for cross-border shoppers across counties. To appropriately model these forces, we blend tools from trade and public finance. Our model features monopolistic competition and differentiated products as in Krugman (1980), pair-wise commodity flows that are disciplined by trade gravity models as in (Allen et al., 2020), public goods and tax rates as in (Suárez Serrato and Zidar, 2016; Fajgelbaum et al., 2019), and the endogenous determination of those policies as in (Ossa, 2014; Ferrari and Ossa, 2023). A key contribution is to combine all of these forces to realistically derive a specific optimal tax rule for subnational governments who set policy in a game theoretic manner while accounting for all of the general equilibrium forces in the prior literature.

2.1. Economy

The economy is composed of J counties indexed by j, and inhabited by a fixed number of n_j identical households with net-of-tax income e_j. In each county j, there is an endogenous number of m_j identical firms, indexed by $\omega \in \Lambda_j$, each producing a differentiated variety of a taxable commodity q under monopolistic competition. We assume that the only way for a resident of a county j to consume a variety produced in another county i is to do cross-border shopping. A consumer can possibly consume in any county of the federation. County j levies a commodity tax rate t_j on the variety of good q produced in j. This tax rate might be positive or zero. We consider the following sequential game. In stage 1, the counties set their tax rates accounting for the mobility of the tax base, and thus engaging in strategic competition with each other. In stage 2, the private economy operates: nationally mobile investments determine the endogenous creation of local firms, and consumers choose their bundles of goods consumed in possibly all counties of the federation. We solve the game backwards.

2.2. Consumers

The representative resident of county j derives utility from consumption of the taxable varieties of good q and the public services provided in their county, $\mathbb{G}_j$, according to:

$$U_j = \left(\sum_i \int_{\Lambda_i} q_{ij}(\omega)^{\frac{\sigma-1}{\sigma}} \mathrm{d}\omega \right)^{\frac{\sigma}{\sigma-1}} \mathbb{G}_j^{\nu}, \tag{1}$$

where $q_{ij}(\omega)$ is the quantity of variety $\omega \in \Lambda_i$ produced in county i consumed by the representative resident of county j. The parameter $\sigma > 1$ is the elasticity of substitution among varieties. Parameter ν governs the marginal willingness to pay for public services.

Each worker inelastically supplies one unit of labor in her county of residence, receiving a wage w_j. She also owns an exogenous endowment, κ_j, of capital that she supplies in the county that provides the highest return. Capital mobility equates the return to capital across counties. As capital will be considered as the numéraire of the economy, the capital return is treated as exogenous and normalized to unity. Moreover, in line with standard assumptions in models with monopolistic competition and entry (Krugman, 1980), each resident owns part of the firms in her county. The total income of the m_j identical local firms is $\int_{\Lambda_j} \rho_j(\omega)\mathrm{d}\omega = m_j\rho_j$. The n_j residents of county j equally share this income.

It follows that the budget constraint of a resident of county j is:

$$\sum_i \int_{\Lambda_i} (1 + t_i + T_i)p_i(\omega)\mu_{ij}q_{ij}(\omega)\mathrm{d}\omega = e_j, \tag{2}$$

where $e_j = (1 - \tau_j)\left(w_j + \kappa_j + m_j\rho_j/n_j\right)$, is individual after-tax income, p_i is the factory gate price of variety i, t_i is county i's sales county tax rate. T_i is the exogenous sales tax rate of the state in which county i is located, τ_j is the exogenous income tax rate of county i's state. Parameter μ_{ij} is an iceberg transportation cost incurred by a resident of j shopping in i. Thus, to consume 1 unit of a good purchased in i, a resident of j needs to buy $\mu_{ij} > 1$ units of goods there. Then, the aggregate income of the residents of county j is:

$$E_j = n_j(1 - \tau_j)\left(w_j + \kappa_j + \frac{m_j\rho_j}{n_j}\right) \tag{3}$$

The expenditure on variety ω purchased by a resident of j in county i is $x_{ij}(\omega) = p_i(\omega)\mu_{ij}q_{ij}(\omega)$. Maximizing utility subject to the constraint, yields the Marshallian demand $x_{ij} = (1 + t_i + T_i)^{-\sigma}[p_i(\omega)\mu_{ij}]^{1-\sigma}P_j^{\sigma-1}e_j$, which is inclusive of the transportation cost and where P_j is the Dixit-Stiglitz price index defined below. Aggregating, we obtain the total value of the consumption of the n_j residents of county j purchasing in county i:

$$X_{ij} = m_i(1 + t_i + T_i)^{-\sigma}(p_i\mu_{ij})^{1-\sigma}P_j^{\sigma-1}E_j, \tag{4}$$

where the Dixit-Stiglitz price index is:

$$P_j = \left(\sum_i m_i[(1 + t_i + T_i)p_i\mu_{ij}]^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \tag{5}$$

which is, as usual, increasing with respect to all local variety prices and to transportation

costs, but includes both the local and state sales tax rates. Intuitively, higher tax rates in other counties raises the living cost in j and act as an "inward multilateral resistance" (Anderson and Van Wincoop, 2003), making j more remote by reducing its access to their varieties.

2.3. Production

In county i, each firm $\omega \in \Lambda_i$ produces its own local variety which is consumed by (possibly) all the residents of the economy. This variety is produced by combining labor, $\ell_i(\omega)$, and mobile capital, $k_i(\omega)$ using the following constant returns to scale technology:

$$q_i(\omega) = \left(\frac{\ell_i(\omega)}{\alpha}\right)^{\alpha} \left(\frac{k_i(\omega)}{1-\alpha}\right)^{1-\alpha} \tag{6}$$

where $\alpha \in (0,1)$ is the labor income share parameter. [3]

In county i, each firm ω chooses its price, $p_i(\omega)$, to maximize profit:

$$\pi_i(\omega) = p_i(\omega)q_i(\omega) - c_i q_i(\omega) - \rho_i$$

where $q_i(\omega) = \sum_j \mu_{ij} q_{ij}(\omega)$ is the aggregate demand for its variety, $c_i \equiv w_i^{\alpha}$ is the unit cost function. Further, firms must incur a cost equal to $\rho_i \equiv c_i f_i$ in order to enter the market, where f_i is the exogenous component of this cost. This fixed cost is equally returned to the owners of the firm (residents of the jurisdiction). Profit maximization pins down the price of the local variety according to the usual optimal pricing rule $p_i = w_i^{\alpha}\sigma/(\sigma-1)$ which is identical for all firms located in i, as the firms are ex ante identical themselves. The price charged by a firm increases with respect to the input prices.

Using the above pricing rule, the total demand of labor in i is:

$$L_i = \frac{\sigma-1}{\sigma}\frac{\alpha Y_i}{w_i} \tag{7}$$

where $Y_i = p_i m_i q_i$ denotes the value of the aggregate output of the m_i firms operating in county i. Free entry of firms implies zero profit which in turn implies that the output of each firm in i is exogenously determined as $q_i^{\mathrm{s}} = (\sigma-1)f_i$ which determines the firm's output (Fujita et al., 2001). The number of firms, m_i, operating in i is endogenously determined by this zero-profit condition. To see it, we can multiply both sides of this condition by $p_i m_i$ to

[3] Note that in general equilibrium, a county with a higher demand for its variety will attract more capital and have more productive workers.

obtain the following intuitive condition:

$$m_i = \frac{Y_i}{(\sigma - 1)p_i f_i} \tag{8}$$

Intuitively, more aggregate output, lower price of the variety (that is, more demand) and lower entry cost imply a larger number of firms operating in i.

2.4. Local and State Government Budget

County i uses its local sales tax revenues $t_i X_i$ with $X_i = \sum_j X_{ij}$ being the total tax base of the county to finance per capita public services, g_i, provided at the endogenous unit cost of p_i. Total public expenditures are therefore $p_i n_i g_i$ for which we assume, without loss of generality as population is fixed, full congestion. Although the focus of the paper is on tax competition in local sales tax rates, t_i, it is also quantitatively important to account for other possible sources of revenues accessible to counties. These sources of revenues are denoted R_i. Thus, the local government i's budget constraint is:

$$t_i X_i + R_i = p_i n_i g_i \,. \tag{9}$$

The alternative sources of revenue, R_i, may reflect other resources such as property taxes and federal grants that allow sales tax rates to be higher or lower. Modeling the endogenous determination of all the alternative sources of revenue is beyond the scope of this paper. Hence, we consider the following parsimonious specification $R_i \equiv p_i n_i \Delta_i$ in which $n_i \Delta_i$ denotes an initial exogenous aggregate endowment of alternative sources of revenue in units of private goods. [4]

In many countries, local governments provides services and raise taxes in the context of a federalist system. Given multiple levels of government tax commodities and earnings in the U.S., our model account for state-level taxes and the services they finance. The budget constraint of county i's state is:

$$\sum_{k \in \mathcal{S}_i} T_k X_k + \sum_{k \in \mathcal{S}_i} n_k \tau_k y_k = \sum_{k \in \mathcal{S}_i} n_k p_k G_k \tag{10}$$

where $\mathcal{S}_i$ is the set of counties in county i's state, and $y_i \equiv e_i/(1-\tau_i)$ is the the individual net-

[4] Assuming that counties are endowed with public services (exogenous Δ_i) rather than with nominal revenues (exogenous R_i) has two advantages. First, there is no need to make assumptions about the location of the residents who finance these other resources. Thus, Δ_i is a utility shifter. Second, if all prices in the economy vary proportionately, private consumption and public services are both unchanged. See Subsection 2.5 for formal details.

of-tax income in which e_i is the gross individual income defined previously in (2). Similarly to the county's public services, the state's public service G_i is fully congestible. Each resident of county i's state receives G_i units of public services. The expenditure on state public services in county i is $p_i n_i G_i$. Further, because income taxes are progressive, the state's income tax rate τ_k varies at the county level depending on its average income.

Having defined public services at the state and local level, $\mathbb{G}_j \equiv \varphi g_j + (1-\varphi)G_j$ is the aggregator of public services provided in j that enters into the utility function. The parameter $\varphi < 1$ governs the marginal rate of substitution between local and state public services, $\varphi/(1-\varphi)$: it measures the amount of state public services that an individual is willing to trade to obtain one unit of local public services. Higher values of φ mean more relative value put on county public services.

2.5. Equilibrium Relation between the Local Economic Variables

Before we turn to the general equilibrium of the economy, let us describe the relations between the economic variables. This section shows that the central economic variable in the model is the price of the local variety which unambiguously determines the levels of most of the local economic variables.

First, the local wage w_i is an increasing function of the price of the local variety p_i as per the optimal pricing rule that can be rewritten as:[5]

$$w_i = \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\alpha}} p_i^{\frac{1}{\alpha}} \tag{11}$$

Thus, higher prices allow the firms to pay higher wages.

Second, inserting the expression of the labor demand (7) into the local labor market clearing condition, $L_i = n_i$, we can express the value of i's total production Y_i as:

$$Y_i = \frac{n_i}{\alpha}\left(\frac{\sigma-1}{\sigma}\right)^{\frac{1-\alpha}{\alpha}} p_i^{\frac{1}{\alpha}} \tag{12}$$

which is an increasing function of the price, p_i. Higher prices increase both the value of total production and incentivize firms to produce more.

Third, inserting (12) into (8), we can express the number of firms as an increasing function of p_i:

$$m_i = \frac{n_i(\sigma-1)^{\frac{1-2\alpha}{\alpha}}}{\alpha f_i \sigma^{\frac{1-\alpha}{\alpha}}} p_i^{\frac{1-\alpha}{\alpha}}. \tag{13}$$

[5] See the Appendix A for the derivation of these equilibrium relations.

Higher prices attract firms into the jurisdiction.

Last, the aggregate payment of $m_i\rho_i$ to the owners can be expressed as an increasing function of the local price. Inserting $m_i\rho_i$ into the local income E_i defined in (3) gives:

$$E_i = \frac{n_i[(\sigma-1)\alpha+1](\sigma-1)^{\frac{1-\alpha}{\alpha}}}{\alpha\sigma^{\frac{1}{\alpha}}} p_i^{\frac{1}{\alpha}} + n_i\kappa_i\,. \tag{14}$$

Higher prices increase total income through both higher wages and owners' payment.

2.6. General Equilibrium of the Private Economy

This section describes the general equilibrium of the private economy, taking as given local taxes as in Suárez Serrato and Zidar (2016) and Fajgelbaum et al. (2019).

As established in Subsection 2.5, all the local variables in the private economy are functions of the local price p_i. Therefore, the general equilibrium consists of solving for a vector of all equilibrium commodity prices in all jurisdictions. These prices are jointly determined by the J local commodity market clearing conditions:

$$Y_i = X_i + t_i X_i + n_i p_i G_i\,. \tag{15}$$

Equation (15) states that the value of total production, Y_i, is equal to the value of the total demand, itself composed of three elements: the local demand for private consumption, X_i, the demand for public services by the local government, $t_i X_i$, and the demand for the state public services, $n_i p_i G_i$.

More specifically, to obtain the general equilibrium of the private economy, we solve the system of market clearing conditions (15) for equilibrium prices p_i using the price indices P_i defined in (5) and the value of state public services G_i defined in (10). Formally, we solve for three sets of equations for all $i = 1, \ldots, J$:

$$(\mathcal{E}_i)\begin{cases} Y_i - (1+t_i)\displaystyle\sum_j m_i(1+t_i+T_i)^{-\sigma} p_i^{1-\sigma}\mu_{ij}^{1-\sigma}P_j^{\sigma-1}E_j - n_i p_i G_i = 0, & (16)\\ P_i^{1-\sigma} - \displaystyle\sum_k m_k(1+t_k+T_k)^{1-\sigma}p_k^{1-\sigma}\mu_{ki}^{1-\sigma} = 0, & (17)\\ \displaystyle\sum_{k\in\mathcal{S}_i} n_k p_k G_i - \sum_{k\in\mathcal{S}_i}\frac{\tau_k}{1-\tau_k}E_k - T_i\sum_{k\in\mathcal{S}_k}\sum_j m_k(1+t_k+T_k)^{-\sigma}p_k^{1-\sigma}\mu_{ij}^{1-\sigma}P_j^{\sigma-1}E_j = 0, & (18)\end{cases}$$

recalling that m_i, E_i and Y_i are one-to-one mapping with respect to p_i (see Subsection 2.5).

The 3-equation system $(\mathcal{E}_i)$ will be referred to as the private economy *partial equilibrium system* in county i, while the $3J$-equation system, $(\mathcal{E}_i)_{i=1,\ldots,I}$, will be called the private economy *general equilibrium system*. Note that the general equilibrium system determines the

equilibrium levels of prices, $\{p_i(\mathbf{t})\}_{i=1,\ldots,J}$, for all counties, with each jurisdiction's price being a function of the tax rates of all counties $\mathbf{t} \equiv (t_1, \ldots, t_J)$. Thus, if any jurisdiction k changes its tax rate, the price, and therefore all other endogenous variables in all other jurisdictions will be affected. For later reference, we denote the *general equilibrium responses*:

$$\frac{\partial p_i}{\partial t_k}, \qquad \frac{\partial P_i}{\partial t_k}, \qquad \frac{\partial G_i}{\partial t_k}, \tag{19}$$

which are obtained by implicitly differentiating the entire general equilibrium system $(\mathcal{E}_i)_{i=1,\ldots,J}$.

2.7. Local Taxation Choice

Let us now turn to the optimal tax choice of the counties in the first stage of the tax competition game. The government of county i chooses its tax rate t_i taking as given and fixed the tax rates in other jurisdictions, and anticipating the responses of the private economy. Formally, it maximizes the aggregate welfare of its residents

$$n_i V_i = \frac{E_i \mathbb{G}_i^{\nu}}{P_i}, \tag{20}$$

subject to the equilibrium system of prices (16)–(18) and to its budget constraint (9). Using the commodity market clearing condition (15), the latter can be expressed as:

$$g_i = \frac{t_i}{1+t_i}\left(\frac{1}{\alpha}\left(\frac{\sigma-1}{\sigma}\right)^{\frac{1-\alpha}{\alpha}} p_i^{\frac{1-\alpha}{\alpha}} - G_i\right) + \Delta_i, \tag{21}$$

which indicates that the direct effect of the tax rate t_i and the price p_i on the local public service g_i is positive, while the effect of G_i is negative. The price of the variety increases the value of production by local firms, which increases the size of the tax base and allows the county to provide more public services. Taking as given the value of local production, an increase in the state's public services crowds out local public services by the market clearing condition (15). This equation makes it also clear that Δ_i will act as a residual, that is, an exogenous shifter of local public services.

For tractability purposes, and consistent with practical local tax-setting behavior, we assume that local governments account for how their tax changes influence their own prices but view the prices elsewhere as given. This assumption is weaker than countless studies of tax competition that assume atomistic jurisdictions (Zodrow and Mieszkowski, 1986; Wilson, 1986; Hoyt, 1991), which implies that jurisdictions do not even affect price changes in their own jurisdiction. This is also a weaker assumption than used in many structural models of (exogenous) state and local tax policy that also rely on atomistic governments (Suárez Serrato and Zidar, 2016; Fajgelbaum et al., 2019). Our government have some market power and thus

change prices elsewhere, but simply do not account for these general equilibrium effects. One can view the counties as behaving myopically—analogous to voters not accounting for price changes in Epple and Romer (1991) and Epple et al. (2001)—so they are not able to predict the change in the prices of nearby jurisdictions.

Formally, we assume that as county i changes its tax rate, t_i, it only accounts for the *partial equilibrium* in i, $(\mathcal{E}_i)$, and ignores the changes on the equilibrium in other counties, $(\mathcal{E}_j)_{j\neq i}$. Implicitly differentiating the partial equilibrium in i defines the *partial equilibrium responses*:

$$\left.\frac{\partial p_i}{\partial t_i}\right|, \qquad \left.\frac{\partial P_i}{\partial t_i}\right|, \qquad \left.\frac{\partial G_i}{\partial t_i}\right|, \tag{22}$$

in which the "vertical bar" aside the derivative distinguishes these partial equilibrium responses from the general equilibrium responses in (19). For later reference, we summarize this assumption as:

Assumption 1. *When county i changes t_i, it only accounts for the partial equilibrium in i, $(\mathcal{E}_i)$, and ignores its change on the equilibrium in other counties, $(\mathcal{E}_j)_{j\neq i}$.*

We will show that Assumption 1 has minimal impact on our baseline results, but evoking it will enable us to further investigate the mechanisms underlying the welfare effects. Notice that although the local government ignores the full *impact* of its policy on economic variables, it always observes correctly the *level* of theses variables. Critically, governments still anticipate that markets in their own jurisdiction will clear.

Having delineated the fundamentals of the government's problems, we now derive the expressions for the Nash tax rates. The first-order condition for a county i can be expressed according to the following open economy Ramsey rule (see Appendix A.2 for the derivation):

$$\frac{t_i}{1+t_i+T_i} = \frac{1 - \overbrace{\frac{\chi_i\lambda_i}{\nu}}^{A} - \overbrace{\frac{\eta_i\phi_i}{\nu}}^{C}}{\varepsilon_i + \underbrace{\frac{\theta_i}{\nu}}_{B}}, \tag{23}$$

where $\varepsilon_i \equiv -[(1+t_i+T_i)/X_i]\partial X_i/\partial t_i| > 0$ is the absolute value of the elasticity of the tax base with respect to the county (gross) sales tax rate, $\chi_i \equiv X_{ii}/X_i$ is the share of county i's tax base (total sales) raised from its residents, $\lambda_i \equiv (R_i + (1-\varphi)n_i p_i G_i/\varphi)/E_i$ is the ratio of non-sales tax revenues to income, and $\theta_i \equiv (1+t_i+T_i)X_{ii}/E_i$ is the after-tax local expenditure share of a resident of county i on the goods produced in i. In addition, our Ramsey rule accounts

for the effect of taxes on welfare through prices via the term $\eta_i \phi_i$.[6]

Note that if $\theta_i = 1$, $\lambda_i = 0$ and $\phi_i = 0$, our Ramsey rule boils down to the standard inverse elasticity rule for optimal commodity taxation.[7] If $\theta_i = 0$, $\lambda_i = 0$ and $\phi_i = 0$, it reduces to the standard inverse elasticity rule for an optimal tariff in a small open economy (Caliendo and Parro, 2022). In order to interpret Term A, note that when χ_i is large, sales tax revenue in i is mainly raised from residents; when λ_i is large, jurisdictions raise a large amount of total revenue from non-sales tax sources. As more tax revenue is raised from residents, there is less ability to export the tax burden to non-residents, which puts downward pressure on local sales tax rate. As non-sales tax revenue sources become larger, the sales tax become less important and there are more instruments to raise revenue from, allowing the jurisdiction to lower the sales tax rate. Thus, there is a substitution effect among sales and non-sales revenue.

When $\theta_i > 0$, Term B is increasing when a resident of i consume a higher share of their income in their own county. Again, as residents like low taxes on their own consumption to increase disposable income, an increase in θ_i puts downward pressure on tax rates.

Term C captures the effects of taxes on prices. When η_i is large, public services provided relative to the size of the local tax base are more significant. This places downward pressure on tax rates because households are willing to pay less for abundant public services due to diminishing marginal utility. When ϕ_i is large, aggregate income, public services and the price index are very sensitive to changes in taxes. This puts downward pressure on taxes if the elasticity on income and public services is larger that the elasticity on the price index.[8]

Fourth, the parameter ν which governs the level of the marginal willingness to pay for public services has a straightforward positive impact on t_i. Further, the share of local public services in total public services, φ, enters the expression for λ_i. A high φ indicates a low marginal rate of substitution between state and local public services ($\mathrm{d}g/\mathrm{d}G = (1-\varphi)/\varphi$), implying a higher local tax rate.

In sum, our Ramsey rule (23) highlights four main possible causes of heterogeneity in the levels of local commodity tax rates. It is one of the most comprehensive of the trade literature. Moreover, our empirical analysis in 3.7 will quantify the relative importance of

[6] The term $\eta_i \equiv n_i p_i (\mathbb{G}_i/\varphi)/X_i$ is the ratio of the public services provision relative to the tax base and $\phi_i \equiv -\left(\varepsilon^i_{E,p} - \varepsilon^i_{P,p} + \nu\varepsilon^i_{G,p}\right)\epsilon^i_{p,t} - \nu\varepsilon^i_{\mathbb{G},G}\,\epsilon^i_{G,t}$ captures the effects of taxes on the local price and the state public service provision where $\varepsilon^i_{y,x}$ [$\epsilon^i_{y,x}$] is the partial equilibrium [semi-]elasticity of y_i with respect to z_i. Our model allows us to sign unambiguously: $\varepsilon^i_{E,p} > 0$ as higher prices increase the local income, and $\varepsilon^i_{P,p} > 0$ and $\varepsilon^i_{\mathbb{G},G} > 0$ which are two mechanical effects. On the contrary, the model does not allow us to predict unambiguously the signs of the partial equilibrium semi-elasticities, $\epsilon^i_{p,t}$ and $\epsilon^i_{G,t}$. However, our quantitative analysis will be able to sign negatively these two elasticities, and sign positively the overall price effect ϕ_i.

[7] In this case, $t_i/(1+t_i+T_i) = 1/(\varepsilon_i + 1/\nu)$ in which $1/\nu$ is the marginal cost of public funds.

[8] In our empirical implementation, ϕ_i will be positive.

these four motives.

2.8. General Equilibrium: Private Economy and Local Taxation Choice

Even though counties take prices in other counties as given by Assumption 1, all equilibrium prices are determined simultaneously. Therefore, solving for the complete equilibrium of the economy requires computing the prices and taxes in all jurisdictions simultaneously. We proceed in two steps.

First, using Assumption 1 and starting from $(\mathcal{E}_i)$, we analytically derive the partial equilibrium responses that each county i anticipates by changing its tax rate: $\partial p_i/\partial t_i|$, $\partial P_i/\partial t_i|$ and $\partial G_i/\partial t_i|$. To do so, we apply the implicit function theorem to $(\mathcal{E}_i)$ by differentiating it with respect to t_i, obtaining $(\mathrm{d}\mathcal{E}_i)$. This allows us to express each county's optimal tax rule (23), as functions of the levels of the key endogenous variables of the model (p_i, P_i and G_i).

Second, we solve for the complete equilibrium of the economy by solving numerically the $4J$-general-equilibrium equation system (5), (10), (15) and (23) for the Nash equilibrium tax rates $\{t_i^\star\}_{i=1}^J$, wage $\{p_i^\star\}_{i=1}^J$, the price indices $\{P_i^\star\}_{i=1}^J$ and state public services, $\{G_i^\star\}_{i=1}^J$.

Comparing our approach to Ossa (2014) and Ferrari and Ossa (2023), we explicitly derive the government's first order condition rather than numerically maximize the objective function of governments. Thus, we exploit an additional equilibrium condition for optimal policies, such that the model can then be computationally applied to a much larger number of jurisdictions (e.g., counties vs. states or countries) in a very efficient manner.

3. From Theory to Empirics

We next bring our general equilibrium model of commodity taxation to the data.

3.1. Data and Summary Statistics

Commodity taxation in the United States is highly decentralized, with sales taxes being set at the state, county and local level. In this paper, we focus on county governments because there is a sufficiently large number to provide ample variation and they are large enough in geographic size to have shopping opportunities. Ignoring Alaska and Hawaii, our sample includes 3,109 counties. In the continental U.S., 13 states (with 488 counties) do not allow municipal or county sales taxation. As we are interested in local tax setting decisions, our analysis focuses on the 2,621 counties located in the 36 states allowing for local taxation. The 488 institutionally constrained counties without local tax authority are however always included as a shopping destination to account for cross-border shopping opportunities.

We use data on sales tax rates for all states, counties and cities for 2011, assuming the data represent the governments choices in equilibrium.[9] To account for the multi-tiered federal structure, the effective county sales tax rate is the sum of its observed county rate plus the average tax rate of the municipalities it includes. State-level tax rates are always included in our quantitative analysis but are taken as exogenous. Among the 2,621 counties that are free to choose their tax rates by state law, 2,219 choose to set a positive county tax rate and 402 (around 15%) choose to set a zero tax rate.

Table 1 reports the list of observed endogenous (Panel A) and exogenous (Panel B) variables we use in the analysis and provides descriptive statistics for taxing counties.[10]

Table 1. Descriptive statistics for taxing counties.

	Var	Mean	SD	Min	Max	Obs
A. Endogenous model variables						
County + avg. municipal sales tax rate (%)	t_i	1.754	1.202	0.007	6	2219
Number of retail firms	m_i	553	1838	2	47704	2219
Average household after-tax income (in $1,000)	e_i	60.299	14.173	31.432	152	2219
Earnings (in $1,000)	w_i	44.587	12.76	17.209	126	2219
Non-sales tax revenue relative to expenditure (%)	$R_i/(p_i n_i g_i)$	89.602	12.261	5.341	100	2219
B. Exogenous model variables						
Population (in 1,000 households)	n_i	37.542	124	0.243	3219	2219
State sales tax rate (%)	T_i	5.191	1.14	0	7.25	2219
State income tax rate (%)	τ_i	2.619	1.664	0	5.835	2219

NOTE— The sample includes the 2,219 taxing counties. Data sources: Agrawal (2015) for sales tax rates, U.S. Census for demographic and income data, County Business Patterns for retail firm counts, NielsenIQ Consumer Panel for cross-border expenditures, and the Annual Survey of State and Local Government Finances for fiscal data. Income tax rates from NBER TAXSIM.

Figure C.1 illustrates the spatial variation in counties' sales tax rates. Figure C.2 shows the spatial distribution of tax types levied at the county and state levels.

3.2. Model Inversion

We invert the model in the following manner.[11] First, we obtain the iceberg transportation costs using data on interjurisdictional shopping patterns. Second, we solve (15) for p_i using

[9] These data are cleaned in a similar manner as Agrawal (2015).
[10] Other socioeconomic variables used in the paper from U.S. census data are reported in Table C.1.
[11] This section focuses on intuition, all technical details are provided in Appendix D. Additionally, Table D.1 summarizes the nature of the main variables of the model and their degree of matching with data

data on t_i, m_i, e_i from Table 1 for different incremental value of σ. Using (11), we then obtain σ by minimizing the variance in log wages predicted by the model versus those in the data. Third, using this value of σ and the implied equilibrium *private* economy endogenous variables, along with the estimated iceberg transportation costs, we obtain the pairwise commodity flows between all jurisdictions, X_{ij}, allowing us to construct local tax bases. In addition, we derive all the partial equilibrium responses at the observed tax rates, (22). Fourth, we calibrate κ_i using data on e_i and f_i using data on m_i. Fifth, ν and φ are estimated to match moments of non-sales tax revenues $R_i/p_i n_i g_i$ in Table 1. Finally, novel to our paper, armed with all inputs to our optimal tax rule except for residual non-sales tax revenues per capita, Δ_i, we solve (23) for Δ_i to match observed local sales tax rates, t_i.

3.3. Estimation of the Transportation Costs: μ_{ij}

Cross-border shopping costs, μ_{ij}, are unobserved and therefore we use a gravity model to predict these transportation costs. Taking logs of the aggregate purchases from residents of j to stores in i, (4), we obtain the standard fixed-effect gravity equation, $\log X_{ij} = \varkappa_i + \vartheta_j - (\sigma - 1)\log \mu_{ij} + \varsigma_{ij}$, where $\varkappa_i$ is a fixed effect that absorbs the sales tax rate and price in the shopping destination, ϑ_j is an origin fixed effect that controls for disposable income, and ς_{ij} is an error term (Head and Mayer, 2014). Following the literature, we assume that the shopping costs take the following functional form: $\mu_{ij} = \exp\left(\sum_k \beta_k z_{ij}^k/(1-\sigma)\right)$, where z_{ij}^k includes the straight-line distance between the county population centroids and other relevant covariates such as an indicator for purchases at home, in a contiguous county, or within different driving times.[12] We therefore estimate the following gravity equation

$$\log X_{ij} = \varkappa_i + \vartheta_j + \sum_k \beta_k z_{ij}^k + \varsigma_{ij} \tag{24}$$

where X_{ij} is county-to-county aggregate expenditure in i of residents of j constructed using the NielsenIQ Consumer Panel data matched with the Retail Scanner Panel (Kilts Center for Marketing, 2010a,b). See Appendix C for how we match consumer locations and purchase locations to determine bilateral consumption patters between jurisdictions. Estimating (24) using a Poisson pseudo-maximum-likelihood approach, we obtain the results reported in

[12] In our setting, it is natural to think of shopping costs being related to the distance between jurisdictions. But, in other contexts, such as globally mobile factors, distance can be replaced by other bilateral frictions such as tariff, certifications or migration restrictions, etc. Note that in 2011, e-commerce represented 4.5% of total retail sales (`https://www.census.gov/retail/index.html`). We expect the growth of online shopping to reduce, though not eliminating the influence of physical distance on shopping costs. Indeed, the recent Supreme Court decision requiring taxes to be paid on online sales has resulted in a new wave of cross-border shopping across borders (Bruce et al., 2023).

Table 2.

Table 2. Gravity regression results.

	(1)	(2)	(3)	(4)	(5)	(6)
Log(distance)	−1.341***	−1.231***	−1.183***	−1.332***	−1.216***	−1.169***
	(0.0974)	(0.0969)	(0.0965)	(0.0967)	(0.0962)	(0.0955)
Home	4.254***	5.123***	5.523***	4.309***	5.212***	5.605***
	(0.568)	(0.583)	(0.590)	(0.565)	(0.580)	(0.586)
Adjacent	5.447***	5.958***	6.203***	5.473***	6.000***	6.239***
	(0.248)	(0.269)	(0.280)	(0.248)	(0.269)	(0.280)
Neighbor60	3.371***	3.822***	4.041***	5.336***	6.073***	6.376***
	(0.193)	(0.215)	(0.226)	(1.129)	(1.149)	(1.159)
Neighbor90		2.145***	2.346***		8.726***	8.973***
		(0.212)	(0.223)		(3.383)	(3.421)
Neighbor120			1.409***			−12.76**
			(0.261)			(5.580)
Neighbor60 × Log(distance)				−0.529*	−0.602*	−0.627**
				(0.305)	(0.309)	(0.312)
Neighbor90 × Log(distance)					−1.599*	−1.611*
					(0.826)	(0.833)
Neighbor120 × Log(distance)						3.174**
						(1.247)
Observations	5,272,737	5,272,737	5,272,737	5,272,737	5,272,737	5,272,737

NOTE— * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The dependent variable is the logarithm of expenditure of a resident of county j in county i. Home: county j itself; Adjacent: i is adjacent but is not home; Neighbor60: i is within 60 minutes of driving time from j but not adjacent to j; Neighbor90: i is between 60 and 90 minutes of driving time from j; Neighbor120: i is between 90 and 120 minutes of driving time from j. Standard errors are two-way clustered at the i and j levels.

A one percent increase in distance between counties i and j lowers purchases in i by a resident of j by 1.34%. The subsequent indicators for purchases in the home county, in adjacent or within 60 minutes driving time counties are positive indicating a preference for consumption in nearby counties rather than those that are far away. In Appendix E.1, we use the different specifications of Table 2 to predict the local expenditure share of each county (θ_i). They all prove to lead very similar results and to be highly correlated with the observed expenditure share in the NielsenIQ data (see Table E.1 and Table E.2). We therefore use the most flexible specification (6) in Table 2.

3.4. Parameter Calibration: α, σ, ν and φ

First, we follow standard practice and parametrize the labor income share α to 2/3. Second, we follow Ahlfedlt et al. (2015) and calibrate the elasticity of substitution σ so as to minimize the square of the difference between the variance of the wages (w_i) predicted by the model and the variance of the observed wages (see Table 1). We perform a grid search of potential values of σ between 1 to 10 with a step size of 0.01 and obtain a value of σ of 4.96 which is close to central estimates in the trade literature (Head and Mayer, 2014). This parameter governs the degree of substitution among of the varieties produced in the different counties. An higher value of σ implies a greater elasticity of the tax base with respect to local sales tax rates and hence a smaller optimal tax rate in equilibrium.

Third, parameter ν which characterizes the level of the marginal willingness to pay for public services and the parameter φ which determines the marginal rate of substitution between state and local public services are estimated jointly. We use the method of moments to estimate these parameters so that the share of non-sales tax revenues in total government revenues (expenditures) in the model, $R_i/p_i n_i g_i$ (see Table 1) matches both the sample mean and the variance of data from the Census of Governments for our sample of taxing counties. Intuitively, our estimation of ν and φ guarantees that the Ramsey rule predicts a correct share of sales tax revenues in total revenues. Our method of estimating these parameters differs from Suárez Serrato and Zidar (2016) or Fajgelbaum et al. (2019) because they do not model tax decisions and therefore do not have an optimal tax rule, thus necessitating that they rely on workers' mobility to reveal their preference for public services.

We obtain a value of $\nu = 0.495$ which means that a resident's desired expenditure share on public services is $\nu/(\nu+1) = 0.332$ which is larger than the value of 0.23 in Fajgelbaum et al. (2019). Our larger estimates are consistent with incumbent voters being more likely to vote for higher taxes than newly settled, hence marginal, residents.

Our method of moments estimation yields $\varphi = 0.276$, so that the marginal rate of substitution between state and local public services is $(1-\varphi)/\varphi = 2.623$. That is, a household is willing to trade one unit of state public services for 2.623 units of local public services. While such a high value is large, it is consistent with local residents seeking to finance local public services (e.g., education) using state rather than local funds. Because state and local services are substitutable, a high value of the MRS, $(1-\varphi)/\varphi$, means that if the residents of county i had to choose *both* state and local funding for education, g_i and G_i, they would select a higher amount from the state than the local government. This is because the residents of i do not fully pay for state funding for education, as it is mostly financed by residents outside of the county.

3.5. Local Fundamentals: Δ_i, κ_i and f_i

Capital Income κ_i and firm's entry cost f_i. We compute the household capital income κ_i by solving (14) using data on individual net income, e_i and we recover the firms' entry cost f_i by solving (13) using data on the number of firms m_i (see Table 1).

Alternative Sources of Revenue R_i. Alternative sources of revenue are $R_i = p_i n_i \Delta_i$, which are governed by the per capita non-sales tax revenue (measured in goods) Δ_i. For each taxing county, given the equilibrium quantities implied by model inversion, we compute Δ_i so that each jurisdiction's Ramsey rule is satisfied. Thus, we can recover R_i for taxing counties.

Next, we need to determine the non-alternative resources R_i of non-taxing counties. This is challenging as these counties' observed zero tax rates as we do not observe their unconstrained optimal (possibly negative) tax rate. To recover the R_i for these counties, we estimate the relationship $R_i = \sum_k \beta_k s_i^k + \epsilon_i$ in taxing counties where s_i^k are a set of socio-economic variables described in Table C.1.

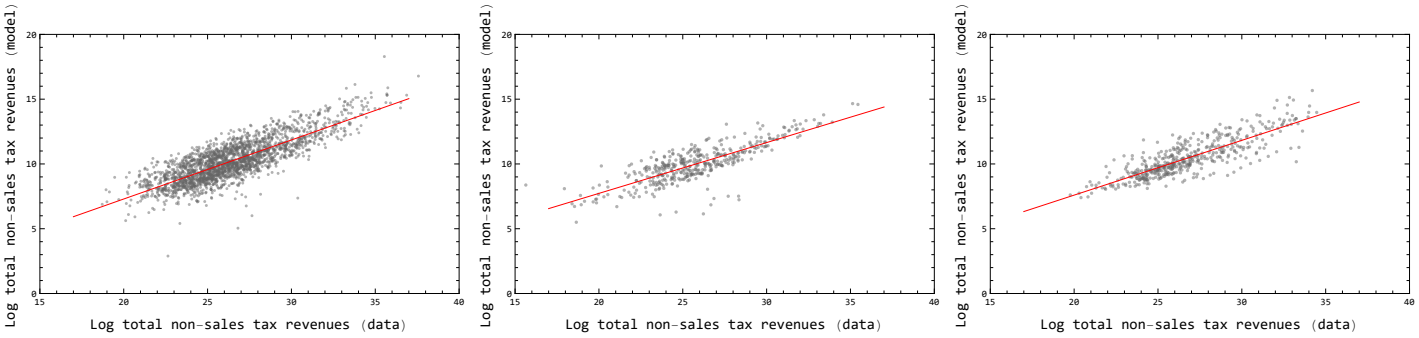
We need to distinguish between the 402 counties which voluntarily choose a zero tax—indicating that their optimal tax rate is negative—and the 488 counties that are forced to set zero due to state restrictions. For the latter counties, we simply set $R_i = \widehat{R}_i = \sum_k \widehat{\beta}_k s_i^k$. However, for the former, we need to choose a sufficiently high R_i such that the optimal tax rate is non-positive. To this aim, we use a conditional bootstrap procedure based on the distribution of $\widehat{\beta}_k s_i^k$ and then assign $R_i = \mathbb{E}[\widehat{R}_i | \partial V_i / \partial t_i \leqslant 0]$, as this condition guarantees that their optimal tax rate is non-positive.

Our procedure distinguishes our approach from prior studies incorporating endogenous government (Ossa, 2014; Ferrari and Ossa, 2023) where the model's predictions of governments' policy do not match with observed data. As our paper is interested in quantifying welfare effects of tax reforms, it is essential that the model predicts accurately observed endogenous tax rates, highlighting yet again, the advantage of exploiting the government's first order condition. A further advantage of our approach is that the counties' alternative sources of revenue are directly observable in the data, allowing us to test the ability of our model to actually match the data.

3.6. Overidentification Checks

We now examine the model's predictions for variables not used in the calibration and for the relationships between variables not directly imposed by the model. Figure 1 shows that counties' alternative sources of revenue R_i, our main structural residual, is highly correlated with observed data. As R_i is computed so that predicted tax rates coincide with observed

ones, non-sales tax revenues predicted by the model are not guaranteed to match with their observed counterparts.



(a) Taxing counties

(b) Non-taxing counties (with tax authority)

(c) Non-taxing counties (without tax authority)

Figure 1. Overidentification check: counties' non-sales tax revenues. This figure shows the correlation between our model's main structural residual—alternative sources of revenue for the county R_i—on the vertical axis with data on observed non-sales tax revenue from the Census of Governments on the horizontal axis. We depict this correlation for three different sub-groups of counties: those that levy local sales taxes (Panel a), non-taxing counties that have the ability to levy sales taxes (Panel b), and non-taxing counties in states that ban local taxes (Panel c). While the residuals in Panel a directly follow from our structural estimation, the residuals for both Panel b and Panel c are recovered using the procedure in Subsection 3.5 that relies on predictions from exogenous observables.

Using data on non-sales tax revenues from the Census of Governments, Figure 1a shows a strong positive correlation with the non-sales tax revenues predicted by our model for the taxing counties. This suggests that our open-economy Ramsey rules accurately represents the policy decision of these counties. An even more striking result, shown in Figure 1b and Figure 1c, is that our taxation rule allows us to predict well the non-sales tax revenues of the non-taxing counties that were not used in the calibration of ν and σ. This suggests that our model should perform well in counterfactual scenarios shocking the tax rate in counties currently setting a zero tax rate.

Our quantitative model perfectly matches observed household income, e_i, by calibrating capital income as described. However, it does not enforce a perfect match between wages, w_i, and observed earnings; instead, it only ensures that their variances coincide. Figure 2 shows that, although not imposed, household wages in the model are positively correlated with those in the data.

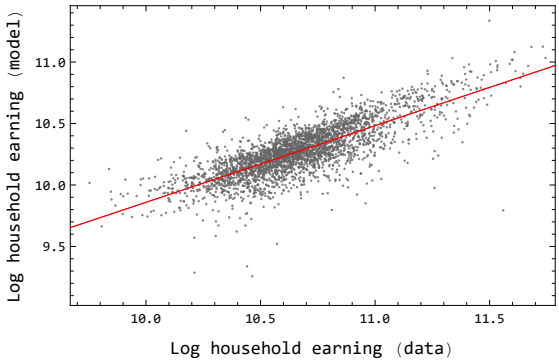


Figure 2. Overidentification check: household earning per county. The sample includes all 3,109 counties. The red line is the linear model fit.

Further, in Appendix E, we show that own-jurisdiction consumption shares in the model match those in the NielsenIQ data. In addition, to demonstrate how well we match the policy choices of local governments, we show that observed tax rates are strongly correlated with various components of the Ramsey rule. In addition, we show that own-jurisdiction consumption shares in the model match those in the NielsenIQ data.

3.7. Results: Tax Decision and Tax Incidence

Table 3 provides our quantification of the different components of the open economy Ramsey rule (23).[13] To the best of our knowledge, this is the first overall picture of the magnitudes and distributions of all the elements of a Ramsey rule for commodity taxes in an open-economy.[14]

Table 3. Components of the open economy Ramsey rule (23): $\frac{t}{1+t+T} = \frac{1-\frac{\chi\lambda}{\nu}-\frac{\eta\phi}{\nu}}{\varepsilon+\frac{\theta}{\nu}}$.

Index	Description	Mean	SD	Min	Max	Obs
ε	Elasticity of demand w.r.t. tax (absolute value)	2.135	0.13	1.292	2.336	2219
θ	Local expenditure share	0.738	0.138	0.076	0.992	2219
χ	Share of total sales from own residents	0.776	0.107	0.057	0.985	2219
λ	Non-sales tax revenue to income ratio	0.350	0.019	0.300	0.440	2219
η	Public services to tax base ratio	0.475	0.110	0.163	1.324	2219
ϕ	Equilibrium price effect	0.418	0.058	0.256	0.940	2219

NOTE— The table reports the values of the components of open-economy Ramsey rule (23), evaluated at the general equilibrium of the economy, for the 2,219 taxing counties.

[13] Table F.1 quantifies the terms of the government's first-order condition in an alternative yet equivalent form.
[14] Several prior contributions used reduced-form approach to estimate components of open-economy Ramsey rule for tariffs and tariff equivalents (Goldberg and Maggi, 1999).

Table 3 indicates that the tax elasticity of demand plays a critical role. Even in a rich spatial open economy, optimal tax rates are still significantly influenced by the elasticity of demand. Our structural estimate of the elasticity with respect to local sales tax rates (2.136) is very close to similar estimates in the reduced-form literature (see, e.g., Baker et al. (2021)'s 2.20). This elasticity has a low standard deviation, suggesting that the elasticities do not vary much across counties. With respect to the role of ϕ_i, as acknowledged in the trade literature (Mayer, 1984; Grossman and Helpman, 1994; Mitra, 1999; Bagwell and Staiger, 1999, 2004), the expected sign and magnitude of it is theoretically ambiguous. This ambiguity arises because a tax cut raises the prices, which in turn have the following direct effects: increased wages, increased public spending, and decreased private consumption. In our setting, this terms is always positive, suggesting the first two effects dominate, raising utility.

Table 4. General equilibrium local and external tax incidence.

	(1)	(2)	(3)	(4)	(5)	(6)
	All counties			20% largest counties j		
	Mean	SD	Obs	Mean	SD	Obs
A. Local incidence $\frac{1}{p_i}\frac{\partial p_i}{\partial t_i}$	−0.6415	0.1043	3,109	−0.5324	0.1366	524
B. External incidence $\frac{1}{p_i}\frac{\partial p_i}{\partial t_j}$						
Adjacent neighbors	0.0428	0.0512	18,474	0.0993	0.0803	3,136
Non-adjacent neighbors within 60 miles	0.0143	0.0216	14,026	0.0332	0.0342	3,042
Non-adjacent neighbors between 60 and 90 miles	0.0058	0.0127	29,279	0.0121	0.024	5,434
Non-adjacent neighbors between 90 and 120 miles	0.0012	0.0097	40,414	0.0005	0.0195	7,155

NOTE— The table reports the pairwise tax incidence. Columns 1 and 2 include all 3,109 counties, while columns 4 to 6 focus on price responses across all counties resulting from a tax change in the top 20% of counties with the largest number of households.

Table 4 presents our estimates for the elasticity of prices with respect to local sales tax rates.[15] We compute those price elasticities by implicitly differentiating the general equilibrium system $(\mathcal{E}_i)_{i=1,\dots,I}$. This yields a matrix of all prices changes $\partial p_i/\partial t_j$ in the economy for a 1 percentage point increase in the tax rate of any jurisdiction. We find that, on average, producer prices decrease by 0.642% after a one percentage point increase of the local sales tax rate. Because $1+t_i$ is close to one, the semi-elasticity in the table can be interpreted (approximately) as a classic elasticity of -0.642 corresponding to a one percent change in $1+t_i$. This contrasts with

[15] Figure F.1 compares the partial and general equilibrium tax incidence on prices.

the full pass-through on consumers estimated in older reduced-form sales tax studies (Poterba, 1996), but is more in line with recent VAT estimates (Benzarti et al., 2020). In the presence of tax base mobility, some of the incidence of the tax should be born by consumers/producers in other jurisdictions. The reduced-form estimates of multi-market estimates are nearly inexistent in the literature. One exception is the work by Harding et al. (2012) who show that the incidence of a state tax increase depends on the distance to the nearest low-tax state border. We find a similar pattern: a one percentage point increase in the sales tax rate of a county increases producer prices in the adjacent county by 0.04%, which quickly decreases as counties further away. The semi-elasticity amounts to 0.001% for counties between 90 and 120 minutes driving time. Columns 4 to 6 report tax incidence generated by the largest counties. As expected, their effects on the price of other counties are much more signficant, as illustrated by the larger means and standard deviations.[16] We can also note that local price tax incidence is smaller in these large counties (columns 1 to 3) suggesting that the demand there is more elastic.

4. The Welfare Effects of Tax Competition

We now use our structural estimates to investigate the welfare effects of tax competition. To do that, we investigate two counterfactual policies: a minimum local tax of 2% that would be uniformly imposed in all states that allow for local sales taxes (Subsection 4.1) and a partial tax harmonization imposing both a minimum and a maximum tax rate of 1% and 2.5%, respectively (Subsection 4.2). We study the role of strategic tax setting by local governments by comparing the welfare effects of both reforms under two: (i) without tax competition, that is, without allowing counties to further changes their tax rates; (ii) with tax competition, that is allowing counties to re-optimize their tax rates afterwards.

To measure the welfare effects of these two tax reforms, we use equivalent variations, that is the amount of income that should be transferred to a representative resident prior to the reform so that her utility increases/decreases up to her after-reform utility level. The higher the equivalent variations the "better" the policy. Given that preferences are homothetic, the general formula of the equivalent variation is $EV_i = (V_i' - V_i)/V_i e_i$. where V_i $[V_i']$ is the pre[post]-reform indirect utility of the resident of i. Note that all welfare effects that we present should be interpreted in the context of changes in the neighborhood of the existing equilibrium, and not as deviations from the social optimum where a planner chooses the local

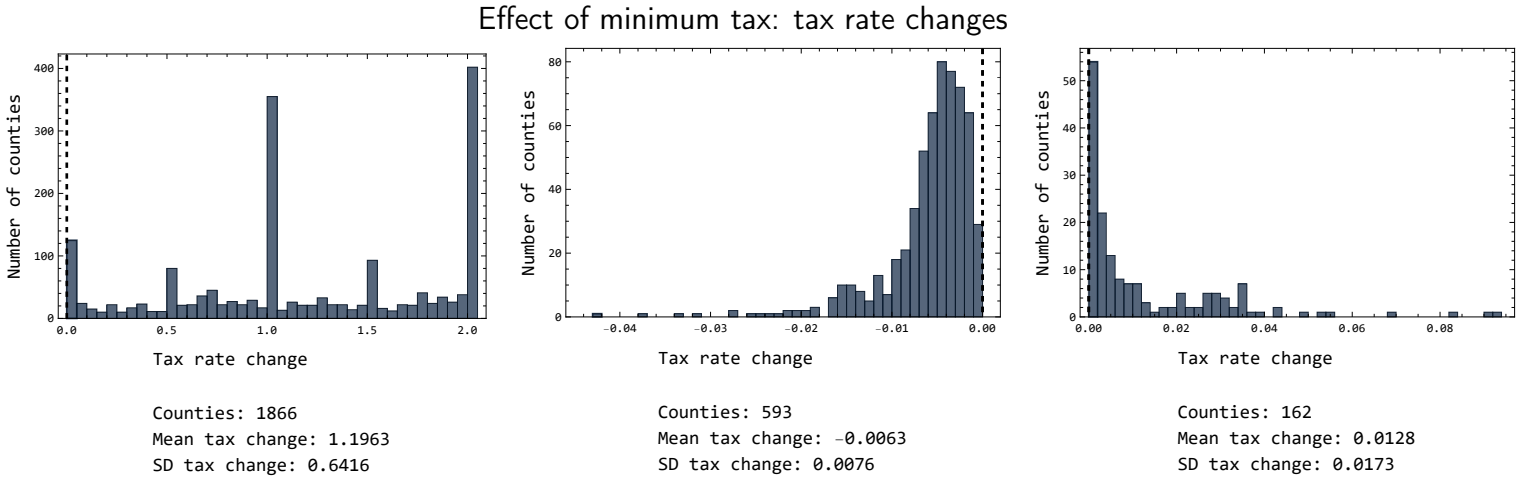
[16] The exceptions are the most remote neighborhoods between 90 and 120 miles which have a slightly positive average tax incidence resulting from the balance between positive and negative incidence.

tax rates for each jurisdiction. While our model can technically solve for the social optimum, we do not do this, as it has little policy relevance.

4.1. The Welfare Effects of a Minimum Tax

We consider a baseline minimum sales tax rate of 2%. As the average county-level sales tax rate is low (around 1.75%, see Table C.1), this would directly constrain the tax setting policy of 69% of the counties leading to a mechanical increase of 1.1 percentage point on average.[17]

Figure 3 represents the effects of the minimum tax on the tax rate chosen by counties in the new general equilibrium (that is, allowing all counties to change their tax rates afterwards). Figure 3a presents the change in tax rate imposed on counties that are directly affected by the minimum tax rate (treated counties). We find that the maximum tax increase to be of 2 percentage points, indicating that no treated county over-react to the minimum tax by setting a tax rate above 2%.



(a) Treated counties.

(b) Non-treated counties with negative tax reactions.

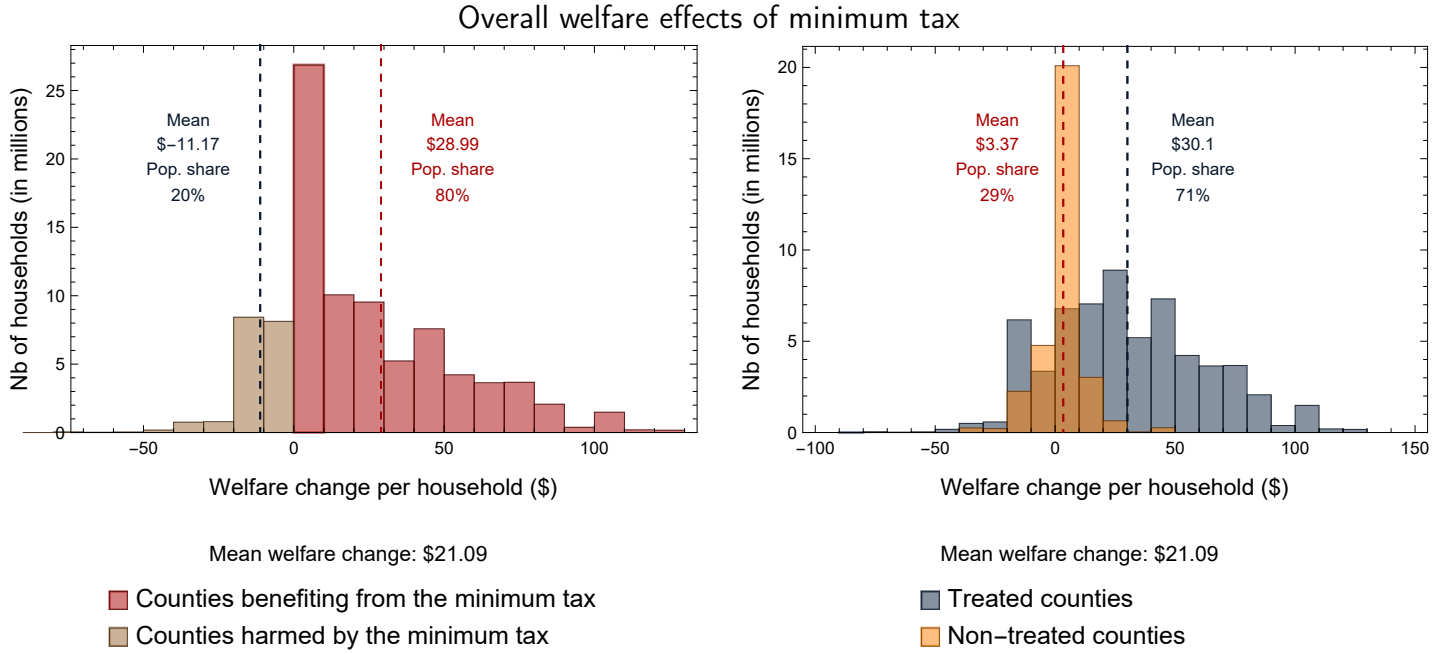
(c) Non-treated counties with positive tax reactions.

Figure 3. Change in tax rate in response to a 2% minimum tax. The figure represents the change in tax rate: $100 \times (t^{after} - t^{before})$.

The strategic responses of the counties with an initial tax rate above 2% (non-treated counties) are represented in Figure 3b and Figure 3c. We find that a significant mass of counties decrease their tax rate (Figure 3b) while fewer counties increase their tax rate in the new equilibrium (Figure 3c). The range of positive reactions is larger than that of negative reactions. For this

[17] Figure G.1 reports for the share of counties constrained by different levels of minimum tax rates and the resulting mechanical tax rate change.

particular reform, a large mass of weakly strategic substitute neighbors dominates the scarcer strategic complement ones, so the average tax response is slightly negative (−0.0036%). In absolute value, the tax adjustments of non-treated counties are small compared to treated counties. This reflects the fact that each county has only a few treated neighbors changing their tax rates.



(a) Separating by winning and losing counties.

(b) Separating by treated and non-treated counties.

Figure 4. Total welfare effects of a minimum tax of 2%. The welfare effects are calculated in our full general equilibrium, allowing treated and non-treated counties to respond strategically. The horizontal axis represents the equivalent variations of the counties weighted by their populations, shown separately for different groups of counties with tax authority. The vertical axes are number of households. Table G.1 in Appendix G provides more details on welfare effects.

Figure 4 presents the welfare effects of the minimum tax, measured by the equivalent variations. We find that residents of treated counties are the actual winners of the policy, while the outcome is mixed in non-treated counties. On average, an individual values the benefits of the policy at $21. This number raises to $30.1 in treated counties and is only $3.4 in non-treated counties. With respect to the magnitude of the welfare changes, it is important to keep in mind that local sales tax rates in the United States are low. Therefore, it is useful to benchmark these numbers with respect to the local sales tax burden faced by households. In this respect, the overall increase in welfare amounts to 5.3% of the per capita local sales tax burden. For treated and non-treated counties, the increase amounts to 8% and 0.5%, respectively.

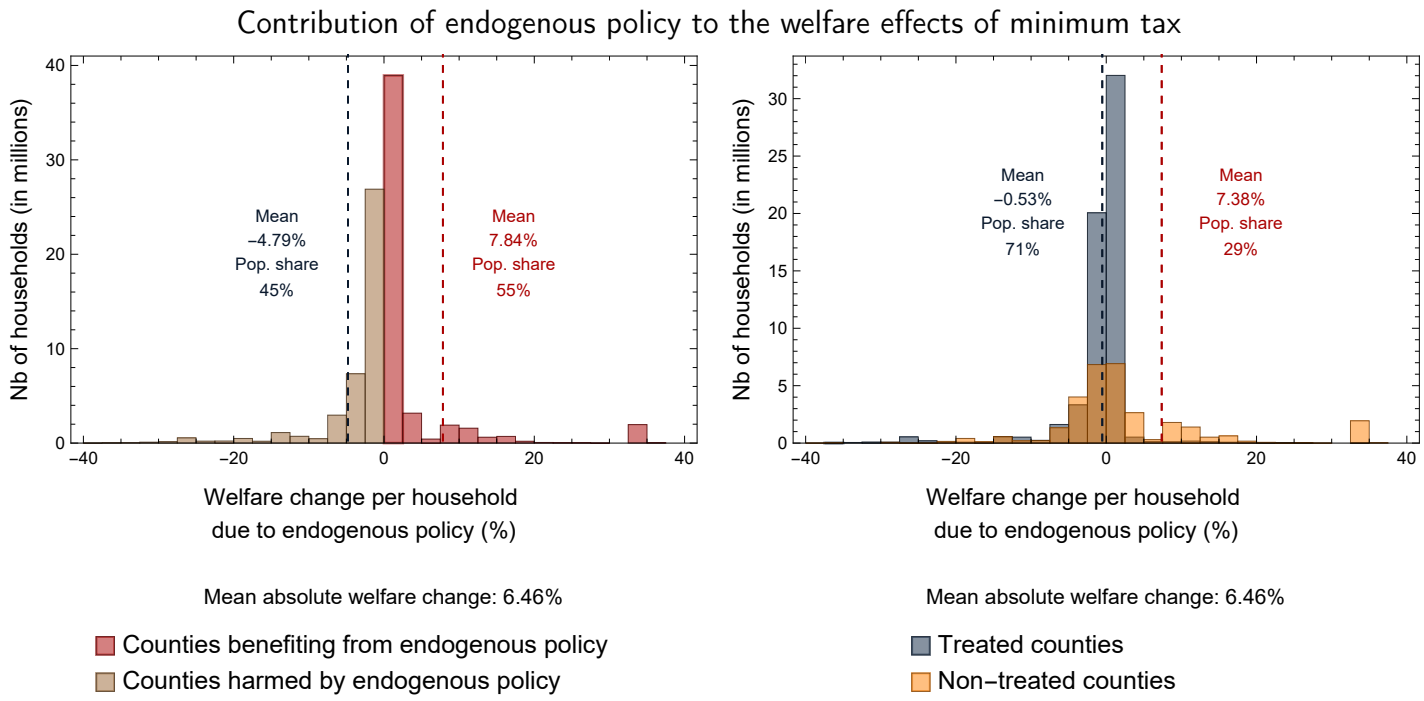
The rationale of this welfare increase is that the minimum tax rate forces treated counties to increase significantly their tax rates so their population benefit from more public services overcoming the cost of paying higher taxes.[18] This is consistent with tax competition leading counties to set too low tax rates in the first place (Zodrow and Mieszkowski, 1986; Wilson, 1986). The small welfare effects on non-treated counties are not surprising as these counties are only indirectly affected by the minimum tax. Note also that the welfare effects are more dispersed among treated counties, reflecting the fact that these counties experience the largest change in their tax rates.

How much of these welfare effects are actually due to endogenous policy responses? We answer this question by comparing the above welfare effects with a counterfactual world in which counties are not allowed to autonomously set their tax rates. For each county we first calculate the equivalent variation with endogenous policy responses EV^{endo} and then the equivalent variation without endogenous responses EV^{exo}. The percent change is then relative to the scenario with endogenous policy responses, $100 \times (EV^{endo} - EV^{exo})/|EV^{endo}|$. As this percent change can be positive and negative, the average effect is reported as the mean of the absolute deviation.

Figure 5 presents the distribution of the difference in equivalent variations due endogenous tax setting. The (absolute value of the) welfare effect of allowing governments to strategically respond amounts to around 6.4%. As a result, not counting for endogenous policy in a quantitative model would lead to substantial biases in the welfare effects. Figure 5 also shows the extent of heterogeneity among winners and losers from endogenous tax setting: 55% of the population benefit from endogenous tax setting with an increase in welfare of 7.8% on average while 45% of the population lose from endogenous tax setting with an average loss of 4.8%. Among treated counties, endogenous policy making accounts for 7.4% of their welfare gains. For non-treated counties, the effect is slightly negative -0.6%, meaning that endogenous tax setting dampens the welfare gains for these counties.[19]

[18] Figures G.2 and G.3 in Appendix G further decomposes the welfare effects of the minimum tax into public and private gains.

[19] Figure G.4 in the Appendix G correlates the change in tax rate and the change in welfare. Results indicate that counties increasing their tax rates are more likely to benefit from endogenous policy responses than counties reducing their tax rates.



(a) Separating by winning and losing counties.

(b) Separating by treated and non-treated counties.

Figure 5. This graph represents the percent change in equivalent variations of a minimum tax of 2% with strategic interactions relative to without strategic interactions. Percent change are defined as $100 \times (EV^{endo} - EV^{exo})/|EV^{endo}|$. The average welfare effect of endogenous policy is computed as the mean absolute value of the welfare change. The sample includes all counties with taxing authority.

4.2. The Welfare Effects of Tax Harmonization

Appendix H studies the welfare effects of (partial) tax harmonization (Fajgelbaum et al., 2019; Hines, 2023) imposing both a minimum and a maximum tax rate of 1% and 2.5%, respectively. This corresponds to a policy in which all states allowing for a local sales tax would require their counties to choose a tax rate within a bandwidth of 0.7 percentage points around the mean tax rate of all counties in those states (around 1.75%). We can therefore investigate whether the welfare effects differ between counties treated from above ("top-treated") or from below ("bottom-treated").

In our baseline scenario of a bandwidth of 0.7 percentage points, partial tax harmonization leads to an overall welfare decrease of $\$-9$ driven by top-treated counties that are forced to decrease their tax rate (see Table H.1 and Figure H.2). These results extend those observed for the introduction of a minimum tax: counties that have to increase (decrease) their tax rate experience a welfare gain (loss), suggesting that observed tax rates are loo low. Comparing our welfare effects with and without endogenous tax setting lead also to a similar conclusion

as for minimum taxes: endogenous policy responses amount on average to 5.6% of the welfare effects with 56% of the population benefiting from endogenous tax setting and 44% of the population losing from it (Figure H.3)

What would be the optimal minimum tax rate? Is partial harmonization preferable to a minimum tax, or could another policy result in higher aggregate welfare? Answering these questions is inherently challenging, as it requires comparing a broad spectrum of policies. Moreover, since such policies inevitably create both winners and losers, it is necessary to adopt a clear stance on the objective function of a social planner. To advance this discussion, we focus instead on the essence of tax competition: the interdependence of tax setting among a network of local jurisdictions. In Section 5, we introduce a new concept—the Policy Network Matrix (PNM)—along with two associated measures of the degree of tax competition: Policy Responsiveness and Policy Impact. In Section 6, we show that Policy Impact is a key determinant of the welfare effects of tax competition and provide evidence that any optimal policy should incorporate this measure into its design.

5. The Policy Network of Tax Reforms

The Policy Network Matrix (PNM) is the extension to a general spatial equilibrium economy of the well-known spatial weight matrix and its coefficients estimated in many prior tax competition papers (see Agrawal et al., 2022, for a review). It is defined as follows.

Definition 1. *The Policy Network Matrix (PNM), denoted* $\boldsymbol{\Omega}$*, is an* $J \times J$ *matrix including all bilateral interjursidiction tax reaction functions evaluated at the general equilibrium of the economy. The element of the* i^{th} *row and* j^{th} *column of the PNM,* ω_{ij} *is the tax response of jurisdiction* i *to a marginal change in jurisdiction* j*'s tax rate, taking as fixed the tax rates in all other counties:* $\omega_{ij} = \partial t_i / \partial t_j$.

Intuitively, the PNM is the first-order tax change of any county to a tax change in any other county (or set of counties) through spatial general equilibrium linkages. It is a matrix with J^2 entries resulting from possibly highly nonlinear tax functions. It differs from the general equilibrium tax changes in our counterfactual exercises as it is derived taking as fixed the tax rates of all other counties.

5.1. Computation of the Policy Network Matrix

The PNM includes all the tax reaction functions evaluated at the general equilibrium. Its computation requires to differentiate the first-order conditions of the local governments introduced in Subsection 2.7, subject to the general equilibrium of the private economy defined in

Subsection 2.6. This section derives in four steps the closed-form expression of the PNM using the implicit function theorem. Importantly, although the following derivation of the PNM is motivated by our particular quantitative model, the resulting formula of the PNM is general and does not assume any particular structure; it applies to any quantitative model.

Step 1: General Equilibrium of the Economy

As the PNM is evaluated at the equilibrium, we first need to compute the general equilibrium of the economy as described in Subsection 2.8. In particular, this step computes the levels of the three key endogenous variables —the prices, p_i, the price indices, P_i, and the state public services, G_i— and their partial equilibrium responses to taxation —$\partial p_i/\partial t_i|$, $\partial P_i/\partial t_i|$ and $\partial G_i/\partial t_i|$ evaluated at their general equilibrium levels $\{t_i^\star\}_{i=1}^J$, $\{p_i^\star\}_{i=1}^J$, $\{P_i^\star\}_{i=1}^J$ and $\{G_i^\star\}_{i=1}^J$.

Step 2: General Equilibrium Economic Responses to Taxes: Tax Incidence

How do economic variables, p_j, P_j an G_j vary in all counties as some (not necessarily all) taxes change exogenously? To answer this question, we need to compute the actual general equilibrium responses to a tax change. We therefore totally differentiate the general equilibrium system $(\mathcal{E}_i)_{i=1...,I}$ which gives $\mathbf{A}\,\mathbf{dZ} = \mathbf{B}\,\mathbf{dt}$, where $\mathbf{dt}' = (\mathrm{d}t_1 \dots \mathrm{d}t_J)$ is the aggregate tax response vector, $\mathbf{dZ}' = (\mathbf{dZ}_1' \dots \mathbf{dZ}_J')$ with $\mathbf{dZ}_i' \equiv (\mathrm{d}p_i \quad \mathrm{d}P_i \quad \mathrm{d}G_i)$ is the aggregate vector of economic changes, $\mathbf{A}$ is a $3J \times 3J$ matrix and $\mathbf{B}$ is a $3J \times J$ matrix which can both be fully computed from the step 1 (their explicit expressions are derived in Appendix I). Inverting this system, we obtain the economic responses to exogenous tax changes:

$$\mathbf{dZ} = \boldsymbol{\Pi}\,\mathbf{dt} \tag{25}$$

where $\boldsymbol{\Pi} \equiv \mathbf{A}^{-1}\,\mathbf{B}$ is a $3J \times J$ matrix which represents the Jacobian of the economic prices with respect to exogenous tax changes. Hereafter, we call this matrix the *price response matrix*.It is important as it allows, for any vector of small exogenous tax changes, to infer the resulting incidence on all the prices of the economy.

Step 3: Behavioral Tax Responses to Economic Changes

The next step is to determine the responses of taxes, $\mathrm{d}t_i$, to changes in the economic variables, $\mathrm{d}p_j$, $\mathrm{d}P_j$ and $\mathrm{d}G_j$. To do so, we need to totally differentiate the governments' first-order conditions based on two important preliminary observations.

First, immediate inspection of the expression of county i's first-order condition (23) indicates that it only includes county i's variables This property is due to Assumption 1. This

is computationally particularly useful because it allows to compute the tax responses to economic variables for each county separately.[20] Second, a specificity of a government's decision rule compared to other economic agents (households and firms) is that this rule depends on (anticipated) price responses ($\partial p_i/\partial t_i|$, $\partial P_i/\partial t_i|$ and $\partial G_i/\partial t_i|$).[21] Hence, differentiation of the government's first-order condition generates second-order terms: the differential of these price derivatives, $\mathrm{d}(\partial p_i/\partial t_i|)$, $\mathrm{d}(\partial P_i/\partial t_i|)$, and $\mathrm{d}(\partial G_i/\partial t_i|)$. Intuitively, these terms capture the fact that, as a government observes an change in the economy, it re-evaluates the responses of economic variables to its policy in order to choose the appropriate tax rate. Although these second-order terms may be small in practice, this need not always be the case.

In sum, the above two observations imply that we need to totally differentiate county i's first-order condition together with the three-equation first-order partial equilibrium system ($\mathrm{d}\mathcal{E}_i$). From the implicit function theorem, total differentiation of this $4J$-equation system can be written in matrix form as $\mathbf{K}_i\mathbf{dV}_i = \mathbf{L}_i\mathbf{dZ}_i$, where $\mathbf{dV}_i' \equiv (\mathrm{d}t_i \quad \mathrm{d}(\partial p_i/\partial t_i|) \quad \mathrm{d}(\partial P_i/\partial t_i|) \quad \mathrm{d}(\partial G_i/\partial t_i|))$ is the vector of local tax and second-order responses, $\mathbf{dZ}_i'$ is the vector of changes in economic variables already introduced, and $\mathbf{K}_i$ is a 4×4 matrix and $\mathbf{L}_i$ is a 4×3 matrix which can both be fully computed from the step 1 (see Appendix I for their explicit expressions). Inverting this system allows to compute the tax and second order responses as $\mathbf{dV}_i = \mathbf{K}_i^{-1}\mathbf{L}_i\mathbf{dZ}_i$, from which we can extract:

$$\mathbf{dt} = \mathbf{H}\,\mathbf{dZ} \tag{26}$$

where $\mathbf{H}$ is a $I \times 3J$ block diagonal matrix. Relation (26) represents the tax response to changes in any economic variables treating changes in prices as exogenous. Importantly, the price changes can result from any possible cause. They may be the result of a tax reform as analyzed in this paper, but they can also be caused by any other policy (such as. e.g., a transportation infrastructure). Here we consider these economic responses to result from a tax change itself. These are the tax incidence effects as described in step 3 below.

Step 4: Policy Network Matrix

Combining steps 2 and 3 allow to compute the tax responses of any jurisdiction to changes in the tax rates by any other jurisdictions. Formally, inserting the price responses (25) into the tax responses (26), we obtain $\mathbf{dt} = \mathbf{O}\,\mathbf{dt}$, where $\mathbf{O} \equiv \mathbf{H}\boldsymbol{\Pi}$. Notice that as a jurisdiction's

[20] Let us reiterate that Assumption 1 has only minimal impacts on our estimates of the welfare effects of endogenous policy setting. The gain in tractability allows us to study the mechanisms underlying these welfare effects.

[21] Immediate derivation of the government's objective function (20) yields: $\frac{1}{E_i}\frac{\partial E_i}{\partial t_i}\Big| - \frac{1}{P_i}\frac{\partial P_i}{\partial t_i}\Big| + \frac{\nu}{\mathbb{G}_i}\frac{\partial \mathbb{G}_i}{\partial t_i}\Big|$

tax rate appears on both sides of the equation, we need to zero-out the diagonal. After trivial matrix manipulation, we get:

$$\mathbf{dt} = \boldsymbol{\Omega}\,\mathbf{dt}, \qquad \text{or equivalently,} \qquad \mathrm{d}t_i = \sum_j \omega_{ij}\mathrm{d}t_j, \tag{27}$$

where $\boldsymbol{\Omega} \equiv (\mathbf{I} - \mathbf{O}^d)^{-1}(\mathbf{O} - \mathbf{O}^d)$. $\mathbf{I}$ is the identity matrix and $\mathbf{O}^d$ is the diagonal matrix whose diagonal elements are the diagonal elements of $\mathbf{O}$, and off-diagonal elements are zero. $\boldsymbol{\Omega}$ is a $J \times J$ non-symmetric matrix in which all the diagonal elements are zeros. It collects the set of endogenous weights composing the Policy Network Matrix.

5.2. Properties of the Policy Network Matrix

The Policy Network Matrix is a spatial general equilibrium measure with three important properties: nonlinearity, endogeneity, and heterogeneity. We discuss each in turn.

In a spatial general equilibrium economy, tax response functions, $t_i = f_i(t_1, ..., t_J)$, are implicitly defined by highly nonlinear first-order conditions. This implies that the slope of these function depend on the levels of the tax rates. This slope of these functions represents the strategic response of i to a small tax change of competitor(s) tax rate(s) in $jn^b i$. Consequently, the PNM will measure marginal effect around the initial equilibrium.

Observation 1 (**Nonlinearity**). *The tax response function is nonlinear. Consequently, the PNM measures marginal tax responses around the initial equilibrium and cannot be used to determine the level of the tax rate.*

Nonlinear tax functions mean that strategic responses may vary widely across jurisdiction pairs. There are two sources of heterogeneity in the policy responses of jurisdictions. First, the tax response function, $t_i = f_i(t_1, \ldots, t_{i-1}, t_{i+1}, \ldots, t_J)$, can be jurisdiction specific—even if jurisdiction have the same tax rates, they can respond differently to a unit change in taxes. Second, even if the function was not jurisdiction-specific, $t_i = f(t_1, \ldots, t_{i-1}, t_{i+1}, \ldots, t_J)$, the slope of the response function near the equilibrium may differ because the equilibrium levels of tax rates are different in the first place.

Typically, for a sample of size J jurisdiction, we need to estimate the J^2 entries of the PNM. This contrasts with the prior reduced-form literature that estimates a single parameter rather than J^2 pairwise responses. Estimating a single response forces all jurisdictions' tax rates to be either strategic substitutes or strategic complements. Yet, both cases could coexist. In other words, strategic responses differ not only in magnitudes, but may also differ in sign depending on the characteristics of the competitor jurisdiction. Only a structural approach

like ours can recover this key heterogeneity. See Appendix J for a discussion that compares our approach with the reduced-form literature.

This leads to Observation 2:

Observation 2 (**Heterogeneity**). *The Policy Network Matrix's components are heterogeneous:*

(i) The Policy Network Matrix is not symmetric.

(ii) The Policy Network Matrix may include positive, negative and zero terms.

One reason why policy responses are heterogeneous is because endogenous price changes and fiscal externalities differ dramatically across space. The PNM is a function of all of these endogenous linkages. Therefore, by definition, it is itself endogenous:

Observation 3 (**Endogeneity**). *The Policy Network Matrix is endogenous.*

An important implication of the endogeneity of the policy network matrix is that in addition to the standard simultaneity of tax rates, the individual elements of the PNM are endogenous. Thus, any reduced-form approach would require both instruments for tax rates and instruments for the elements of the weight matrix.

The PNM is a powerful tool for two reasons: first, it allows to recover the linkages and the extent of competition between jurisdictions. While the prior literature has resorted to ad hoc proxies (e.g., contiguity) the PNM places places no a priori constraints on who/where the competitors are. Second, the PNM can be used to approximate, still accurately, the effects of different counterfactual policy scenarios near the equilibrium without the need to solve for complex and computationally intensive general equilibrium effects in the case of a large number of jurisdictions.[22] This is stated in Observation 4 and formally derived in Appendix J.2.

Observation 4. *Evaluation of counterfactual policy scenarios accounting for strategic responses of governments can be assessed using the PNM and the general equilibrium response price response matrix. Formally, for any counterfactual exercise that exogenously changes the tax rates in a set of jurisdictions,*

(i) compute the change in the tax rates of all other jurisdictions using the PNM,

(ii) compute the change in the general equilibrium prices due to changes in the tax rates in all jurisdictions using (25)*,*

[22] As the PNM is a local approximation of the tax responses near the observed equilibrium, we assess in Appendix J.3 the accuracy of this approximation by comparing the tax change predicted by the PNM with the tax change obtained by solving for the general equilibrium; they are highly correlated.

(iii) the impacts on economic variables can then be measured by differentiation of conditions (11)–(14).

Observation 4 extends the *network effects of trade shocks* characterized Allen et al. (2020) (steps *ii* and *iii*) by accounting for the extra network effects of strategic governments' decisions (step *i*). The usefulness of step *i* of Observation 4 will be shown in Section 6.

5.3. Summarizing the PNM: Policy Responsiveness and Policy Impacts

While the PNM yields all pairwise relationships in the economy, when study thousands of local governments, it is useful to construct economically-meaningful summary measures of this matrix. We propose two such measures—policy responsiveness and policy impact—the first of which is consistent with prior reduced-form studies, while the latter is novel to the literature and will be the relevant measure that drives the welfare effects of tax competition.

Policy responsiveness is obtained by row-standardizing the policy network matrix, making it comparable to reduced-form spatial weight matrices that are usually standardized so each row sums to unity. Denote each element of the PNM, where i indexes rows and j indexes columns, as $\omega_{ij} = \partial t_i / \partial t_j$. Then, the row-sum of these elements yields policy responsiveness β_i for each jurisdiction i. It measures how jurisdiction i's tax rate *responds* to a simultaneous 1 unit change in the tax rates of all other jurisdictions.

Definition 2 (**Policy Responsiveness**)**.** *The policy responsiveness (PR) of jurisdiction i is:*

$$\beta_i \equiv \sum_j \omega_{ij} = \sum_j \frac{\partial t_i}{\partial t_j}. \tag{28}$$

To link to prior reduced form work, policy responsiveness is analogous to coefficient b from a regression of $t_i = a + b\bar{t_i} + e_i$ where $\bar{t_i}$ is the spatial lag of competitor tax rates (Brueckner, 2003). However, relative to this literature which estimates a single slope parameter b, note that our policy responsiveness is allowed to vary across jurisdictions, thus allowing us to quantify the extent of heterogeneous responses in Subsection 6.1.

If, instead, the PNM is column-standardized rather than row-standardized, a new important measure emerges: policy impact. It measures the aggregate impact of a one unit increases in jurisdiction j's tax rate on all other jurisdictions tax rates. While policy responsiveness yields the effect of the economy on a single jurisdiction, policy impact yields the effect of a singe jurisdiction on the economy.

Definition 3 (**Policy Impact**). *The policy impact (PI) of jurisdiction j is:*

$$\gamma_j \equiv \sum_i \omega_{ij} = \sum_i \frac{\partial t_i}{\partial t_j}. \tag{29}$$

Policy impact is novel to the tax competition literature because estimating the effect of a single (small) jurisdiction on the rest of the economy is challenging. This stems from the premise that reduced-form researchers do not have enough degrees of freedom to estimate all pairwise responses in the economy. As shown in Subsection 6.2, policy impact will be more heterogeneous across jurisdictions than policy responsiveness.

In practice, β_i and γ_i for a given county need not be similar. For example, a large county may be little influenced by other counties but have a significant impact on them. We will quantify and compare both both measures and their heterogeneity across all U.S. counties. While we have defined each of these terms by summing over the entire row or column, they can easily be extended to summations over a smaller set (e.g., neighboring) jurisdictions.

Although the PR and the PI will in general differ for a particular county, an important property is that, on average, both are equal. This is summarized in the following proposition:

Observation 5 (**Average Tax Competition Effect**). *The average policy responsiveness is equal to the average policy impact:*

$$\overline{\beta} = \overline{\gamma},$$

where $\overline{\beta} \equiv \sum_i \beta_i/J$ is the mean of the PRs and $\overline{\gamma} \equiv \sum_j \gamma_j/J$ is the mean of the PIs.

Proof. The proof mechanically follows from Definitions 2 and 3. Indeed, $\overline{\beta} = \sum_i \beta_i/J = \sum_i \sum_j \omega_{ij}/J = \sum_j \gamma_j/J = \overline{\gamma}$. □

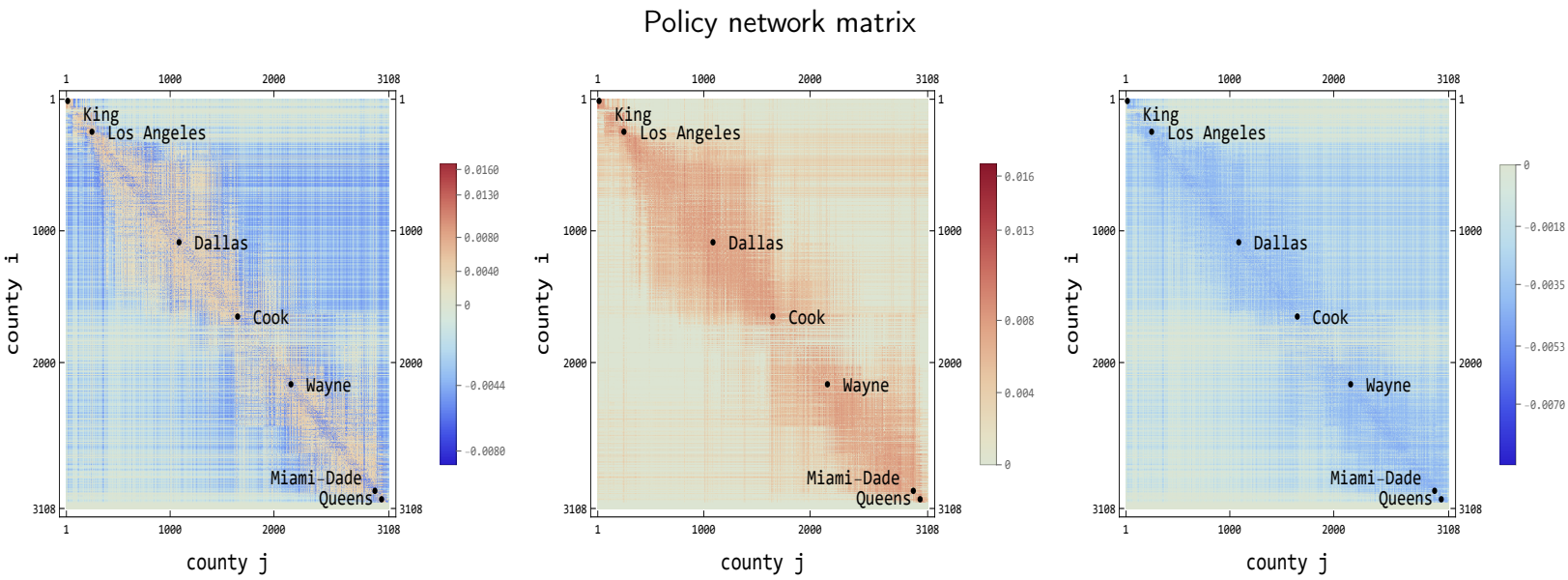
Observation 5 is important for analyzing quantitatively tax competition. It guarantees that the policy responsiveness, β_i, and the policy impacts, γ_i, are comparable measures on average.[23] In the extreme case in which all jurisdictions have the same responsiveness to tax competition, and in which they all trigger the same aggregate impacts on their neighbors, Observation 5 implies that a jurisdiction's exposure and impact are equal, i.e. $\forall i, \beta_i = \gamma_i$.

6. Policy Network Matrix and Welfare Effects

We now quantify the PNM and its summary measures in the context of local sales tax rate competition.

[23] An implicit assumption for Observation 5 to hold is that the PNM is a square matrix. If policy impact and policy responsiveness are calculated by summing over a subset of jurisdictions, this property will not hold.

6.1. Policy Network Matrix



(a) All elements of the PNM $\partial t_i/\partial t_j$.

(b) Positive elements of the PNM ($\partial t_i/\partial t_j > 0$).

(c) Negative elements of the PNM ($\partial t_i/\partial t_j < 0$).

Figure 6. Policy Network Matrix. The figure represents the elements of the PNM for the 2,219 taxing counties. Counties are sorted by distance from the most northwest county. The set "Californian couties" includes (from top to bottom): Los Angeles county, San Bernardino county, Orange county, Riverside county, Sand Diego county, and Maricona county. These county are all slightly below Clark county. A cell of the matrix has element $\partial t_i/\partial t_j$ where i represents a row and j a column. For the 890 counties i, we set $\partial t_i/\partial t_j = 0$.

Figure 6.a plots all the elements of the Policy Network Matrix, $\partial t_i/\partial t_j$, for the counties allowed to set local tax rates where the vertical axis represents county i and the horizontal axis represents county j. Counties are sorted by distance from the most northwest county such that counties that are near to each other will appear close to each other in the PNM. The PNM reveals that although often concentrated nearby, competitors need not be contiguous.

As acknowledge in models of oligopolistic competition, strategic variables may be either complements or substitutes with competitors (Bulow et al., 1985), highlighting two possible offsetting economic forces:

1. *tax base effects*: a tax increase in j expands the tax base of competitor jurisdictions i, creating incentives for those jurisdictions to raise their tax rate because of the larger base and the desire to engage in tax exporting,

2. *price effects*: a tax increase in j increases the price of that variety paid by residents of

i, which jurisdiction i seeks to compensate by lowering its tax rate.

Figure 6.b and Figure 6.c decompose the PNM into positive and negative values, showing that different pairs of jurisdictions can be either complements or substitutes to each other. Comparing panels b and c reveals that direct neighbors are more likely to be strategic complements, while remote neighbors are more likely be strategic substitutes (or not engaged in strategic competition). This result is intuitive: tax base effects are strongest among proximate neighbors. On the contrary, price effects dominate for more remote jurisdictions.

Table 5. Spatial gradient of the components of the PNM.

	$\partial t_i/\partial t_j > 0$		$\partial t_i/\partial t_j < 0$	
	Mean	SD	Mean	SD
Adjacent neighbors	0.0022	0.0047	−0.0023	0.0052
Non-adjacent neighbors within 60 miles	0.0016	0.0036	−0.0007	0.0016
Non-adjacent neighbors between 60 and 90 miles	0.0012	0.0032	−0.0003	0.001
Non-adjacent neighbors between 90 and 120 miles	0.001	0.0028	−0.0002	0.0005

Table 5 shows that policy reactions are indeed stronger in absolute value when jurisdictions are close to each other. Although distance is a powerful force in determining the heterogeneity of responses, it is *not* the only force—this can be seen by the dark long lines in Figure 6. Our model allows this to depend on other location fundamental such as size, socio-economic variables, and political characteristics, which we will explore subsequently. The fact that elements of the PNM can be heterogeneous across multiple dimensions adds substantial flexibility relative to prior models that only allow contiguity or distance to matter. Finally, while the numbers in the table may appear small, they are the pair-wise responses and not the aggregate responses estimated in studies of tax reaction functions. This leads us to our summary measures of policy responsiveness and policy impact.

6.2. Policy Responsiveness and Policy Impact

First focusing on policy responsiveness, Panel A of Table 6 indicates that if all other counties in the economy increase their tax rate by one percentage point, the average county response is to increase its tax rate by 0.09 percentage points. This aggregate effect masks some of the heterogeneity by summing both positive and negative pairwise responses. The second row of this panel show that on average, 20% of a given jurisdiction's responses are positive and thus 80% of these pairwise responses are negative. Yet, as the aggregate effect is positive, this shows that despite being less frequent, complementary responses are much larger in magnitude.

The slope of the tax reaction functions are in the lower range of those in prior tax competition work which estimate that if its average neighbors' tax rate increase by one percentage point a sales tax jurisdiction increases its tax rate by 0.10 and 0.35 percentage points (Devereux et al., 2007; Agrawal, 2016). These estimates, using ad hoc assumptions on who competitors are, provide the link from the reduced-form literature to our measure of policy responsiveness.

Table 6. Policy Responsiveness, Policy Impact, strategic complementarity and strategic substitutability of the 2,403 counties with tax authorities.

	Mean	SD	Min	Max	Obs
A. Policy Responsiveness					
Policy responsiveness (β_i)	0.085	0.033	−0.188	0.212	2621
Share of positive reactions in β_i (%)	20.04	23.86	2.9	97.46	2621
B. Policy Impact					
Policy impact (γ_i)	0.085	0.274	−0.395	5.55	2621
Share of positive reactions in γ_i (%)	21.06	8.52	8.91	89.48	2621

NOTE— β_i and γ_i are sums over the 3,019 counties in the sample. The standard deviations of the positive and negative shares are equal because two vectors with a constant component-wise sum have equal standard deviations.

Next, focusing on policy impact, Panel B of Table 6 indicates—consistent with Observation 5—the mean policy impact is very similar to the mean policy policy responsiveness.[24] In words, on average, a one unit change in a given county's tax rate raises the tax rate of all other counties by 0.085 percentage points.

Importantly, while the average policy responsiveness and policy impact are similar, the standard deviation of policy impact is 8.3 times larger than policy responsiveness. Policy impact is much more heterogeneous across jurisdictions than policy responsiveness. We next turn to why one of the metrics is more heterogeneous than the other and what characteristics of jurisdictions drive this heterogeneity.

Further evidence of this difference between PR and PI are reported in Figure 7 which represents these two indicators with respect to population quantiles —Figure J.2 in the Appendix reports the specific cases of the states of New York and California.

[24] In theory, both means should be identical, but in this table we only report the averages over the 2,403 counties with taxation authority. The average over all counties is indeed the same for PI and PR.

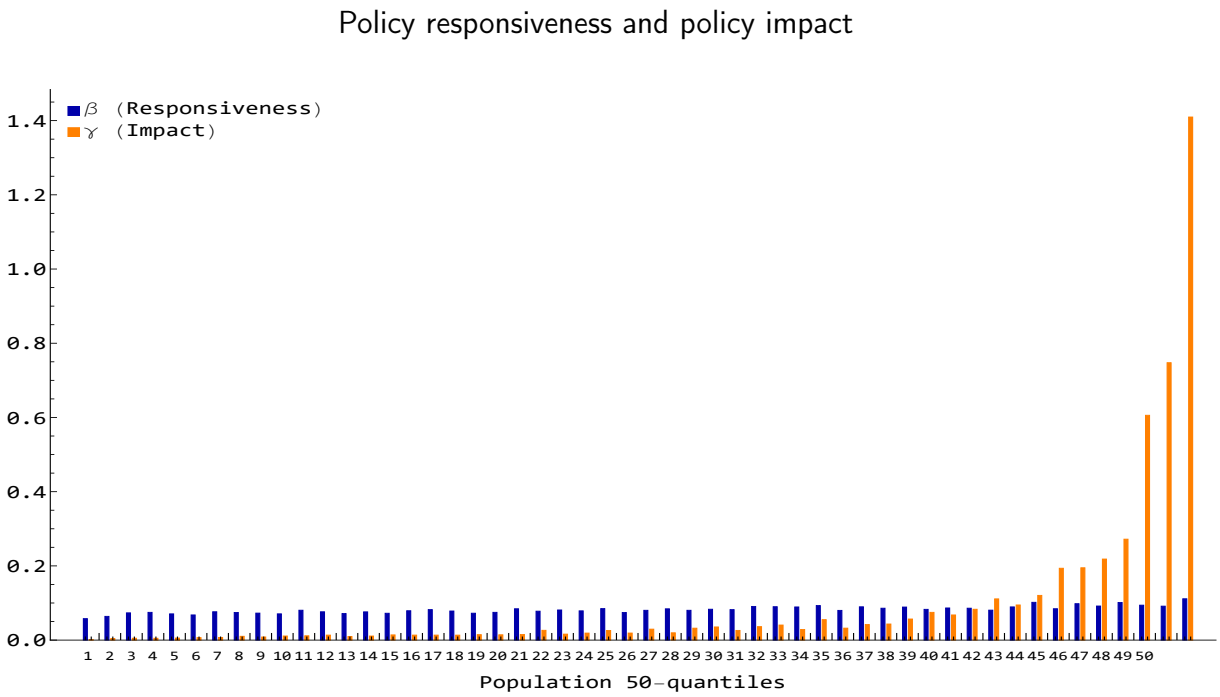


Figure 7. Policy responsiveness and policy impact with respect to the county population.

Figure 7 confirms that the responsiveness of all counties are essentially similar even though several larger counties like New York and Los Angeles are in the lower range. It also confirms that the impact are strongly heterogeneous with only a few large counties having an impact being non-negligible. Among them, the largest counties have strikingly high PIs.

Table 7 reports the results of the regressions of the PR and the PI of the counties on the exogenous variables, focusing on the effects of size of the jurisdiction and the size of nearby competitor jurisdictions. The focus in this table is on population because the own-jurisdiction and neighboring jurisdictions populations explains most of the variation in our new metric, policy impact. In particular a regression of policy impact on population variables yields an R^2 of 0.59, while adding other variables only increases this to 0.65. This contrasts with policy responsiveness where these variables do not explain much of the variation ($R^2 = 0.04$).

In addition to explaining little of the variation, own-jurisdiction population has no significant correlation with policy responsiveness. At best, policy responsiveness has a slight correlation with neighboring jurisdiction population. Population is not able to explain much of policy responsiveness because, by definition, it captures the effects from changes in the rest of the economy.

Turning to policy impact, relative population sizes are the key explanatory variables. With respect to own-jurisdiction population, bigger jurisdictions have a higher impact on the rest

of the economy. The negative relationship with neighboring population further indicates that it is *relative* size that matters, though the relationship with own-population is almost three times larger than neighboring population.

Table 7. Policy responsiveness, policy impact and covariates.

	(1)	(2)	(3)	(4)
	Responsiveness β		Impact γ	
Population n_i	−0.002	0.015	1.722***	2.753***
	(0.006)	(0.012)	(0.526)	(0.552)
Population squared n_i^2		−0.009		−0.524***
		(0.007)		(0.140)
Population of an average neighbor within 120 miles n_i^{neigh}	−0.031	−0.139***	−0.806**	−0.938***
	(0.023)	(0.022)	(0.302)	(0.343)
Population squared of an average neighbor within 120 miles $n_i^{neigh\,2}$		0.137***		−0.006
		(0.019)		(0.320)
N	2621	2621	2621	2621
Adjusted R squared	0.685	0.694	0.594	0.647
Adjusted R squared (no control and no state FE)	0.034	0.036	0.519	0.589
Marginal effect of n_i		0.014		2.716***
		(0.012)		(0.543)
Marginal effect of n_i^{neigh}		−0.129***		−0.938***
		(0.021)		(0.328)

NOTE— * $p < 0.10$, ** $p < 0.5$, *** $p < 0.1$. Standard errors in parentheses are clustered at the state level. The sample includes all counties with tax authority. All population variables are in millions for readability. All the regressions include state fixed effects and the county control variables reported in Table C.1.

Panel B indicates that, as expected, opposite effects are observed for the policy impact. A county's tax rate responds more to a joint increase in its neighbors' tax rates the larger these neighbors. This effect is intuitive, as bigger neighbors are expected to generate larger tax base spillovers. In sum, these results show that in order to understand the policy responses of a county one needs to consider not only its size, but also the size of the other counties with which it directly interacts.

6.3. Policy Impact and Welfare Effects

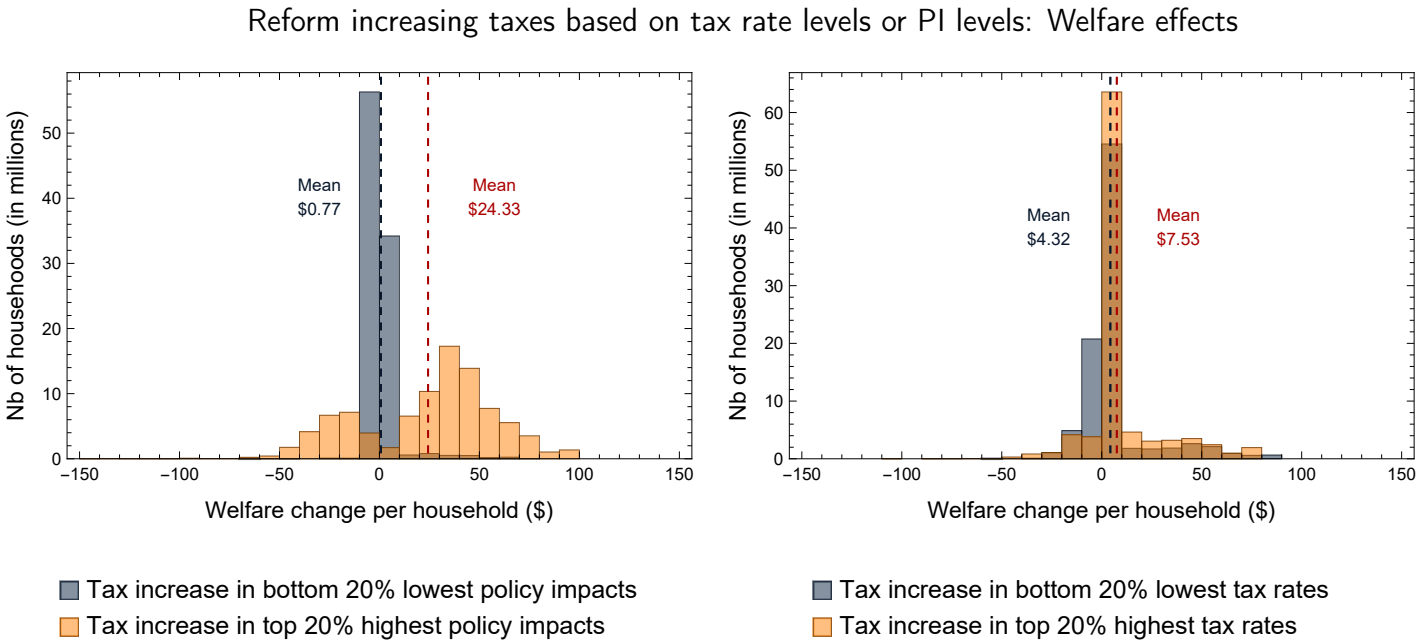
The policy network matrix provides useful information for designing potential tax reforms. It may help policymakers to target subgroups of jurisdictions according to their policy impact or, as shown in Table 7, by using a close proxy to it such as population.

To illustrate this, this section considers several different counterfactual exercises that target different sub-groups of jurisdictions. The first imposes a tax increase of 1 percentage point for the bottom 20% of counties with the lowest policy impact The second imposes the same tax increase, but now for the top 20% of counties with the highest policy impact. We compare these scenarios with conventional reforms where policy makers target jurisdictions based on the level of the jurisdiction's tax rates (the top/bottom 20% with the highest/lowest tax rate). In all reforms, we impose a 1 percentage point increase, but we allow these jurisdictions to further change their tax rates in response to tax changes in the rest of the economy.[25]

Figure 8 offers intuitive insights on how to target tax coordination policies. A policy targeting jurisdictions with the largest policy impacts generates larger welfare effects than targeting low impact jurisdictions. In addition, comparing interventions that target based on policy impact have larger effects than when targeting based on the level of the tax rate, as is done with minimum or maximum tax rates. In addition to comparing the overall welfare effects of the reform, we can compare the heterogeneity of how welfare changes across jurisdiction. When targeting based on the level of the tax rate, the distribution for targeting the highest and lowest tax jurisdictions are similar (Figure 8.b). However, with respect to policy impact, targeting high policy impact jurisdiction leads to a more dispersed distribution (higher variance) yet right-shifted (higher mean) distribution than targeting low policy impact jurisdiction.

As shown in Appendix J.5, targeting high policy impact jurisdictions results in a wider range of strategic tax adjustment in addition to a wider range of welfare effects among non-treated counties. Focusing on the initially non-treated counties, most raise their tax rates in response as high policy impact jurisdictions now set higher rates, but still these jurisdiction experience overall welfare losses. This welfare loss arise because residents of non-treated jurisdictions now pay higher taxes that that benefit residents of the high policy impact jurisdictions (large jurisdictions). The welfare loss of higher prices by non-treated residents is partially offset by higher taxes and public services at home, but not enough to provide welfare gains because of the small tax bases in low policy impact (small jurisdictions).

[25] Appendix J.5 provides summary statistics on each of these target groups and supplements the results presents the results presented in this section.



(a) Reform based on policy impact levels

(b) Reform based on tax rate levels

Figure 8. Total welfare effects of a targeted 1 percentage point increase in tax rates. In each case, 20% of the counties are constrained to increase their tax rates by 1 percentage point. All 2,621 counties with tax authority are subsequently allowed to change their taxes endogenously. The welfare effects (equivalent variation) include all counties with tax authority and are weighted by the counties populations.

7. Conclusion

Designing optimal policies when both economic linkages across heterogeneous jurisdictions and their own policy setting are endogenous is notoriously difficult. This paper makes two contributions in this direction. First, it introduces endogenous policies in a quantitative spatial equilibrium model that features thousands of heterogeneous jurisdictions that compete both at the intensive and the extensive margins. We bring this model to the data to match local tax rates for all US counties, drawing on an elegant open-economy Ramsey rule. We show that various minimum-tax or tax-harmonization policies increase aggregate welfare, providing evidence that tax competition leads to socially suboptimal tax rates and is therefore harmful. Our key result underscores the importance of endogeneizing policy responses when conducting counterfactual analyses. We estimate that ignoring endogenous policy responses can bias the estimates of the welfare effect of introducing minimum sales tax rate of 2% among U.S. counties by about 6.5%.

Second, our Ramsey rule for optimal tax rates allows us to derive and quantify all bilateral policy linkages, thus identifying the key players in a tax competition game. Specifically,

jurisdictions can be ranked according to two measures: the effect of each jurisdiction on the broader economy (policy impact) or the effect of the economy on each jurisdiction (policy responsiveness). We show our novel measure of policy impact is more critical for welfare than policy responsiveness. We show that targeted interventions focusing on key jurisdictions with the largest effect on the economy as a whole—that is, high-policy impact jurisdictions—will improve welfare by six times as much as traditional policies targeting low tax rates. However, while such targeted interventions increase welfare overall, the welfare effects are heterogeneous and some households may even lose due to higher prices.

Contrary to the conventional wisdom that the presence of low-tax jurisdictions constrain the tax-setting of high-tax jurisdictions, our results suggest that increasing the tax rates of high-impact jurisdictions (even if they already have relatively high tax rates) can yield larger welfare gains. In practice, measuring policy impact is complex and endogenous, but we find a strong correlation between policy impact and jurisdiction size. As a result, even simple policy rules that force larger jurisdictions to raise their tax rates relative to smaller jurisdictions improves welfare substantially. Intuitively, in a competitive equilibrium, tax rates of large (high-tax) and small (low-tax) jurisdictions may be too low, making public services inefficiently provided everywhere. In other words, the conventional view is that zero(low)-tax jurisdiction are parasitic on revenues in high-tax jurisdictions, but in equilibrium zero(low)-tax jurisdictions might be the *result* of lower taxes everywhere else, *not the cause*. This is consistent with recent empirical work in local public finance showing that spending on local public services (education) is inefficiently low (Bayer et al., 2020)—especially so in urban and suburban jurisdictions.

Our approach and findings have broader applications. Many public policy settings, among which tariff-setting, regulatory competition, or environmental standards, exhibit similar strategic interactions where focusing on high-impact players can enhance welfare more effectively than uniform rules based on observed policy choices. For instance, in setting minimum wages, targeting low-wage sectors (or local labor markets) might be less effective than focusing on sectors (local markets) whose wage policy exerts large external effects on others. Similarly, in industrial organization or environmental policy, regulations targeting firms that can most influence efficient technology adoption of other firms rather than those firms that simply pollute the most may be more effective.

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A. Model

This appendix derives the equations of the model introduced in Section 2. Appendix A.1 derives the conditions for the private economy. Appendix A.2 derives the open-economy Ramsey rule.

A.1. Private Economy

Consumption Side The Marshallian demand for the variety $\omega \in \Lambda_i$ produced in county i of a resident of county j is:

$$q_{ij}(\omega) = [(1 + t_i + T_i)p_i(\omega)\mu_{ij}]^{-\sigma} P_j^{\sigma-1} e_j, \tag{A.1}$$

where the individual net-of-tax income is:

$$e_j = (1 - \tau_j)\left(w_j + \kappa_j + \frac{\int_{\Lambda_j} \rho_j(\omega)\mathrm{d}\omega}{n_j}\right),$$

and the Dixit-Stiglitz price index is:

$$P_j = \left(\sum_i \int_{\Lambda_i} [(1 + t_i + T_i)p_i(\omega)\mu_{ij}]^{1-\sigma}\mathrm{d}\omega\right)^{\frac{1}{1-\sigma}}.$$

The aggregate private and public demand for variety ω is:

$$q_i^{\mathrm{D}}(\omega) = \sum_j n_j \mu_{ij} q_{ij}(\omega) + t_i \sum_j n_j \mu_{ij} q_{ij}(\omega) + s_i \sum_j n_j \mu_{ij} q_{ij}(\omega), \tag{A.2}$$

where $s_i \equiv n_i G_i / \sum_j \int_{\Lambda_i} n_j \mu_{ij} q_{ij}(\omega)\mathrm{d}\omega$ is the ratio of the amount of state public services to the private demand for the varieties produced in i. The first term in (A.2) is the aggregate demand for variety ω from the consumers of all counties j. The second and third terms are the demands for variety ω of the local and state public sectors, respectively. Inserting (A.1) into (A.2) and collecting terms, we obtain:

$$q_i^{\mathrm{D}}(\omega) = (1 + t_i + s_i) \sum_j \mu_{ij} [(1 + t_i + T_i)p_i(\omega)\mu_{ij}]^{-\sigma} P_j^{\sigma-1} n_j e_j. \tag{A.3}$$

Production Side In county i, the variety ω is produced by identical firms combining labor, ℓ_i, and capital, k_i, with the following constant returns to scale technology:

$$q_i(\omega) = \left(\frac{\ell_i(\omega)}{\alpha}\right)^{\alpha} \left(\frac{k_i(\omega)}{1 - \alpha}\right)^{1-\alpha} \tag{A.4}$$

The firm's cost function cost function is $w_i^\alpha q_i(\omega) + \rho_i$ where ρ_i is the entry cost defined as:

$$\rho_i \equiv w_i^\alpha f_i. \tag{A.5}$$

The firm's conditional labor demand is:

$$\ell_i(\omega) = \frac{\alpha q_i(\omega)}{w_i^{1-\alpha}}. \tag{A.6}$$

Firm ω chooses its price $p_i(\omega)$ to maximize its profit:

$$\pi_i(\omega) = p_i(\omega)q_i(\omega) - w_i^\alpha q_i(\omega) - \rho_i, \tag{A.7}$$

subject to the aggregate demand $q_i(\omega) = q_i^{\mathrm{D}}(\omega)$ as defined in (A.3). The first-order condition leads to the standard price setting rule of a monopolistic competing firm:

$$p_i(\omega) = \frac{\sigma}{\sigma - 1} w_i^\alpha. \tag{A.8}$$

The price setting equation (A.8) makes clear that, as expected, all firms located in county i behave identically by choosing the same price $p_i(\omega)$. It follows that the mass of firms in county i is given by $m_i = \int_{\Lambda_i} \mathrm{d}\omega$. Also, in the rest of this appendix, argument ω will be suppressed from prices $p_i(\omega)$, and quantities $q_i(\omega)$ and $\ell_i(\omega)$.

We can derive the expression of the total labor demand $L_i \equiv m_i \ell_i$ by inserting (A.8) into (A.6):

$$L_i = \frac{\sigma - 1}{\sigma} \frac{\alpha Y_i}{w_i},$$

where:

$$Y_i \equiv p_i m_i q_i \tag{A.9}$$

is the value of the aggregate output in i. This proves condition (7). Morevover, inverting the pricing rule (A.8), we obtain the wage setting equation:

$$w_i = \left(\frac{\sigma - 1}{\sigma}\right)^{\frac{1}{\alpha}} p_i^{\frac{1}{\alpha}}. \tag{A.10}$$

which proves the equilibrium condition (11).

Firm Entry Firms' entry and exit imply that zero profit prevails in each county. Inserting the price expression (A.8) and the expression of the entry cost (A.5) into (A.7), the zero-profit condition is equivalent to:

$$q_i = (\sigma - 1) f_i, \tag{A.11}$$

which defines the equilibrium output of each firm located in i. Multiplying each side by $m_i p_i$ and rearranging, we get:

$$m_i = \frac{Y_i}{(\sigma - 1) p_i f_i}, \tag{A.12}$$

which proves condition (8).

Relation between the Local Variables Next, we derive the equilibrium relation stated in Subsection 2.5 and the expression of public service (21). We already derived the wage setting equation (11) in (A.10). Then, inserting the labor market clearing condition $L_i = n_i$ into (A.1), we obtain:

$$Y_i = \frac{n_i}{\alpha} \left(\frac{\sigma - 1}{\sigma} \right)^{\frac{1-\alpha}{\alpha}} p_i^{\frac{1}{\alpha}} \tag{A.13}$$

which proves the expression of the value of the output (12).

Inserting (A.13) into (A.12), we obtain:

$$m_i = \frac{n_i (\sigma - 1)^{\frac{1-2\alpha}{\alpha}}}{\alpha f_i \sigma^{\frac{1-\alpha}{\alpha}}} p_i^{\frac{1-\alpha}{\alpha}}. \tag{A.14}$$

which proves the expression of the number of firms (13).

Inserting (A.10) and (A.5) into (A.1) and using firms' symmetry, we can express the aggregate local income as:

$$E_i \equiv n_i e_i = (1 - \tau_i) n_i \left(\frac{(\sigma - 1)^{\frac{1}{\alpha}}}{\sigma^{\frac{1}{\alpha}}} p_i^{\frac{1}{\alpha}} + \kappa_i + \frac{m_i w_i^{\alpha} f_i}{n_i} \right),$$

which becomes after inserting (A.14) and (A.10) and collecting terms:

$$E_i = (1 - \tau_i) \frac{n_i [(\sigma - 1)\alpha + 1] (\sigma - 1)^{\frac{1-\alpha}{\alpha}}}{\alpha \sigma^{\frac{1}{\alpha}}} p_i^{\frac{1}{\alpha}} + (1 - \tau_i) n_i \kappa_i, \tag{A.15}$$

which proves the expression stated in (14).

Last, solving the market clearing condition (15) for X_i and inserting (A.13), we obtain:

$$X_i = \frac{1}{1 + t_i} \left(\frac{n_i}{\alpha} \left(\frac{\sigma - 1}{\sigma} \right)^{\frac{1-\alpha}{\alpha}} p_i^{\frac{1}{\alpha}} - n_i p_i G_i \right). \tag{A.16}$$

Inserting this expression into the county's budget constraint (9), using $R_i = p_i n_i \Delta_i$ and solving for g_i yields:

$$g_i = \frac{t_i}{1 + t_i} \left(\frac{1}{\alpha} \left(\frac{\sigma - 1}{\sigma} \right)^{\frac{1-\alpha}{\alpha}} p_i^{\frac{1-\alpha}{\alpha}} - G_i \right) + \Delta_i, \tag{A.17}$$

which proves the expression of local public services g_i stated in (21).

A.2. Open-Economy Ramsey Taxation Rule

This appendix derives the open-economy Ramsey rule (23). The objective function of county i can be written as:

$$W_i = \frac{E_i \mathbb{G}_i^\nu}{P_i}, \tag{A.18}$$

where the public services $\mathbb{G}_i$ is given by:

$$\mathbb{G}_i = \varphi g_i + (1-\varphi) G_i. \tag{A.19}$$

Note that the government's budget constraint (9) allows us to write the public services as:

$$\mathbb{G}_i = \varphi g_i + (1-\varphi) G_i = \varphi \left(\frac{t_i X_i}{n_i p_i} + \Delta_i \right) + (1-\varphi) G_i, \tag{A.20}$$

Under Assumption 1, differentiation of (A.18) leads to the first-order condition:

$$\frac{\mathrm{d}W_i}{\mathrm{d}E_i}\frac{\mathrm{d}E_i}{\mathrm{d}p_i}\left.\frac{\partial p_i}{\partial t_i}\right| + \frac{\mathrm{d}W_i}{\mathrm{d}P_i}\left(\left.\frac{\partial P_i}{\partial t_i}\right| + \frac{\mathrm{d}P_i}{\mathrm{d}p_i}\left.\frac{\partial p_i}{\partial t_i}\right| \right) + \frac{\mathrm{d}W_i}{\mathrm{d}\mathbb{G}_i}\left(\left.\frac{\partial \mathbb{G}_i}{\partial t_i}\right| + \frac{\mathrm{d}\mathbb{G}_i}{\mathrm{d}p_i}\left.\frac{\partial p_i}{\partial t_i}\right| + \frac{\mathrm{d}\mathbb{G}_i}{\mathrm{d}X_i}\left.\frac{\partial X_i}{\partial t_i}\right| + \frac{\mathrm{d}\mathbb{G}_i}{\mathrm{d}G_i}\left.\frac{\partial G_i}{\partial t_i}\right| \right) = 0,$$

where:

$$\frac{\mathrm{d}W_i}{\mathrm{d}P_i} = -\frac{E_i \mathbb{G}_i^\nu}{P_i^2}, \qquad \frac{\mathrm{d}W_i}{\mathrm{d}E_i} = \frac{\mathbb{G}_i^\nu}{P_i}, \qquad \frac{\mathrm{d}W_i}{\mathrm{d}\mathbb{G}_i} = \nu \frac{E_i \mathbb{G}_i^{\nu-1}}{P_i}, \qquad \frac{\mathrm{d}P_i}{\mathrm{d}p_i} = \frac{\mathrm{d}P_i}{\mathrm{d}p_i} + \frac{\mathrm{d}P_i}{\mathrm{d}m_i}\frac{\mathrm{d}m_i}{\mathrm{d}p_i}.$$

Inserting these expressions into the first-order condition and collecting terms, we obtain:

$$-\frac{E_i}{P_i}\left.\frac{\partial P_i}{\partial t_i}\right| + \frac{\nu E_i}{n_i p_i \mathbb{G}_i}\left(n_i p_i \left.\frac{\partial \mathbb{G}_i}{\partial t_i}\right| + n_i p_i \frac{\mathrm{d}\mathbb{G}_i}{\mathrm{d}X_i}\left.\frac{\partial X_i}{\partial t_i}\right| \right) + \left(\frac{\mathrm{d}E_i}{\mathrm{d}p_i} - \frac{\mathrm{d}E_i}{\mathrm{d}P_i}\frac{\mathrm{d}P_i}{\mathrm{d}p_i} + \frac{\nu E_i}{\mathbb{G}_i}\frac{\mathrm{d}\mathbb{G}_i}{\mathrm{d}p_i} \right)\left.\frac{\partial p_i}{\partial t_i}\right| + \frac{\mathrm{d}\nu E_i}{\mathrm{d}\mathbb{G}_i}\frac{\mathrm{d}\mathbb{G}_i}{\mathrm{d}G_i}\left.\frac{\partial G_i}{\partial t_i}\right| = 0. \tag{A.21}$$

Differentiating the price index (5), we obtain:

$$\left.\frac{\partial P_i}{\partial t_i}\right| = \frac{P_i X_{ii}}{E_i}, \qquad \frac{\mathrm{d}P_i}{\mathrm{d}p_i} = \frac{(1+t_i+T_i)P_i X_{ii}}{E_i p_i}, \qquad \frac{\mathrm{d}P_i}{\mathrm{d}m_i} = -\frac{(1+t_i+T_i)P_i X_{ii}}{(\sigma-1)E_i m_i}. \tag{A.22}$$

Differentiating the number of firms (8) and income (3) leads:

$$\frac{\mathrm{d}m_i}{\mathrm{d}p_i} = \frac{1-\alpha}{\alpha}\frac{m_i}{p_i}, \qquad \frac{\mathrm{d}E_i}{\mathrm{d}p_i} = \frac{E_i - n_i(1-\tau_i)\kappa_i}{\alpha p_i}. \tag{A.23}$$

Differentiating public services (A.20) gives

$$\left.\frac{\partial \mathbb{G}_i}{\partial t_i}\right| = \varphi \frac{X_i}{n_i p_i}, \qquad \frac{\mathrm{d}\mathbb{G}_i}{\mathrm{d}p_i} = -\varphi \frac{t_i X_i}{n_i p_i^2}, \qquad \frac{\mathrm{d}\mathbb{G}_i}{\mathrm{d}X_i} = \varphi \frac{t_i}{n_i p_i}, \qquad \frac{\mathrm{d}\mathbb{G}_i}{\mathrm{d}G_i} = 1-\varphi. \tag{A.24}$$

Inserting (A.22), (A.24) and (A.23) into (A.21), and collecting terms, we obtain:

$$-X_{ii}+\frac{\varphi\nu E_i}{n_i p_i \mathbb{G}_i}\left(X_i+t_i\left.\frac{\partial X_i}{\partial t_i}\right|\right)-\phi_i E_i=0, \tag{A.25}$$

where ϕ_i is the effects of taxes on the local price and the state public service provision:

$$\phi_i=-\left(\frac{p_i}{E_i}\frac{\mathrm{d}E_i}{\mathrm{d}p_i}-\frac{p_i}{P_i}\frac{\mathrm{d}P_i}{\mathrm{d}p_i}+\frac{\nu p_i}{\mathbb{G}_i}\frac{\mathrm{d}\mathbb{G}_i}{\mathrm{d}p_i}\right)\frac{1}{p_i}\left.\frac{\partial p_i}{\partial t_i}\right|-\frac{\nu G_i}{\mathbb{G}_i}\frac{\mathrm{d}\mathbb{G}_i}{\mathrm{d}G_i}\frac{1}{G_i}\left.\frac{\partial G_i}{\partial t_i}\right|,$$

or equivalently:

$$\phi_i=-\left(\varepsilon^i_{E,p}-\varepsilon^i_{P,p}+\nu\varepsilon^i_{G,p}\right)\epsilon^i_{p,t}-\nu\varepsilon^i_{\mathbb{G},G}\,\epsilon^i_{G,t}.$$

Inserting (A.20) into the first-order condition (A.25) and collecting terms, leads to:

$$-\left(t_i X_i+R_i+\frac{1-\varphi}{\varphi}n_i p_i G_i\right)X_{ii}+\nu E_i\left(1+\frac{t_i}{X_i}\left.\frac{\partial X_i}{\partial t_i}\right|\right)X_i-\frac{n_i p_i \mathbb{G}_i}{\varphi}\phi_i E_i=0.$$

Finally, after a few trivial algebraic manipulations, we obtain:

$$\frac{t_i}{1+t_i+T_i}=\frac{1-\dfrac{R_i+\frac{1-\varphi}{\varphi}n_i p_i G_i}{\nu E_i}\times\dfrac{X_{ii}}{X_i}-\dfrac{n_i p_i \mathbb{G}_i/\varphi}{X_i}\times\dfrac{\phi_i}{\nu}}{-\dfrac{1+t_i+T_i}{X_i}\left.\dfrac{\partial X_i}{\partial t_i}\right|+\dfrac{(1+t_i+T_i)X_{ii}}{\nu E_i}},$$

which can be more compactly written as:

$$\frac{t_i}{1+t_i+T_i}=\frac{1-\dfrac{\lambda_i\chi_i}{\nu}-\dfrac{\eta_i\phi_i}{\nu}}{\varepsilon_i+\dfrac{\theta_i}{\nu}},$$

by introducing the following notation:

$$\varepsilon_i\equiv-\frac{1+t_i+T_i}{X_i}\left.\frac{\partial X_i}{\partial t_i}\right|,\quad \theta_i\equiv\frac{(1+t_i+T_i)X_{ii}}{E_i},\quad \chi_i\equiv\frac{X_{ii}}{X_i},\quad \lambda_i\equiv\frac{R_i+\frac{1-\varphi}{\varphi}n_i p_i G_i}{E_i},\quad \eta_i\equiv\frac{n_i p_i \mathbb{G}_i/\varphi}{X_i}.$$

This proves (23).

B. Economic Incidence of Taxation and General Equilibrium

This appendix derives the partial and general equilibrium economic marginal responses to a change in the local sales tax rate. The implicit function theorem allows us to derive explicitly these responses at the equilibrium. To this end, taxes are treated as exogenous in this appendix. Appendix B.1 derives the responses of local economic variables. Appendix B.2 derives the general equilibrium responses. Appendix B.3 derives the partial equilibrium responses as anticipated by local governments according to Assumption 1. Appendix B.4 derives an alternative tax setting rule that will be used in the computation of the Policy Network Matrix. Appendix B.5 states the formal characterization of the general equilibrium of the economy.

B.1. Local Economic Responses

Recall that, at the general equilibrium, all endogenous variables in the economy are functions of the sales tax rates of all counties. Let the variable $\mathrm{T} = t_1, \ldots, t_J$ stand for any sales tax rate(s). Differentiating the local equations (A.10), (A.13), (A.14) and (A.15), we obtain the responses of the private economy variables to taxation:

$$\frac{\partial w_i}{\partial \mathrm{T}} = \frac{w_i}{\alpha p_i} \frac{\partial p_i}{\partial \mathrm{T}}, \tag{B.1}$$

$$\frac{\partial Y_i}{\partial \mathrm{T}} = \frac{Y_i}{\alpha p_i} \frac{\partial p_i}{\partial \mathrm{T}}, \tag{B.2}$$

$$\frac{\partial m_i}{\partial \mathrm{T}} = \frac{1-\alpha}{\alpha} \frac{m_i}{p_i} \frac{\partial p_i}{\partial \mathrm{T}}, \tag{B.3}$$

$$\frac{\partial E_i}{\partial \mathrm{T}} = \frac{E_i - n_i(1-\tau_i)\kappa_i}{\alpha p_i} \frac{\partial p_i}{\partial \mathrm{T}}, \tag{B.4}$$

Differentiating (A.16), we obtain the response of the value of the demand for the local variety to taxation:

$$\frac{\partial X_i}{\partial \mathrm{T}} = -\frac{X_i}{1+t_i} \frac{\partial t_i}{\partial \mathrm{T}} + \left(\frac{Y_i}{\alpha p_i} - n_i G_i \right) \frac{1}{1+t_i} \frac{\partial p_i}{\partial \mathrm{T}} - \frac{n_i p_i}{1+t_i} \frac{\partial G_i}{\partial \mathrm{T}}, \tag{B.5}$$

Differentiating (A.17) and replacing Δ_i using the budget constraint (9), we obtain the response of public local services to taxation:

$$\frac{\partial g_i}{\partial \mathrm{T}} = \frac{X_i}{n_i(1+t_i)p_i} \frac{\partial t_i}{\partial \mathrm{T}} + \frac{(\sigma-1)^{\frac{1-\alpha}{\alpha}}(1-\alpha) t_i p_i^{\frac{1-2\alpha}{\alpha}}}{\sigma^{\frac{1-\alpha}{\alpha}} \alpha^2 (1+t_i)} \frac{\partial p_i}{\partial \mathrm{T}} - \frac{t_i}{1+t_i} \frac{\partial G_i}{\partial \mathrm{T}}, \tag{B.6}$$

in which $\partial t_i / \partial \mathrm{T} = 1$ if $\mathrm{T} = t_i$ and $\partial t_i / \partial \mathrm{T} = 0$ otherwise.

B.2. General Equilibrium Economic Responses

Next, using the above derivatives, we differentiate the general equilibrium system of the private economy $\mathcal{E}_i$ defined in (16)–(18), that we restate here for convenience:

$$Y_i - (1+t_i)\sum_j X_{ij} - n_i p_i G_i = 0, \tag{B.7}$$

$$P_i^{1-\sigma} - \sum_k m_k (1+t_k+T_k)^{1-\sigma} p_k^{1-\sigma} \mu_{ki}^{1-\sigma} = 0, \tag{B.8}$$

$$\sum_{k\in\mathcal{S}_i} n_k p_k G_i - \sum_{k\in\mathcal{S}_i} \frac{\tau_k}{1-\tau_k} E_k - T_i \sum_{k\in\mathcal{S}_k}\sum_j m_k X_{kj} = 0, \tag{B.9}$$

where X_{ij} is defined as in (4).

Commodity Market Clearing Differentiating (4) and inserting (B.3) and (B.4), we obtain the general equilibrium response of the value of the cross-border consumption to taxation:

$$\frac{\partial X_{ij}}{\partial \mathrm{T}} = X_{ij}\left(-\frac{\sigma}{t_i+T_i+1}\frac{\partial t_i}{\partial \mathrm{T}} + \frac{1-\alpha\sigma}{\alpha p_i}\frac{\partial p_i}{\partial \mathrm{T}} + \frac{E_j - n_j(1-\tau_j)\kappa_j}{\alpha E_j p_j}\frac{\partial p_j}{\partial \mathrm{T}} + \frac{\sigma-1}{P_j}\frac{\partial P_j}{\partial \mathrm{T}}\right), \tag{B.10}$$

which holds for any j, including i. Then, inserting (B.10) into (B.5) and collecting terms, we obtain the expression of the general equilibrium commodity market differential condition:

$$\sum_j \mathcal{W}_{ij}\frac{\partial p_j}{\partial \mathrm{T}} + \sum_j \frac{(\sigma-1)X_{ij}}{P_j}\frac{\partial P_j}{\partial \mathrm{T}} + \sum_j \mathcal{I}_{ij}\frac{p_j n_j}{1+t_j}\frac{\partial G_j}{\partial \mathrm{T}} = \sum_j \mathcal{I}_{ij} X_j\left(\frac{\sigma}{1+t_j+T_j} - \frac{1}{1+t_j}\right)\frac{\partial t_j}{\partial \mathrm{T}}, \tag{B.11}$$

where $\mathcal{I}_{ij}$ is the indicator variable that is equal to 1 if $j = i$ and 0, otherwise, and $\mathcal{W}_{ij}$ is defined as:

$$\mathcal{W}_{ij} \equiv \mathcal{I}_{ij}\frac{\alpha G_j p_j n_j + (1-\alpha\sigma)(1+t_j)X_j - Y_j}{\alpha p_j (1+t_j)} + \frac{(E_j - n_j(1-\tau_j)\kappa_j)X_{ij}}{\alpha E_j p_j}.$$

Price Index Differentiating the price index equation (B.8) and using (B.3), we obtain the general equilibrium price index differential equation:

$$\sum_j \mathcal{Z}_{ij}\frac{(1-\alpha\sigma)}{\alpha p_j}\frac{\partial p_j}{\partial \mathrm{T}} + \sum_j \mathcal{I}_{ij}\frac{\partial P_j}{\partial \mathrm{T}} = \sum_j \mathcal{Z}_{ij}\frac{(\sigma-1)}{1+t_j+T_j}\frac{\partial t_j}{\partial \mathrm{T}}, \tag{B.12}$$

in which $\mathcal{Z}_{ij}$ is defined as:

$$\mathcal{Z}_{ij} \equiv \frac{P_i^\sigma}{\sigma-1} m_j [(1+t_j+T_j)p_j \mu_{ji}]^{1-\sigma}.$$

State Budget Constraint Differentiating the state budget constraint (B.9) and using (B.10), we obtain the general equilibrium differential state budget constraint:

$$\sum_j \mathcal{S}_{ij}\mathcal{K}_{ij}\frac{\partial p_j}{\partial \mathrm{T}} + \sum_j \mathcal{S}_{ij}\mathcal{L}_{ij}\frac{\partial G_j}{\partial \mathrm{T}} = -\sum_j \mathcal{S}_{ij}\frac{T_i X_j}{1+t_j}\frac{\partial t_j}{\partial \mathrm{T}}, \tag{B.13}$$

where $\mathcal{S}_{ij}$ is the indicator variable that is equal to 1 if j is in the same state as i and 0, otherwise, and $\mathcal{L}_{ij}$ and $\mathcal{K}_{ij}$ are defined as:

$$\mathcal{L}_{ij} \equiv \mathcal{I}_{ij}\overline{p}_j + T_i \sum_j \frac{n_j p_j}{1+t_j} \qquad \textit{with} \quad \overline{p}_j \equiv \sum_{k\in\mathcal{S}_j} n_k p_k,$$
$$\mathcal{K}_{ij} \equiv n_j G_i + T_i\left(\frac{G_j n_j}{1+t_j} - \frac{Y_j}{\alpha p_j\,(1+t_j)}\right) + \frac{\tau_j}{1-\tau_j}\frac{n_j(1-\tau_j)\kappa_j - E_j}{\alpha p_j}.$$

In sum, the $3J$ general equilibrium response equations (B.11), (B.12) and (B.13) are linear equations in the $3J$ responses $\partial p_j/\partial \mathrm{T}$, $\partial P_j/\partial \mathrm{T}$ and $\partial G_j/\partial \mathrm{T}$. Thus, at any general equilibrium of the economy, we can compute a unique $3J$-vector of general equilibrium economic response to any tax change $\mathrm{d}\mathrm{T} = t_k$ for any $k = 1, \ldots, J$.

B.3. Partial Equilibrium Economic Responses

According to Assumption 1, government i anticipates the partial equilibrium responses in its own county and takes all variables in other counties as given. Formally, the partial equilibrium responses in county i, $\partial p_i/\partial t_i|$, $\partial P_i/\partial t_i|$ and $\partial G_i/\partial t_i|$ are defined by (B.11), (B.12), (B.13) for $j = i$, $\mathrm{d}\tau = \mathrm{d}t_i$, and such that $\partial p_k/\partial t_i| = \partial P_k/\partial t_i| = \partial G_k/\partial t_i| = 0$, for all $k \neq i$. Specifically, the partial equilibrium commodity market differential condition in county i is:

$$\mathcal{W}_{ii}\left.\frac{\partial p_i}{\partial t_i}\right| + \frac{(\sigma-1)X_{ii}}{P_i}\left.\frac{\partial P_i}{\partial t_i}\right| + \frac{p_i n_i}{1+t_i}\left.\frac{\partial G_i}{\partial t_i}\right| = X_i\left(\frac{\sigma}{1+t_i+T_i} - \frac{1}{1+t_i}\right). \tag{B.14}$$

The partial equilibrium price index differential equation in county i is:

$$\mathcal{Z}_{ii}\frac{(1-\alpha\sigma)}{\alpha p_i}\left.\frac{\partial p_i}{\partial t_i}\right| + \left.\frac{\partial P_i}{\partial t_i}\right| = \mathcal{Z}_{ii}\frac{(\sigma-1)}{1+t_i+T_i}. \tag{B.15}$$

The partial equilibrium differential state budget constraint in county i is:

$$\mathcal{K}_{ii}\left.\frac{\partial p_i}{\partial t_i}\right| + n_i p_i\left(1+\frac{T_i}{1+t_i}\right)\left.\frac{\partial G_i}{\partial t_i}\right| = -\frac{T_i X_i}{1+t_i}. \tag{B.16}$$

At any general equilibrium, the 3-equation system (B.14)–(B.16) uniquely defines the 3 partial equilibrium price responses $\partial p_i/\partial t_i|$, $\partial P_i/\partial t_i|$ and $\partial G_i/\partial t_i|$ in county i.

B.4. An Alternative Tax Setting Rule

Next, we derive an alternative tax setting rule used to compute the general equilibrium and the Policy Network Matrix. This tax rule aligns with our open-economy Ramsey rule but is more general as its derivation does not require Assumption 1. Additionally, this tax rule is more operational as it establishes that the tax rate t_i of a county i depends solely on three fundamental local endogenous variables—the price p_i, the price index P_i, and the state public services G_i—as well as on the responses of these variables to local taxation. In other words, given these three local variables, no variables from other counties directly influence the local tax rate: economic linkages are entirely mediated through P_i and G_i.

Differentiating the aggregate utility (A.18), county i's first-order condition can be written as:

$$\frac{1}{E_i}\frac{\partial E_i}{\partial t_i} - \frac{1}{P_i}\frac{\partial P_i}{\partial t_i} + \frac{\varphi\nu}{\mathbb{G}_i}\left(\frac{\partial g_i}{\partial t_i} + \frac{1-\varphi}{\varphi}\frac{\partial G_i}{\partial t_i}\right) = 0. \tag{B.17}$$

Note that derivatives do not have side bars indicating that Assumption 1 is not used in the derivation of the expressions. Besides, differentiating the government budget constraint (9), we get:

$$\frac{\partial g_i}{\partial t_i} = \frac{1}{n_i p_i}\left(X_i + t_i\frac{\partial X_i}{\partial t_i} + \frac{t_i X_i}{p_i}\frac{\partial p_i}{\partial t_i}\right). \tag{B.18}$$

Inserting this public good response (B.18) into the first-order condition (B.17), we get:

$$\frac{1}{E_i}\frac{\partial E_i}{\partial t_i} - \frac{1}{P_i}\frac{\partial P_i}{\partial t_i} + \frac{\varphi\nu}{\mathbb{G}_i}\left[\frac{1}{n_i p_i}\left(X_i + t_i\frac{\partial X_i}{\partial t_i} + \frac{t_i X_i}{p_i}\frac{\partial p_i}{\partial t_i}\right) + \frac{1-\varphi}{\varphi}\frac{\partial G_i}{\partial t_i}\right] = 0.$$

Then, a few algebraic manipulations entail the following general tax rule:

$$t_i = \frac{\dfrac{\mathbb{G}_i n_i p_i}{\varphi\nu}\left(\dfrac{1}{E_i}\dfrac{\partial E_i}{\partial t_i} - \dfrac{1}{P_i}\dfrac{\partial P_i}{\partial t_i}\right) + X_i + \dfrac{1-\varphi}{\varphi}n_i p_i\dfrac{\partial G_i}{\partial t_i} - \dfrac{t_i X_i}{p_i}\dfrac{\partial p_i}{\partial t_i}}{-\dfrac{\partial X_i}{\partial t_i}}, \tag{B.19}$$

which is particularly tractable and will be used in the inversion of the model.

Last, deriving the Policy Network Matrix requires the tax rule to be linear in the economic responses. To do so, we insert (B.1), (B.4), and (B.5) into (B.19), which leads to:

$$t_i = \mathcal{M}_p^i\frac{\partial p_i}{\partial t_i} + \mathcal{M}_P^i\frac{\partial P_i}{\partial t_i} + \mathcal{M}_G^i\frac{\partial G_i}{\partial t_i}, \tag{B.20}$$

where:

$$\mathcal{M}_P^i = \frac{n_i p_i t_i\,(1+t_i)\,[\varphi g_i + (1-\varphi)G_i]}{\varphi\nu P_i X_i}, \qquad \mathcal{M}_G^i = \frac{n_i p_i t_i[(2\varphi-1)t_i + \varphi - 1]}{\varphi X_i},$$

and $\mathcal{M}_p^i = \mathcal{M}_{pg}^i g_i + \mathcal{M}_{pG}^i G_i + \mathcal{M}_{p1}^i$ in which:

$$\mathcal{M}_{pg}^i = \frac{n_i t_i \left(1+t_i\right)\left[(\alpha\nu-1)E_i + (1-\tau_i)\kappa_i n_i\right]}{\alpha\nu E_i X_i},$$
$$\mathcal{M}_{pG}^i = \frac{n_i t_i \big[(1-\varphi)(1-\tau_i)\kappa_i n_i \left(1+t_i\right) - E_i\left(1-\varphi+t_i(1-\varphi-\alpha\nu)\right)\big]}{\varphi\alpha\nu E_i X_i},$$
$$\mathcal{M}_{p1}^i = -\frac{t_i[\alpha\Delta_i n_i p_i \left(1+t_i\right) + t_i Y_i]}{\alpha p_i X_i}.$$

Importantly, the tax rules (B.19) and (B.20) make clear that the tax rate of county i depends solely on the *local* endogenous variables p_i, P_i and G_i and on their responses to *local* taxation $\partial p_i/\partial t_i$, $\partial P_i/\partial t_i$ and $\partial G_i/\partial t_i$.[26] This means that inter-jurisdiction spillovers only affect the tax chosen by county i by changing the price index P_i, the state public services G_i and their responses to local taxation $\partial P_i/\partial t_i$ and $\partial G_i/\partial t_i$. This property is not trivial because Assumption 1 has not been used to derive (B.19) and (B.20).

As explained in Appendix I, Assumption 1 will prove particularly useful to compute the Policy Network Matrix. We then simply need to replace the general equilibrium responses $\partial p_i/\partial t_i$, $\partial P_i/\partial t_i$ and $\partial G_i/\partial t_i$ —that solve the full general equilibrium response system $(\mathrm{d}\mathcal{E}_j)$ for all $j = 1, \ldots, J$— by the partial equilibrium $\partial p_i/\partial t_i|$, $\partial P_i/\partial t_i|$ and $\partial G_i/\partial t_i|$ — that only solve the local equilibrium system $(\mathrm{d}\mathcal{E}_i)$. That is, the government tax rule that we will use is:

$$t_i = \mathcal{M}_p^i \left.\frac{\partial p_i}{\partial t_i}\right| + \mathcal{M}_P^i \left.\frac{\partial P_i}{\partial t_i}\right| + \mathcal{M}_G^i \left.\frac{\partial G_i}{\partial t_i}\right|, \tag{B.21}$$

instead of its general equilibrium version (B.20) with $\mathcal{M}_p^i$, $\mathcal{M}_P^i$ and $\mathcal{M}_G^i$ being still defined as above.

B.5. A Formal Characterization of the General Equilibrium

First, equilibrium equations (B.7), (B.8) and (B.9) implicitly define the levels of the economic variables p_i, P_i and G_i. Second, the partial equilibrium response system (B.14), (B.15) and (B.16) define the responses $\partial p_i/\partial t_i|$, $\partial P_i/\partial t_i|$ and $\partial G_i/\partial t_i|$. Third, the tax setting rule (B.21) implicitly defines the tax rate t_i. In sum, the $7J-$equation general equilibrium system:

$$\Big\{(\text{B.7}), (\text{B.8}), (\text{B.9}), (\text{B.14}), (\text{B.15}), (\text{B.16}), (\text{B.21})\Big\} \tag{B.22}$$

jointly determines equilibrium levels of the $7J$ variables t_i, p_i, P_i, G_i, $\partial p_i/\partial t_i|$, $\partial P_i/\partial t_i|$ and $\partial G_i/\partial t_i|$.

[26] Recall from (A.15), (A.17) and (A.16) that E_i, g_i and X_i can be expressed as functions of only the three central local variables p_i, P_i and G_i.

C. Data and Descriptive Statistics

C.1. Data Sources

Table D.1 describes the sources of the data used in the analysis. Cross-sectional tax rates from 2011 are used with only slight modifications from Agrawal (2015). Local tax rates in the U.S. are set at the state, county, town, and sub-municipal level. Agrawal (2015) obtains these tax rates from a proprietary sales tax software company and then merges the data to jurisdictions by name matching. For further details on the tax rate database, see Agrawal (2015) and Agrawal (2014). To account for the multi-tiered federal structure, the effective county sales tax rate is the sum of its observed county rate plus the average tax rate of the municipalities it includes.

We supplement sales tax rate data with state income tax rates calculated using NBER TAXSIM.

Data on the number of firms are constructed from County Business Patterns data. We use the total number of retail establishments in NAICS codes 44, 45, and 72. Data on population, households, earnings, and wages come from the United States Census.

Sales tax revenue, other source revenue, total revenues, and total expenditures are from the Annual Survey of State and Local Government Finances.

Data on cross-border expenditures are calculated using the NielsenIQ Consumer Panel. NielsenIQ contains county information for each household, but for some stores only includes the three digit zip code of the store (which can cross county lines). For a subset of stores, including drug stores, convenience stores, groceries, and mass merchandisers, the retailers in the consumer panel are matched to the retail scanner data set. From the retail scanner data, we extract matches between the store and the county, yielding a match rate of approximately 50% for firms. These 50% of firms are then perfectly matched to a particular county. The remaining observations that are observed in the three-digit zip code file but not the matched dataset are then assigned a county using the following procedure. First, if a three digit zip code does not cross-county lines, those sales are allocated to that unique county. In cases where zip codes cross county lines, those sales are apportioned using the share of retail firms in each county of the three-digit zip code. This yields our pair-wi

In the estimation of our gravity equation (24), we make use of indicator variables denoting whether counties are within 60 minutes driving time, between 60 and 90 minutes driving time and between 90 and 120 minutes driving time. To operationalize these measures, we calculate the population-weighted centroid of each county. We then use a network dataset containing the complete U.S. road network (both major and minor roads), along with driving speeds,

to calculate driving costs. When optimizing driving, we follow a hierarchical system — we prioritize highways and major roads over back roads. We then calculate "travel areas" for each county. A travel area is a region that encompasses all accessible streets within a given number of driving minutes from the population centroid. We calculate 60 minute, 90 minute, and 120 minute service areas. Agrawal (2015) shows that 60 minutes is the extent of cross-border shopping, but given we use the centroids rather than the boundary of the polygons, longer distances may be relevant because individuals near the border do not need to incur the time driving within the county. For example, a 60-minute service area for a county centroid includes all the streets that can be reached within 60 minutes of driving from that point.

C.2. Descriptive Statistics

Table C.1. Descriptive statistics for socio-demographic variables in taxing counties.

	Mean	SD	Min	Max	Obs
Area	974	1369	1.999	20057	2219
% Male	50.015	2.375	40.85	67.69	2219
Median age	40.291	5.251	21.6	63.8	2219
% White	82.828	16.088	3.91	100	2219
% Agriculture	7.048	7.29	0	48.7	2219
% Households with public assistance	2.42	1.608	0	21.94	2219
% Foreign born	3.122	3.825	0	36.52	2219
% Workers working in state of residence	96.049	7.033	30.15	100	2219
Housing unit: median number of rooms	5.597	0.444	3.3	7.5	2219
% Senior	16.38	4.452	3.29	46.72	2219
% High school education	80.287	8.804	25.61	96.77	2219
Private/public school attendance	0.108	0.073	0	0.62	2219
Housing unit: age	37.161	11.676	9	72	2219
% Vote Democratic candidate in 2000 or 2008	40.62	14.067	7.816	92.457	2219
% Vote Democratic candidate in 2004 or 2012	37.776	14.926	6.275	93.386	2219
Border crossing with Mexico	0.008	0.09	0	1	2219
Border crossing with Canada	0.009	0.095	0	1	2219
Coastline	0.067	0.25	0	1	2219

C.3. Geography of Taxation

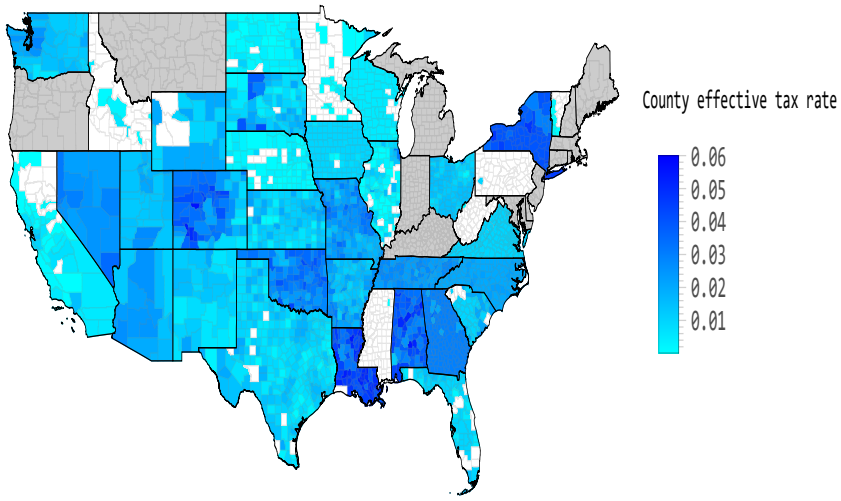


Figure C.1. County+city tax rates. In white are the 402 non-taxing counties with tax authority. In gray are the 488 non-taxing counties without tax authority. The intensity of blue in the 2,219 taxing counties denotes the level of county tax rate plus the average tax rate of the municipalities it includes.

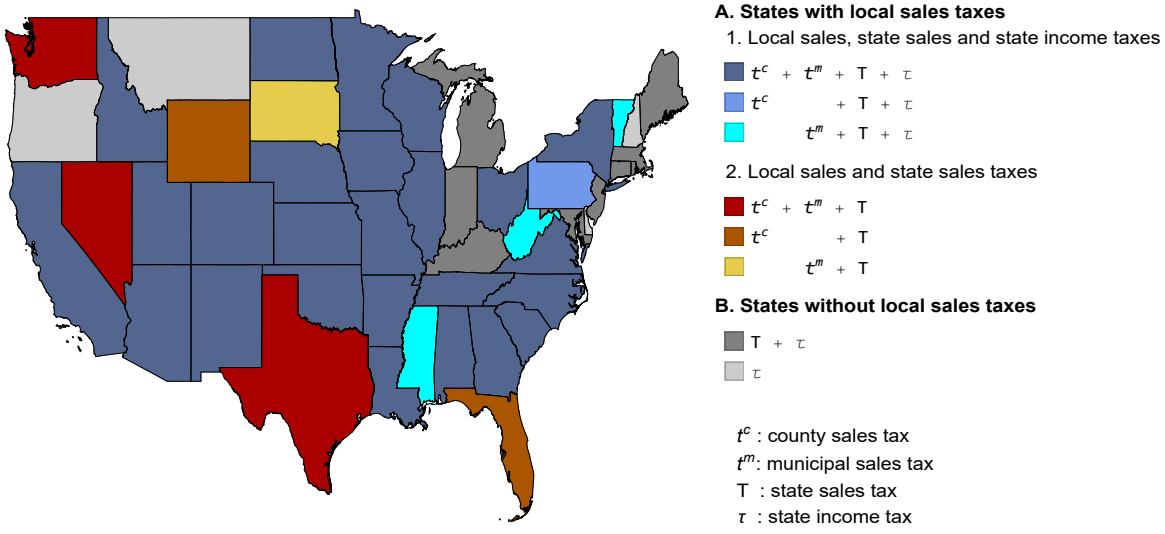


Figure C.2. Types of taxation per government level in the U.S. states. All counties are allowed to levy property taxes.

D. Model Inversion

D.1. From Theory to Data

Table D.1 summarizes the relationships between the data used in this paper and the structural parameters of our model. Section D.2 details our algorithm to compute the equilibrium prices p_i and our estimation of the elasticity of substitution σ. Sections D.3 and D.4 explain how we recover the structural residuals of our model as well as preference parameters for public services ν and φ.

Table D.1. Characteristics of the main model variables and parameters.

Variable	Value	Description	Match	Method	Data source
A. Endogenous variables (data)					
t_i		Effective county tax rate	Exact		Agrawal (2015)
m_i		Number of firms	Exact		County Business Patterns
e_i		Household after-tax income	Exact		U.S. Census
w_i		Household earnings	Variance		U.S. Census
$R_i/(p_i n_i g_i)$		Non-sales tax revenue to expenditure ratio	MM		ASSLGF
X_{ij}		Cross-border expenditure of the residents of j in i	Gravity		NielsenIQ Consumer Panel
B. Exogenous variables (data)					
n_i		Number of households	Exact		U.S. Census
T_i		State sales tax rate	Exact		Agrawal (2015)
τ_i		State income tax rate	Exact		NBER TAXSIM
C. Exogenous local fundamentals (structural residuals)					
κ_i		Capital endowment		Match y_i	
f_i		Firm fixed entry cost		Match m_i	
Δ_i		County public service endowment		Match $R_i/(p_i n_i g_i)$	
D. Exogenous parameters					
σ	4.96	Elasticity of substitution among varieties		Match w_i	
α	2/3	Labor share in firm cost		Calibration	
ν	0.5	Preference for public services		Match $R_i/(p_i n_i g_i)$	
φ	0.27	Preference for local versus state public services		Match $R_i/(p_i n_i g_i)$	
μ_{ij}		Iceberg cost		Gravity regression	

NOTE— ASSLGF: Annual Survey of State and Local Government Finances; MM: method of moment; "Variance": minimize difference of variance between observed and model variable.

D.2. Equilibrium prices p_i

This section describes our algorithm to compute the equilibrium prices p_i. We use data on our endogenous variables —income E_i, number of firms m_i, tax rates t_i— as well as on our exogenous variables —population n_i, state tax rates T_i and τ_i— together with α parametrized

as 2/3. To determine the value of σ, equilibrium prices are computed for incremental values of σ. We obtain σ by minimizing the squared difference between the variance of model-predicted wages $\text{Var}[w(\sigma)]$ and the variance of observed wages in the data $\text{Var}[w^{\text{data}}]$. Formally, we obtain σ by solving:

$$\sigma = \arg\min_{\sigma_0} \left(\text{Var}[w(\sigma_0)] - \text{Var}[w^{\text{data}}]\right)^2.$$

Computation of the equilibrium prices p_i uses the following six-step algorithm.

Step 0. We initialize p_i.

Step 1. We compute the wages from (11):

$$w_i = \left(\frac{\sigma - 1}{\sigma}\right)^{\frac{1}{\alpha}} p_i^{\frac{1}{\alpha}}. \tag{D.1}$$

and the other local variables: Y_i from (12), m_i from (13) and E_i from (14).

Setp 2. We compute the price indices (5):

$$P_j = \left(\sum_i m_i[(1 + t_i + T_i)p_i\mu_{ij}]^{1-\sigma}\right)^{\frac{1}{1-\sigma}}. \tag{D.2}$$

Setp 3. We compute the value of the demand X_i from (4):

$$X_i = \sum_j m_i(1 + t_i + T_i)^{-\sigma}(p_i\mu_{ij})^{1-\sigma}P_j^{\sigma-1}E_j. \tag{D.3}$$

Setp 4. We compute the state public services as defined in (10):

$$G_i = \frac{T_i \sum_{k\in\mathcal{S}_i} X_k + \sum_{k\in\mathcal{S}_i} \frac{\tau_k}{1-\tau_k} E_k}{\sum_{k\in\mathcal{S}_i} n_k p_k}.$$

Setp 5. Inserting the expression of Y_i (12) and w_i (11) into the commodity market clearing (15) allows to update the market price:

$$p_i = \frac{\sigma}{\sigma - 1}\left(\frac{\sigma - 1}{\sigma}\frac{\alpha}{n_i}[(1 + t_i)X_i + n_i p_i G_i]\right)^{\alpha}.$$

Setp 6. We repeat this loop from step 0 until convergence.

D.3. Capital Income κ_i and Firm Entry Cost f_i

The non-labor income κ_i is computed so that the observed income match the theoretical income (3):

$$\kappa_j = \frac{1}{r}\left(\frac{E_j}{(1 - \tau_j)n_j} - \frac{(\sigma - 1)\alpha + 1}{(\sigma - 1)\alpha}w_j\right).$$

The entry cost is calibrated so that the observed number of firms matches the theoretical

number of firms (8):

$$f_i = \frac{Y_i}{(\sigma - 1)p_i m_i}.$$

D.4. Preference for Public Services ν, φ and Non-Sales Tax Revenues Δ_i

Inserting the definition of $\mathbb{G}_i$ (A.19) into (B.19) and rearranging, we obtain an expression for the share of the county's sales taxes in its expenditure:

$$\frac{t_i X_i}{n_i p_i g_i} = t_i X_i \left(\nu \frac{-t_i \left.\frac{\partial X_i}{\partial t_i}\right| - X_i - \frac{1-\varphi}{\varphi} n_i p_i \left.\frac{\partial G_i}{\partial t_i}\right| + \frac{t_i X_i}{p_i} \left.\frac{\partial p_i}{\partial t_i}\right|}{\frac{1}{E_i} \left.\frac{\partial E_i}{\partial t_i}\right| - \frac{1}{P_i} \left.\frac{\partial P_i}{\partial t_i}\right|} - \frac{1-\varphi}{\varphi} n_i p_i G_i \right)^{-1},$$

which is the theoretical revenue share of sales taxes in total revenues of county i. We choose ν and φ such that the first two stastictical moments of this theoretical revenue share match the observed moments in the data:

$$\mathbb{E}\left[\frac{t_i X_i}{n_i p_i g_i}\right] = \text{mean}(share_i), \qquad \mathbb{V}\left[\frac{t_i X_i}{n_i p_i g_i}\right] = \text{variance}(share_i),$$

where $share_i$ is the observed share of non-sales tax revenue in the total tax revenues of the county. Notice that we also tried versions in which the denominator of $share_i$ could alternatively be the total expenditure of the county. This does not change significantly the values of ν and φ.

We now turn to the computation of the non-sales tax revenues Δ_i. The first-order condition (B.17) can be rearranged:

$$g_i + \frac{1-\varphi}{\varphi} G_i = \nu \left(\frac{1}{P_i} \left.\frac{\partial P_i}{\partial t_i}\right| - \frac{1}{E_i} \left.\frac{\partial E_i}{\partial t_i}\right| \right)^{-1} \left(\left.\frac{\partial g_i}{\partial t_i}\right| + \frac{1-\varphi}{\varphi} \left.\frac{\partial G_i}{\partial t_i}\right| \right),$$

in which the definiton of $\mathbb{G}_i$ (A.19) has been inserted. Then, using and the government budget constraint (9), we can compute the non-sales tax endowment Δ_i:

$$\Delta_i = \nu \left(\frac{1}{P_i} \left.\frac{\partial P_i}{\partial t_i}\right| - \frac{1}{E_i} \left.\frac{\partial E_i}{\partial t_i}\right| \right)^{-1} \left(\left.\frac{\partial g_i}{\partial t_i}\right| + \frac{1-\varphi}{\varphi} \left.\frac{\partial G_i}{\partial t_i}\right| \right) - \frac{1-\varphi}{\varphi} G_i - \frac{t_i X_i}{n_i p_i}. \tag{D.4}$$

E. Overidentification Checks

We examine in this Section the model's predictions for variables not used in the calibration and for relations between variables not directly imposed by the model. We begin with assessing the ability of the model to predict observed local consumption shares (Appendix E.1). Then, we check the empirical relevance of the Ramsey rule in the setting of observed tax rates (Appendix E.2).

E.1. Local Expenditure Shares

Table E.1 compares observed local consumption shares for the sample of 2,051 counties included in the NielsenIQ dataset with local consumption shares predicted by our model.[27] Predicted local consumption shares are defined as $X_{jj}/\sum_i X_{ij}$ and are calculated for six different predictions of transportation costs $\widehat{\mu}_{ij}$ corresponding to the six specifications of the gravity equation reported in Table 2, as well as the corresponding equilibrium prices.

[27] The observed sample consists of transactions from the NielsenIQ dataset, which covers all 3,109 counties as shopping locations but only 2,051 counties as places of residence.

Table E.1. Summary statistics local expenditure share.

		(1)	(2)	(3)	(4)	(5)	(6)
	Observed	Predictions					
		A. All counties					
Mean	0.671	0.737	0.736	0.736	0.737	0.736	0.736
SD	0.308	0.142	0.14	0.139	0.142	0.14	0.139
Max	1	0.993	0.993	0.992	0.993	0.993	0.992
Min	0	0.047	0.067	0.078	0.046	0.066	0.077
Obs	2051	3109	3109	3109	3109	3109	3109
		B. Restriction to the observed sample					
Mean	0.671	0.775	0.774	0.773	0.775	0.773	0.773
SD	0.308	0.125	0.124	0.123	0.125	0.124	0.123
Max	1	0.993	0.993	0.992	0.993	0.993	0.992
Min	0	0.348	0.345	0.344	0.347	0.34	0.34
Obs	2051	2051	2051	2051	2051	2051	2051
Neighborhood (miles)		60	90	120	60	90	120
Neighborhood×log(dist)		NO	NO	NO	YES	YES	YES

NOTE— The observed sample consists the 2,051 counties included in the NielsenIQ dataset as place of residence.

Results show that the specification of the gravity regression does not alter significantly the local expenditure share. Predicted local expenditure shares are on average a little bit higher than observed ones and feature a lower variance. This is not surprising given the NielsenIQ dataset does not cover all counties to the same extent. We formally test in Table E.2 the relationship between observed and the predicted local consumption shares by regression the former on the latter and obtain a slope correlation close to one.

Table E.2. Relationship between observed and the predicted local expenditure share.

$\left(\frac{X_{jj}}{\sum_i X_{ij}}\right)^{observed}$ on $\left(\frac{X_{jj}}{\sum_i X_{ij}}\right)^{predicted}$	(1)	(2)	(3)	(4)	(5)	(6)
	1.054^{***}	1.077^{***}	1.087^{***}	1.053^{***}	1.076^{***}	1.086^{***}
	(0.049)	(0.049)	(0.05)	(0.049)	(0.049)	(0.05)
Neighborhood (miles)	60	90	120	60	90	120
Neighborhood×log(dist)	NO	NO	NO	YES	YES	YES

NOTE— * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors in parentheses are clustered at the state level. The sample includes the 2,051 counties included in the NielsenIQ dataset as place of residence.

E.2. Testing the Open-Economy Ramsey Rule

This appendix examines the correlations between observed tax rates and empirical measures of different components of the open-economy Ramsey rule (23) introduced in Subsection 2.4.

E.2.1. Local Expenditure Share θ_i

According to the open-economy Ramsey rule, the local expenditure share of a household puts a downward pressure on the sales tax rate. Table E.3 examines this relationship for different sample of counties and different specifications.

Table E.3. Regression of local tax rates on local expenditure shares in the data.

	(1)	(2)	(3)	(4)
t_i on $\theta_i^{\text{observed}}$	−34.79***	−21.87**	−22.10**	−13.12
	(9.255)	(9.355)	(9.002)	(9.033)
Controls	NO	YES	NO	YES
Non-taxing counties	NO	NO	YES	YES
N	1430	1430	1672	1672

NOTE— * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses are clustered at the state level. The dependent variable is the county plus average municipal sales tax rate. The local expenditure X_{ii} in $\theta_i = (1 + t_i + T_i)X_{ii}/E_i$ is computed using NielsenIQ data. Control variables are listed in Table C.1.

Table E.3 reports negative and significant point estimates that confirm the expected negative effect of the local expenditure share on the sales tax rates.[28] Including non-taxing counties introduces some noise as their tax rates are corner solutions of the Ramsey rule, hence these counties are not affected by marginal changes in the components of the Ramsey rule.

E.2.2. Tax Export Incentive χ_i

The discussion of the open-economy Ramsey rule suggests that a fundamental determinant of the level of a county's tax rate is the trade-off between local private consumption and public service provision, or equivalently, the tax export motive. According to this result, a county in which the consumption of own residents represents a large share of the tax base would set a

[28] The large point estimates are due to the fact that the scale of t_i (mean: 1.2%) is much larger than that of θ_i (mean: 0.003%).

relatively lower tax rate. To investigate empirical evidence of this tax determinant, Table E.4 examines the relationship between taxes and a proxy for the share of total sales from own residents in the data.

Table E.4. Regression of local tax rates on the shares of total sales from own residents in the data.

	(1)	(2)	(3)	(4)
t_i^{county} on ${\chi_i}^{\text{observed}}$	−0.00406***	−0.00235*	−0.00325**	−0.00228*
	(0.00137)	(0.00132)	(0.00130)	(0.00124)
Controls	NO	YES	NO	YES
Non-taxing counties	NO	NO	YES	YES
N	1369	1369	1596	1596

NOTE— * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses are clustered at the state level. The dependent variable is the county tax rate. The share of total sales from own residents $\chi_i = X_{ii}/X_i$ is computed using NielsenIQ data restricting counties shopping neighborhood to 120 miles. All regressions include the control variables listed in Table C.1.

The negative coefficients suggest that, as predicted by our model, counties whose tax base is mostly composed of local consumption have relatively lower tax rates. This result turns statistically significant as we also include non-taxing counties. This suggests that the decision to set a non-zero tax rate (extensive margin) is driven by the tax export motive.

E.2.3. Non-sales tax revenue to income ratio λ_i

The Ramsey rule also suggests that a county sets lower sales tax rate the higher non-sales tax revenues. To examine this effect, we focus on the counties' own revenue sources and control for the state transfer using state fixed effects.

Table E.5. Regression of local tax rates on non-sales tax revenues to income ratio in the data.

	(1)	(2)	(3)	(4)
t_i on $\left(\frac{R_i}{E_i}\right)^{\text{observed}}$	−1.254	−0.937	−1.896***	−1.919***
	(0.961)	(0.756)	(0.607)	(0.517)
Controls	NO	YES	NO	YES
Non-taxing counties	NO	NO	YES	YES
N	2213	2213	2615	2615

NOTE— * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The dependent variable is the county plus average municipal tax rate. All regressions include state fixed effects. Control variables are listed in Table C.1.

Table E.5 suggests that the leverage effect played by other sources of revenue operates at the extensive margin as the coefficient on non-sales tax revenues to income ratio turns statistically significant only when including non-taxing counties.

F. Tax Incidence and Tax Decision

This appendix supplements Subsection 3.7.

Figure F.1 compares for the 2219 taxing counties the incidence of a tax increase on prices evaluated under the partial equilibrium (under Assumption 1) and under the general equilibrium.

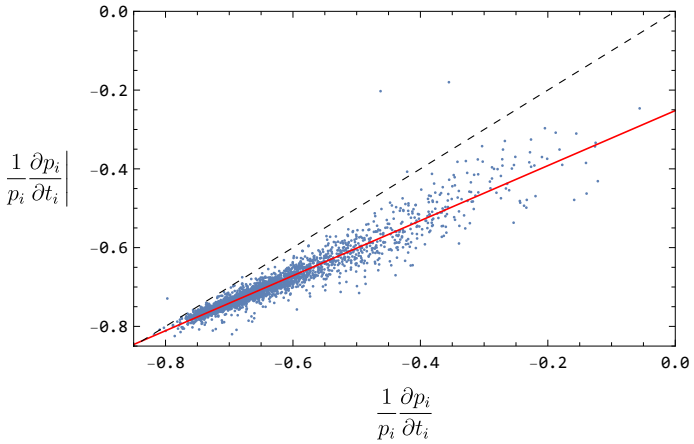


Figure F.1. Partial versus general equilibrium tax incidence. The dashed line represents the 45 degree line. The slope and intercept of the regression line (in red) are 0.69 and −0.25, respectively.

Results indicate that the incidence on prices is negative for all counties. This is true both

in partial and in general equilibrium. Another interesting insight is that partial equilibrium effects are larger in absolute value than their general equilibrium counterparts. This is intuitive as under Assumption 1 counties do not account for the positive price effect of their own tax policy in other counties. More importantly Figure F.1 reveals that both are strongly correlated and quite similar. This is reassuring and suggests that our tax setting rule is indeed reasonable.

Table F.1 quantifies the different component of our tax setting rule. Panel A reports the sample average and dispersion measures of the price incidence shown in Figure F.1. Panel B presents a quantification of the components of an alternative formulation of the government's first order condition:

$$\frac{1}{E_i}\frac{\partial E_i}{\partial t_i}\bigg| - \frac{1}{P_i}\frac{\partial P_i}{\partial t_i}\bigg| + \frac{\nu}{\mathbb{G}_i}\frac{\partial \mathbb{G}_i}{\partial t_i}\bigg| = 0. \tag{F.1}$$

Panel C decomposes the effect of a tax increase on the valuation of public services between services provided by local governments (g) and by states (G).

Table F.1. Effects of taxes on the government's first-order conditions' variables.

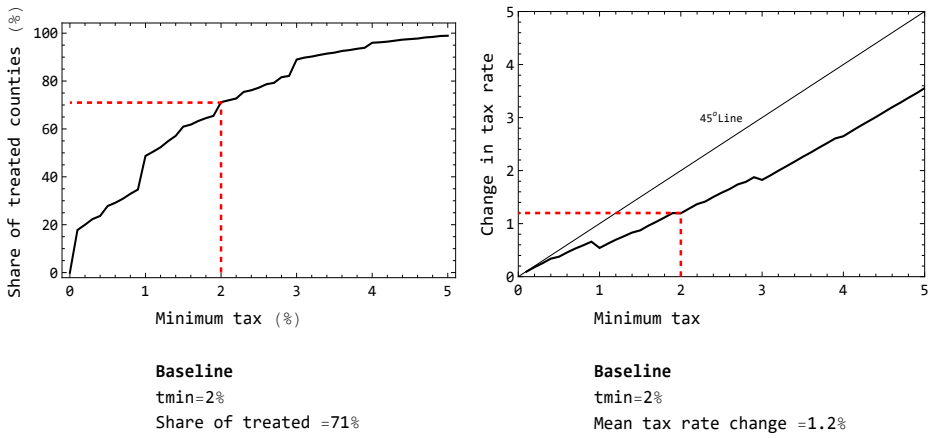
Variable	Equilibrium	Mean	SD	Min	Max	Obs
A. Tax incidence						
$\frac{1}{p_i}\frac{\partial p_i}{\partial t_i}$	General	−0.636	0.108	−0.786	−0.056	2219
$\frac{1}{p_i}\frac{\partial p_i}{\partial t_i}\bigg\vert$	Partial	−0.696	0.078	−0.825	−0.18	2219
B. Component of the government's first-order condition						
$\frac{1}{E_i}\frac{\partial E_i}{\partial t_i}\bigg\vert$	Partial	−0.732	0.115	−1.397	−0.199	2219
$\frac{1}{P_i}\frac{\partial P_i}{\partial t_i}\bigg\vert$	Partial	0.248	0.095	0.021	0.76	2219
$\frac{\nu}{\mathbb{G}_i}\frac{\partial \mathbb{G}_i}{\partial t_i}\bigg\vert$	Partial	0.98	0.116	0.478	1.544	2219
C. Local and state public services						
$\frac{\varphi}{1-\varphi}\frac{\nu}{g_i}\frac{\partial g_i}{\partial t_i}\bigg\vert$	Partial	1.305	1.037	0.303	25.021	2219
$\frac{\nu}{G_i}\frac{\partial G_i}{\partial t_i}\bigg\vert$	Partial	−0.36	0.126	−0.711	0.000	2219

The decomposition presented in Panel B indicates that, at the equilibrium, a tax increase has a positive welfare effect on residents through a higher provision of public services. This welfare gain is compensated by a reduction in income and by an increase in the price index. Our quantification suggests that the former effect is more important than the latter. Panel C indicates that local policy crowds out some of the state policy. The reason is that, the reduction in prices and in wages that follows a tax increase lowers both the sales and income tax revenues collected by the state.

G. Supplementary Results on Minimum Taxation

This appendix supplements the results in Subsection 4.1 by providing more results on the welfare effects of minimum tax reforms.

Figure G.1 reports the share of counties constrained by a minimum tax and the resulting mechanical tax rate increase for different levels of minimum tax. As the average county-level tax rate is low (around 1.75%, see Table 1), the share of treated counties increases rapidly.



(a) Share of treated counties. **(b)** Change in tax rate of treated counties.

Figure G.1. Share of treated counties and their average mechanical increase in tax rate according to the level of the minimum tax. The red dashed line represents our baseline case of $t^{min} = 2\%$.

G.1. Overall Welfare Effects

Table Table G.1 complements the welfare effects of the introduction of our baseline minimum tax rate of 2% for treated (initially below 2%) and for non-treated (initially above 2%) counties under our two counterfactual scenarios of endogenous tax setting (Panel A) and exogenous tax setting (Panel B).

Table G.1. The welfare effects of a minimum tax of 2%

	Winner share (%)	Welfare change ($)				Population (millions)	Nb counties
		Mean	Median	Decile 10	Decile 90		
A. Endogenous taxation							
All counties	80.3	21.1	11.7	−11.6	65.7	93.6	2621
Non-treated counties	76.2	3.4	3.7	−5.0	11.8	31.6	755
Treated counties	82.4	30.1	27.1	−11.6	71.0	62.0	1866
B. Exogenous taxation							
All counties	80.4	20.9	11.8	−11.6	67.5	93.6	2621
Non-treated counties	76.2	2.9	3.7	−6.8	11.8	31.6	755
Treated counties	82.5	30.1	27.1	−11.6	71.7	62.0	1866

NOTE— Welfare change: per household equivalent variation ($). Winner share: share of households with positive equivalent variation. Population refers to the number of households.

G.2. Decomposition of the Effects of a Minimum Tax

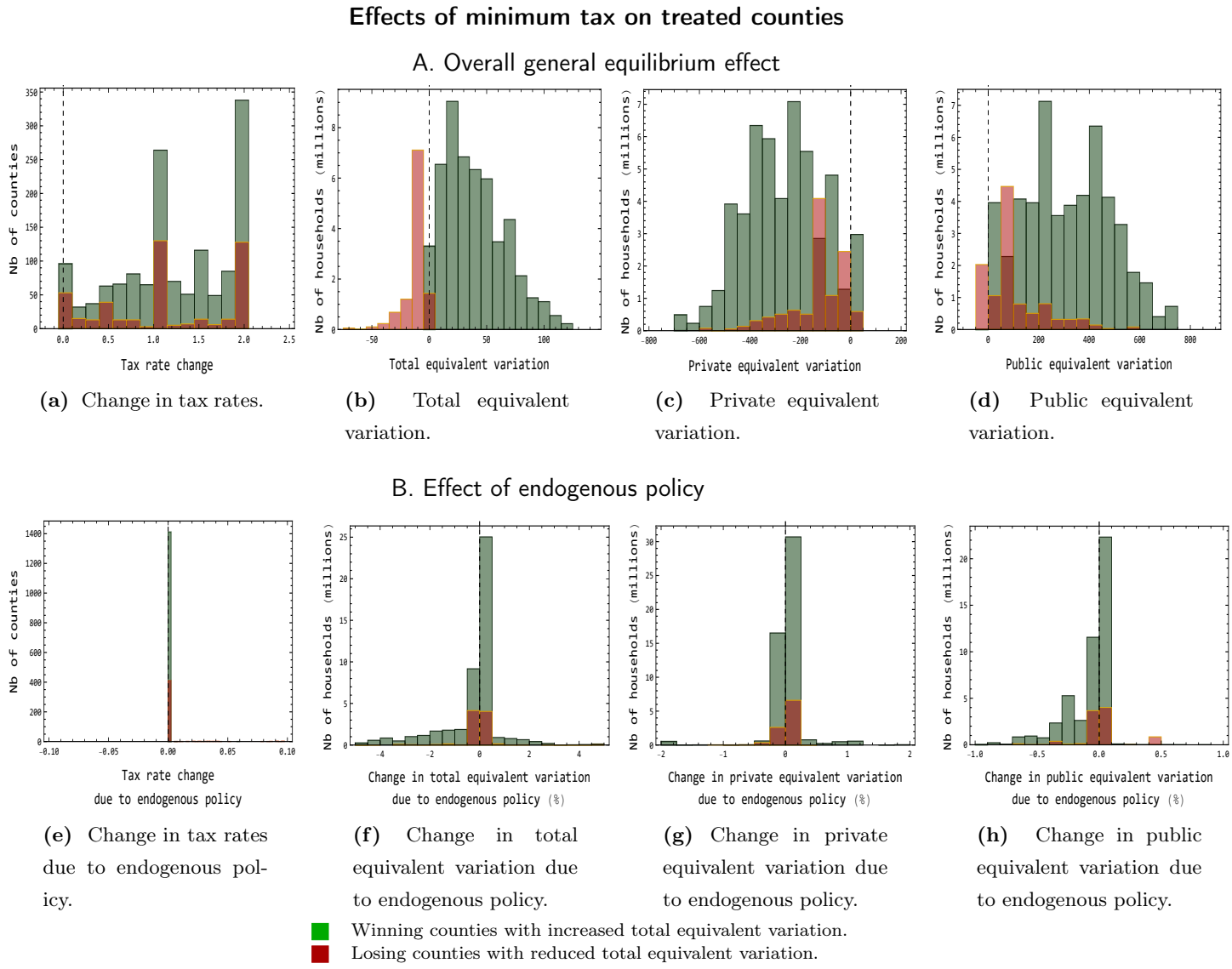
In this section, we decompose the effects of the minimum tax into public and private equivalent variations. In our model, the equivalent variation formula implies that the total welfare effects for a resident of county i is:

$$EV_i = \frac{\frac{E_i'\mathbb{G}_i'^{\nu}}{P_i'} - \frac{E_i\mathbb{G}_i^{\nu}}{P_i}}{\frac{E_i\mathbb{G}_i^{\nu}}{P_i}} E_i \qquad EV_i^{public} = \frac{\frac{E_i'}{P_i'} - \frac{E_i}{P_i}}{\frac{E_i}{P_i}} E_i \qquad EV_i^{private} = \frac{\mathbb{G}_i'^{\nu} - \mathbb{G}_i^{\nu}}{\mathbb{G}_i^{\nu}} E_i \tag{G.1}$$

in which the latter two terms are equivalent variations focusing on the disposable income effect or on the public service effects, respectively. Note that as the percentage change in welfare are relatively small, the following approximation is roughly satisfied for each county:

$$EV_i \approx EV_i^{public} + EV_i^{private},$$

which shows that we decompose the overall welfare effects on each county into public and private welfare effects.



(a) Change in tax rates.

(b) Total equivalent variation.

(c) Private equivalent variation.

(d) Public equivalent variation.

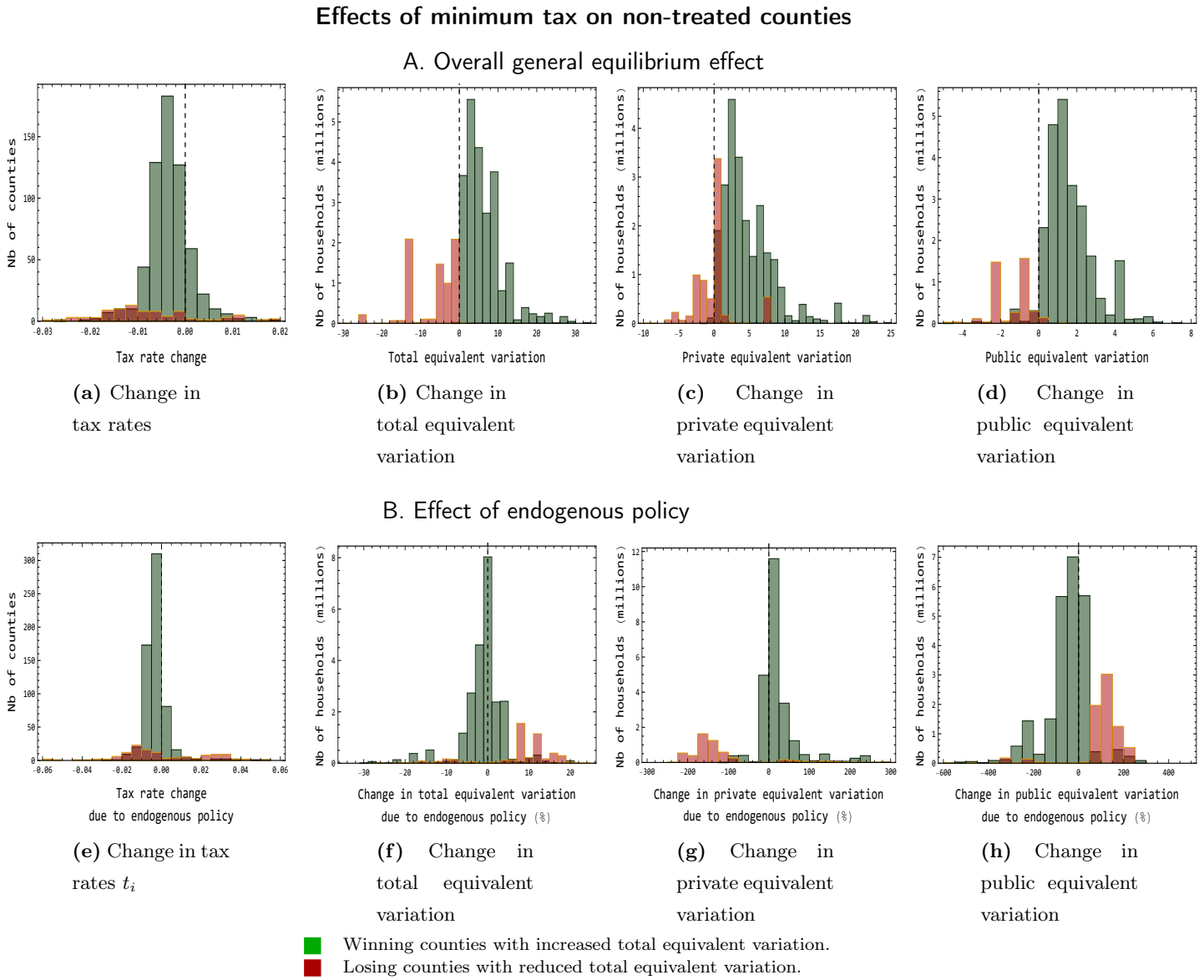
(e) Change in tax rates due to endogenous policy.

(f) Change in total equivalent variation due to endogenous policy.

(g) Change in private equivalent variation due to endogenous policy.

(h) Change in public equivalent variation due to endogenous policy.

Figure G.2. Effect of a minimum tax of 2% on treated counties. Figure G.2a–Figure G.2d assume exogenous tax rates. Figure G.2e–Figure G.2h represent the level of the variable under endogenous taxation minus the level under exogenous tax rates. In Figure G.2a and Figure G.2e, the change in tax rate is computed as $100 \times (t^{after} - t^{before})$.



(a) Change in tax rates

(b) Change in total equivalent variation

(c) Change in private equivalent variation

(d) Change in public equivalent variation

(e) Change in tax rates t_i

(f) Change in total equivalent variation

(g) Change in private equivalent variation

(h) Change in public equivalent variation

Figure G.3. Effect of a minimum tax of 2% on non-treated counties. Figure G.3a–Figure G.3d assume exogenous tax rates. Figure G.3e–Figure G.3h represent the level of the variable under endogenous taxation minus the level under exogenous tax rates. In Figure G.3a and Figure G.3e, the change in tax rate is computed as $100 \times (t^{after} - t^{before})$.

G.3. Tax Rate Change and Welfare

Figure G.4 in the Appendix G correlates changes in tax rate between endogenous and exogenous tax setting and the percent change in welfare due to endogenous policy responses. Results indicates that in general, counties increasing more (or reducing less) their tax rates are more likely to benefit from endogenous policy responses than other counties. This suggests

that the level of public services is initially too low, so counties benefit from increasing their tax rates.

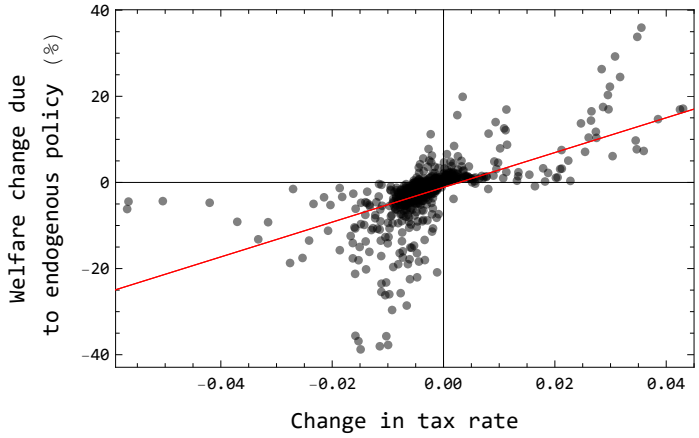
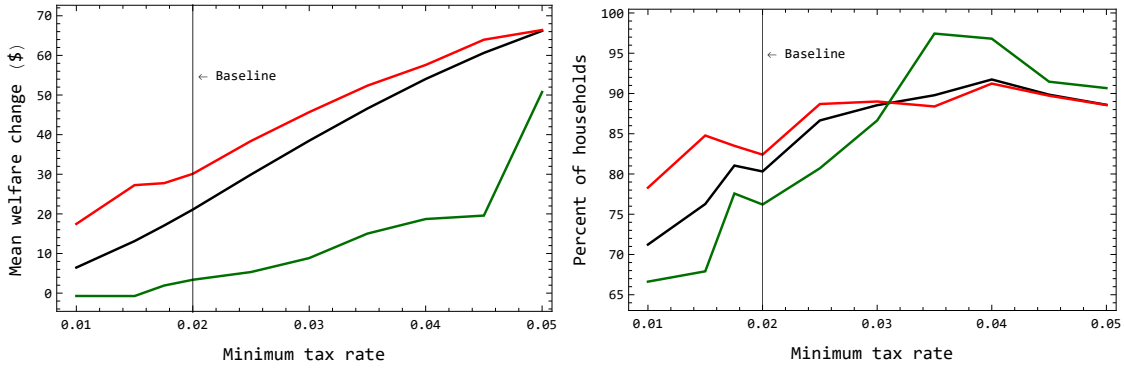


Figure G.4. Correlation between the percent change in welfare due to endogenous tax setting responses and tax changes. Sample of non-treated counties in our baseline for a minimum tax of 2%. The y-axis is defined as $100\times(EV_i^{endo}-EV_i^{exo})/|EV_i^{endo}|$. The x-axis is the change in tax rates between endogenous and exogenous tax setting: $100\times(t_i^{endo}-t_i^{exo})$. The regression line is shown in red.

G.4. Various Levels of Minimum Taxes

In this appendix, we examine how the welfare effects of a minimum tax and the share of population benefiting from it —and who would plausibly support such initiative at the political level— varies with the minimum tax level.

Figure G.5a shows the welfare changes for treated, non-treated counties and for all counties. Welfare gains are higher for treated counties, indicating that those required to raise their tax rate the most also benefit the most. Additionally, welfare increases monotonically with the level of the minimum tax rate. However, given the initially low local sales tax rates, it would be not be surprising that setting higher minimum tax rates than the ones considered here could eventually reduce welfare gains. This is supported by Figure G.5b that indicates that after approximately 4% the share of households benefiting from a minimum tax starts decreasing.



(a) Welfare change per household.

(b) Share of households benefiting from the minimum tax.

Figure G.5. Welfare change and share of households benefiting from minimum taxes. The number of treated and non-treated counties changes with the level of the minimum tax.

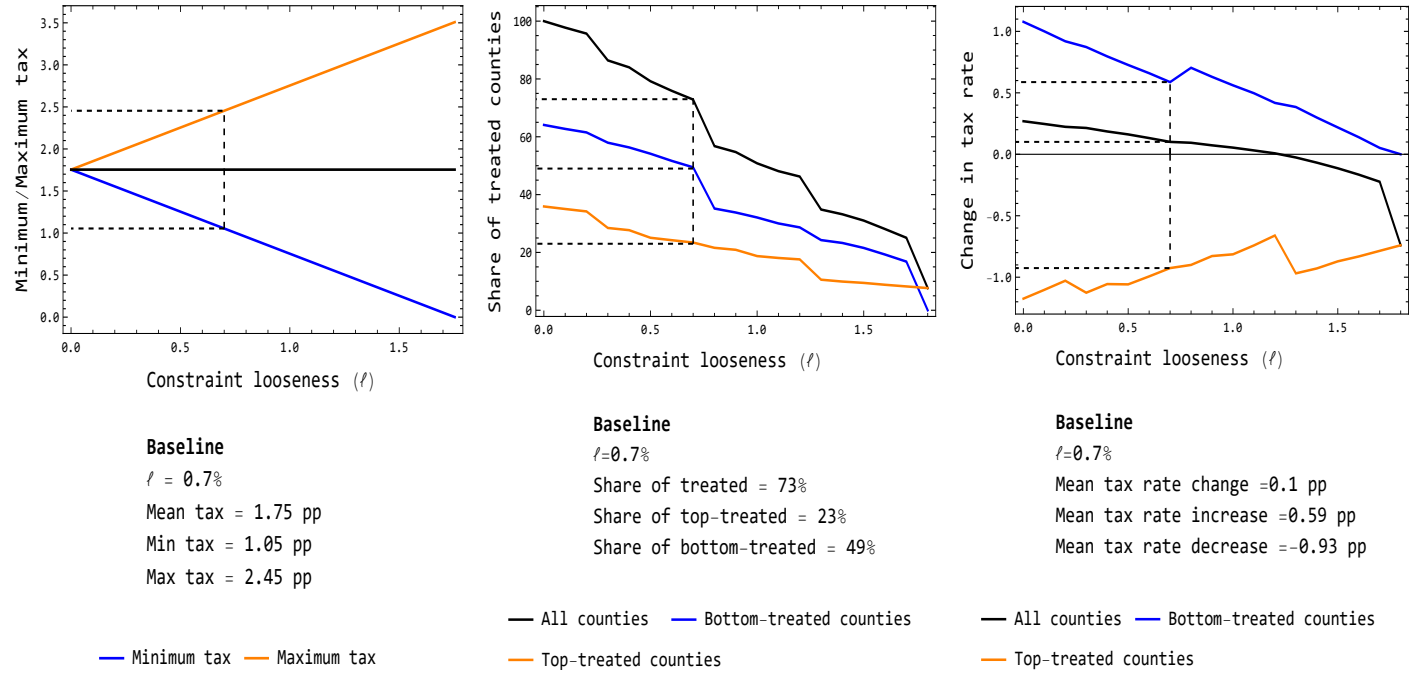
H. The Welfare Effects of Tax Harmonization

This appendix supplements the discussion in Subsection 4.2 by studying the welfare effects of (partial) tax harmonization (Fajgelbaum et al., 2019; Hines, 2023). Formally, the constraint consists of imposing a bandwidth, $[t^{mean} - \ell, t^{mean} + \ell]$, around the average tax rate (around 1.75%, see Table 1). [29] The parameter, $\ell \in [0, t^{mean}]$, measures the degree of looseness of the tax harmonization constraint. Thus, unlike a minimum tax rate, counties can be treated from above ("top-treated") or from below ("bottom-treated").

H.1. Partial Tax Harmonization Reforms

Figure H.1 reports the mechanical change in tax rates for different degrees of looseness. Figure H.1a shows how the degree of looseness translates in terms of minimum and maximum tax rates. Figure H.1b shows that bottom-treated counties represent the majority of the treated counties for low levels of ℓ. In other words, counties that set relatively high tax rates are relatively few but they set particularly high tax rates.

[29] The harmonized tax is the county tax rate, t_i, and not the total local + state sales tax rate incurred by the consumer, $t_i + T_i$.



(a) Relation between looseness and minimum/maximum tax rates.

(b) Share of treated counties.

(c) Mechanical tax change of treated counties.

Figure H.1. Share of treated counties and their average change in tax rate according to the degree of looseness of the tax harmonization constraint. Figure H.1a represents the implication of the tax constraint looseness, ℓ, in terms of a minimum tax, $t^{min} = t^{mean} - \ell$, and a maximum tax, $t^{max} = t^{mean} + \ell$, where $t^{mean} = 1.75\%$ is the sample average tax rate. The dashed line represents our baseline $\ell = 0.7\%$.

Figure H.1c shows that, indeed, the tax harmonization reform imposes larger tax increases than the tax decreases. These considerations are important because we can expect the welfare effects in top-treated counties to go in the opposite direction of the welfare changes in the bottom-treated counties. This implies that the aggregate welfare effects is ambiguous and depends on whether the welfare effects of the relatively large tax cuts imposed on few top-treated counties will dominate the welfare effects of the relatively small tax increase on many bottom-treated counties.

H.2. Welfare Effects

Table H.1 summarizes the welfare effects of the policy for the baseline tax harmonization looseness of 0.7 percentage points. As expected, top-treated counties incur welfare losses (−$56 per household) and only 13% of their population benefits from the reform. On the contrary, bottom-treated counties benefit from welfare gains of $16 and the vast majority (71%) of the population in these counties benefit from the reform. Overall, the welfare effect including also

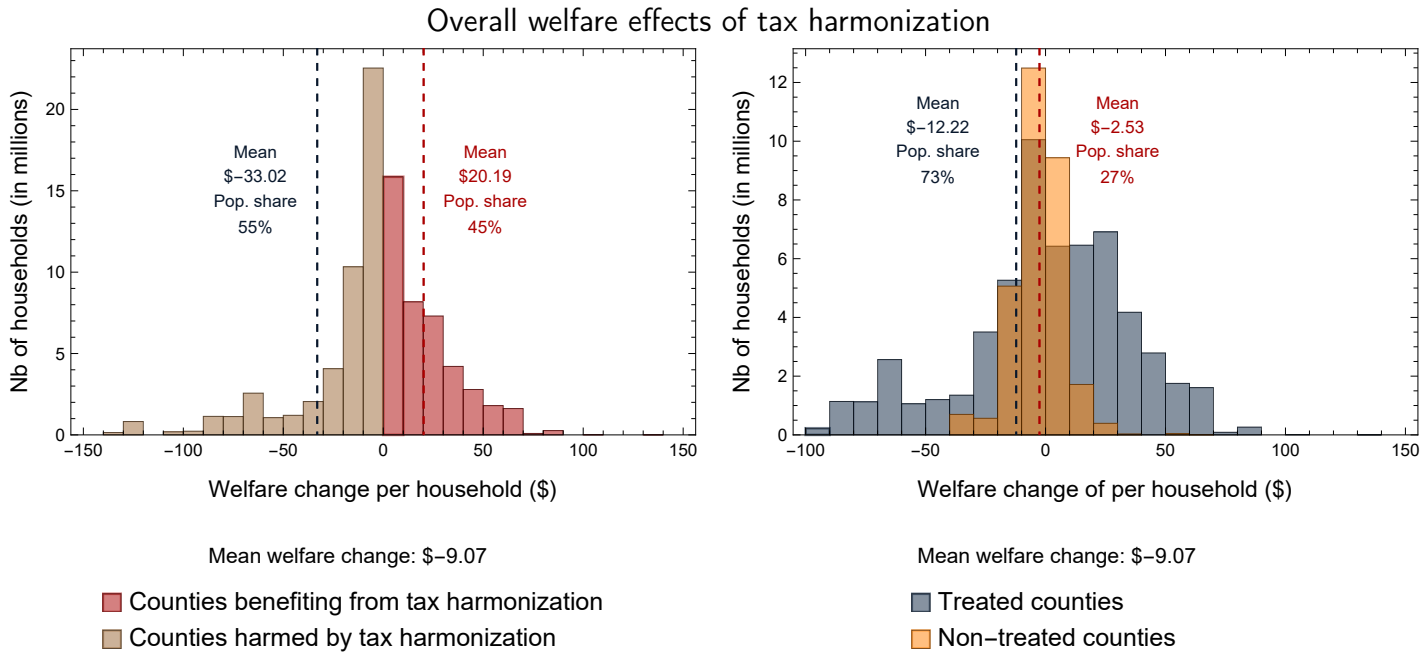
non-treated counties is negative (−$9) and only 45% of the population would benefit from a partial tax harmonization. These results extend those observed for the introduction of a minimum tax: counties that have to increase (decrease) their tax rate experience a welfare gain (loss), suggesting that taxes are observed tax rates are indeed too low.

Table H.1. The welfare effects of a partial tax harmonization $[t^{mean} - \ell, t^{mean} + \ell]$ with looseness $\ell = 0.7\%$.

	Winner share (%)	Welfare change ($)				Population (millions)	Nb counties
		Mean	Median	Decile 10	Decile 90		
A. Endogenous taxation							
All counties	45.0	−9.1	−1.4	−65.0	34.0	93.6	2621
Non-treated counties	38.2	−2.5	−1.6	−12.2	6.7	30.5	711
Treated counties	48.3	−12.2	−1.1	−82.1	40.7	63.1	1910
Top-treated counties	13.3	−55.9	−40.3	−161	3.7	24.9	614
Bottom-treated counties	71.1	16.2	14.6	−13.9	49.3	38.2	1296
B. Exogenous taxation							
All counties	44.9	−9.2	−1.5	−65.0	34.9	93.6	2621
Non-treated counties	38.1	−3.1	−1.8	−14.5	7.6	30.5	711
Treated counties	48.3	−12.1	−1.2	−82.4	41.4	63.1	1910
Top-treated counties	12.6	−56.0	−40.3	−161	3.9	24.9	614
Bottom-treated counties	71.5	16.5	14.9	−13.7	49.8	38.2	1296

NOTE— Welfare change: per household equivalent variation ($). Winner share: share of households with positive equivalent variation. Population refers to the number of households.

Figure H.2 presents the distribution of the welfare effects of our baseline tax harmonization scenario distinguishing between winners and losers as well as between treated and non-treated counties. 45% of the population that would benefit from the policy value it at $20 while the 45% of the population losing from it incur a welfare loss of $\$-33$. On average both treated and non-treated counties are harmed by a partial tax harmonization but the effect is, as expected, more dispersed for treated counties that counts counties required to increase and to decrease their tax rate.

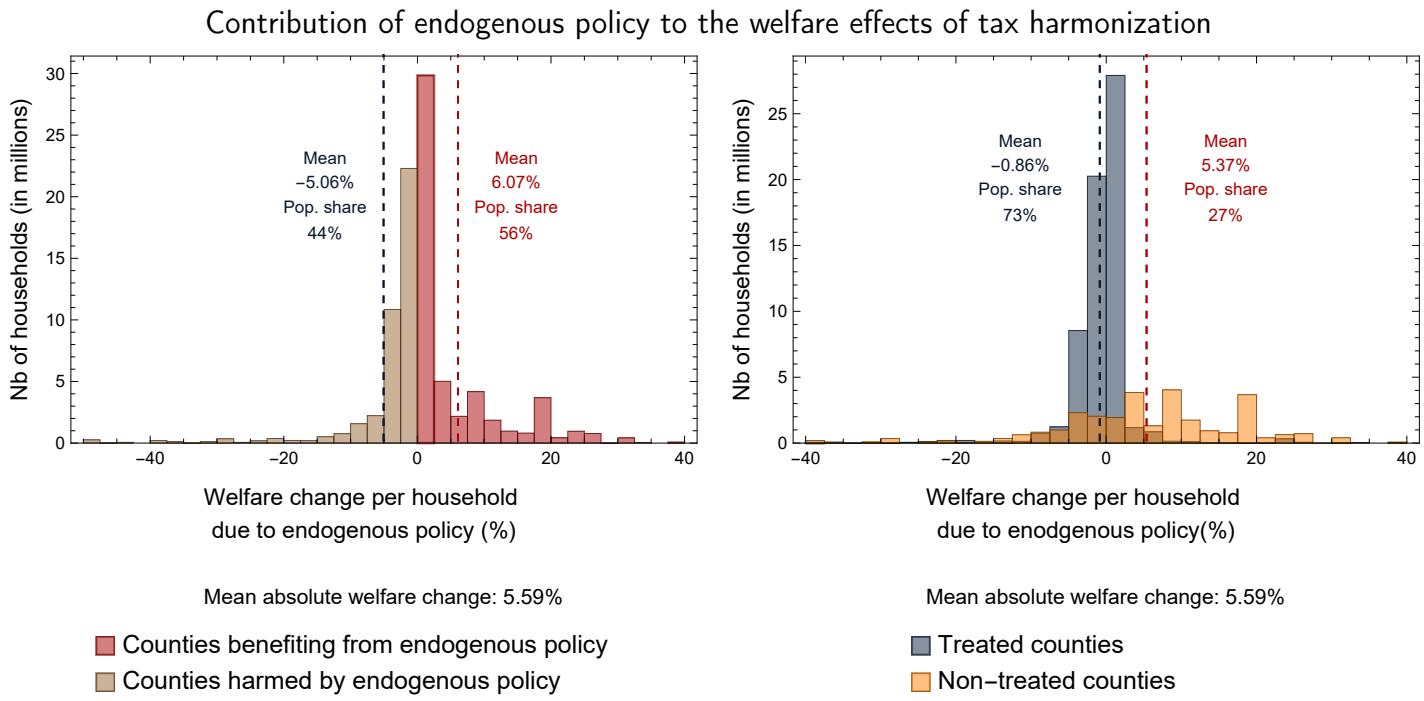


(a) Separating by winning and losing counties.

(b) Separating by treated and non-treated counties.

Figure H.2. Total welfare effects as tax harmonization with looseness 0.7% is imposed. The welfare effects are calculated in our full general equilibrium, allowing treated and non-treated counties to respond strategically. The horizontal axis represents the equivalent variations of the counties weighted by their populations, shown separately for different groups of counties with tax authority. The vertical axes are number of households.

Figure H.3 presents the distribution of the difference in equivalent variations due endogenous tax setting. The (absolute value of the) welfare effect of allowing governments to strategically respond amounts to around 5.6%. Figure H.3 also shows the extent of heterogeneity among winners and losers from endogenous tax setting: 56% of the population benefit from endogenous tax setting with an increase in welfare of 6% on average while 44% of the population lose from endogenous tax setting with an average loss of 5%. Among non-treated counties, endogenous policy making accounts for 5.4% of their welfare gains. For non-treated counties, the effect is slightly negative −0.9%. Figures H.4 and H.5 in Appendix H.3 further decompose the welfare effects of partial harmonization into public and private gains.



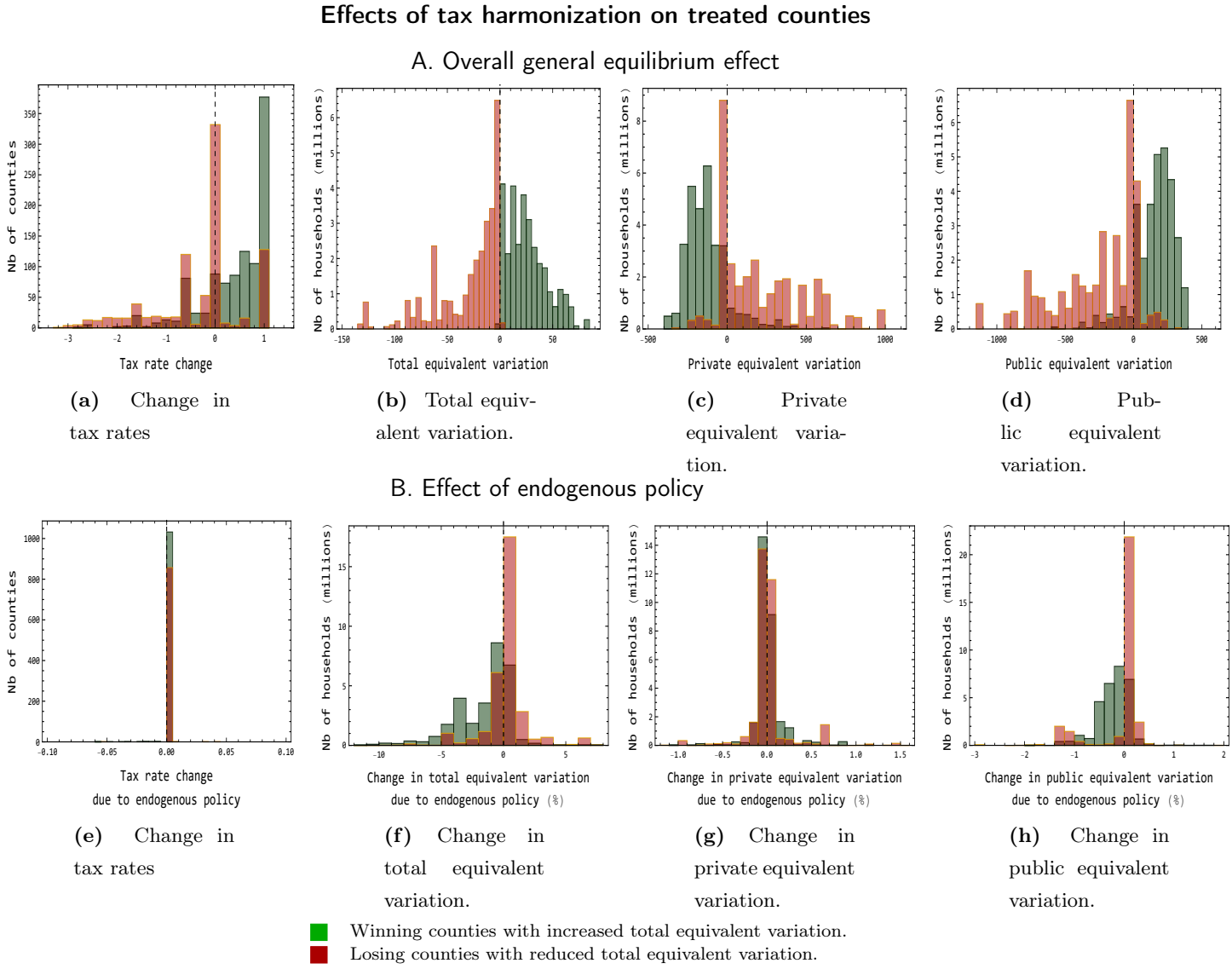
(a) Separating by winning and losing counties.

(b) Separating by treated and non-treated counties.

Figure H.3. This graph represents the percent change in equivalent variations of tax harmonization (looseness of 0.7%) with strategic interactions relative to without strategic interactions. Percent change are defined as $100 \times (EV^{endo} - EV^{exo})/|EV^{endo}|$. The average welfare effect of endogenous policy is computed as the mean absolute value of the welfare change. The sample includes all counties with taxing authority.

These results align with Fajgelbaum et al. (2019) who also argue that tax harmonization can in theory generate ambiguous welfare outcome. They however find that imposing a complete tax harmonization on U.S. states (with a degree of looseness of 0) leads to higher welfare on average. The contrast with our findings is not surprising, as the welfare effects of such reforms depend critically on the distribution of tax rates relative to the imposed constraints. Another key difference is that we do not impose a complete tax harmonization; instead, some counties are not directly treated. On average, these counties incur a welfare loss (−$2.5).

H.3. Decomposition of the Effects of Partial Harmonization



(a) Change in tax rates

(b) Total equivalent variation.

(c) Private equivalent variation.

(d) Public equivalent variation.

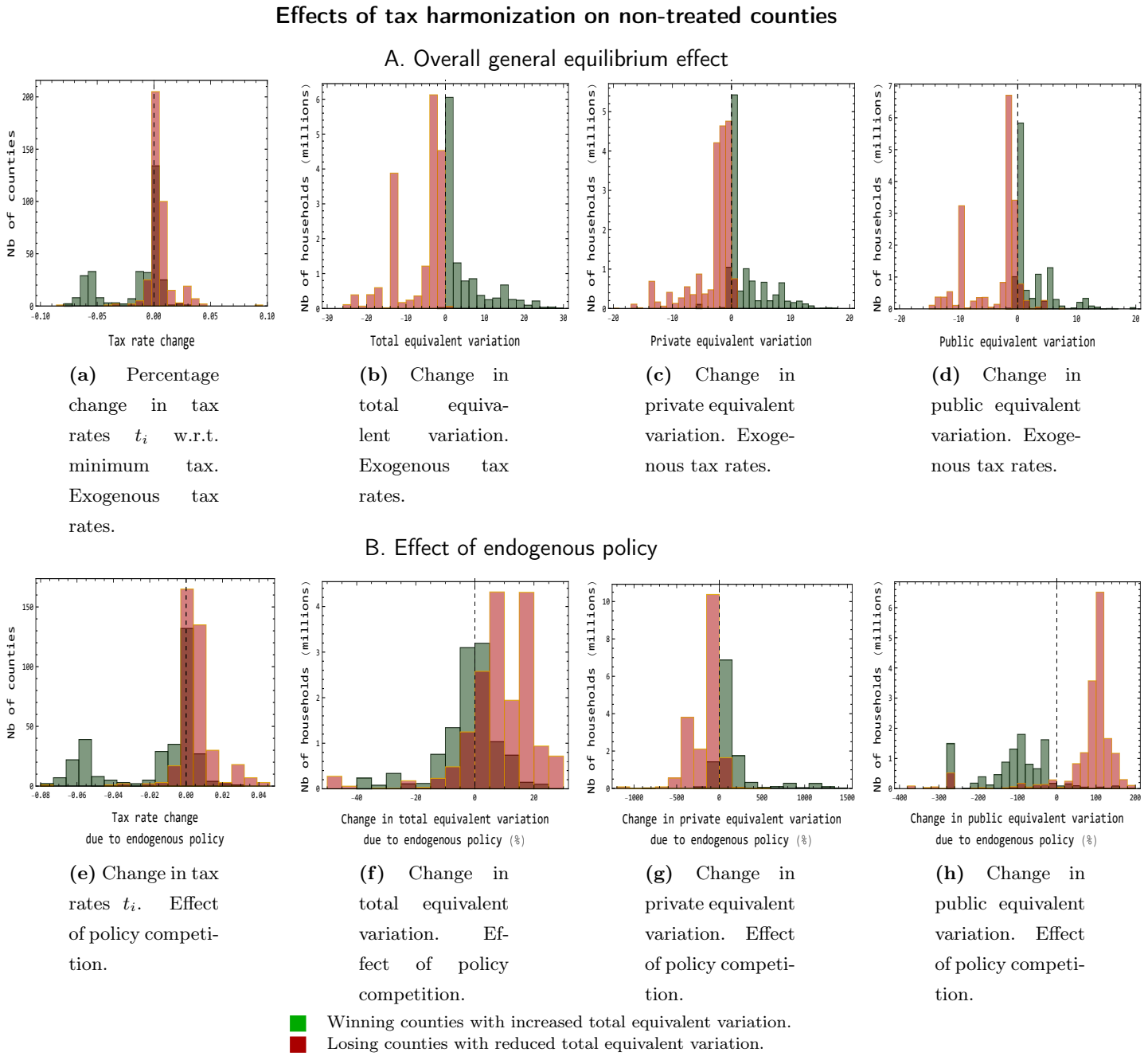
(e) Change in tax rates

(f) Change in total equivalent variation.

(g) Change in private equivalent variation.

(h) Change in public equivalent variation.

Figure H.4. Effect of a tax harmonization $[t^{mean} - \ell, t^{mean} + \ell]$ with looseness $\ell = 0.7\%$ on treated counties. Figure H.4a–Figure H.4d assume exogenous tax rates. Figure H.4e–Figure H.4h represent the level of the variable under endogenous taxation minus the level under exogenous tax rates. In Figure H.4a and Figure H.4e, the change in tax rate is computed as $100 \times (t^{after} - t^{before})$.



(a) Percentage change in tax rates t_i w.r.t. minimum tax. Exogenous tax rates.

(b) Change in total equivalent variation. Exogenous tax rates.

(c) Change in private equivalent variation. Exogenous tax rates.

(d) Change in public equivalent variation. Exogenous tax rates.

(e) Change in tax rates t_i. Effect of policy competition.

(f) Change in total equivalent variation. Effect of policy competition.

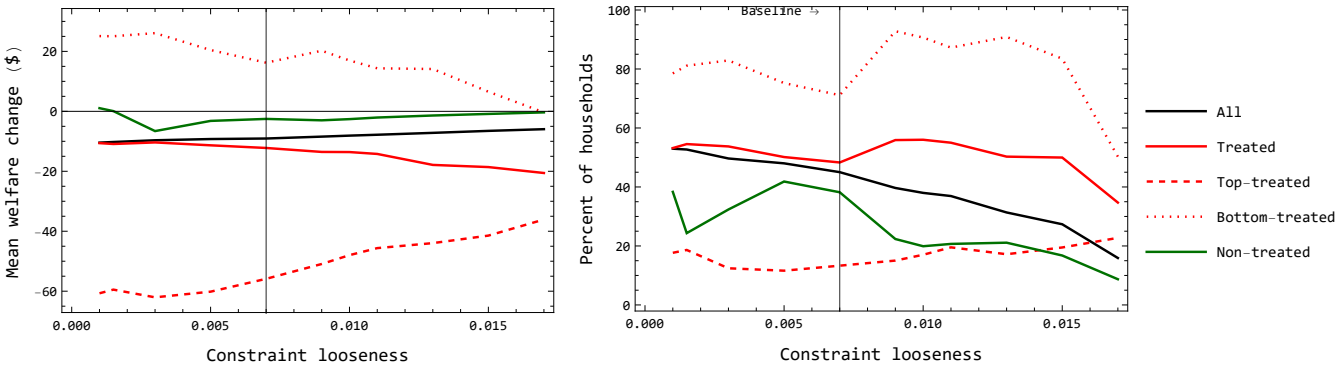
(g) Change in private equivalent variation. Effect of policy competition.

(h) Change in public equivalent variation. Effect of policy competition.

Figure H.5. Effect of a tax harmonization $[t^{mean} - \ell, t^{mean} + \ell]$ with looseness $\ell = 0.7\%$ on non-treated counties. Figure H.5a–Figure H.5d assume exogenous tax rates. Figure H.5e–Figure H.5h represent the level of the variable under endogenous taxation minus the level under exogenous tax rates. In Figure H.5a, the percentage change in tax rate is relative to the minimum tax: $100 \times (t^{after} - t^{before})$.

H.4. Various Levels of Looseness

To provide a more comprehensive view of the welfare effects of partial tax harmonization, Figure H.6 reports the average welfare change and the share of households benefiting from a partial tax harmonization for different levels of constraint looseness.



(a) Welfare change per household. **(b)** Share of households benefiting from a partial tax harmonization.

Figure H.6. Welfare change and share of households benefiting from a partial tax harmonization. The number of treated and non-treated counties changes with the level of degree of looseness tax.

Stricter rules (lower looseness) reduce overall welfare —driven by top-treated counties forced to decrease their tax rate— but are also more likely to be supported by a majority of the population. This indicates that welfare gains and losses are not distributed equally: losses are large but concentrated among top-treated counties that are also relatively small.

I. Derivation of the Policy Network Matrix

This appendix derives the Policy Network Matrix introduced in Section 5. Although the J tax reaction functions are only defined implicitly by nonlinear system of taxation rules and general equilibrium conditions, the slopes of these tax reaction functions can be explicitly computed at the equilibrium. Using the implicit function theorem and differentiating twice the equilibrium system, we derive closed-form expressions for the $J \times J$ pairwise tax reaction slopes evaluated at the equilibrium.

We apply the four-step procedure described in Section 5. Step 1 evaluates the general equilibrium of the economy (Appendix I.1). Step 2 computes the general equilibrium response system (Appendix I.2). Step 3 derives the system of tax responses to economic changes (Appendix I.3). Finally, step 4 uses the results of the previous steps to derive the closed-form expression of the PNM (Appendix I.4). To maintain readability, the extensive list of explicit derivatives supporting the computations in step 3 is reported separately in Appendix I.5.

I.1. Step 1: General Equilibrium

As described in Appendix B.5, the $7J-$equation system (B.22) jointly determines equilibrium numeric values of the $7J$ variables t_i, p_i, P_i, G_i, $\partial p_i/\partial t_i|$, $\partial P_i/\partial t_i|$ and $\partial G_i/\partial t_i|$.

I.2. Step 2: General Equilibrium Economic Response System

Using total differential notation, the economic response equations (B.11), (B.12), (B.13) can be summarized in matrix form as:[30]

$$\mathbf{A}^{\pi}\,\mathbf{dZ}^{\pi} = \mathbf{B}\,\mathbf{dt}, \tag{I.1}$$

in which the tax change vector $\mathbf{dt}$ and the economic response vector $\mathbf{dZ}^{\pi}$ are defined as:

$$\mathbf{dt} = \begin{pmatrix} \mathrm{d}t_1 \\ \vdots \\ \mathrm{d}t_J \end{pmatrix}, \qquad \mathbf{dZ}^{\pi} = \begin{pmatrix} \mathbf{dp} \\ \mathbf{dP} \\ \mathbf{dG} \end{pmatrix},$$

in which the price response vector $\mathbf{dp}$, the price index response vector $\mathbf{dP}$ and the state public services response vector $\mathbf{dG}$ are defined as:

[30] The π superscript on any matrix or vector $\mathbf{X}$ indicates that $\mathbf{X}^{\pi}$ is a permutation of the actual matrix or vector $\mathbf{X}$ that will be used to compute the policy network matrix, as explained below.

$$\mathbf{dp} = \begin{pmatrix} \mathrm{d}p_1 \\ \vdots \\ \mathrm{d}p_J \end{pmatrix}, \qquad \mathbf{dP} = \begin{pmatrix} \mathrm{d}P_1 \\ \vdots \\ \mathrm{d}P_J \end{pmatrix}, \qquad \mathbf{dG} = \begin{pmatrix} \mathrm{d}G_1 \\ \vdots \\ \mathrm{d}G_J \end{pmatrix},$$

and the economic response equations (B.11), (B.12), (B.13) imply that the matrices $\mathbf{A}^\pi$ and $\mathbf{B}^\pi$ are defined as:

$$\mathbf{A}^\pi = \begin{pmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} & \mathbf{A}_{13} \\ \mathbf{A}_{21} & \mathbf{A}_{22} & \mathbf{A}_{23} \\ \mathbf{A}_{31} & \mathbf{A}_{32} & \mathbf{A}_{33} \end{pmatrix}, \qquad \mathbf{B} = \begin{pmatrix} \mathbf{B}_1 \\ \mathbf{B}_2 \\ \mathbf{B}_3 \end{pmatrix},$$

in which the submatrices of $\mathbf{A}^\pi$ are matrices of dimension $J \times J$ with the following elements:

$$\begin{aligned} \mathbf{A}_{11} &= \Big(\mathcal{W}_{ij}\Big) & \mathbf{A}_{12} &= \left(\frac{(\sigma-1)X_{ij}}{P_j}\right), & \mathbf{A}_{13} &= \left(\frac{\mathcal{I}_{ij}p_j n_j}{1+t_j}\right), \\ \mathbf{A}_{21} &= \left(\mathcal{Z}_{ij}\frac{(1-\alpha\sigma)}{\alpha p_j}\right), & \mathbf{A}_{22} &= \Big(\mathcal{I}_{ij}\Big), & \mathbf{A}_{23} &= \Big(0\Big), \\ \mathbf{A}_{31} &= \Big(\mathcal{S}_{ij}\mathcal{K}_{ij}\Big), & \mathbf{A}_{32} &= \Big(0\Big), & \mathbf{A}_{33} &= \Big(\mathcal{S}_{ij}\mathcal{L}_{ij}\Big), \end{aligned}$$

and, similarly, the submatrices of $\mathbf{B}$ are matrices of dimension $J \times J$ with elements:

$$\begin{aligned} \mathbf{B}_1 &= \left(\mathcal{I}_{ij}X_j\left(\frac{\sigma}{1+t_j+T_j} - \frac{1}{1+t_j}\right)\right), \\ \mathbf{B}_2 &= \left(\frac{(\sigma-1)\mathcal{Z}_{ij}}{1+t_j+T_j}\right), \\ \mathbf{B}_3 &= \left(-\mathcal{S}_{ij}\frac{T_i X_j}{1+t_j}\right). \end{aligned}$$

Finally, in order to compute the policy network matrix, we need each submatrix to gather a single county information, as will become clear later. To this end, we apply a permutation $\mathcal{P}$ to rows of the economic response vector $\mathbf{dZ}^\pi$ introduced earlier, thereby defining the matrix $\mathbf{dZ}$ such that:

$$\mathbf{dZ} = \begin{pmatrix} \mathbf{dZ}_1 \\ \vdots \\ \mathbf{dZ}_J \end{pmatrix}, \qquad \text{with } \mathbf{dZ}_i = \begin{pmatrix} \mathrm{d}p_i \\ \mathrm{d}P_i \\ \mathrm{d}G_i \end{pmatrix}, \tag{I.2}$$

where $\mathbf{dZ}_i$ is county i's economic reponse vector. Thus, the economic response system (I.1) can be equivalently re-written as:

$$\mathbf{A}\,\mathbf{dZ} = \mathbf{B}\,\mathbf{dt}, \tag{I.3}$$

where $\mathbf{A}$ is obtained by applying the permutation $\mathcal{P}$ to the columns of $\mathbf{A}^{\pi}$. Then, solving for $\mathbf{dZ}$, we obtain:

$$\mathbf{dZ} = \boldsymbol{\Pi}\,\mathbf{dt}, \tag{I.4}$$

where $\boldsymbol{\Pi} \equiv \mathbf{A}^{-1}\,\mathbf{B}$. this proves the economic response system (25).

I.3. Step 3: Tax-Response-to-Economic-Changes System

The taxation rule (B.21) and the three first-order differential conditions (B.14), (B.15) and (B.16) can be compactly written as:

$$\mathcal{X}_p^i \left.\frac{\partial p_i}{\partial t_i}\right| + \mathcal{X}_P^i \left.\frac{\partial P_i}{\partial t_i}\right| + \mathcal{X}_G^i \left.\frac{\partial G_i}{\partial t_i}\right| + \mathcal{X}_t^i = 0, \qquad \forall,\, \mathcal{X} \in \{\mathcal{M};\mathcal{A};\mathcal{B};\mathcal{C}\}, \tag{I.5}$$

where $\mathcal{M}$, $\mathcal{A}$, $\mathcal{B}$ and $\mathcal{C}$ will be explicitly defined in Appendix I.5. Totally differentiating these four first-order differential equilibrium conditions with respect to τ, we get the second-order differential equilibrium conditions, for $\mathcal{X} \in \{\mathcal{M};\mathcal{A};\mathcal{B};\mathcal{C}\}$:[31]

$$\frac{\mathrm{d}\mathcal{X}_i}{\mathrm{d}t_i}\mathrm{d}t_i + \mathcal{X}_p^i\,\mathrm{d}\left(\left.\frac{\partial p_i}{\partial t_i}\right|\right) + \mathcal{X}_P^i\,\mathrm{d}\left(\left.\frac{\partial P_i}{\partial t_i}\right|\right) + \mathcal{X}_G^i\,\mathrm{d}\left(\left.\frac{\partial G_i}{\partial t_i}\right|\right) = -\frac{\mathrm{d}\mathcal{X}_i}{\mathrm{d}p_i}\mathrm{d}p_i - \frac{\mathrm{d}\mathcal{X}_i}{\mathrm{d}P_i}\mathrm{d}P_i - \frac{\mathrm{d}\mathcal{X}_i}{\mathrm{d}G_i}\frac{\partial G_i}{\partial \mathrm{T}}, \tag{I.6}$$

where:

$$\frac{\mathrm{d}\mathcal{X}_i}{\mathrm{d}t_i} = \mathcal{X}_{pt}^i \left.\frac{\partial p_i}{\partial t_i}\right| + \mathcal{X}_{Pt}^i \left.\frac{\partial P_i}{\partial t_i}\right| + \mathcal{X}_{Gt}^i \left.\frac{\partial G_i}{\partial t_i}\right| + \mathcal{X}_{tt}^i, \qquad \frac{\mathrm{d}\mathcal{X}_i}{\mathrm{d}p_i} = \mathcal{X}_{pp}^i \left.\frac{\partial p_i}{\partial t_i}\right| + \mathcal{X}_{Pp}^i \left.\frac{\partial P_i}{\partial t_i}\right| + \mathcal{X}_{Gp}^i \left.\frac{\partial G_i}{\partial t_i}\right| + \mathcal{X}_{tp}^i,$$
$$\frac{\mathrm{d}\mathcal{X}_i}{\mathrm{d}P_i} = \mathcal{X}_{pP}^i \left.\frac{\partial p_i}{\partial t_i}\right| + \mathcal{X}_{PP}^i \left.\frac{\partial P_i}{\partial t_i}\right| + \mathcal{X}_{GP}^i \left.\frac{\partial G_i}{\partial t_i}\right| + \mathcal{X}_{tP}^i, \qquad \frac{\mathrm{d}\mathcal{X}_i}{\mathrm{d}G_i} = \mathcal{X}_{pG}^i \left.\frac{\partial p_i}{\partial t_i}\right| + \mathcal{X}_{PG}^i \left.\frac{\partial P_i}{\partial t_i}\right| + \mathcal{X}_{GG}^i \left.\frac{\partial G_i}{\partial t_i}\right| + \mathcal{X}_{tG}^i,$$

in which the 16 terms $\mathcal{X}_{pt}^i$, $\mathcal{X}_{Pt}^i$, etc. stand for derivatives that are provided in Appendix I.3. The 4-equation second-order differential system (I.6) allows to compute the 4 local variables $\mathrm{d}t_i$, $\mathrm{d}(\partial p_i/\partial t_i|)$, $\mathrm{d}(\partial P_i/\partial t_i|)$, and $\mathrm{d}(\partial G_i/\partial t_i|)$. In matrix form, the system (I.6) can be written as:

$$\mathbf{K}\cdot\mathbf{dV} = \mathbf{L}\cdot\mathbf{dZ} \tag{I.7}$$

[31] Assumption 1 is particularly useful to compute the policy network matrix which requires to compute not only the gradient of $(p_i \quad P_i \quad G_i)'$ with respect to t_i —which is computationally not costly— but also the hessian of this vector with respect to the tax vector $(t_1,\ldots,t_J)$. The latter would be computationally extremely demanding as it would require to compute $3\times(J+1)J/2$ second-order derivatives (i.e. 14,503,485 terms for our 3,109-county sample), $\partial^2 var_i/\partial(\partial t_j \partial t_i)$ for $var = p, P, G$. Assumption 1 reduces this computation to $3J$ general second-order terms $\mathrm{d}(\partial var_i/\partial\partial t_i)$.

where $\mathbf{dZ}$ is defined as in (I.2), and:

$$\mathbf{dV} = \begin{pmatrix} \mathbf{dV}_1 \\ \vdots \\ \mathbf{dV}_J \end{pmatrix} \quad \text{with} \quad \mathbf{dV}_i = \begin{pmatrix} \mathrm{d}t_i \\ \mathrm{d}\left(\frac{\partial p_i}{\partial t_i} \middle| \right) \\ \mathrm{d}\left(\frac{\partial P_i}{\partial t_i} \middle| \right) \\ \mathrm{d}\left(\frac{\partial G_i}{\partial t_i} \middle| \right) \end{pmatrix}$$

System (I.7) can be solved for $\mathbf{dV}$ by matrix inversion: $\mathbf{dV} = \mathbf{K}^{-1}\mathbf{L}\,\mathbf{dZ}$ from wich we can extract:

$$\mathbf{dt} = \mathbf{H}\,\mathbf{dZ}. \tag{I.8}$$

I.4. Step 4: Policy Network Matrix

Inserting the economic response system (I.4) into the tax response system (I.8), we obtain:

$$\mathbf{dt} = \mathbf{O}\,\mathbf{dt}, \tag{I.9}$$

where $\mathbf{O} \equiv \mathbf{H}\boldsymbol{\Pi}$. The $J \times J$ matrix $\mathbf{O}$ in (I.9) includes all the pairwise tax reaction slopes. However, it also includes non-zero diagonal terms representing own-jurisdiction terms that need to be eliminated to be able to interpret $\mathbf{O}$ as a tax reaction matrix. To do so, we define the matrix $\mathbf{O}^d$ as the diagonal matrix including the diagonal of $\mathbf{O}$ on its diagonal and zeros off-diagonal. Then, we subtract $\mathbf{O}^d$ from each side of (I.9) and obtain:

$$\left(\mathbf{I} - \mathbf{O}^d\right)\mathbf{dt} = \left(\mathbf{O} - \mathbf{O}^d\right)\mathbf{dt},$$

which, by inversion, is equivalent to:

$$\mathbf{dt} = \boldsymbol{\Omega}\mathbf{dt},$$

where $\boldsymbol{\Omega}$ is the policy network matrix defined as:

$$\boldsymbol{\Omega} \equiv \left(\mathbf{I} - \mathbf{O}^d\right)^{-1}\left(\mathbf{O} - \mathbf{O}^d\right).$$

This proves the expression stated in Section 5.

I.5. Detailed Components of the Tax Response System

This section provides the detailed derivations of the explicit derivatives required to support the computations in step 3 of the procedure described in Appendix I.3. Specifically, we derive the derivatives necessary to quantify the equation system (I.6). To do so, we first recall

the first-order differential equilibrium conditions that include the three first-order differential conditions (B.14), (B.15) and (B.16), and the taxation rule (B.21), respectively:

$$\mathcal{A}_i \equiv \underbrace{\mathcal{W}_{ii}}_{\mathcal{A}_p^i} \frac{\partial p_i}{\partial t_i}\Big| + \underbrace{(\sigma-1)\frac{X_{ii}}{P_i}}_{\mathcal{A}_P^i} \frac{\partial P_i}{\partial t_i}\Big| + \underbrace{\frac{p_i n_i}{1+t_i}}_{\mathcal{A}_G^i} \frac{\partial G_i}{\partial t_i}\Big| + \underbrace{X_i\left(\frac{1}{1+t_i} - \frac{\sigma}{1+t_i+T_i}\right)}_{\mathcal{A}_t^i} = 0 \quad \text{(I.10)}$$

$$\mathcal{B}_i \equiv \underbrace{\frac{(1-\alpha\sigma)}{\alpha p_i}}_{\mathcal{B}_p^i} \frac{\partial p_i}{\partial t_i}\Big| + \underbrace{\mathcal{Z}_{ii}^{-1}}_{\mathcal{B}_P^i} \frac{\partial P_i}{\partial t_i}\Big| + \underbrace{0}_{\mathcal{B}_G^i} \frac{\partial G_i}{\partial t_i}\Big| + \underbrace{\frac{(1-\sigma)}{1+t_i+T_i}}_{\mathcal{B}_t^i} = 0 \quad \text{(I.11)}$$

$$\mathcal{C}_i \equiv \underbrace{\mathcal{K}_{ii}}_{\mathcal{C}_p^i} \frac{\partial p_i}{\partial t_i}\Big| + \underbrace{0}_{\mathcal{C}_P^i} \frac{\partial P_i}{\partial t_i}\Big| + \underbrace{n_i p_i\left(1+\frac{T_i}{1+t_i}\right)}_{\mathcal{C}_G^i} \frac{\partial G_i}{\partial t_i}\Big| + \underbrace{\frac{T_i X_i}{1+t_i}}_{\mathcal{C}_t^i} = 0 \quad \text{(I.12)}$$

$$\mathcal{D}_i \equiv \underbrace{\left(\mathcal{D}_{pg}^i\, g_i + \mathcal{D}_{pG}^i\, G_i + \mathcal{D}_{p1}^i\right)}_{\mathcal{D}_p^i} \frac{\partial p_i}{\partial t_i}\Big| + \mathcal{D}_P^i \frac{\partial P_i}{\partial t_i}\Big| + \mathcal{D}_G^i \frac{\partial G_i}{\partial t_i}\Big| + \underbrace{(-1)}_{\mathcal{D}_t^i} = 0 \quad \text{(I.13)}$$

where X_{ii} is as defined in (4), X_i is as defined in (A.16), $\mathcal{W}_{ii}$, $\mathcal{Z}_{ii}$ and $\mathcal{K}_{ii}$, are as defined in (B.11), (B.12), (B.13), respectively, and $\mathcal{D}_{pg}^i \equiv \mathcal{M}_{pg}^i/t_i$, $\mathcal{D}_{pG}^i \equiv \mathcal{M}_{pG}^i/t_i$, $\mathcal{D}_{p1}^i \equiv \mathcal{M}_{p1}^i/t_i$, $\mathcal{D}_P^i \equiv \mathcal{M}_P^i/t_i$ and $\mathcal{D}_G^i \equiv \mathcal{M}_G^i/t_i$ are as defined in (B.20). In sum, all these terms can, again, be expressed as functions of the four key local endogenous variables, p_i, P_i, G_i and t_i, only This system is equivalent to the more compact system expressed in (I.5). Totally differentiating this system, we obtain the second-order differential system (I.6) in which the following derivatives need to be computed:

$$\begin{aligned}
&\mathcal{X}_{pp}^i \equiv \frac{\mathrm{d}\mathcal{X}_p^i}{\mathrm{d}p_i}, && \mathcal{X}_{pP}^i \equiv \frac{\mathrm{d}\mathcal{X}_p^i}{\mathrm{d}P_i}, && \mathcal{X}_{pG}^i \equiv \frac{\mathrm{d}\mathcal{X}_p^i}{\mathrm{d}G_i}, && \mathcal{X}_{pt}^i \equiv \frac{\mathrm{d}\mathcal{X}_p^i}{\mathrm{d}t_i},\\
&\mathcal{X}_{Pp}^i \equiv \frac{\mathrm{d}\mathcal{X}_P^i}{\mathrm{d}p_i}, && \mathcal{X}_{PP}^i \equiv \frac{\mathrm{d}\mathcal{X}_P^i}{\mathrm{d}P_i}, && \mathcal{X}_{PG}^i \equiv \frac{\mathrm{d}\mathcal{X}_P^i}{\mathrm{d}G_i}, && \mathcal{X}_{Pt}^i \equiv \frac{\mathrm{d}\mathcal{X}_P^i}{\mathrm{d}t_i},\\
&\mathcal{X}_{Gp}^i \equiv \frac{\mathrm{d}\mathcal{X}_G^i}{\mathrm{d}p_i}, && \mathcal{X}_{GP}^i \equiv \frac{\mathrm{d}\mathcal{X}_G^i}{\mathrm{d}P_i}, && \mathcal{X}_{GG}^i \equiv \frac{\mathrm{d}\mathcal{X}_G^i}{\mathrm{d}G_i}, && \mathcal{X}_{Gt}^i \equiv \frac{\mathrm{d}\mathcal{X}_G^i}{\mathrm{d}t_i},\\
&\mathcal{X}_{tp}^i \equiv \frac{\mathrm{d}\mathcal{X}_t^i}{\mathrm{d}p_i}, && \mathcal{X}_{tP}^i \equiv \frac{\mathrm{d}\mathcal{X}_t^i}{\mathrm{d}P_i}, && \mathcal{X}_{tG}^i \equiv \frac{\mathrm{d}\mathcal{X}_t^i}{\mathrm{d}G_i}, && \mathcal{X}_{tt}^i \equiv \frac{\mathrm{d}\mathcal{X}_t^i}{\mathrm{d}t_i}.
\end{aligned}$$

for each $\mathcal{X} \in \{\mathcal{A};\mathcal{B};\mathcal{C};\mathcal{D}\}$.

Derivatives of $\mathcal{A}_p^i$ Differentiating $\mathcal{A}_p^i$ as defined in (I.10) with respect to p_i, P_i, G_i and t_i, respectively, we obtain:

$$\frac{\mathrm{d}\mathcal{A}_p^i}{\mathrm{d}p_i} = \frac{\alpha(\alpha\sigma-1)\left(G_i n_i p_i + (1+t_i)\,X_i\right) - \alpha(\sigma-1)Y_i}{\alpha^2 p_i^2(1+t_i)} - \frac{(\alpha(\sigma+1)-2)X_{ii}\left(E_i - \kappa_i n_i\left(1-\tau_i\right)\right)}{\alpha^2 p_i^2 E_i},$$

$$\frac{\mathrm{d}\mathcal{A}_p^i}{\mathrm{d}P_i} = \frac{(\sigma-1)X_{ii}\left(E_i - \kappa_i n_i\left(1-\tau_i\right)\right)}{\alpha E_i p_i P_i},$$
$$\frac{\mathrm{d}\mathcal{A}_p^i}{\mathrm{d}G_i} = \frac{(\alpha(\sigma+1)-1)n_i}{\alpha\left(1+t_i\right)},$$
$$\frac{\mathrm{d}\mathcal{A}_p^i}{\mathrm{d}t_i} = \frac{\left(\alpha\sigma-1\right)\left(1+t_i\right)X_i + Y_i - \alpha G_i n_i p_i}{\alpha p_i\left(1+t_i\right)^2} - \frac{\sigma X_{ii}\left(E_i - \kappa_i n_i\left(1-\tau_i\right)\right)}{\alpha p_i E_i\left(1+t_i+T_i\right)}.$$

Derivatives of $\mathcal{A}_P^i$ Differentiating $\mathcal{A}_P^i$ as defined in (I.10) with respect to p_i, P_i, G_i and t_i, respectively, we obtain:

$$\frac{\mathrm{d}\mathcal{A}_P^i}{\mathrm{d}p_i} = \frac{(\sigma-1)X_{ii}\left((2-\alpha\sigma)E_i - \kappa_i n_i\left(1-\tau_i\right)\right)}{\alpha E_i p_i P_i},$$
$$\frac{\mathrm{d}\mathcal{A}_P^i}{\mathrm{d}P_i} = \frac{(\sigma-2)(\sigma-1)X_{ii}}{P_i^2},$$
$$\frac{\mathrm{d}\mathcal{A}_P^i}{\mathrm{d}G_i} = 0,$$
$$\frac{\mathrm{d}\mathcal{A}_P^i}{\mathrm{d}t_i} = -\frac{(\sigma-1)\sigma X_{ii}}{P_i\left(1+t_i+T_i\right)}.$$

Derivatives of $\mathcal{A}_G^i$ Differentiating $\mathcal{A}_G^i$ as defined in (I.10) with respect to p_i, P_i, G_i and t_i, respectively, we obtain:

$$\frac{\mathrm{d}\mathcal{A}_G^i}{\mathrm{d}p_i} = \frac{n_i}{1+t_i}, \qquad \frac{\mathrm{d}\mathcal{A}_G^i}{\mathrm{d}P_i} = \frac{\mathrm{d}\mathcal{A}_G^i}{\mathrm{d}G_i} = 0, \qquad \frac{\mathrm{d}\mathcal{A}_G^i}{\mathrm{d}t_i} = -\frac{n_i p_i}{\left(1+t_i\right)^2}.$$

Derivatives of $\mathcal{A}_t^i$ Differentiating $\mathcal{A}_t^i$ as defined in (I.10) with respect to p_i, P_i, G_i and t_i, respectively, we obtain:

$$\frac{\mathrm{d}\mathcal{A}_t^i}{\mathrm{d}p_i} = \frac{\left(\left(\sigma-1\right)\left(1+t_i\right)-T_i\right)\left(\alpha G_i n_i p_i - Y_i\right)}{\alpha p_i\left(1+t_i\right)^2\left(1+t_i+T_i\right)},$$
$$\frac{\mathrm{d}\mathcal{A}_t^i}{\mathrm{d}P_i} = 0,$$
$$\frac{\mathrm{d}\mathcal{A}_t^i}{\mathrm{d}G_i} = \frac{n_i p_i\left(\sigma(1+t_i) - (1+t_i+T_i)\right)}{(1+t_i)^2(1+t_i+T_i)},$$
$$\frac{\mathrm{d}\mathcal{A}_t^i}{\mathrm{d}t_i} = \frac{X_i\left(2(\sigma-1)\left(1+t_i\right)^2 + (\sigma-4)\left(1+t_i\right)T_i - 2T_i^2\right)}{\left(1+t_i\right)^2\left(1+t_i+T_i\right)^2}.$$

Derivatives of $\mathcal{B}_p^i$ Differentiating $\mathcal{B}_p^i$ as defined in (I.11) with respect to p_i, P_i, G_i and t_i, respectively, we obtain:

$$\frac{\mathrm{d}\mathcal{B}_p^i}{\mathrm{d}p_i} = -\frac{1-\alpha\sigma}{\alpha p_i^2},$$

and $\mathrm{d}\mathcal{B}_p^i/\mathrm{d}P_i = \mathrm{d}\mathcal{B}_p^i/\mathrm{d}G_i = \mathrm{d}\mathcal{B}_p^i/\mathrm{d}t_i = 0$.

Derivatives of $\mathcal{B}_P^i$ Differentiating $\mathcal{B}_P^i$ as defined in (I.11) with respect to p_i, P_i, G_i and t_i, respectively, we obtain:

$$\frac{\mathrm{d}\mathcal{B}_P^i}{\mathrm{d}p_i} = \frac{(1-\alpha\sigma)\mathcal{Z}_i}{\alpha p_i}, \qquad \frac{\mathrm{d}\mathcal{B}_P^i}{\mathrm{d}P_i} = \frac{\sigma\mathcal{Z}_i}{P_i}, \qquad \frac{\mathrm{d}\mathcal{B}_P^i}{\mathrm{d}G_i} = 0, \qquad \frac{\mathrm{d}\mathcal{B}_P^i}{\mathrm{d}t_i} = -\frac{(\sigma-1)\mathcal{Z}_i}{1+t_i+T_i}.$$

Derivatives of $\mathcal{B}_G^i$ Differentiating $\mathcal{B}_G^i$ as defined in (I.11) with respect to p_i, P_i, G_i and t_i, respectively, we obtain $\mathrm{d}\mathcal{B}_G^i/\mathrm{d}p_i = \mathrm{d}\mathcal{B}_G^i/\mathrm{d}P_i = \mathrm{d}\mathcal{B}_G^i/\mathrm{d}G_i = \mathrm{d}\mathcal{B}_G^i/\mathrm{d}t_i = 0$.

Derivatives of $\mathcal{B}_t^i$ Differentiating $\mathcal{B}_t^i$ as defined in (I.11) with respect to p_i, P_i, G_i and t_i, respectively, we obtain: $\mathrm{d}\mathcal{B}_t^i/\mathrm{d}p_i = \mathrm{d}\mathcal{B}_t^i/\mathrm{d}P_i = \mathrm{d}\mathcal{B}_t^i/\mathrm{d}G_i = 0$, and:

$$\frac{\mathrm{d}\mathcal{B}_t^i}{\mathrm{d}t_i} = -\frac{1-\sigma}{(1+t_i+T_i)^2}.$$

Derivatives of $\mathcal{C}_p^i$ Differentiating $\mathcal{C}_p^i$ as defined in (I.12) with respect to p_i, P_i, G_i and t_i, respectively, we obtain:

$$\begin{aligned}
\frac{\mathrm{d}\mathcal{C}_p^i}{\mathrm{d}p_i} &= \frac{(\alpha-1)\left((1-\tau_i)T_iY_i + (1+t_i)\tau_i\left(E_i - \kappa_i n_i(1-\tau_i)\right)\right)}{\alpha^2 p_i^2(1+t_i)(1-\tau_i)},\\
\frac{\mathrm{d}\mathcal{C}_p^i}{\mathrm{d}P_i} &= 0,\\
\frac{\mathrm{d}\mathcal{C}_p^i}{\mathrm{d}G_i} &= \frac{n_i(1+t_i+T_i)}{1+t_i},\\
\frac{\mathrm{d}\mathcal{C}_p^i}{\mathrm{d}t_i} &= \frac{T_i(Y_i - \alpha G_i n_i p_i)}{\alpha p_i(1+t_i)^2}.
\end{aligned}$$

Derivatives of $\mathcal{C}_P^i$ Differentiating $\mathcal{C}_P^i$ as defined in (I.12) with respect to p_i, P_i, G_i and t_i, respectively, we obtain: $\mathrm{d}\mathcal{C}_P^i/\mathrm{d}p_i = \mathrm{d}\mathcal{C}_P^i/\mathrm{d}P_i = \mathrm{d}\mathcal{C}_P^i/\mathrm{d}G_i = \mathrm{d}\mathcal{C}_P^i/\mathrm{d}t_i = 0$.

Derivatives of $\mathcal{C}_G^i$ Differentiating $\mathcal{C}_G^i$ as defined in (I.12) with respect to p_i, P_i, G_i and t_i, respectively, we obtain:

$$\frac{\mathrm{d}\mathcal{C}_G^i}{\mathrm{d}p_i} = 1 + \frac{T_i}{1+t_i}, \qquad \frac{\mathrm{d}\mathcal{C}_G^i}{\mathrm{d}P_i} = \frac{\mathrm{d}\mathcal{C}_G^i}{\mathrm{d}G_i} = 0, \qquad \frac{\mathrm{d}\mathcal{C}_G^i}{\mathrm{d}t_i} = -\frac{n_i p_i T_i}{(1+t_i)^2}.$$

Derivatives of $\mathcal{C}_t^i$ Differentiating $\mathcal{C}_t^i$ as defined in (I.12) with respect to p_i, P_i, G_i and t_i, respectively, we obtain:

$$\frac{\mathrm{d}\mathcal{C}_t^i}{\mathrm{d}p_i} = \frac{T_i\left(Y_i - \alpha G_i n_i p_i\right)}{\alpha p_i \left(1+t_i\right)^2}, \qquad \frac{\mathrm{d}\mathcal{C}_t^i}{\mathrm{d}P_i} = 0, \qquad \frac{\mathrm{d}\mathcal{C}_t^i}{\mathrm{d}G_i} = -\frac{n_i p_i T_i}{\left(1+t_i\right)^2}, \qquad \frac{\mathrm{d}\mathcal{C}_t^i}{\mathrm{d}t_i} = -\frac{2T_i X_i}{\left(1+t_i\right)^2}.$$

Derivatives of $\mathcal{D}_p^i$ The term $\mathcal{D}_p^i$ in (I.13) is more complex to differentiate because it includes several composite terms: $\mathcal{D}_p^i = \mathcal{D}_{pg}^i g_i + \mathcal{D}_{pG}^i G_i + \mathcal{D}_{p1}^i$ where $\mathcal{D}_{pg}^i$, $\mathcal{D}_{pG}^i$ and $\mathcal{D}_{p1}^i$ are as defined in (B.20). Thus, differentiating $\mathcal{D}_p^i$ with respect to p_i, we obtain:

$$\frac{\mathrm{d}\mathcal{D}_p^i}{\mathrm{d}p_i} = \mathcal{D}_{pg}^i \frac{\mathrm{d}g_i}{\mathrm{d}p_i} + \frac{\mathrm{d}\mathcal{D}_{pg}^i}{\mathrm{d}p_i} g_i + \frac{\mathrm{d}\mathcal{D}_{pG}^i}{\mathrm{d}p_i} G_i + \frac{\mathrm{d}\mathcal{D}_{p1}^i}{\mathrm{d}p_i},$$

in which:

$$\begin{aligned}
\frac{\mathrm{d}g_i}{\mathrm{d}p_i} &= \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1-\alpha}{\alpha}} \frac{(1-\alpha)t_i p_i^{\frac{1}{\alpha}-2}}{\alpha^2\left(1+t_i\right)}, \\
\frac{\mathrm{d}\mathcal{D}_{pg}^i}{\mathrm{d}p_i} &= \frac{\mathcal{D}_{pg}^i}{1+t_i}\left(\frac{G_i n_i}{X_i} + \frac{\kappa_i n_i \left(1+t_i\right)\left(1-\tau_i\right)\left(E_i - \kappa_i n_i\left(1-\tau_i\right)\right)}{\alpha E_i p_i\left((1-\alpha\nu)E_i - \kappa_i n_i\left(1-\tau_i\right)\right)} - \frac{Y_i}{\alpha p_i X_i}\right), \\
\frac{\mathrm{d}\mathcal{D}_{pG}^i}{\mathrm{d}p_i} &= \frac{\mathcal{D}_{pG}^i}{1+t_i}\left(\frac{G_i n_i}{X_i} + \frac{\delta\kappa_i n_i(1-\tau_i)(1+t_i)^2(E_i - \kappa_i n_i(1-\tau_i))}{\alpha p_i E_i(E_i(\delta + t_i(\delta-\alpha\nu)) - \delta\kappa_i n_i(1+t_i)(1-\tau_i))} + \frac{Y_i}{\alpha p_i X_i}\right), \\
\frac{\mathrm{d}\mathcal{D}_{p1}^i}{\mathrm{d}p_i} &= \frac{\mathcal{D}_{p1}^i}{\alpha p_i}\left(\frac{\alpha G_i n_i p_i - Y_i}{(1+t_i)X_i} + \frac{(1-\alpha)t_i Y_i}{\alpha\Delta_i n_i p_i\left(1+t_i\right) + t_i Y_i}\right),
\end{aligned}$$

where $\delta \equiv (1-\varphi)/\varphi$. By inspection of the expression of $\mathcal{D}_p^i$ we can see that the price index P_i does not directly appear, so that $\mathrm{d}\mathcal{D}_p^i/\mathrm{d}P_i = 0$. However, state public services are present in the expression of $\mathcal{D}_p^i$. Differentiating this expression with respect to G_i, we obtain:

$$\frac{\mathrm{d}\mathcal{D}_p^i}{\mathrm{d}G_i} = \mathcal{D}_{pg}^i \frac{\mathrm{d}g_i}{\mathrm{d}G_i} + \frac{\mathrm{d}\mathcal{D}_{pg}^i}{\mathrm{d}G_i} g_i + \frac{\mathrm{d}\mathcal{D}_{pG}^i}{\mathrm{d}G_i} G_i + \mathcal{D}_{pG}^i + \frac{\mathrm{d}\mathcal{D}_{p1}^i}{\mathrm{d}G_i},$$

in which:

$$\frac{\mathrm{d}g_i}{\mathrm{d}G_i} = -\frac{t_i}{1+t_i}, \qquad \frac{\mathrm{d}\mathcal{D}_{pg}^i}{\mathrm{d}G_i} = \frac{\mathcal{D}_{pg}^i n_i p_i}{\left(1+t_i\right)X_i}, \qquad \frac{\mathrm{d}\mathcal{D}_{pG}^i}{\mathrm{d}G_i} = \frac{\mathcal{D}_{pG}^i n_i p_i}{\left(1+t_i\right)X_i}, \qquad \frac{\mathrm{d}\mathcal{D}_{p1}^i}{\mathrm{d}G_i} = \frac{\mathcal{D}_{p1}^i n_i p_i}{(1+t_i)X_i}.$$

Differentiating $\mathcal{D}_p^i$ with respect to t_i, we obtain:

$$\frac{\mathrm{d}\mathcal{D}_p^i}{\mathrm{d}t_i} = \mathcal{D}_{pg}^i \frac{\mathrm{d}g_i}{\mathrm{d}t_i} + \frac{\mathrm{d}\mathcal{D}_{pg}^i}{\mathrm{d}t_i} g_i + \frac{\mathrm{d}\mathcal{D}_{pG}^i}{\mathrm{d}t_i} G_i + \frac{\mathrm{d}\mathcal{D}_{p1}^i}{\mathrm{d}t_i},$$

in which:

$$\frac{\mathrm{d}g_i}{\mathrm{d}t_i} = \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1-\alpha}{\alpha}} \frac{p_i^{\frac{1-\alpha}{\alpha}}}{\alpha(1+t_i)^2} - \frac{G_i}{(1+t_i)^2},$$

$$\frac{\mathrm{d}\mathcal{D}^i_{pg}}{\mathrm{d}t_i} = \frac{2\mathcal{D}^i_{pg}}{1+t_i},$$
$$\frac{\mathrm{d}\mathcal{D}^i_{pG}}{\mathrm{d}t_i} = \frac{\mathcal{D}^i_{pG}}{1+t_i}\frac{E_i(2\delta-\alpha\nu+2t_i(\delta-\alpha\nu))-2\delta\kappa_i n_i(1+t_i)(1-\tau_i)}{E_i(\delta+t_i(\delta-\alpha\nu))-\delta\kappa_i n_i(1+t_i)(1-\tau_i)},$$
$$\frac{\mathrm{d}\mathcal{D}^i_{p1}}{\mathrm{d}t_i} = \frac{\mathcal{D}^i_{p1}}{1+t_i}\left(\frac{Y_i}{\alpha\Delta_i n_i p_i\left(1+t_i\right)+t_i Y_i}+2\right).$$

Derivatives of $\mathcal{D}^i_P$ Differentiating $\mathcal{D}^i_P$ as defined in (I.13) with respect to p_i, P_i, G_i and t_i, respectively, we obtain:

$$\frac{\mathrm{d}\mathcal{D}^i_P}{\mathrm{d}p_i} = \frac{n_i}{\alpha\nu p_i P_i X_i^2}\left(p_i\left(g_i+\delta G_i\right)\left(\alpha G_i n_i p_i+\alpha\left(1+t_i\right)X_i-Y_i\right)+\frac{1-\alpha}{\alpha}\left(\frac{\sigma-1}{\sigma}\right)^{\frac{1-\alpha}{\alpha}}t_i X_i p_i^{\frac{1}{\alpha}}\right),$$
$$\frac{\mathrm{d}\mathcal{D}^i_P}{\mathrm{d}P_i} = -\frac{n_i p_i\left(1+t_i\right)\left(g_i+\delta G_i\right)}{\nu P_i^2 X_i},$$
$$\frac{\mathrm{d}\mathcal{D}^i_P}{\mathrm{d}G_i} = \frac{n_i p_i\left(n_i p_i\left(g_i+\delta G_i\right)+X_i\left(\delta+(\delta-1)t_i\right)\right)}{\nu P_i X_i^2},$$
$$\frac{\mathrm{d}\mathcal{D}^i_P}{\mathrm{d}t_i} = \frac{2n_i p_i\left(g_i+\delta G_i\right)+X_i}{\nu P_i X_i}.$$

Derivatives of $\mathcal{D}^i_G$ Differentiating $\mathcal{D}^i_G$ as defined in (I.13) with respect to p_i, P_i, G_i and t_i, respectively, we obtain:

$$\frac{\mathrm{d}\mathcal{D}^i_G}{\mathrm{d}p_i} = -\frac{n_i\left(\delta+(\delta-1)t_i\right)\left(\alpha G_i n_i p_i+\alpha\left(1+t_i\right)X_i-Y_i\right)}{\alpha\left(1+t_i\right)X_i^2},$$
$$\frac{\mathrm{d}\mathcal{D}^i_G}{\mathrm{d}P_i} = 0,$$
$$\frac{\mathrm{d}\mathcal{D}^i_G}{\mathrm{d}G_i} = -\frac{n_i^2 p_i^2\left(\delta+(\delta-1)t_i\right)}{\left(1+t_i\right)X_i^2},$$
$$\frac{\mathrm{d}\mathcal{D}^i_G}{\mathrm{d}t_i} = \frac{n_i p_i\left(1-2\delta-2(\delta-1)t_i\right)}{\left(1-t_i\right)X_i}.$$

Derivatives of $\mathcal{D}^i_t$ Differentiating $\mathcal{D}^i_t$ as defined in (I.13) with respect to p_i, P_i, G_i and t_i, respectively, we obtain $\mathrm{d}\mathcal{D}^i_t/\mathrm{d}p_i = \mathrm{d}\mathcal{D}^i_t/\mathrm{d}P_i = \mathrm{d}\mathcal{D}^i_t/\mathrm{d}G_i = \mathrm{d}\mathcal{D}^i_t/\mathrm{d}t_i = 0$.

J. Supplementary Material on the Policy Network Matrix

This appendix supplements Section 5 by relating the policy network matrix to prior reduced-form weight matrices in the tax competition literature.

J.1. Relation to Traditional Tax Competition Literature

An element of the PNM is equal to $\omega_{ij} = \beta_i \mathrm{w}_{ij}$, and the tax responses (27) can be written as:

$$\mathbf{dt} = \boldsymbol{\beta} \circ \mathbf{W}\,\mathbf{dt}, \qquad \text{or equivalently,} \qquad \mathrm{d}t_i = \beta_i \sum_j \mathrm{w}_{ij}\mathrm{d}t_j, \tag{J.1}$$

where $\boldsymbol{\beta}' \equiv (\beta_1 \dots \beta_J)$ is the PR vector, and $\mathbf{W} = (\mathrm{w}_{ij})$ is the row-standardized matrix associated with the PNM, i.e. $\boldsymbol{\Omega} = \boldsymbol{\beta} \circ \mathbf{W}$. The operator $\circ$ stands for an Hadamard product of vector and matrix, such that $\boldsymbol{\beta} \circ \mathbf{W} \equiv \mathbf{diag}\,(\boldsymbol{\beta})\,\mathbf{W}$, in which $\mathbf{diag}(\boldsymbol{\beta})$ is the matrix with diagonal $\boldsymbol{\beta}$ and zeros off diagonal.

The expressions in (J.1) is reminiscent of the tax reaction functions estimated in the empirical tax competition literature pioneered by (Brueckner and Saavedra, 2001). The PNM plays the same role as standard spatial weight matrices considered in the tax competition literature. However, as the PNM is more general it has a number of properties that critically differ from standard spatial weight matrices. The next section states these differences and establishes the general properties of the PNM.

Table J.1. Measuring tax competition: structural approach versus traditional approach.

	(1)	(2)	(3)
	Structural approach		Reduced-form approach
Tax response function	$\mathbf{t} = \mathbf{f}(\mathbf{t}, \mathbf{Z}, \boldsymbol{\varepsilon})$ $t_i = f_i(t_1, \dots, t_J, Z_{1i}, \dots, Z_{Ki}, \varepsilon_i)$ nonlinear		$\mathbf{t} = \beta\mathbf{W}\mathbf{t} + \mathbf{Z}\boldsymbol{\theta} + \boldsymbol{\varepsilon}$ $t_i = \beta \sum_j \mathrm{w}_{ij} t_j + \sum_k Z_{ki}\theta + \varepsilon_i$ nonlinear
Marginal tax response function	$\mathbf{dt} = \boldsymbol{\Omega}\mathbf{dt}$ $\mathrm{d}t_i = \sum_j \omega_{ij}\mathrm{d}t_j$ linear	$\mathbf{dt} = \boldsymbol{\beta} \circ \mathbf{W}\mathbf{dt}$ $\mathrm{d}t_i = \beta_i \sum_j \mathrm{w}_{ij}\mathrm{d}t_j$ linear	$\mathbf{dt} = \beta\mathbf{W}\mathbf{dt}$ $\mathrm{d}t_i = \beta \sum_j \mathrm{w}_{ij}\mathrm{d}t_j$ linear
Policy Network Matrix (PNM)	$\boldsymbol{\Omega}$ endogenous	$\boldsymbol{\beta} \circ \mathbf{W}$ endogenous	$\beta\,\mathbf{W}$ exogenous
Policy responsiveness (PR)		$\boldsymbol{\beta} \in \mathbb{R}^I$ endogenous	$\beta \in \mathbb{R}$ exogenous
Weight matrix		$\mathbf{W}$ endogenous	$\mathbf{W}$ exogenous

Note: Columns (1) and (2) are equivalent, only the notation differ, they represent the approach described in Subsection 5.1. Column (3) represent the traditional reduced-form approach (Brueckner and Saavedra, 2001). $f_i(\cdot)$ is a nonlinear function implicitly defined by the local government's first-order condition. Z_{ki} [ε_i] are control variables [residuals] which are parts of weights ω_{ij}.

The immediate implication of Observation 2 is that the overall weight matrix, $\mathbf{W}$, and Policy Responsiveness measure, $\boldsymbol{\beta}$, are not accurate instruments to measure tax competition. Better description of tax competition can be obtained by decomposing the weight matrix and policy responsiveness into positive and negative tax reactions, such as:

$$\mathbf{dt} = \boldsymbol{\beta}^{+} \circ \mathbf{W}^{+}\mathbf{dt} + \boldsymbol{\beta}^{-} \circ \mathbf{W}^{-}\mathbf{dt} \tag{J.2}$$

where $\mathbf{W}^{+}$ is a $J \times J$ row-standardized matrix that includes the non-negative terms of $\mathbf{W}$ (and has zero in places of negative elements of $\mathbf{W}$) and is associated with the positive $\boldsymbol{\beta}^{+}$. Similarly, the row-standardized matrix $\mathbf{W}^{-}$ includes the absolute value of the non-positive terms of $\mathbf{W}$ and is associated with the negative $\boldsymbol{\beta}^{-}$. In words, this representation decomposes of the tax reactions depending on whether a complement strategy or a substitute strategy is adopted, as summarized in Observation 6.

Observation 6. *The weight matrix can be meaningfully decomposed into two row-standardized weight matrices: one including the non-negative elements of the overall weight matrix, and the other including the non-positive elements of the overall weight matrix. Likewise, the Policy Responsiveness can be decomposed into two vectors associated with these two matrices, respectively.*

Like nonlinearity, heterogeneity in itself does not disqualify the traditional linear reduced-form approach to estimating tax reactions. Non-modeled heterogeneity would be simply captured by the residuals of the linear regression. However, the residuals of a linear regression are endogenous variables of the economic model correlated with the weight matrix and the tax rates, leading to the classical endogeneity or reflection problem famously explained by Manski (1993), as stated in Observation 3

J.2. PNM and Counterfactual Evaluation

This appendix proves Observation 4 which states that the elements of the PNM and the price response matrix are sufficient to recover the effects of such a reform on all the economic variables including the policy variables.

First, one needs to decompose the overall differential tax vector $\mathbf{dt}$ into a first part including the non-treated taxing counties, $\mathbf{dt}_1$ and a second part including the treated counties and those which are not free to choose their tax rates, $\mathbf{dt}_2 = \mathbf{dt}_2^c$. The superscript "$c$" indicates the counterfactual level of a variable. We also decompose the PNM accordingly, so that:

$$\boldsymbol{\Omega} \equiv \begin{pmatrix} \boldsymbol{\Omega}_{11} & \boldsymbol{\Omega}_{12} \\ \boldsymbol{\Omega}_{21} & \boldsymbol{\Omega}_{22} \end{pmatrix}, \qquad \mathbf{dt} \equiv \begin{pmatrix} \mathbf{dt}_1 \\ \mathbf{dt}_2 \end{pmatrix},$$

so that, assuming that the non-treated jurisdictions do not further change their tax rates, the tax competition condition (27) implies that:[32]

$$\mathbf{dt}_1^c = (\mathbf{I} - \boldsymbol{\Omega}_{11})^{-1}\boldsymbol{\Omega}_{12}\mathbf{dt}_2^c, \tag{J.3}$$

which defines the endogenous general equilibrium policy responses of the non-treated jurisdictions, $\mathbf{dt}_1^c$, as a function of the exogenous policy change of the treated jurisdictions $\mathbf{dt}_2^c$. Notice that these general equilibrium policy responses capture the feedback effects of the change in the policy of a non-treated county on the others non-treated counties.

Thus, we can define the equilibrium vector of counterfactual policies as $\mathbf{dt}^{\mathbf{c}\prime} \equiv (\mathbf{dt}_1^{c\prime} \quad \mathbf{dt}_2^{c\prime})$. Then, from (25), we can compute the effect of the reform on the equilibrium prices:

$$\mathbf{dZ}^c = \boldsymbol{\Pi}\,\mathbf{dt}^c, \tag{J.4}$$

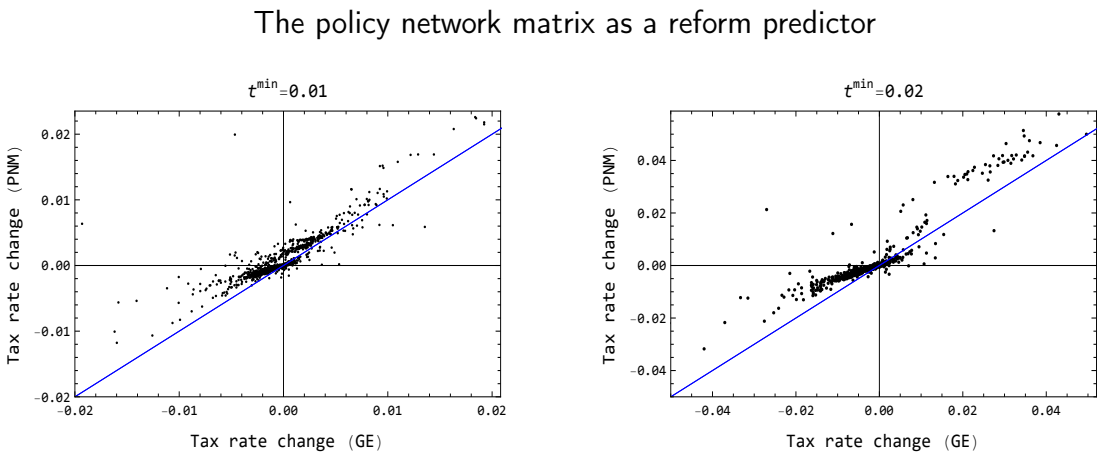
where $\mathbf{dZ}^{c\prime} = (\mathbf{dZ}_1^{c\prime} \dots \mathbf{dZ}_J^{c\prime})$ in which $\mathbf{dZ}_i^{c\prime} \equiv (\mathrm{d}p_i^c \quad \mathrm{d}P_i^c \quad \mathrm{d}G_i^c)$ is the vector of price changes. In sum, condition (J.3) and (J.4) prove that for any reform vector, $\mathbf{dt}_2^c$, the PNM, $\boldsymbol{\Omega}$, and the price response matrix, $\boldsymbol{\Pi}$, are sufficient to compute the effect of the reform on all economic variables.

In sum, evaluation of counterfactual policy senarios accounting for strategic responses of governments can be assessed using the PNM and the general equilibrium response price response matrix. Formally, for an exogenous policy change, $\mathrm{d}t_2$, the impacts on local governments policy can be measured using condition (J.3), the impacts on equilibrium prices can be measured using condition (J.4), the impacts on economic variables can then be measured by trivial differentiation of conditions (11)–(14).

J.3. Accuracy of the PNM for Counterfactual Evaluation

As the PNM is a local approximation of the tax responses near the observed equilibrium, it is important to get a sense of the accuracy of this approximation.

[32] In this approximation, the tax responses of the non-treated jurisdictions, $\mathbf{dt}_2$, are treated as exogenous. The extent to which this assumption is valid as all jurisdiction can respond endogenously to the initial policy choc will be assessed in Section 6.



(a) Simulation of a minimum tax of 1%.

(b) Simulation of a minimum tax of 2%.

Figure J.1. Prediction of effects of the reform on tax responses of non-treated counties, using the PNM versus solving for the full general equilibrium. The blue line represents the 45 degree line. The tax rate changes have been multiplied by 100, so they need to be interpreted as percentage points.

Figure J.1 represents the tax change predicted by the PNM for a minimum tax rate of one percent (Panel a) and a minimum tax rate of two percent (Panel b) along with the tax change obtained by solving for the general equilibrium. It indicates that both are strongly positively correlated, and that and that most points are close to the 45 degree line. As expected, the approximation becomes weaker the larger the policy change is. These results suggest that the PNM can be a good instrument for counterfactual evaluation of marginal tax reforms.

J.4. Policy Responsiveness and Policy Impact in Two States

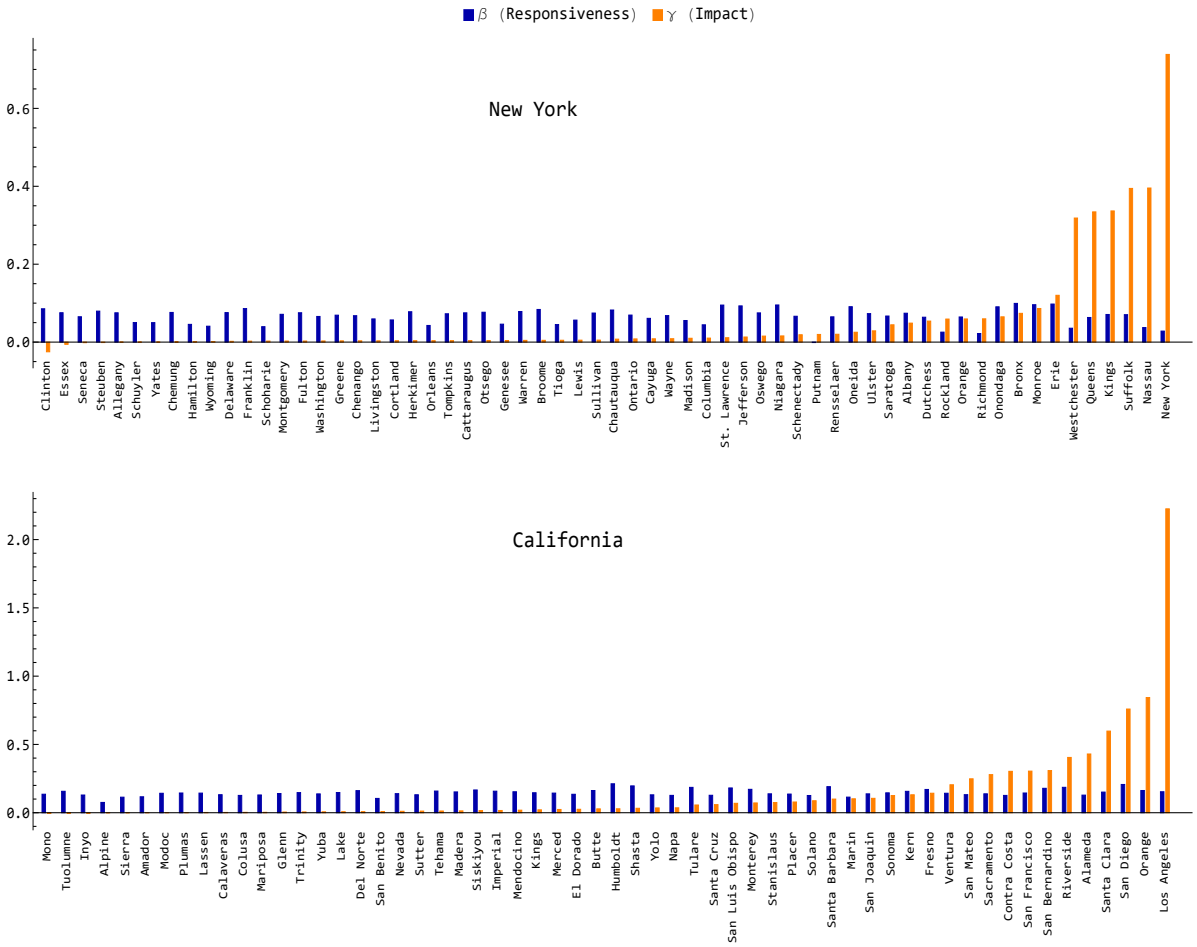


Figure J.2. Policy responsiveness and policy impact in New York State and in California.

J.5. Policy Impact and Welfare

This appendix supplements the results on policy impact and welfare effects in Subsection 6.3.

J.5.1. Descriptive Statistics

Table J.2. Descriptive statistics for the treated groups in the policy experiments.

	Top 20% PI			Bottom 20% PI		
	Mean	SD	Obs	Mean	SD	Obs
Policy impact (γ)	0.349	0.534	524	−0.002	0.021	525
Tax rate (t)	0.014	0.013	524	0.028	0.013	525
Number of households (n)	129,527	233,948	524	6,149	13,818	525
Household income (y)	68,846	16,131	524	52,752	10,108	525

NOTE— The left panel reports results for the top 20% counties with highest policy impact. The right panel reports results for the bottom 20% counties with lowest policy impact.

J.5.2. Additional Results

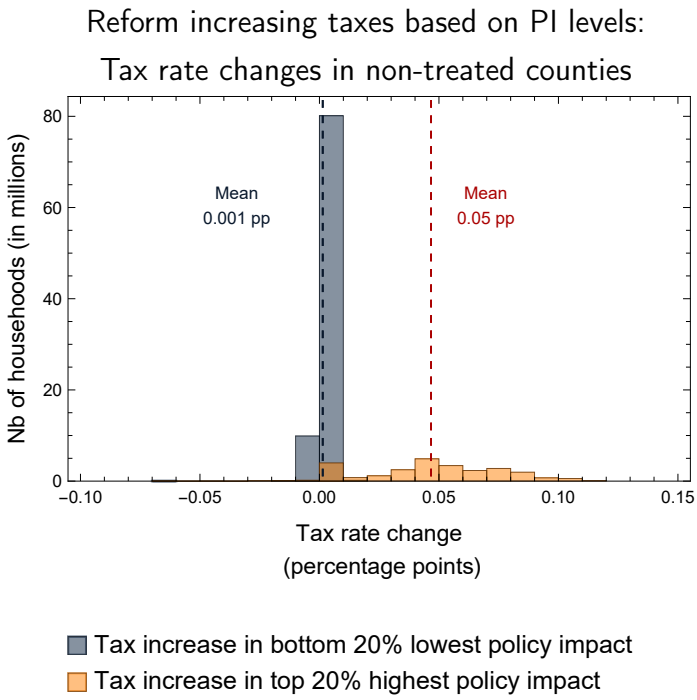


Figure J.3. Tax rate change following a targeted 1 percentage point minimum tax increase. The reported effects are those on the 80% counties that are not treated. Tax rates are chosen freely by all counties in equilibrium. The sample includes counties in states allowing for county-level taxation.

Figure J.3 represents the tax responses of the 60% counties that are never treated. As expected, a tax increase at the top of the distribution of the policy impact induces significantly larger tax responses than a tax increase at the bottom of the distribution does. The policy network matrix is thus informative of the expected tax responses from policy reforms. The tax responses in Figure J.3 are indeed of the same magnitude as the policy impact measures. The treated group of counties with low impacts has slighlty negative policy impacts close to zero.

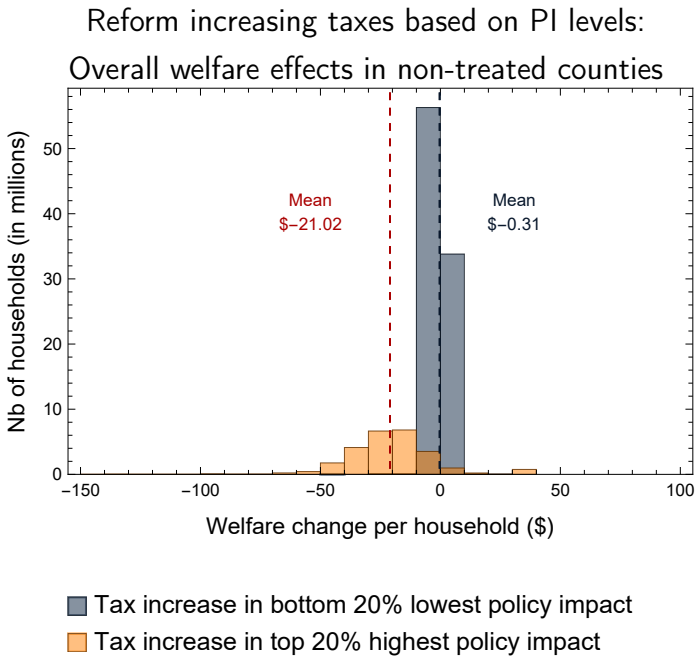


Figure J.4. Total welfare effects of a targeted 1 percentage point increase in tax rates. The reported effects are those on the 80% counties that are not treated. Tax rates are chosen freely by all counties in equilibrium. The sample includes counties in states allowing for county-level taxation.

Figure J.4 represents the welfare effects of our two experiments on the 60% counties that are never treated. These effects are statistically zero on average for the reform targeting the bottom of the distribution of the policy impacts. However, as the top of the distribution is imposed a tax increase, the welfare decreases significantly in the non-treated counties. This reflects the fact that the significant amount of cross-border shopping to the treated counties becomes more expensive.

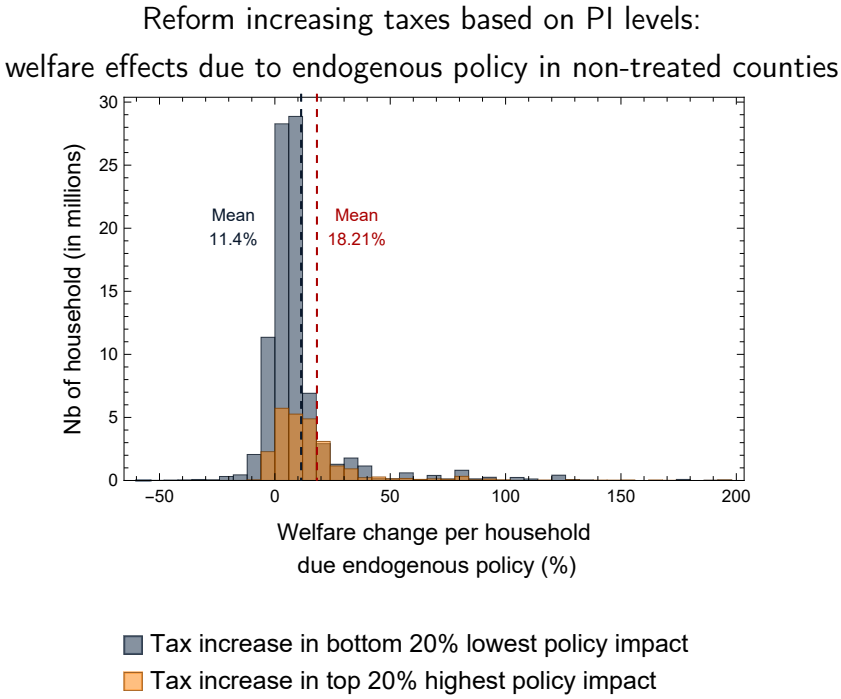


Figure J.5. This graph represents the percent change in equivalent variations of increasing taxes based on PI levels with strategic interactions relative to without strategic interactions. Percent change are expressed in absolute values as $100 \times |(EV^{endo} - EV^{exo})|/|EV^{endo}|$. The reported effects are those on the 80% counties that are not treated. The sample includes counties in states allowing for county-level taxation.

Figure J.5 represents the welfare effects due to tax competition. As expected, for the reform affecting the counties with larger policy impacts, tax competition entails significant welfare effects, while the reform on counties with small impact generates small tax competition effects. The signs of the welfare changes are opposite, in line with the signs of the policy impacts. The large-impact counties spur other counties to raise their tax rates and thus improve the welfare by providing more public services there, while the low-impact counties generate tax cuts and thus reduce the welfare elsewhere.