ELSEVIER

Journal of Public Economics 91 (2007) 451–479

JOURNAL OF PUBLIC ECONOMICS

www.elsevier.com/locate/econbase

Horizontal and vertical indirect tax competition: Theory and some evidence from the USA

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Received 20 April 2004; received in revised form 3 July 2006; accepted 5 July 2006
Available online 19 October 2006

Abstract

This paper provides a simple but general theoretical framework for analyzing simultaneous vertical and horizontal competition in excise taxes, which includes several previous contributions as special cases. It allows for both elastic individual demand for the taxed good, and cross-border shopping (and smuggling). It then estimates equations informed by the theory on a panel of US state and federal excise taxes on cigarettes and gasoline. The results are generally consistent with the theory, when the characteristics of the markets for the goods are taken into account. Taxes in neighboring states have a significant and large effect in the case of cigarettes. The possibility of smuggling cigarettes from low tax states also plays a role. In the case of gasoline, taxes in neighboring states do not play a significant role; however, there is evidence in this case of vertical competition.

JEL classification: H70; H71; H77
Keywords: Tax competition; Excise taxes; Cross-border shopping; Smuggling

1. Introduction

This paper provides a simple theoretical framework for analyzing simultaneous vertical and horizontal competition in excise taxes, and estimates equations informed by the theory on a panel of US state and federal excise taxes on cigarettes and gasoline. The theory integrates existing models of vertical competition in indirect taxes (particularly Keen, 1998) with existing models of horizontal competition in indirect taxes generated by cross-border shopping (Kanbur and Keen,

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0047-2727/$ - see front matter
doi:10.1016/j.jpubeco.2006.07.005

1993; Nielsen, 2001). The results are generally consistent with the theory, when the different characteristics of the markets for the goods are taken into account.

Our theoretical framework extends Kanbur and Keen (1993), Nielsen (2001) by allowing individual demand for the taxed good to be price-elastic, and conversely, extends Keen (1998) by allowing households to be mobile between different tax jurisdictions (states in what follows). The model allows considerable asymmetry between states: they can differ in size, population density, and the cost of cross-border shopping for the residents. Within this framework, we provide a comprehensive analysis of the signs and relative magnitudes of horizontal and vertical tax responses. The horizontal (vertical) tax response measures how a given state's optimal tax responds to a change in other states' taxes (the federal tax).

Our results are the following. First, under very weak conditions, the horizontal response is positive. This considerably generalizes the results of Kanbur and Keen (1993) and Nielsen (2001). On the other hand, as is already known from Keen (1998), the vertical response can be of either sign. But, there is interaction between vertical and horizontal tax competition: an increase in horizontal competition (lower mobility costs) makes it more likely that the vertical response is positive.

Moreover, we can say something about the relative magnitude of vertical and horizontal responses. When individual demand for the good is relatively price-inelastic, and incentives for inter-state arbitrage (cross-border shopping or smuggling) are strong, the tax set in any state is likely to be strongly positively responsive to taxes set in neighboring states, but unresponsive to the federal tax. Conversely, when individual demand for the good is relatively price-elastic, and incentives for inter-state arbitrage are weak, the tax set in any state is likely to be unresponsive to taxes set in neighboring states, and responsive to the federal tax, although this response may be positive or negative. As argued below, the first case describes the market for cigarettes in the US well, and the second case the market for gasoline.

The overall implication is that the correct empirical specification should allow the tax in any state to depend on both the federal tax and the (weighted average of) other state's taxes, with the relative size of these effects depending on the characteristics of the commodity. Existing empirical studies of US state excise taxes allow for either vertical tax responses (Besley and Rosen, 1998), or horizontal ones (Nelson, 2002; Rork, 2003), but not both, and thus, in our view, estimate mis-specified regressions.

This is confirmed by our empirical results. First, for cigarettes, we find that when the federal excise tax and a weighted average of other state taxes are both included as separate regressors in a system of equations simultaneously determining state excise taxes on cigarettes, then only the coefficient on the weighted average of other state taxes is significant, and it is positive. A one percentage point increase in the average of neighboring states' tax rates induces, in the long run, a 0.7 percentage point increase in state i's tax rate.

The case of gasoline is best characterized as one where demand for the good is somewhat price-inelastic, and incentives for inter-state arbitrage are weak. In this case, the theory predicts that the response of a state tax to taxes in other states and the federal tax is likely to be weak, and this is broadly what we find. The coefficient on the weighted average of other state taxes is generally insignificant, but there is some evidence that the vertical response is positive.

Finally, we extend our empirical analysis by modelling the occurrence of tax changes, rather than their magnitude. The nominal[1] rates of tax, both state and federal, are changed rather infrequently, and it is of interest to explain when a change occurs. We model this using a probit specification, where the probability of a change in the state tax can depend both on the federal tax and the weighted average of other state taxes. We find that the latter has a positive effect on the

[1] In the main part of the empirical work, we use the real i.e. inflation-adjusted taxes.

probability of a change in the cigarette tax, but not in the case of gas taxes. The federal tax may now possibly have a negative effect on the probability of a change in the state gas tax, but this is quite consistent with the theory.

Our empirical results refine the findings of the well-known paper[2] by Besley and Rosen (1998), who find that changes in US federal excise taxes on cigarettes and gasoline have significantly positive impacts on the corresponding state taxes, conditioning on a number of economic and demographic controls. However, as just remarked, their approach did not allow for "horizontal" strategic interaction: taxes in other US states were not included as regressors[3]. So, our empirical work can be regarded as testing the robustness of their empirical results by allowing for horizontal interaction. We find that in the case of both cigarette and gasoline taxes, their findings are not robust to the introduction of horizontal interactions, and moreover, we have a theoretical explanation for this. It is also worth noting that their specification also did not include a lagged dependent variable (LDV). Our results indicate an LDV is appropriate, given the very strong serial correlation in state taxes. But, inclusion of an LDV itself reduces the significance of federal taxes.

This paper is organized as follows. First, we discuss some salient features of the markets for cigarettes and gasoline in the US. Then in the subsequent sections, we present our theoretical framework, our empirical specification, our data, and our econometric results. Related literature, other than that discussed here, is covered in the last section, along with our conclusions.

2. The US cigarette and gasoline markets

In any US state, the base of an unit excise tax is the volume of legal sales of that good. This can vary with the excise taxes in three ways. First, if demand by residents in that state is elastic, an increase in the tax may induce them to buy less of that good. Second, consumers may decide to buy that good (legally) in another state where the retail price is lower (cross-border shopping). Third, an increase in the tax will increase the incentives for illegal smuggling of the good into the state[4].

There is now considerable econometric evidence on the price elasticity of demand for both cigarettes and gasoline in the US. First, the personal elasticity of demand for cigarettes differs by both age and gender in the US, with the elasticity being lower for older consumers (Harris and Chan, 1999) and for women (Chaloupka, 1991), but consensus figure for the long-run price elasticity of demand is in the region of −0.5. For gasoline, a recent survey of a number of studies gives a consensus value of the long-run elasticity in the region from −0.8 to −1.0. (Dahl and Sterner, 1991). So, the demand for gasoline is somewhat more elastic than that for cigarettes.

How much cross-border shopping and smuggling[5] is there in the cigarette and gasoline markets? Neither of these activities are formally measured. In the case of cigarettes, anecdotal and indirect survey evidence suggests that both activities are widespread (Fleenor, 1998). And some

[2] It is also worth noting Benjamin and Dougan (1997), but this is less closely related to the tax competition literature.

[3] Their specification also did not include a lagged dependent variable (LDV). Our results indicate an LDV is appropriate, given the very strong serial correlation in taxes. But, inclusion of an LDV itself reduces the significance of federal taxes.

[4] The distinction between the two is that cross-border shopping is for personal consumption and is small-scale. The borderline of legality in the case of cigarettes is provided by the Contraband Cigarette Act of 1978, which prohibits single shipments, sale or purchase of more than 60,000 cigarettes not bearing the tax stamp of the state in which they are found.

[5] Large-scale commercial smuggling is done in two ways. First, cigarettes are purchased from distributors in low-tax states who are paid not to attach a tax stamp. The cigarettes are then transported to a high-tax state where counterfeit stamps are used to allow their sale alongside legal cigarettes. Second, via diversion, where smugglers purchase from manufacturers (tax-free) who do not declare these sales. These cigarettes are then counterfeit stamped and sold in high-tax states alongside legal cigarettes.

papers have developed methodologies to measure indirectly the amount of cross-border shopping and smuggling (Fleenor, 1998; Saba et al., 1995; Thursby and Thursby, 2000). These papers share the common feature that they develop a structural two-equation (or multi-equation) model. One equation explains observed legal sales per capita in terms of price, income, demographic characteristics and the extent of inward or outward cross-border shopping and/or smuggling. The other relates the extent of unobservable cross-border shopping or smuggling to observable economic determinants, such as the tax differential. Assuming that this second structural equation can be identified, a state-by-state forecast of the level of cross-border shopping or smuggling can then be made.

The most comprehensive study is by Fleenor (1998), who models separately cross-border shopping, commercial smuggling, and non-taxable within state purchases (from military bases and Native American reservations). He finds that smuggling and cross-border sales account for 7.8% and 3.6% of final sales in the US as a whole, and these figures are much higher for some states e.g. 15.7% and 18.4% respectively for New York state.

For gasoline, by contrast, there seems to be no evidence that cross-border shopping or smuggling is an issue. This is probably because the generally low taxes on gasoline in the US, combined with the long distances to state borders, make cross-border shopping uneconomic. However, it is possible that if consumers are cross-border shopping for other items, they also will buy gasoline, especially if retailers accommodate them, and there is some evidence that this occurs on the US side of the US–Canadian border[6] where the price differential for gasoline is much greater (De Franco et al., 1998).

3. A theoretical framework

3.1. The model

We construct a simple but quite general theoretical framework to inform our estimation of tax reaction functions. This framework can be thought of an extension of Keen (1998) to allow for horizontal tax externalities, or conversely an extension of Kanbur and Keen (1993) to allow for elastic individual demand for the taxed good.

There are two states, $i=1, 2$ in a federation. Each state sets a specific origin-based excise tax t_i on a commodity e.g. cigarettes. The federal government also sets a specific tax T on the same commodity, so there is sharing of the tax base. We assume that the producer price of the commodity is fixed in both states, being p_i in state i, so the consumer price in state i is $q_i=p_i+t_i+T$. Without much loss of generality, assume $p_1=p_2=0$. In state i, every consumer values x units of the commodity at $u(x)$, where $u(.)$ is a strictly increasing and concave utility function: utility is linear in the other untaxed (numeraire) good used as payment.

States may differ in size, with n_i being the total number of residents in state $i=1$, 2. As in Kanbur and Keen (1993) and Nielsen (2001), the model has a spatial structure: the residents of state i are uniformly distributed along a line of length l_i. The two lines meet at a common border.

[6] *"Market places are created along the northern tier because customers who travel to these areas to buy one product will also buy other products from other stores. A Canadian shopper may come down to purchase a carton of cigarettes, but while he is in town, he often picks up other excise-tax-sensitive goods such as beer or liquor. And he will probably fill up his car with gas too. Gasoline is an especially interesting case because you have to consume the product to purchase it. Would someone drive up to 100 miles round-trip only to fill up his tank with cheaper gasoline? Probably not. But would they purchase the cheaper gas if the gas station is adjacent to the grocery store selling the beer and cigarettes they are buying anyway?"* De Franco et al. (1998).

We denote the proportion of the population of state of i who reside at distance $d \le l_i$ or less from the border by $\phi_i d$, so ϕ_i is the uniform population density. Obviously, $n_i = \phi_i l_i$.

Each consumer in state i at distance d from the border can either purchase[7] the good in state i, paying q_i, or can travel to the border and pay q_j, plus any associated travel costs. We assume that the activity of transporting x units from the border to a location d units from the border requires $c_i(x, d)$ units of the numeraire good for a resident of country i.

The usual way in which cross-border shopping takes place in the US is that the consumer drives to the border, purchases the good, and returns home. For high-value commodities such as cigarettes, where the weight and volume are both small, it is clear that the cost of this activity does not vary much with the quantity purchased, holding distance to the border fixed.[8] On the other hand, the time and fuel costs of travel to the border can reasonably be taken as linear in the distance to the border, d. So, this suggests a specification[9] of the transport cost function $c_i(x, d) = c_i d$, where is the cost per unit distance travelled i.e. the costs of transport are fixed or independent of x.

So, the cross-border shopping decision can be characterized as follows. Let

$$v(q) = \max_x \{u(x) - qx\}, \quad x(q) = \operatorname{argmax}\{u(x) - qx\}$$

be the indirect utility and individual demand for the taxed good by a resident of i when the price is q. Note that transport costs do not affect individual demand because (i) there are no price effects, as transport costs are independent of the quantity purchased; (ii) there are no income effects on demand, as they are paid in the numeraire good, and utility is linear in that good. Moreover due to (i), a consumer will never shop in both jurisdictions. So, consumer in i will cross-shop in j if and only if $q_i > q_j$ and she lives at distance

$$\frac{1}{c_i}(v(q_j) - v(q_i)) = d_i \tag{3.1}$$

or less from the border.

We can now see that this model encompasses several existing models in the literature as special cases.

1. If cross-border shopping is prohibitively costly, ($c_i = \infty$, $i = 1, 2$), then there are no horizontal tax externalities and the model is exactly that considered by Keen (1998).
2. Assume that demand is inelastic i.e. $x_i' = 0$ or $x_i(q) = \bar{x}_i$ and that there is no federal government i.e. $T = 0$. In this case, if the states are the same length ($l_1 = l_2$), the model reduces to the Kanbur and Keen (1993) model. If the states have the same population density ($\phi_1 = \phi_2$), we obtain the Nielsen (2001) model.
3. If countries are symmetric in every respect (country size, population density, shopping costs), then the model is a special case of Hoyt (2001) and Lucas (2004) where governments maximise revenue, rather than supply public goods.

[7] One interpretation of this assumption is that there are retail outlets densely scattered across every state, so the distance to the nearest retail outlet is minimal.

[8] In the case of gasoline, the same is true with the obvious exception that the capacity of the vehicle (i.e. the gas tank) is more likely to be a constraint. We will ignore this complication in what follows.

[9] Our analysis would go through with minor modifications if the unit cost of transport $c(x, s)/x$ is a more general decreasing function of x. In this case, to economize on transport costs, the consumer will only shop in one jurisdiction, which is the key feature of the analysis.

Also, note while Keen (1998), Kanbur and Keen (1993) and Nielsen (2001) studied the slopes of reaction functions, the papers by Hoyt (2001) and Lucas (2004) do not: they are concerned with the issue of the design of intergovernmental grants. So, our paper is the first, we believe, to analyze commodity tax reaction functions in a federal setting with cross-border shopping, and where the assumption of inelastic demand made by Kanbur and Keen (1993) and Nielsen (2001) is relaxed.

3.2. The tax base

Because all households have the same demand function $x(q)$, the tax base in i is $X_i=x(q_i)s_i(q_i, q_j)$ where $s_i(q_i, q_j)$ is the number of shoppers in state i, and

$$s_i(q_i, q_j) = \begin{cases} n_i - \rho_i(v(q_j) - v(q_i)) & \text{if} \quad q_i \geq q_j \\ n_i + \rho_j(v(q_i) - v(q_j)) & \text{if} \quad q_j \geq q_i \end{cases} \tag{3.2}$$

where $\rho_i = \frac{\phi_i}{c_i}$ measures the responsiveness of cross-border shoppers in region i to tax differentials. To understand Eq. (3.2), note first that if $q_i=q_j$, there is no cross-border shopping, and the tax base is comprised of the demand of all domestic residents, $n_i x_i(q_i)$. Next, if $q_i>q_j$, there is *outward* cross-border shopping from i: from Eq. (3.1), all residents of i at distance $\frac{1}{c_i}(v(q_j)-v(q_i)) = d_i$ or less from the border will buy in state j, leading to a reduction in the number of shoppers of $\phi_i d_i=\rho_i(v(q_j)-v(q_i))$. If on the other hand, $q_i<q_j$, there is *inward* cross-border shopping from j: from Eq. (3.1), all residents of j at distance $\frac{1}{c_j}(v(q_i)-v(q_j)) = d_j$ or less from the border will buy in state i, leading to an increase in the number of shoppers of $\phi_j d_j=\rho_j(v(q_i)-v(q_j))$.

3.3. Nash tax equilibrium and tax reaction functions

Now consider the choice of tax in state i. For simplicity (and following Kanbur and Keen, 1993; Keen, 1998) we assume that state governments are revenue-maximisers. The revenue in state i is $R_i(t_1, t_2)=t_i X_i(t_i+T, t_j+T)$, recalling that $q_i=t_i+T$. So, the optimal t_i maximises R_i, given t_j, T fixed, giving rise to a reaction function $t_i=r_i(t_j,T)$. We are interested in the properties of these reaction functions. Because of the fact that individual demand is allowed to be elastic, we cannot solve explicitly for these reaction functions (unlike Kanbur and Keen, 1993; Nielsen, 2001). Moreover, if the countries are not symmetric (in the sense that $\rho_i \neq \rho_j$) these reaction functions may be discontinuous when $t_1=t_2$. This is because when $\rho_i \neq \rho_j$, it is clear from Eq. (3.2) that s_i — and therefore R_i — is not differentiable at $t_1=t_2$. Therefore, a Nash equilibrium in taxes may not exist[10].

However, if a Nash equilibrium does exist, it will be at a point in (t_1, t_2) — space away from $t_1=t_2$, and so reaction functions will be continuous — and indeed, differentiable— in the neighborhood of the Nash equilibrium (for an illustration of this point, see e.g. Fig. 3 in Kanbur and Keen, 1993). Establishing conditions sufficient for existence is beyond the scope of this paper. In what follows, we simply assume that a Nash equilibrium always exists and therefore that slopes of the reaction functions are well-defined in the neighborhood of Nash equilibrium.

3.4. Nash equilibrium taxes

Before moving to analyze the slopes of reaction functions, it is convenient to obtain a characterization of Nash equilibrium taxes. Given that a Nash equilibrium exists, equilibrium

[10] Kanbur and Keen make two assumptions on reservation prices (A1 and A2 in their paper) sufficient to ensure that equilibrium exists.

taxes are implicitly defined by the first-order conditions for the optimal choice of t_1, t_2. The first-order condition for t_i is

$$\frac{\partial R_i}{\partial t_i} = X_i + t_i \frac{\partial X_i}{\partial q_i} = 0 \tag{3.3}$$

Without loss of generality, we focus on the situation where at equilibrium, $q_1 \geq q_2$ i.e. state 1 is the high-tax state. This will cover two cases. First, $q_1 = q_2$ in the symmetric version of the model, and second, $q_1 > q_2$ in the asymmetric version.

Simple rearrangement of Eq. (3.3) gives the usual formula that the tax (in ad valorem form) is inversely proportional to the elasticity of the tax base i.e.

$$\frac{t_i}{q_i} = \frac{1}{-\frac{q_i}{X_i}\frac{\partial X_i}{\partial q_i}} \tag{3.4}$$

where from Eq. (3.2), the elasticity of aggregate demand can be written as the sum of two elasticities:

$$-\frac{q_i}{X_i}\frac{\partial X_i}{\partial q_i} = \varepsilon_i + \sigma_i.$$

Here, $\varepsilon_i = -\frac{q_i x'(q_i)}{x(q_i)}$ is simply the elasticity of the individual demand for the good sold in state i. Moreover, σ_i is the elasticity of the number of shoppers in i with respect to q_i. First, in the symmetric version of the model, $q_1 = q_2$ and so from Eq. (3.2), $\sigma = \frac{q\rho x(q)}{n}$. Second, by assumption, $q_1 > q_2$ in the asymmetric version, so again[11] from Eq. (3.2),

$$\sigma_1 = \frac{q_1 \rho_1 x(q_1)}{s_1}, \sigma_2 = \frac{q_2 \rho_1 x(q_2)}{s_2}$$

So, when the model is symmetric, the common Nash tax is $\hat{t} = \hat{q}/(\varepsilon + \sigma)$, where ε is the elasticity of demand of any consumer evaluated at the price $\hat{q} = T + \hat{t}$, and $\sigma = \rho q \hat{x}(\hat{q})/n$. So, as the size of the country becomes large (n large) given a fixed population density at the border, cross-border shopping becomes relatively unimportant in determining the Nash tax. Conversely, as ρ becomes large for fixed n (either because population density at the border becomes high, or the costs of cross-border shopping per unit of distance become small), tax competition becomes more intense and $\hat{t}$ falls, eventually to zero.

3.5. The slopes of the tax reaction functions

Eq. (3.3) implicitly determines t_i as a function of t_j and T. Our interest is now in how t_i responds to t_j and T i.e. the "slopes" of the reaction function. Totally differentiating Eq. (3.3) implies:

$$\frac{\partial t_i}{\partial t_j} = \frac{1}{D_i}\left[\frac{\partial X_i}{\partial q_j} + t_i \frac{\partial^2 X_i}{\partial q_i \partial q_j}\right], \frac{\partial t_i}{\partial T} = \frac{1}{D_i}\left[\frac{\partial X_i}{\partial q_i} + \frac{\partial X_i}{\partial q_j} + t_i\left(\frac{\partial^2 X_i}{\partial q_i^2} + \frac{\partial^2 X_i}{\partial q_i \partial q_j}\right)\right] \tag{3.5}$$

where

$$D_i = -\left[2\frac{\partial X_i}{\partial q_i} + t_i \frac{\partial^2 X_i}{\partial q_i^2}\right] > 0 \tag{3.6}$$

[11] Note that ρ_1 appears in σ_2, as there is inward cross-border shopping into state 2 in equilibrium.

as the stationary point of R_i is a maximum. The presence of second derivatives of X_i make these generally difficult to evaluate, but we begin with two special cases where it is easy to sign them.

Proposition 1. *(i) If $c_i=\infty$, so that there is no cross-border shopping, then in the neighborhood of Nash equilibrium:*

$$\frac{\partial t_i}{\partial t_j}=0,\frac{\partial t_i}{\partial T}=\frac{n_i(x_i{'}+tx_i{''})}{D_i} \tag{3.7}$$

(ii) If $x_i(q)=\overline{x}_i$, so that individual demand is inelastic, then in the neighborhood of Nash equilibrium:

$$\frac{\partial t_i}{\partial t_j}=\frac{\rho_i(\overline{\mathrm{x}}_i)^2}{D_i}=\frac{1}{2}>0,\frac{\partial t_i}{\partial T}=0 \tag{3.8}$$

Proof. See Appendix. □

Some comments are in order at this point. First, in the case of inelastic demand we have the striking result that state taxes *do not react at all* to federal taxes. The intuition for this is clear. With inelastic demand, a shopper buys a fixed amount of the good in either state, so all he cares about is the difference in the consumer prices, which is of course equal to the difference in state taxes i.e. $q_j-q_i=t_j-t_i$. The federal tax does not affect his decision, and consequently, the tax base in state i, $X_i(q_i, q_j)$ is independent of T.

Second, it is also worth noting that in the case of inelastic demand, under otherwise quite general conditions (i.e. when countries may differ in size, population density, transport costs and tastes), the slope of the "horizontal" reaction function is 0.5! This is a strong empirical prediction of the inelastic demand model.

Third, in the case with no cross-border shopping, the argument of Keen (1998) applies to show that $\frac{\partial t_i}{\partial T}$ can be *positive* or *negative*, depending on the curvature of the demand function. For example, if demand is linear ($x''=0$), then it is immediate from Eq. (3.7) that $\frac{\partial t_i}{\partial T}<0$, but if demand is iso-elastic ($x=q^{-\varepsilon}$) it can be shown (see below) that $\frac{\partial t_i}{\partial T}>0$.

Turning to the general case where there is both cross-border shopping and elastic demand, how do the results of Proposition 1 generalize? First, even with no cross-border shopping, we cannot expect to sign the "vertical" slope $\frac{\partial t_i}{\partial T}$. So, we would not expect a definite sign in the general case. Rather, our main theoretical result is that even with elastic demand, the horizontal reaction function slopes are positive. This holds even with all the possible asymmetries allowed for in the model, plus the presence of a federal tax.

Proposition 2. *In the neighborhood of Nash equilibrium,* $\frac{\partial t_1}{\partial t_2}, \frac{\partial t_2}{\partial t_1}>0$.

Proof. See Appendix. □

This result is completely general, given our framework: it holds even if states differ in population size, population density, and cross-border shopping costs. The main restriction of our framework is that individual preferences are the same in both states i.e. $x_i(q)=x_j(q)$. If preferences are different, the following result can be established:[12] the slope of the reaction function in the high-tax state— say state 1— is always positive (i.e. $\frac{\partial t_1}{\partial t_2}>0$) and moreover, if (a) $\varepsilon_2(q)\geq\varepsilon_1(q)$,or

[12] The proof is available from the authors on request.

(b) $-\frac{x_1(q)}{x_1'(q)}$ is non-increasing in q, $\frac{\partial t_2}{\partial t_1}>0$ also. So even with preference heterogeneity, sufficient conditions for both reaction functions to have a positive slope are not too strong[13].

A special case is where the model is symmetric, in which case the slopes of tax reaction functions, evaluated at the symmetric equilibrium, reduce to simple formulae in terms of elasticities. This can also give us some insight into how the vertical tax response varies with the degree of horizontal tax competition.

Proposition 3. *In the symmetric case, at symmetric Nash equilibrium, the slopes of horizontal and vertical reaction functions can be written*

$$\frac{\partial t_i}{\partial t_j}=\frac{\sigma^2}{D},\frac{\partial t_i}{\partial T}=\frac{\varepsilon(\sigma-\varepsilon-\eta)}{D} \tag{3.9}$$

where $\eta=qx''/x'$, $D=2(\varepsilon+\sigma)^2+\varepsilon\eta-3\varepsilon\sigma>0$.

Proof. See Appendix. □

Note some special cases. First, if cross-border shopping is prohibitively costly ($\rho=\sigma=0$), Eq. (3.9) reduces to Keen's formula (3.7) in elasticity form; in particular, interesting special cases of Keens's formula are if demand is linear ($\eta=0$), in which case $\frac{\partial \mathrm{t_i}}{\partial \mathrm{T}}=-0.5<0$, and if demand is iso-elastic, in which case $\eta=-(\varepsilon+1)$, so $\frac{\partial t_i}{\partial T}=1/(\varepsilon-1)>0$.

Note also that there is an *interaction* between vertical and horizontal tax competition. Say that there is an increase in horizontal tax competition if σ increases (this can be caused by an increase in the density of the population at the border, ϕ, or a fall in the cost of cross-border shopping, c). Given that D is positive from the second-order conditions for optimal choice of t_i, we see from Eq. (3.9) that an increase in horizontal competition (a larger σ) makes it more likely that the vertical slope $\frac{\partial t_i}{\partial T}$ is positive. Moreover, given that $\frac{\partial t_i}{\partial T}$ is positive and not too large — which is our empirical finding — it is easy to see[14] that $\frac{\partial t_i}{\partial T}$ is increasing in σ.

Finally, Proposition 3 also gives us a handle on the relative size of the slopes of the horizontal and vertical reaction functions as predicted by the model. From Proposition 3, the ratio of the two is clearly

$$\frac{\partial t_i/\partial t_j}{\partial t_i/\partial T}=\frac{\sigma^2}{\varepsilon(\sigma-\varepsilon-\eta)} \tag{3.10}$$

However, to interpret this, we need estimates of ε, σ and η, preferably at the level of US states. It is possible to such find estimates in the case of cigarettes Baltagi and Levin (1986, 1992) for ε and σ of 0.3 and 0.05 respectively[15]. However, as is clear from Eq. (3.10), the ratio also depends

[13] For example, condition (a) is likely to hold, as the tax in state i is inversely related to ε_i, as we have seen, and (b) holds, for example, if x_1 (q) is linear.

[14] From Eq. (3.9), $\frac{\partial(\partial t_i/\partial T)}{\partial\sigma}=\frac{1}{D}\left[\varepsilon-\frac{\partial t_i}{\partial T}(4\sigma+\varepsilon)\right]$. This is positive as long as $\frac{\partial t_i}{\partial T}<\frac{\varepsilon}{4\sigma+\varepsilon}$. Using the estimates $\sigma=0.05$ and $\varepsilon=0.3$ from Baltagi and Levin (1986, 1992), we see that this is just $\frac{\partial t_i}{\partial T}<0.6$.

[15] They estimate a dynamic demand equation using a panel of US states, over the period 1963–1988 in their most recent study. The dependent variable is per capita consumption of cigarettes (packs per capita) and explanatory variables include the retail price per pack in the state, and the minimum or maximum price in geographically neighboring states. From fixed-effects estimation of the model on the larger data-set the "in-state" price effect ($\varepsilon+\sigma$ in our notation) gives an estimated price elasticity of 0.35, and the "neighbor state" effect (just σ)gives a price elasticity with respect to the minimum price (or maximum price — it is little different) of neighboring states of about 0.05.

on the curvature of the demand function, η, for which we have no direct estimates. Our empirical results below suggest that the ratio (3.10) is positive and greater than unity, which implies that η is negative and close to $\sigma-\varepsilon=-0.25$. As $\eta=0$ with linear demand and $\eta=-(1+\varepsilon)=-1.3$ with iso-elastic demand, this implies a demand function somewhere in between these two cases is consistent with our empirical findings.

Generally, it is not possible for the theoretical model make a precise prediction about the relative slopes of the reaction functions, even given estimates of ε and σ. All we can say in general is that (i) except in the extreme cases identified in Proposition 1, both horizontal and vertical slopes are likely to be non-zero; (ii) from Proposition 2, quite robustly, horizontal slopes are positive.

3.6. Smuggling

Our basic model follows Kanbur and Keen (1993) and Nielsen (2001) in assuming that tax bases are mobile between states solely because of cross-border shopping. However, as emphasized in Section 2, in the case of cigarettes, the activities of cross-border shopping and commercial smuggling co-exist. As described by Fleenor (1998), there are two main forms of cigarette smuggling in the US. The first involves large purchases of tax-paid cigarettes in low-tax states which are then transported to high-tax states and sold there. The second involves the diversion of cigarettes which are destined for export and therefore bear no federal or state tax. We focus on the first case[16] as it seems that in the US, this is the main form of smuggling (Fleenor, 1998).

For convenience, assume a monopoly smuggler who faces a strictly increasing and strictly convex cost of smuggling z units of the good across the border of $C(z)$. Also, assume w.l.o.g. that $q_1>q_2$, and for convenience that states are symmetric. Assume that the smuggler is a price-taker in state 2 i.e. he buys from retail outlets there. The first question is what price the smuggler will set in state 1. He will never set a price above q_1 as any resident of state 1 can buy the good at price q_1 from a retail outlet without any transport cost. If he sets a price $q_1-\varepsilon$, he can undercut the retail outlets, and thus sell to all residents who do not cross-border shop. It is therefore convenient to assume[17] that parameters are such that this demand is at least as great as the amount he is willing to supply, for all feasible taxes. In this case, the amount smuggled, z, solves $C'(z)=q_1-q_2$ i.e. $z(q_1-q_2)$. Note that from the properties of C, $z'>0$, $z''<0$. Then, the tax base in state i becomes

$$X_i(q_i,q_j)=\begin{cases}(n+\rho(v(q_i)-v(q_j)))x(q_i)-z(q_i-q_j), & q_i\geq q_j\\ (n+\rho(v(q_i)-v(q_j)))x(q_i)+z(q_j-q_i) & q_i<q_j\end{cases} \tag{3.11}$$

Using Eq. (3.11), it is easily checked that at symmetric equilibrium, Propositions 1–3 are modified as follows. First, trivially, if there is no cross-border shopping or smuggling, part (i) of Proposition 1 still applies. Second, if individual demand is completely inelastic, then clearly $\frac{\partial t_i}{\partial T}=0$ even with smuggling, as smuggling from j to i, $z(q_i-q_j)=z(t_i-t_j)$ only depends on the *difference* between the state taxes and is thus independent of T. Moreover, if individual demand is completely inelastic, $\frac{\partial t_i}{\partial T}$ can be shown to have a positive slope between zero and one. So, Proposition 1 generalizes almost completely.

[16] The second case is extensively discussed by Rizzo (2003).

[17] Such conditions can easily be developed. The demand is $n-\rho(\upsilon(q_2)-\upsilon(q_1))$. Assume for convenience that $u(0)=0$, and that there is a choke price $\overline{q}=u'(0)<\infty$. Then, as no government will ever set a tax with $T+t>\overline{q}$, demand is bounded below by $n-\rho(\upsilon(\overline{q})-\upsilon(T))$ i.e. when the government of 1 sets the maximum [possible tax, and when $t_2=0$. So, then all we require is that $n-\rho(\upsilon(\overline{q})-\upsilon(T))>s(\overline{q}-T)$.

4. Empirical specification

Our theory suggests that t_i is a function of both t_j and T. In practice, we allow t_i to depend on a state fixed effect α_i, a vector of state-specific controls, $\mathbf{Y}_i$, and also (given that we have panel data) a vector of federal-level controls, $\mathbf{Z}$. This gives a specification in the most general form of

$$t_{is} = \alpha_i + \sum_{j \neq i} \beta_{ij} t_{js} + \gamma T_s + \delta' \mathbf{Y}_{is} + \phi' \mathbf{Z}_s + \varepsilon_{is}$$

where $i=1,..n$ denotes a state, and $s=1,...S$ a time-period. However, this cannot be estimated as it stands, as there are too many parameters β_{ij} to be estimated. The usual procedure in this case is to estimate

$$t_{is} = \alpha_i + \beta t_{-i,s} + \gamma T_s + \delta' \mathbf{Y}_{is} + \phi' \mathbf{Z}_s + \varepsilon_{is} \tag{4.1}$$

where $t_{-i,s}$ is the weighted average of other states' taxes i.e.

$$t_{-i,s} = \sum_{j \neq i} \omega_{ij} t_{js}, \tag{4.2}$$

and ω_{ij} are exogenously chosen weights, normalized so that $\Sigma_{j \neq i} \omega_{ij} = 1$. This is a widely used procedure and there is considerable discussion of the appropriate weights in the literature.[18]

We consider four possible weighting schemes for Eq. (4.2). The first is very simple; weights are assumed to be *uniform* i.e. $\omega_{ij} = \frac{1}{n-1}$, all i, j. While giving a useful benchmark, this is unlikely to work well, especially for commodities such as cigarettes where the tax base is mobile due to cross-border shopping and smuggling. New York state is likely to react to a cut in the excise tax in cigarettes in a neighboring state such as New Jersey in order to prevent outward cross-border shopping, but is unlikely to do so if California cuts its tax.

An alternative weighting scheme that allows from this argument are *neighbor weights*

$$\omega_{ij} = \begin{cases} \dfrac{1}{n_i} & \text{if} \quad j \in N_i \\ 0 & \text{if} \quad j \notin N_i \end{cases}$$

where N_i is the set of states that border state i, and $n_i = N_i$. A possible problem with these weights is that they treat neighboring states with short or lightly populated common borders in the same way as those with long or densely populated borders. But in the latter case, other things equal, the number of possible cross-border shoppers will be much greater, and thus the response of the home state's tax base to a cut in tax in the neighboring state will be larger.

We allow for this by specifying the following weights which we call *neighbor density weights*:

$$\omega_{ij} = \begin{cases} l_{ij}\delta_{ij} / \sum_{j \in N_i} l_{ij}\delta_{ij} & \text{if} \quad j \in N_i \\ 0 & \text{if} \quad j \notin N_i \end{cases}$$

where l_{ij} is the length (in miles) of the border between state i and j, and δ_{ij} is the population density in the border region. We calculate δ_{ij} as the total population of all counties in states i and j adjacent to the common border, divided by the total area of these counties[19].

A final weighting scheme is intended to capture the smuggling of cigarettes. Instead of focusing on neighboring states, we consider the three states with very low tax rates on cigarettes:

[18] See Brueckner (2003) for a survey of empirical techniques.

[19] The data are from the US Census Bureau, with population figures for 1986.

Kentucky, North Carolina and Virginia. In the case of the form of smuggling analysed above, we would expect the cigarettes to be purchased in one of these states and sold illegally in a high-tax state. We construct a uniform-weighted average of the tax rates of these three states, and assume that this average represents the tax rate at which smugglers can obtain cigarettes.

If states do react to each others' taxes, then $t_{-i,s}$ is, almost by definition, endogenous. We therefore use an IV approach. We use the weighted average of some of the neighbors' control variables as instruments:

$$\mathbf{Z}_{is} = \sum_{j \neq i} \omega_{ij} \mathbf{Y}_{js}.$$

The federal tax may also be endogenous. Following Besley and Rosen (1998), we instrument this with the federal deficit to GDP ratio and the federal unemployment rate. We test the validity of the instrument sets using a standard test of over-identifying restrictions. We treat the control variables, specified below, as exogenous. We have performed standard tests of exogeneity for the control variables; with occasional exceptions, there is no evidence of endogeneity.

We present standard errors that are robust to heteroskedasticity. In addition, we cluster errors by year in order to allow for spatial correlation. This is more likely to be a problem since we are not able to include time dummies because the federal level variables vary only over time. In fact, even in the absence of federal variables, we cannot use time dummies when $\omega_{ij} = \frac{1}{n}$, since in this case, the weighted average can be written as the average across all states — that varies only over time — less the dependent variable divided by the number of states. However, as a robustness check for the case of cigarette taxes, in Table 2, we investigate for the neighbor and neighbor-density weighting schemes, the effects of dropping the federal tax variables (which are not significant in these specifications in Table 1) and instead including time dummies.

To allow for possible serial correlation we include a lagged dependent variable. Of course, this introduces a correlation with the state fixed effect. To deal with this, we instrument the lagged dependent variable by including the second lag of the dependent variable in the instrument set. The final specification estimated is therefore:

$$t_{is} = \alpha_i + \theta t_{i,s-1} + \beta t_{-i,s} + \gamma T_s + \delta' \mathbf{Y}_{is} + \phi' \mathbf{Z}_s + \varepsilon_{is} \tag{4.3}$$

We can now turn to what signs and magnitudes we might expect for the main parameters of interest, β and γ, given the theoretical discussion in Section 3 and the stylized facts about cross-border shopping and elasticities of demand presented in Section 2. First, in the case of cigarettes, individual demand is highly inelastic, and because cigarettes are light and high-value, there is a considerable amount of smuggling and cross-border shopping in response to tax differentials. So, in the case of cigarettes, we might expect that β will be large and positive, but that γ will be close to zero. In the case of gasoline, there is very little direct evidence of cross-border shopping taking place, possibly because of higher transport costs. So we might expect β to be smaller, and possibly not significant. Given that the individual elasticity of demand is probably somewhat larger than for tobacco, the sign and magnitude of γ in the case of gasoline is harder to judge.

5. Data

We constructed a panel of data from 48 US states over 21 years, 1977–1997 inclusive. Data definitions, summary statistics, and sources are given in Table A1 in Appendix B. We do not use the two states which do not share borders with any other states, Alaska and Hawaii. For each

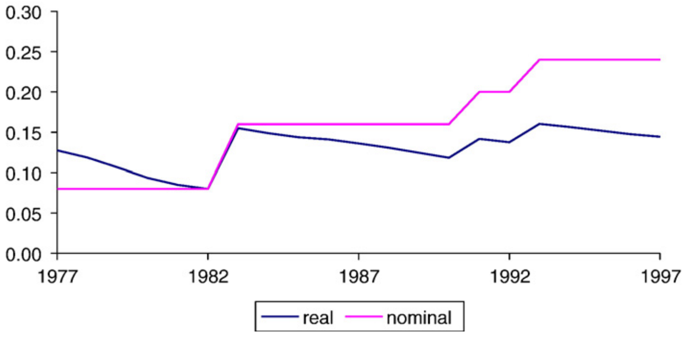

Fig. 1. Federal Cigarette Tax Rate, cents per pack: Real (1982 = 100) v Nominal.

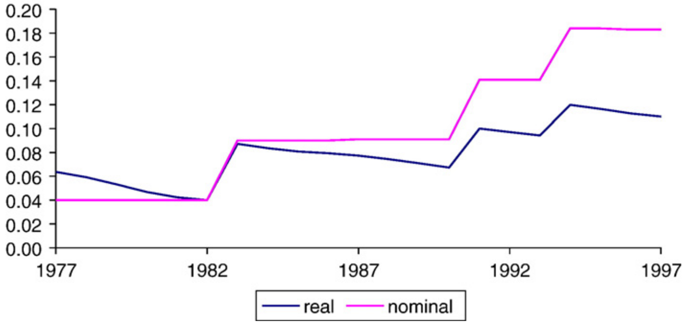

Fig. 2. Federal Gasoline Tax Rate, cents per Gallon: Real (1982 = 100) v Nominal.

observation, we collected data on state level and federal level unit taxes on cigarettes and gasoline from the World Tax Database maintained at the Office of Tax Policy Research at the University of Michigan.[20] (We do not allow for ad valorem taxes, since to incorporate them we would need to have reliable data on prices, which we do not). As shown above, these tax rates form the main focus of our analysis: we aim to investigate the extent to which the tax rate in any one state depends on the federal tax rate and the tax rate in other states.

The nominal state level unit taxes on cigarettes have ranged from 2 cents to 83 cents per pack of twenty, with an average of 20 cents. Perhaps not surprisingly three states stand out with low unit tax rates. These are all tobacco-producing states: Kentucky, South Carolina and Virginia. The nominal federal unit tax on cigarettes has increased in jumps over the period from 8 cents to 24 cents per pack. Nominal state unit gasoline taxes vary between 4 cents and 38 cents per gallon, with an average of around 14 cents. The nominal federal gasoline tax has increased in jumps from 4 cents to 18.3 cents per gallon, with an average of 10 cents. Initially, we use the inflation-adjusted (real) values of the state and federal taxes in our regression analysis: this is because it is plausible that governments target real values, rather than nominal ones.

The difference between real and nominal taxes is shown in Figs. 1 and 2 for federal cigarette and gasoline taxes; state taxes shown a similar pattern. It is clear from Figs. 1 and 2 that nominal rates tend to change infrequently. The real rates used in the regressions below therefore reflect the

[20] See www.OTPR.org.

existing nominal rate and the cumulative inflation since the previous change in the nominal rate. To at least partially control for this factor, we include the change in the consumer price index in each period as a control variable. An alternative approach, where the discrete decision to keep the excise constant or change it is modelled, is described in Section 7.

Finally, in estimating the determinants of state unit taxes, we need to control for other factors, at both state and federal level. Appendix B lists a number of control variables, and gives some basic descriptive statistics. These include: federal economic variables (GDP, unemployment and the consumer price index); the domestic production of the relevant commodity within each state; state economic variables (income per capita, unemployment, the federal grant to the state and the income tax rate); state demographic variables (population, and the proportion of young and old); and state political factors (the party of the governor, the proportion of democrats in the House and in the Senate, and a dummy variable indicating whether the current governor is term-limited).

6. Results

We begin, in Table 1, with a discussion of cigarette taxes. Note that in all specifications we include state-specific fixed effects. Column 1 presents a specification very similar to Besley and Rosen (1998), which includes the federal tax, but excludes the average of other states' tax rates, and instruments the federal tax by the federal deficit/GDP ratio and unemployment. This is because, although we have modelled the federal tax as exogenous in our theoretical work, ultimately, it is determined endogenously, because it is a choice variable of central government.

Consistently with Besley and Rosen, we find that the federal tax has a significantly positive effect on the state tax, raising state excise duties on cigarettes on average by around 0.28 cents for a 1 cent increase in the real federal tax. Several controls are significant, generally having plausible signs. However, there are both theoretical and empirical reasons to suppose that this is a mis-specification. First, our theoretical model suggests that other states' taxes should play a role. Second, the equation fails the test of over-identifying restrictions, and there is evidence of severe serial correlation.

We address each of these problems in turn. First, because taxes change only infrequently, as observed above, it is highly likely that serial correlation is due to omission of a lagged dependent variable. In column 2, we add a lagged dependent variable. As is well known, this lagged dependent variable is correlated with the fixed effects, and thus treating it as exogenous may lead to biased estimates[21]. So, we treat the lagged dependent variable as endogenous and include the second lag in the instrument set. The lagged dependent variable is strongly significant, as might be expected, given only periodic changes in the nominal rate. The equation now passes the serial correlation test. Note also that the addition of the lagged dependent variable reduces the value of the coefficient on the federal tax and also makes it insignificant, although it still has a *t*-statistic greater than 1.

Column 2 implies that a one cent increase in the federal excise tax on cigarettes tends to raise state excise duties on cigarettes on average by around 0.12 cents in the short run and 0.47 cents in the long run, although this effect is no longer significant at the 5% level. In the context of our model above, and ignoring horizontal effects, this suggests strong convexity of the individual demand for cigarettes. However, some indication of mis-specification in column 2 in the absence

[21] In fact, OLS estimate of column 2 generates a coefficient on the lagged dependent variable of 0.760, hardly different from the 0.766 of the IV specification, and most of the other coefficients are also very similar.

Table 1
Cigarette Tax Rates

	IV	IV	IV	IV	IV
Weighting	–	–	Uniform	Neighbour	Density
Federal tax rate	0.283	0.118	0.103	0.082	0.081
	(2.41)*	(1.52)	(1.76)	(1.16)	(1.12)
Weighted mean state's tax rates	–	–	0.200	0.277	0.156
			(1.63)	(4.01)**	(2.36)*
State tax rate t-1	–	0.747	0.747	0.720	0.721
		(10.13)**	(10.07)**	(9.68)**	(9.39)**
Federal GDP	32.36	10.773	3.918	0.706	6.468
	(1.61)	(1.15)	(0.33)	(0.08)	(0.69)
Population	−0.041	−0.020	−0.023	−0.029	−0.024
	(0.43)	(0.37)	(0.42)	(0.57)	(0.46)
State GDP	−0.102	0.108	0.118	0.202	0.158
	(0.32)	(0.34)	(0.37)	(0.66)	(0.50)
Income per capita	2.757	0.842	0.388	−1.019	−0.551
	(0.50)	(0.38)	(0.17)	(0.53)	(0.26)
Unemployment	−0.02	0.166	0.176	0.097	0.122
	(0.08)	(1.34)	(1.46)	(0.83)	(0.99)
Proportion young	1.874	0.123	0.027	−0.180	−0.091
	(5.95)**	(0.61)	(0.15)	(0.81)	(0.52)
Proportion old	0.353	0.008	0.037	−0.250	−0.126
	(0.45)	(0.03)	(0.14)	(0.87)	(0.52)
Tobacco production	−0.374	0.482	0.509	0.022	0.252
	(0.46)	(2.50)*	(2.49)*	(0.11)	(1.45)
Gas production	−0.002	0.052	0.049	0.008	−0.134
	(0.00)	(0.24)	(0.22)	(0.04)	(0.67)
Grant per capita	−23.807	−13.860	−26.970	−22.368	−15.437
	(0.67)	(1.21)	(1.76)	(2.11)*	(1.39)
Income tax rate	0.792	0.281	0.230	0.084	0.187
	(2.00)	(1.96)	(1.72)	(0.61)	(1.29)
Party of Governor	−0.003	−0.001	−0.001	0.001	−0.000
	(0.52)	(0.66)	(0.61)	(0.42)	(0.02)
House prop Democrat	0.058	0.036	0.038	0.015	0.026
	(1.62)	(2.35)*	(2.54)*	(1.22)	(1.76)
Senate prop Democrat	−0.017	−0.003	−0.001	−0.003	0.001
	(0.42)	(0.19)	(0.10)	(0.19)	(0.06)
Election Dummy	0.003	0.003	0.003	0.003	0.003
	(1.64)	(1.99)	(1.88)	(2.12)*	(1.94)
Governor term limited	0.000	0.002	0.002	0.002	0.002
	−(0.03)	(0.79)	(0.83)	(0.63)	(0.93)
Debt	8.233	1.407	1.509	0.819	1.272
	(3.27)**	(0.90)	(0.95)	(0.48)	(0.80)
Inflation index	0.000	0.012	0.014	0.017	0.011
	(0.01)	(0.77)	(0.83)	(1.12)	(0.74)
Over-id test	0.019	0.032	0.123	0.21	0.43
Serial correlation test	0.00	0.35	0.41	0.52	0.43
Observations	1008	912	912	912	912
R-squared	0.77	0.88	0.88	0.88	0.89

1. Instruments. Column 1: federal deficit/GDP, federal unemployment, Column 2: federal deficit/GDP, federal unemployment, state tax rate($t-2$), Columns 3–5: federal deficit/GDP, federal unemployment, state tax rate($t-2$), weighted means of other state's population, proportion young, proportion old, debt, election dummy, governor term limit dummy.
2. T-statistics are given in parentheses. Standard errors are robust to heteroscedasticity, and are clustered by year to allow for spatial correlation in the errors. The test of over-identifying restrictions is robust to heteroscedasticity (see Wooldridge, 2002, p 123: it is distributed as $\chi^2(d)$ where d is the degrees of freedom: the table gives the p-value). The serial correlation test gives the p-value when including lagged residuals in the equation. *denotes significance at 5%, ** denotes significance at 1%.

of the tax rates of neighboring states is indicated by the failure of the test of over-identifying restrictions. This mis-specification is not surprising in view of our theoretical results.

In the remaining columns we introduce the possibility of horizontal tax competition by adding the weighted average of the tax rates of other 47 states to the regression for each state. The three columns correspond to three of the possible sets of weights described above: column 3 represents uniform weights, column 4 neighbor weights and column 5 neighbor-density weights. In each case, the average is instrumented with a selection of the weighted control variables of the other states, where the weight used for the instruments is the same as that used for the average of tax rates. The federal tax rate is instrumented as in column 2. The first stage regressions (not reported) indicate that the instruments explain a considerable amount of the variation of the endogenous variables. The R^2 for the first stage regressions varies from 0.81 to 0.99; the R^2 tends to be slightly higher in explaining the weighted average of other states' taxes; but the difference compared to explaining the federal tax rate is not large. In each column, at least some control variables remain significant; there is no evidence of serial correlation, and the test of over-identifying restrictions is passed in all cases at conventional significance levels.

In all three cases, introducing the weighted average of other states' tax rates reduces the coefficient on the federal tax rate, and also its statistical significance. In fact, moving to neighbor weights and neighbor-density weights reduces the significance still further. Overall, it is clear that — conditional on including the weighted average of other states tax rates — the federal tax rate plays no role in determining the home state tax rate.

Except in the case of uniform weights (column 3), however, the weighted average of other states' tax rates is significant. This is to be expected: if there is tax competition induced by cross-border shopping and smuggling, the tax rates of neighbors are likely to be most important. However, the coefficient β is higher in column 4 than in column 5. Based on the case of the neighbor-density weights in column 5, the results indicate that a one cent increase in the average of neighboring states' tax rates would induce an increase in state i's tax rate of 0.16 cents in the short run, rising to 0.57 cents in the long run.

The results for cigarette taxes therefore broadly support the propositions from the theory above. Given that the demand for cigarettes is relatively inelastic, an increase in the federal tax does not have a very significant effect on demand. As a result, states do not need to respond to changes in the federal tax rate. However, cigarettes are easily transportable and hence highly mobile. As a result, state legislators must take into account the tax rates charged in neighboring states. The evidence presented here suggests that there is a large effect; broadly, that state i matches most of any increases or decreases in neighboring states' taxes in the long run.

One problem with the specification in Table 1 is that the presence of federal variables, which vary only over time, preclude the use of time dummies which might otherwise capture aggregate shocks which create a common effect across states on cigarette tax rates. As noted above, even if we drop federal variables, we still cannot introduce time dummies in the case of the uniform-weighted average. However, in Table 2, we present a robustness check on the results in columns 4 and 5 of Table 1. In columns 1 and 3 we show the results of dropping the federal level variables from the specifications in columns 4 and 5 of Table 1 respectively. And in columns 2 and 4, we then add year dummies to each of the specifications in columns 1 and 3 of Table 2. The table indicates that the results are robust to the inclusion of time dummies. The coefficients on the weighted average of other states' taxes are close to those in columns 4 and 5 of Table 1; and this is true whether or not time dummies are included. Comparing the cases with and without time dummies in Table 2, there is only a very small difference. This strongly suggests that, in the specification in Table 1, we are adequately controlling for common shocks across states.

Table 2
Cigarette tax rates with year dummies, but without federal variables

	Neighbor weights		Density weights	
	Without year dummies	With year dummies	Without year dummies	With year dummies
Weighted mean state's tax rates	0.256	0.267	0.152	0.139
	(3.60)**	(3.02)**	(2.39)*	(1.96)
State tax rate$_{t-1}$	0.722	0.732	0.720	0.735
	(9.69)**	(10.27)**	(9.39)**	(9.98)**
Population	−0.031	−0.023	−0.024	−0.017
	(0.60)	(0.43)	(0.47)	(0.32)
State GDP	0.215	0.194	0.171	0.149
	(0.69)	(0.61)	(0.54)	(0.46)
Income per capita	−0.574	−0.254	0.424	0.188
	(0.28)	(0.11)	(0.18)	(0.07)
Unemployment	0.103	0.056	0.100	0.087
	(1.28)	(0.47)	(1.19)	(0.68)
Proportion young	−0.164	−0.083	−0.049	−0.040
	(0.70)	(0.39)	(0.27)	(0.22)
Proportion old	−0.238	−0.261	−0.105	−0.083
	(0.82)	(0.76)	(0.42)	(0.30)
Tobacco Production	0.058	0.038	0.261	0.300
	(0.30)	(0.15)	(1.52)	(1.47)
Gas production	−0.021	0.093	−0.166	−0.016
	(0.09)	(0.38)	(0.78)	(0.07)
Grant per capita	−21.675	−11.692	−16.266	−14.501
	(2.12)*	(0.73)	(1.52)	(0.95)
Income tax rate	−0.001	0.060	0.062	0.127
	(0.01)	(0.27)	(0.52)	(0.53)
Party of Governor	0.001	0.001	0.000	−0.000
	(0.40)	(0.34)	(0.01)	(0.08)
House prop Democrat	0.019	0.017	0.028	0.031
	(1.56)	(1.22)	(1.91)	(1.92)
Senate prop Democrat	−0.003	−0.003	−0.000	0.002
	(0.24)	(0.20)	(0.01)	(0.12)
Election dummy	0.003	0.001	0.003	0.001
	(1.63)	(0.51)	(1.45)	(0.38)
Governor term limited	0.002	0.002	0.003	0.002
	(0.80)	(0.62)	(1.06)	(0.88)
Debt	0.807	0.654	1.263	1.160
	(0.47)	(0.36)	(0.78)	(0.69)
Inflation index	0.021	0.023	0.022	0.025
	(2.27)*	(2.17)*	(2.30)*	(2.29)*
Over-id test	0.33	0.78	0.81	0.94
Serial correlation test	0.44	0.71	0.37	0.58
Observations	912	912	912	912
R-squared	0.88	0.89	0.89	0.89

1. Instruments and all econometric issues are dealt with as in Table 1, except that all federal level variables have been excluded.

Before turning to gasoline taxes, we examine the role of cigarette smuggling. As described above, we construct a uniform-weighted average of the three very low tax rates in Kentucky, North Carolina and Virginia, and take this to reflect the tax rates at which smugglers can obtain

Table 3
Cigarette tax rates and smuggling

	IV	IV	IV
Weighting	density	density	density
Federal tax rate	0.084	0.090	0.077
	(1.12)	(1.50)	(1.37)
Weighted mean state's tax rates	0.138	–	0.128
	(2.22)*		(2.05)
Mean tax rates in KY, NC and VA	–	0.826	0.589
		(1.77)	(1.28)
State tax rate$_{t-1}$	0.723	0.742	0.721
	(9.28)**	(9.92)**	(9.32)**
Federal GDP	9.270	16.764	11.506
	(0.96)	(1.71)	(1.15)
Population	−0.025	−0.027	−0.028
	(0.48)	(0.50)	(0.53)
State GDP	0.167	0.141	0.170
	(0.52)	(0.44)	(0.53)
Income per Capita	−0.608	−0.220	−1.095
	(0.28)	(0.09)	(0.49)
Unemployment	0.144	0.201	0.154
	(1.11)	(1.57)	(1.19)
Proportion young	−0.103	−0.052	−0.172
	(0.55)	(0.27)	(1.00)
Proportion old	−0.156	−0.016	−0.127
	(0.61)	(0.06)	(0.48)
Tobacco production	−3.014	−3.606	−2.961
	(1.93)	(2.01)	(1.85)
Gas production	−0.065	0.089	−0.060
	(0.30)	(0.38)	(0.29)
Grant per capita	−18.470	−34.593	−31.554
	(1.57)	(1.88)	(1.81)
Income tax rate	0.211	0.272	0.206
	(1.40)	(2.00)	(1.47)
Party of Governor	0.000	−0.001	0.000
	(0.10)	(0.42)	(0.10)
House prop Democrat	0.027	0.037	0.029
	(1.72)	(2.39)*	(1.88)
Senate prop Democrat	−0.002	−0.003	−0.001
	(0.14)	(0.23)	(0.10)
Election dummy	0.004	0.004	0.004
	(2.08)	(2.27)*	(2.27)*
Governor term limited	0.002	0.002	0.002
	(0.68)	(0.55)	(0.63)
Debt	1.236	1.431	1.356
	(0.75)	(0.87)	(0.81)
Inflation index	0.009	0.015	0.013
	(0.64)	(0.82)	(0.79)
Over-id test	0.37	0.30	0.15
Serial correlation test	0.48	0.39	0.45
Observations	855	855	855
R-squared	0.86	0.85	0.86

1. Instruments and all econometric issues are dealt with as in Table 1. Instruments for the weighted average of tax rates in Kentucky, North Carolina and Virginia are based on unweighted averages of those three states, using the same control variables.

cigarettes. In Table 3, we then examine the role played by this average tax rate on the tax rates set in the remaining 45 states. To start, we first reproduce column 5 of Table 1, but estimated only over these 45 states.[22] The results are very similar to those in column 5 of Table 1, indicating that dropping these three states does not have a significant impact. The coefficient on the neighbor-density weighted average of other states is very close to that in Table 1. The federal tax rate remains insignificant.

In column 2 we replace the neighbor-density weighted average of other states' tax rate with the uniform-weighted average from the three low tax states. This variable has a large and but not quite significant coefficient. This therefore provides some prima facie evidence that other states respond to the smuggling opportunities created by the existence of very low tax rate states. In column 3, we include both of these variables reflecting tax rates in other states. The neighbor-density weighted average tax rate remains positive and significant, although the coefficient is lower relative to that in column 1. The coefficient on the average tax rate in the three low tax states also drops in value and is less significant. Overall, then, there is some evidence that the opportunity for smuggling plays some role in the setting of state tax rates on cigarettes, although this does not dominate the role played by cross-border shopping.

In Table 4, we turn to gasoline taxes. The estimation strategy and format of the table is the same as that for Table 1; and first-stage regression results are similar to those for cigarette tax rates. In columns 1 and 2, we first investigate the role played by the federal tax, abstracting from any effect of taxes in other states. Again, in column 1, we have no lagged dependent variable, and the equation is estimated by IV, with the same instruments used as column 1 of Table 1 i.e. the federal debt/GDP ratio and the federal unemployment rate. Again, there is evidence of very strong serial correlation.

Column 2 adds a lagged dependent variable, and expands the instrument set to include the second lag of the dependent variable. The control variables are jointly significant, and the test of over-identifying restrictions is in this case passed in column 2. However, in both columns 1 and 2, the coefficient on the federal tax rate is insignificant. Columns 3–5 include weighted averages of other states' tax rates. This weighted average is never significant, and in column 5 is the wrong sign. But for the weighting scheme which most closely reflects the possibility of cross-border shopping, the neighbor-density weights, the federal tax rate is significant, with a larger effect than in column 2. So, overall, there is at best very limited evidence of horizontal tax competition in tax rates on gasoline, and no evidence at all in the case of neighbor-density weights. This reflects the discussion above, where we argued that we would expect less horizontal tax competition in the case of gasoline relative to cigarettes, since the costs of cross-border shopping (relative to the benefits) are much higher than for cigarettes. However, there is some evidence of vertical competition in gasoline taxes, especially when neighbor-density weights are used for state taxes.

To conclude, we have found that there is quite robust evidence of strategic interaction between states in the case of cigarette taxes, but not gasoline taxes. For gasoline taxes, there is some weaker evidence that state taxes respond to the federal tax. One final question is on the interpretation of the strategic interaction between states in the case of cigarette taxes. It is well-known that generally, strategic interaction can be generated by either tax competition or yardstick

[22] Note that in the case, since the weighted average varies only over time, it is again not possible to include time dummies.

Table 4
Gasoline tax rates

	IV	IV	IV	IV	IV
Weighting	–	–	Uniform	Neighbour	Density
Federal tax rate	0.132	0.094	0.033	0.077	0.122
	(1.09)	(1.80)	(0.87)	(1.54)	(2.30)*
Weighted mean state's tax rates	–	–	0.131	0.191	−0.099
			(0.99)	(1.28)	(0.67)
State tax rate $t-1$	–	0.766	0.763	0.738	0.784
		(14.44)**	(14.16)**	(10.91)**	(12.65)**
Federal GDP	21.72	4.611	3.802	1.351	6.665
	(2.07)*	(0.82)	(0.67)	(0.24)	(1.04)
Population	0.124	0.032	0.029	0.026	0.036
	(1.37)	(2.13)*	(1.99)	(2.06)	(2.79)*
State GDP	−0.61	−0.158	−0.149	−0.136	−0.169
	(2.27)*	(1.98)	(1.91)	(1.96)	(2.27)*
Income per capita	4.421	0.758	0.478	1.264	0.130
	(0.98)	(0.73)	(0.52)	(1.02)	(0.08)
Unemployment	0.059	0.114	0.124	0.116	0.110
	(0.46)	(2.70)*	(3.14)**	(2.90)**	(2.57)*
Proportion young	0.372	−0.135	−0.135	−0.171	−0.129
	(2.25)*	(2.14)*	(2.27)*	(2.63)*	(1.99)
Proportion old	0.758	0.260	0.201	0.192	0.289
	(1.43)	(2.61)*	(2.35)*	(2.01)	(3.25)**
Tobacco production	0.036	0.081	0.073	0.045	0.093
	(0.05)	(0.45)	(0.41)	(0.26)	(0.49)
Gas production	−0.083	−0.314	−0.359	−0.337	−0.280
	(0.19)	(1.28)	(1.33)	(1.24)	(1.07)
Grant per capita	−25.19	−27.660	−23.067	−22.308	−31.416
	(1.25)	(3.58)**	(2.76)*	(2.49)*	(3.85)**
Income tax rate	−0.476	−0.096	−0.085	−0.037	−0.118
	(2.66)*	(1.03)	(0.92)	(0.43)	(1.20)
Party of Governor	−0.001	−0.001	−0.001	−0.001	−0.001
	(0.56)	(1.27)	(1.24)	(1.09)	(0.94)
House prop Democrat	0.035	0.010	0.009	0.005	0.012
	(1.89)	(1.47)	(1.24)	(0.78)	(1.60)
Senate prop Democrat	−0.02	−0.005	−0.006	−0.005	−0.004
	(1.47)	(0.88)	(0.97)	(0.80)	(0.77)
Election dummy	−0.001	−0.001	−0.001	−0.001	−0.001
	(0.84)	(1.34)	(1.60)	(1.47)	(1.19)
Governor term limited	−0.003	−0.001	−0.001	−0.001	−0.001
	(1.27)	(0.87)	(0.53)	(0.65)	(0.95)
Debt	1.278	0.580	0.528	0.382	0.670
	(0.92)	(1.62)	(1.53)	(1.23)	(1.85)
Inflation index	−0.055	−0.015	−0.009	−0.012	−0.018
	(3.51)**	(1.62)	(1.10)	(1.59)	(2.04)
Over-id test	0.85	0.14	0.033	0.40	0.45
Serial correlation test	0.00	0.28	0.29	0.67	0.26
Observations	1008	912	912	912	912
R-squared	0.67	0.88	0.88	0.88	0.87

1. Instruments and all econometric issues are dealt with as in Table 1.

competition (Besley and Smart, 2003). The good performance of neighbor weights as opposed to uniform weights suggests that tax competition is at work[23].

7. Explaining tax changes

One feature of the federal and state nominal excise taxes is that they are changed infrequently. For example, Fig. 1 shows the nominal and real federal excises on cigarettes and gasoline. Each is changed only twice in nominal terms over the 20-year sample period. This of course means that the real value of the tax varies considerably over the time period, again as shown in Fig. 1. Also, when taxes are changed, they tend to be changed by large amounts. One possible interpretation of this pattern is that there are fixed political costs to raising excise taxes to match inflation: voters will remember the fact that an increase took place, rather than the precise amount of the increase. When these fixed costs are large, state governments will adjust taxes infrequently, but when they do so, will adjust them up to some "target" tax which will depend on cumulative inflation since the last increase, plus current economic variables of relevance. These may include current values of other states' taxes and the federal tax.

Table 5 reports regressions that model the tax changes that we observe in our data set. These regressions are not a direct test of the theory developed in Section 3 above, because our adjustment cost story is very informal. Nevertheless, the inclusion of the federal and weighted average state tax in these regressions is a robustness check on the results so far. The dependent variable is 1 if a nominal tax increase occurred in that period, and zero otherwise[24]. We regress this on essentially the same variables as in Tables 1 and 4. The coefficients reported are the ordinary probit coefficients, not the marginal effects.

In columns 1 and 3, we include the contemporaneous values of the federal tax rate and the neighbor-density weighted average of other states' tax rates. We also include the cumulative inflation since the last tax increase took place. And we include the lagged own state tax rate, and all the controls — including state dummies — used in the previous regressions. All tax rates except those to generate the dependent variables are in real terms. Given the possible endogeneity of the contemporaneous values of the federal tax rate and other states' tax rates, for robustness in columns 2 and 4 we replace these with lagged values.

Columns 1 and 2 present the results for cigarette taxes. In both cases, the lagged home state tax rate is negative and significant in both specifications, as would be expected: the lower the tax rate, the more likely the state government is to increase it. Also in both cases, the cumulative inflation since the last tax rate increase is positive and significant in both specifications, also as expected: the higher inflation, the greater the reduction in real tax rate if the nominal rate is unchanged. The neighbor-weighted average tax rate is positive and

[23] We did investigate this further, by allowing the coefficients β and γ to vary with the size of population able to cross-border shop (living on either side of the border), relative to the total state population. Specifically, with tax competition, we would expect β to be larger for these states where the size of population living close to either side of the border relative to the total state population (call this the *cross-border shopping ratio*) is large. Also, as described in Section 3.5 above, such states are also more likely to engage in vertical competition i.e. γ is likely to be larger, given that it is positive. We ranked states by their cross-border shopping ratio, and split the state into two groups — those above and below a cut-off point in this ratio. It turned out, that β and γ did not differ significantly according to whether the state was above or below the cutoff.

[24] No tax falls in nominal terms in our sample.

Table 5
Probit analysis

	Cigarette taxes		Gasoline taxes	
Dependent variable = 1 if increase in nominal tax rate, 0 otherwise				
State tax rate$_{t-1}$	−11.498	−10.037	−20.159	−19.540
	(3.50)**	(2.68)**	(3.93)**	(3.81)**
Federal tax rate$_t$	1.780	–	−5.908	–
	(0.68)		(1.13)	
Weighted mean state's tax rates$_t$	10.589	–	1.306	–
	(4.15)**		(0.22)	
Federal tax rate$_{t-1}$	–	5.347	–	−17.143
		(2.09)*		(4.00)**
Weighted mean state's tax rates$_{t-1}$	–	7.447	–	−7.678
		(4.65)**		(1.32)
Cumulative inflation	1.325	1.315	−0.126	−0.095
	(2.26)*	(2.13)*	(0.46)	(0.32)
Federal GDP	121.489	196.788	−461.140	52.710
	(0.28)	(0.46)	(1.13)	(0.14)
Population	0.936	1.185	7.340	7.493
	(0.26)	(0.33)	(3.25)**	(3.45)**
State GDP	−2.998	−4.122	−22.314	−22.886
	(0.22)	(0.31)	(2.10)*	(2.13)*
Income per capita	13.696	64.978	236.695	229.621
	(0.08)	(0.43)	(2.26)*	(2.09)*
Unemployment	−0.504	4.542	10.040	5.919
	(0.08)	(0.70)	(2.16)*	(1.21)
Proportion young	−1.299	−0.601	7.457	15.508
	(0.13)	(0.06)	(0.92)	(1.81)
Proportion old	−14.83	−9.19	29.75	22.59
	(0.93)	(0.52)	(2.08)*	(1.67)
Tobacco production	65.44	68.52	24.20	23.61
	(0.98)	(0.91)	(0.56)	(0.59)
Gas production	−25.31	−16.39	−35.87	−38.07
	(0.94)	(0.57)	(1.19)	(1.26)
Grant per capita	−1.81	−1.97	−2.41	−2.04
	(2.40)*	(2.63)**	(2.02)*	(1.72)
Income tax rate	−11.033	−7.069	−23.537	−32.340
	(1.30)	(0.93)	(2.45)*	(3.03)**
Party of Governor	−0.122	−0.146	0.038	0.036
	(1.02)	(1.32)	(0.31)	(0.27)
House prop Democrat	2.549	2.813	1.187	0.867
	(2.89)**	(3.11)**	(0.95)	(0.70)
Senate prop Democrat	0.071	−0.085	−0.661	−0.745
	(0.08)	(0.11)	(1.09)	(1.16)
Election dummy	0.200	0.193	−0.257	−0.255
	(2.01)*	(2.05)*	(1.90)	(1.94)
Governor term limited	0.020	0.039	−0.181	−0.175
	(0.10)	(0.19)	(1.18)	(1.12)
Debt	170.104	148.356	72.752	79.945
	(2.33)*	(2.16)*	(1.50)	(1.61)
Observations	880	880	940	940
Pseudo R-squared	0.21	0.19	0.20	0.21

significant in both specifications — whether contemporaneous (column 1) or lagged (column 1). This is in line with the results in Table 1: a higher tax rate amongst neighboring states induces a higher tax rate in the home state, and also makes the home state government more likely to increase its tax rate. Less clear is the effect of the federal tax rate. In the contemporaneous specification, it is insignificant, as in Tables 1 and 2. However, in the lagged specification, the coefficient is positive and significant. Amongst the control variables, there appears to be a belief that increasing cigarette taxes is popular: there is more likely to be an increase in an election year. State houses controlled by Democrats are also more likely to increase cigarette taxes.

The results for gasoline taxes are shown in columns 3 and 4. The lagged home state tax rate is again negative and significant, although in this case cumulative inflation is not significant. As in Table 4, for gasoline taxes, the neighbor-weighted average tax rate does not play a significant role in determining tax increases. Like the case of cigarettes, the federal tax rate does play a role, but only in the lagged specification. In this case, however, it has a negative effect — this is consistent with the theoretical framework, although it is not observed in the other results. Amongst the control variables, it is interesting to note that gasoline tax rises do not appear to be popular: state governments are less likely to raise gasoline taxes in an election year.

8. Related literature and conclusions

8.1. Related literature

This paper is related to several different literatures, other than the papers already mentioned. First, there is now a significant theoretical literature on vertical tax competition (see for example Keen (1998) and the earlier work cited there, as well as Besley and Rosen (1998)). However, in our view, most of these papers do not provide a theoretical model adequate to capture the strategic interactions in excise taxes between US state and federal governments because they do not allow for horizontal tax competition. Keen and Kotsogiannis (2002, 2004) do consider both vertical and horizontal competition, but focus on capital, rather than commodity taxes, and moreover, focus on the question of how the introduction of vertical tax competition is likely to affect equilibrium taxes: they do not provide results on the slopes of tax reaction functions. Finally, Rizzo (2003) studies a model of vertical and horizontal interaction in excise taxes of the Kanbur and Keen (1993) type. This model is complementary to ours. In our theoretical model, the federal tax affects the state tax through the mechanism that it reduces individual demand for the good (and thus if demand is completely inelastic, as in the Kanbur and Keen (1993) model, then the federal tax has no effect). In Rizzo's model, demand is assumed inelastic, and an interaction between federal and state taxes is generated by allowing for smuggling activity, which is increasing in the federal tax.

Second, other than Besley and Rosen (1998), which has already been discussed in the introduction, there is also a small but growing empirical literature on interdependence between

Notes to Table 5:

1. 4 states did not change the nominal rate of cigarette tax over this period; and one did not change the nominal rate of gasoline tax. These states have been dropped from the relevant regressions.

2. Robust z-statistics in parentheses; standard errors are clustered by year.

state or provincial and federal taxes. Esteller-More and Sole-Olle (2001) study strategic interaction between US states and federal government in the setting of income taxes, along the lines of Besley and Rosen. Like us, they do allow for horizontal interactions between state income taxes. Hayashi and Boadway (1997) test for vertical and horizontal interaction in the setting of Canadian provincial corporate taxes. Finally, Rizzo (2003) studies the interactions between Canadian provinces (and neighboring US states) and Canadian federal taxes. However, the theoretical approach, and thus the hypotheses being tested, are somewhat different to this paper.

Finally, there is also an empirical literature which has examined only horizontal tax competition in the setting of US excise taxes[25]. Two recent examples of this literature are Nelson (2002) and Rork (2003).[26] Both of these papers consider horizontal tax effects for a number of taxes, including both cigarettes and gasoline. The empirical approaches used in these papers differ from each other in a number of ways, including the years investigated, the control variables used, the econometric specification, and the matrix used for weighting the tax rates in other states. However, they both conclude that tax rates in neighboring states play a significant role in determining state level tax rates on both cigarettes and tobacco. Nelson (2002) finds a larger effect for gasoline, while Rork (2003) finds a similar effect for taxes on both goods. The empirical approach in this paper shares some features of each of these papers. Perhaps most notably, our preferred weighting matrix is similar (although not identical) to that used by Nelson in that it accounts for population density at the borders between states. However, neither of these papers consider vertical competition. Incorporating the federal tax rate, and using a different overall empirical approach, we find results for gasoline taxation in particular which differ from these papers, but which nevertheless fit with our theoretical framework.

8.2. Conclusions

In this paper we have investigated vertical and horizontal tax competition for cigarette and gasoline unit taxes in the USA. We have developed a simple theoretical framework in which the role played by the tax rates in other states depends on the proportion of each state's population which might cross the border to take advantage of lower tax rates. This clearly depends on transport costs. We distinguish between cross-border shopping and smuggling. The role played by federal level taxes depends both on the elasticity of demand for the commodity and the costs of cross-border shopping and smuggling.

Given an inelastic demand for cigarettes, and low transport costs, the model suggests that federal taxes would have little effect on state taxes, but that the tax rates in neighboring states would play an important role. This is exactly the pattern of results we find in Table 1 for taxes on cigarettes. Our central estimate is that a one cent increase in the neighbor-density weighted average of the unit tax in other states would induce a rise in the home tax rate of 0.7 cents in the long run, implying an important effect of cross-border shopping. We also find some

[25] There is of course, an empirical literature studying horizontal interactions in local business taxes, particularly in the US (Brueckner, 1998; Brett and Pinkse, 2000; Heyndels and Vuchelen, 1998). This literature is well-surveyed in Brueckner (2003).

[26] Several earlier papers also find links between cigarettes sales in one state and the level of tobacco taxation in other states: see, for example, Baltagi and Levin (1986, 1992), Becker et al. (1994) and Coates (1986).

evidence of a role played by the opportunity for smuggling, although this does not dominate the role played by cross-border shopping. Finally, we find that the responsive to cigarette tax rates in neighboring states depends on the scale of possible cross-border shopping. States where a relatively small proportion of the population live in the border region tend not to respond to the tax rates in neighboring states.

For gasoline, it is likely that the elasticity of demand is higher while transport costs are also higher. This would indicate a less important role for the tax rates in neighboring states, but possibly a greater role for the federal tax. This is also supported by our empirical evidence in Table 3. The neighbor-weighted average of the unit tax in other states does not play a significant role in determining the home state's tax rate on gasoline. However, in our preferred specification, the federal tax plays a significant role, indicating the presence of some vertical competition.

As a robustness check, and because state governments tend to adjust unit taxes on cigarettes and gasoline only infrequently, we also investigated the determinants of the decision to raise taxes. These results are consistent with the main results.

Acknowledgement

We would like to thank participants at the UK Public Economics conference in December 2003 for their helpful comments, especially Tim Besley and Jim Hines. We are grateful to the Office of Tax Policy Research at the University of Michigan for providing data on US excise tax rates. Finally, we are grateful to Leonzio Rizzo for the many useful conversations and the use of some data.

Appendix A. Proofs of Propositions

Proof of Proposition 1. (i) If $c_i=\infty$, so that there is no cross-border shopping, $X_i=n_i x(q_i)$. So

$$\frac{\partial X_i}{\partial q_i}=n_i x_i', \frac{\partial^2 X_i}{\partial q_i^2}=n_i x_i'', \frac{\partial X_i}{\partial q_j}=\frac{\partial^2 X_i}{\partial q_i \partial q_j}=0 \tag{.1}$$

Substituting these expressions in Eq. (3.5) gives the result Eq. (3.7). (ii) If demand is inelastic i.e. $x_i(q)=\bar{x}$, then $v(q)=v-\bar{x}q$ as long as $q\leq v$. So, from Eq. (3.2),

$$X_i(q_i,q_j)=n_i\bar{x}+\rho_i(q_j-q_i)\bar{x}^2 \tag{.2}$$

giving

$$\frac{\partial X_i}{\partial q_j}=-\frac{\partial X_i}{\partial q_i}=\rho_i\bar{x}^2, \frac{\partial^2 X_i}{\partial q_i^2}=\frac{\partial^2 X_i}{\partial q_i \partial q_j}=0 \tag{.3}$$

Substituting Eq. (.3) into Eq. (3.5) gives Eq. (3.8), except for the result that the slope is 0.5. To see that, note that from Eq. (.2),

$$R_i=t_iX_i=t_i[n_i\bar{x}+\rho_i(t_j-t_i)\bar{x}^2]$$

So, by direct calculation, $D_i=\frac{\partial^2 R_i}{\partial t_i^2}=2\rho_i\bar{x}^2$. □

Proof of Proposition 2. W.l.o.g., let state 1 be the high-tax state and assume that $x'(q)<0$ everywhere (if $x'(q)=0$, then reaction functions have a slope of 0.5, as explained in the text). So, from Eq. (3.5), $\frac{\partial t_1}{\partial t_2}>0$ iff

$$\frac{\partial X_1}{\partial q_2}+t_1\frac{\partial^2 X_1}{\partial q_1 \partial q_2}>0 \tag{.4}$$

From Eq. (3.2), we first calculate

$$\frac{\partial X_1}{\partial q_2}=\rho_1 x(q_2)x(q_1),\frac{\partial^2 X_1}{\partial q_1 \partial q_2}=\rho_1 x(q_2)x'(q_1) \tag{.5}$$

Also, from Eq. (3.4),

$$t_1=\frac{q_1}{\varepsilon_1+\sigma_1}<\frac{q_1}{\varepsilon_1}=-\frac{x(q_1)}{x'(q_1)} \tag{.6}$$

So, combining Eqs. (.4),(.5),(.6), we get:

$$\frac{\partial X_1}{\partial q_2}+t_1\frac{\partial^2 X_1}{\partial q_1 \partial q_2}>\rho_1 x(q_2)x(q_1)+\left(-\frac{x(q_1)}{x'(q_1)}\right)\rho_1 x_1(q_2)x_1{}'(q_1)=0$$

So, $\dfrac{\partial t_1}{\partial t_2}>0$, as required.

(ii) Now consider the low-tax state 2: $\dfrac{\partial t_2}{\partial t_1}>0$ if

$$\frac{\partial X_2}{\partial q_1}+t_2\frac{\partial^2 X_2}{\partial q_2 \partial q_1}>0 \tag{.7}$$

But

$$\frac{\partial X_2}{\partial q_1}=\rho_1 x_1(q_2)x_1(q_1)>0,\frac{\partial^2 X_2}{\partial q_2 \partial q_1}=\rho_1 x_1(q_1)x_1'(q_2)<0 \tag{.8}$$

So, from Eqs. (.7), (.8), we require

$$\frac{x_1(q_2)}{-x_1'(q_2)}>t_2 \tag{.9}$$

First, note from Eq. (3.4), that

$$t_2=\frac{q_2}{\varepsilon_2+\sigma_2}<\frac{q_2}{\varepsilon_2}=-\frac{x(q_2)}{x'(q_2)}$$

So, this verifies Eq. (.9). □

Proof of Proposition 3. At the symmetric equilibrium, it is easily calculated that

$$\frac{\partial X_i}{\partial q_i} = x' - \rho x^2, \frac{\partial X_i}{\partial q_j} = \rho x^2, \frac{\partial^2 X_i}{\partial q_i^2} = x'' - 3\rho x x', \frac{\partial^2 X_i}{\partial q_i \partial q_j} = \rho x x'$$

where x, x', x'' are the level and derivatives of individual demand evaluated at the equilibrium consumer price $q=t+T$. So, by substitution into Eq. (3.5), using also Eq. (3.6), we get, after some rearrangement

$$\frac{\partial t_i}{\partial t_j} = \frac{\rho x^2 + \frac{t}{q} q \rho x x'}{-\left[2(x' - \rho x^2) + \frac{t}{q} q (x'' - 3\rho x x')\right]} = \frac{\rho x q + \frac{t}{q}\left(\frac{q x'}{x}\right)\rho x q}{-\left[2\left(\frac{q x'}{x}\right) - 2\rho x q + \frac{t}{q}\left(\frac{q x'}{x}\right)\left(\frac{q x''}{x'} - 3\rho x q\right)\right]}$$

$$= \frac{\sigma - \frac{1}{\sigma+\varepsilon}\varepsilon\sigma}{\left[2\varepsilon + 2\sigma + \frac{1}{\sigma+\varepsilon}\varepsilon(\eta - 3\sigma)\right]} = \frac{\sigma^2}{2(\varepsilon+\sigma)^2 + \varepsilon\eta - 3\varepsilon\sigma}$$

In the same way:

$$\frac{\partial t_i}{\partial T} = \frac{x' + \frac{t}{q} q (x'' - 2\rho x x')}{-\left[2(x' - \rho x^2) + \frac{t}{q} q (x'' - 3\rho x x')\right]} = \frac{\left(\frac{q x'}{x}\right) + \frac{t}{q}\left(\frac{q x'}{x}\right)\left(\frac{q x''}{x'} - 2\rho x q\right)}{-\left[2\left(\frac{q x'}{x}\right) - 2\rho x q + \frac{t}{q}\left(\frac{q x'}{x}\right)\left(\frac{q x''}{x'} - 3\rho x q\right)\right]}$$

$$= \frac{-\varepsilon - \frac{1}{\sigma+\varepsilon}\varepsilon(\eta - 2\sigma)}{\left[2\varepsilon + 2\sigma + \frac{1}{\sigma+\varepsilon}\varepsilon(\eta - 3\sigma)\right]} = \frac{\varepsilon(\sigma - \varepsilon - \eta)}{2(\varepsilon+\sigma)^2 + \varepsilon\eta - 3\varepsilon\sigma}$$

as required. □

Appendix B. Variable definitions, sources, and summary statistics

Definition	Source	Obs	Mean	Min	Max
Tax variables					
State gasoline unit tax, $ per gallon*	www.OTPR.org	1008	0.115	0.024	0.240
State cigarette unit tax, $ per pack of 20*	www.OTPR.org	1008	0.165	0.014	0.504
Federal unit tax on gasoline, $ per gallon*	www.OTPR.org	1008	0.080	0.04	0.12.0
Federal unit cigarette tax, $ per pack of 20*	www.OTPR.org	1008	0.130	0.08	0.160
Control variables					
Gross state product (GSP) $trillion	Bureau of Economic Analysis	1008	0.080	0.0053	0.621
Fraction of GSP generated by tobacco production	Bureau of Economic Analysis	1008	0.002	0	0.062
Fraction of GSP generated by gasoline production	Bureau of Economic Analysis	1008	0.005	0	0.047
State unemployment rate	Bureau of Labor Statistics	1008	0.064	0.022	0.180
State income per capita, $**	Bureau of Economic Analysis	1008	12558.26	8081.29	21634.69

(continued on next page)

Appendix B (*continued*)

Definition	Source	Obs	Mean	Min	Max
State debt, $m**	Bureau of Economic Analysis	1008	4227.59	70.45	44973.25
Grant per capita, $**	Consolidated Federal Funds Reports program US Census Bureau	1008	459.13	223.40	1022.56
State population, 10 m	US Census	1008	0.502	0.041	3.22
Proportion of state population over 65 yrs ("old")	US Census	1008	0.121	0.074	0.185
Proportion of state population 5–17 yrs old ("young")	US Census	1008	0.197	0.154	0.265
Control variables					
Governor incumbent cannot run by law (1 = yes; 0 = no)	Statistical Abstract of the United States	1008	0.229	0	1
Party of governor (1 = Dem; 1 = Rep; 2 = other)	Statistical Abstract of the United States	1008	0.512	0	2
Proportion of state House that is Democratic	Statistical Abstract of the United States	1008	0.590	0.157	0.981
Proportion of state Senate that is Democratic	Statistical Abstract of the United States	1008	0.598	0.143	1
Dummy = 1 when an election occurs	Statistical Abstract of the United States	1008	0.256	0	1
State income tax rate	Bureau of Economic Analysis	1008	0.112	0.076	0.160
Gross Domestic Product $trillion	OECD-Economic Outlook	1008	4898.69	2031.4	8300.8
Federal unemployment rate	OECD-Economic Outlook	1008	0.069	0.049	0.097

* All unit taxes are deflated by the 1982 federal CPI.

** This variable is multiplied by 10^6 when used in the regression analysis above.

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