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Horizontal and Vertical Indirect Tax Competition: Theory and Some Evidence from the USA*

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Abstract

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. We also examine the role played by smuggling. The results are generally consistent with the theory, when the characteristics of the markets for the goods are taken into account. For neither good do federal excise taxes affect state taxes. Taxes in neighboring states have a significant and large effect in the case of cigarettes, and a much weaker effect in the case of gasoline. we also find that in the setting of cigarette taxes, concerns about cross-border shopping play a more important role than concerns about smuggling.

Keywords: tax competition, excise taxes, cross-border shopping, smuggling
JEL Classification Numbers: H70,H71,H77

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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 (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[1] suggests that 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 we find that when the federal excise tax and a weighted average of other state taxes are 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 a 0.6 percentage point increase in state i's tax rate. The case of gasoline is best characterized as one where demand for the good is relatively price-inelastic, and incentives for inter-state arbitrage are weak. In this case, the theory predicts that the response of a state tax to both 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 positive and significant in some specifications, but not in our preferred case which reflects most closely the possibility of cross-border shopping.

This paper is related to several different literatures. First, there is now a significant theoretical literature on vertical tax competition (Besley and Rosen (1998), Goodspeed (2002), Keen (1998), Keen and Kotsogiannis (2002a,b), and Rizzo (2003)). However, in

[1] Our theoretical analysis also finds that the effect of the federal tax on the state tax is more likely to be positive in the presence of cross-border shopping.

our view, for various reasons, none of these papers provides a theoretical model adequate to capture the strategic interactions in excise taxes between US state and federal governments. Besley and Rosen (1998) and Keen (1998) study only vertical tax competition i.e. the states are assumed not to interact with each other. Keen and Kotsogiannis (2002a,b) 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. Goodspeed (2002) also focusses on income taxes, although there is some discussion of the response of state taxes to the federal tax. Finally, Rizzo (2003) studies a model of vertical and horizontal interaction in excise taxes of the Kanbur-Keen (1993) type. This model is complementary to ours. In our theoretical model, outlined below, 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-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, there is also a complementary small but growing empirical literature on interdependence between US state taxes and federal taxes. The earliest significant contribution[2] is that of Besley and Rosen (1998), who find that changes in 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, their approach did not allow for "horizontal" strategic interaction: taxes in other US states were not included as regressors. 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.[3]

Finally, there is also an empirical literature which has examined horizontal tax competition in the setting of US excise taxes. Two recent examples of this literature are Nelson

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

[3] Two other papers should be noted here. Esteller-More and Sole-Olle(2001) study strategic interaction between US states 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. Finally, Rizzo(2003) studies the interactions between Canadian provinces (and neighbouring US states) and Canadian federal taxes. However, the theoretical approach, and thus the hypotheses being tested, are somewhat different to this paper.

(2002) and Rork(2003).[4] 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.

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, before briefly concluding.

2. Cross-Border Shopping, Smuggling, and Elasticities of Demand

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[5].

There is now considerable econometric evidence on the price elasticity of demand for both cigarettes and gasoline in the US. First, elasticity of demand for cigarettes differs

[4] 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), Becker et al (1994) and Coates (1986).

[5] 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.

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 the overall 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 of -0.8 to -1.0. (Dahl and Sterner, 1991).

How much cross-border shopping and smuggling[6] 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 papers have developed methodologies to measure indirectly the amount of cross-border shopping and smuggling (Fleenor (1998), Saba, Beard, Eklund, and Ressler (1995), and 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.

For example, Saba, Beard, Eklund, and Ressler (1995) present a model of cross-border shopping, and calculate the percentage of total consumers in a state who are estimated to shop in neighboring states. Except for a few states, this figure is below 1%. Thursby and Thursby (2000) model commercial smuggling, rather than cross-border shopping, and estimate the former to be about between 0.5% and 7% of final sales, depending on the year. 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). Some of his results are reported below.

[6] 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.

Estimates of State Cigarette Consumption by Supply Source, 1997[1]

	Taxable Sales	Smuggling	Cross-Border Sales	Other[2]	Tax[3]
United States	86.7	7.8	3.6	1.9	34.9
Massachusetts	71.3	10.2	17.9	0.6	69.7
New York	64.4	15.7	18.4	1.5	58.9
Michigan	69.7	22.7	5.4	2.2	75.0
Kentucky	99.9	0.0	0.0	0.1	3.0

1. Source: Fleenor (1998).
2. Sales from military bases, Native American reservations, Mexico.
3. State plus local taxes, cents per pack of 20 cigarettes in 97$.

This table illustrates a number of features of cigarette taxes and cross-border activity. First. tax rates vary enormously between states - for the 5 states in the Table, from 3 cents in Kentucky to 70 cents in Massachusetts. Second, cross-border shopping and smuggling can account for a substantial part of consumption - over one third of all consumption in New York, for example. Third, there is a clear negative correlation between tax rates and cross-border activity; we explore this more formally below.

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[7], where the price differential for gasoline is much greater (DeFranco et al., 1998).

[7] *"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.? "* DeFranco et .al. (1998)

3. A Theoretical Framework

3.1. The Model

We construct a simple theoretical framework to inform our estimation of tax reaction functions, which can be interpreted as 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. We also extend the basic model to allow for commercial smuggling: the results are quire robust to this extension.

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 $p_1 = p_2 = 0$. 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.

We assume that the total number of residents of each state $i = 1, 2$ is normalized at unity. Moreover, the proportion of consumers in each state at distance s or less from the border is just s i.e. consumers are uniformly spatially distributed. Each consumer in state i at distance s from the border can either purchase[8] the good in state i, paying q_i, or can travel to the border at a cost c per unit of distance and pay q_j, plus any associated travel costs. We assume that the activity of transporting x units from the border to a location s units from the border requires $c(x, s)$ units of the numeraire good.

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[9]. 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[10] of the transport cost function $c(x, d) = cd$, where is the cost per unit

[8] 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.

[9] 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.

[10] 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

distance travelled i.e. the costs of transport are independent of x.

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

$$v(q) = \max_x \{ u(x) - qx \}, \ x(q) = \arg\max \ \{u(x) - qx\}$$

be the indirect utility and individual demand for the good when the price is q. Note that transport costs do not affect demand as they are are paid in the numeraire good, and utility is linear in that good. Moreover, as transport costs are fixed, 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

$$d \leq \frac{1}{c}(v(q_j) - v(q_i))$$

from the border. This model encompasses two important special cases.

1. Prohibitively costly cross-border shopping($c = \infty$).In this case, there are no horizontal tax externalities and the model is exactly that considered by Keen (1998).

2. Inelastic demand i.e. $x' = 0$ or $x(q) = \overline{x}$. In this case, the model is a symmetric version[11] of the Kanbur-Keen (1993) or Nielsen (2001) models.

3.2. Analysis

Assuming for convenience that the total number of residents of each state $i = 1, 2$ is normalized at unity, it is then easily calculated that the tax base in i, denoted X, is

$$X(q_i, q_j) = (1 + \rho(v(q_i) - v(q_j)))x(q_i) \tag{3.1}$$

where $\frac{1}{c} = \rho$ measures the responsiveness of cross-border shopping to tax differentials.

If $q_i \geq q_j$, $v(q_i) < v(q_j)$, then there is outward cross-border shopping from i, and only a fraction of residents of i purchase the good in i, and they buy $x(q_i)$ units each. If on the other hand, $q_i < q_j$, $v(q_i) > v(q_j)$, then there is inward cross-border shopping; total sales in i comprise the purchases of domestic residents, $x(q_i)$, plus the purchases of inward cross-shoppers.

It is easily checked from (3.1) that in the general case where individual demand is elastic i.e. $x'(q) < 0$, and there is cross-border shopping ($\rho > 0$) then $-X_1 > X_2 > 0$,

only shop in one jurisdiction, which is the key feature of the analysis. For a multi-period analysis of optimal taxation in a single country with scale economies in cross-border shopping, see Scharf(1999).

[11] That is, it is a special case of the Kanbur-Keen model where total population, and population density is the same in both countries.

where subscripts denote derivatives. This is because X is generally decreasing in q_i for *two* reasons. First, consumers in state i may purchase fewer units of the good when the price increases, and second, consumers in state i may decide (depending on transport costs) to cross-border shop. On the other hand, X is increasing in q_j *only* because consumers in state j may decide to cross-border shop i.e. buy the good in state i instead. So, there is a key asymmetry here in the effects of changes in the states' own consumer price and the consumer price of the neighboring state on the tax base of the home state.

Note also two special cases. First, suppose demand is inelastic in which case take $\overline{x} = 1$. In this case, $v(q) = 1 - q$, so $X(q_i, q_j) = 1 + \rho(q_j - q_i)$ and so $-X_1 = X_2 = \rho$. Conversely, if transport costs are prohibitive (i.e. $\rho = 0$, then $X = x(q)$ and so $X_1 = x'$ and $X_2 = 0$.

Now consider the choice of tax in state i. For simplicity (and following Kanbur and Keen (1993), and Keen (1998)) we assume that state governments are revenue-maximisers. The revenue in state i is $R_i = t_i X(t_i + T, t_j + T)$, recalling that $q_i = t_i + T$. So, the first-order condition for the optimal choice of t_i is

$$\frac{\partial R_i}{\partial t_i} = X + t_i X_1 = 0 \tag{3.2}$$

Equation (3.2) implicitly determines t_i as a function of t_j and T. Our interest is in how t_i responds to t_j and T i.e. the the "slopes" of the reaction function. Totally differentiating (3.2) implies:

$$\frac{\partial t_i}{\partial t_j} = \frac{X_2 + t_i X_{12}}{D}, \ \frac{\partial t_i}{\partial T} = \frac{X_1 + X_2 + t_i(X_{11} + X_{12})}{D} \tag{3.3}$$

where $D = -\frac{\partial^2 R_i}{\partial t_i^2} > 0$ as the stationary point of R_i is a maximum. The presence of X_{11}, X_{12} in the slope formulae make these generally difficult to evaluate, but there are two special cases where it is easy to sign them.

1. *Inelastic Demand.* Here, as noted above, $-X_1 = X_2 = \rho > 0$, and $X_{11} = X_{12} = 0$. So, in this case, from (3.3),

$$\frac{\partial t_i}{\partial t_j} = \frac{\rho}{D} > 0, \ \frac{\partial t_i}{\partial T} = 0$$

i.e. we have the striking result that state taxes *do not react at all to federal taxes.* The intuition for this is clear; in this case, the tax base in state i, $X(q_i, q_j)$ depends only on the *difference* in consumer prices (as this determines the cross-border shopping decision), and $q_i - q_j = t_i + T - (t_j + T) = t_i - t_j$ i.e. T nets out.

2. *No Cross-Border Shopping.* Here, as noted above, $X_1 = x'(q),\ X_{11} = x''(q),\ X_2 = X_{12} = 0$. So we have from (3.3) that

$$\frac{\partial t_i}{\partial t_j} = 0,\ \frac{\partial t_i}{\partial T} = \frac{x'(q) + tx''(q)}{D} \tag{3.4}$$

In this case, the argument of Keen (1998) applies to show that $\frac{\partial t_i}{\partial T}$ can be positive or negative. In particular, if demand is linear ($x'' = 0$), then $\frac{\partial t_i}{\partial T} < 0$, but if demand is iso-elastic ($x = q^{-\varepsilon}$) is can be shown[12] that $\frac{\partial t_i}{\partial T} > 0$.

To make progress in the general case with elastic demand and cross-shopping, by direct calculation from (3.1), using $x(q) = -v'(q)$ by Roy's identity, we have

$$\begin{aligned} X_1(q_i, q_j) &= (1 + \rho(v(q_i) - v(q_j)))x'(q_i) - \rho[x(q_i)]^2 \\ X_2(q_i, q_j) &= \rho x(q_i)x(q_j) \\ X_{11}(q_i, q_j) &= (1 + \rho(v(q_i) - v(q_j)))x''(q_i) - 3\rho x(q_i)x'(q_i) \\ X_{12}(q_i, q_j) &= \rho x(q_j)x'(q_i) \end{aligned} \tag{3.5}$$

Evaluating these at a symmetric Nash equilibrium in state taxes with $t_1 = t_2 = t$, and thus $q_1 = q_2 = q$, we have:

$$\begin{aligned} X_1 &= x' - \rho x^2 \\ X_2 &= \rho x^2 \\ X_{11} &= x'' - 3\rho x x' \\ X_{12} &= \rho x x' \end{aligned} \tag{3.6}$$

where x, x', x'' are evaluated at q. Then, from (3.6) and (3.2), the Nash equilibrium tax rate is given by

$$\frac{t}{q} = \frac{1}{\sigma + \varepsilon},\ \varepsilon = \frac{-qx'}{x},\ \sigma = \rho q x. \tag{3.7}$$

Again, note two special cases. If cross-border shopping is prohibitive, $\rho = 0$ and we have the standard inverse elasticity formula $t/q = 1/\varepsilon$ for the optimal tax. If demand is inelastic, $\varepsilon = 0$, then $t/q = 1/\sigma$, where σ is the the elasticity of X with respect to q_i, *holding individual demand $x(q_i)$ constant*, and thus measures the part of the elasticity of demand deriving from cross-border shopping.

In this general case, we can say the following about the responses $\frac{\partial t_i}{\partial t_j}$, $\frac{\partial t_i}{\partial T}$. First, consider the horizontal tax response. Substituting from (3.7) into (3.3) we see that

$$\frac{\partial t_i}{\partial t_j} = \frac{\rho x^2}{D}\left(1 - \frac{t}{q}\varepsilon\right) = \frac{\rho x^3}{D}\frac{\sigma}{\sigma + \varepsilon} > 0. \tag{3.8}$$

[12] Then $x' + tx'' = x' - xx''/x' = q^{-(\varepsilon+1)} > 0$.

So, the response of t_i to t_j is *always positive* in the neighborhood of symmetric equilibrium, and is larger, the larger is ρ i.e. the easier is cross-border shopping.

Now consider the vertical tax response. Substituting from (3.7) into (3.3) we see that

$$\frac{\partial t_i}{\partial T} = \frac{x' + t(x'' - 2\rho x x')}{D} \tag{3.9}$$

Note that if cross-border shopping is prohibitively costly ($\rho = 0$), (3.9) reduces to Keen's formula (3.4) for the vertical tax response. However, in the general case, the formula is different: the presence of the term in ρ makes it more likely, other things equal, that the vertical response (3.9) will be positive. In particular, it is possible to show that (i) even if demand is linear ($x'' = 0$), then $\frac{\partial t_i}{\partial T}$ can be positive; (ii) if demand is iso-elastic ($x = q^{-\varepsilon}$), then $\frac{\partial t_i}{\partial T}$ is always positive. This contrasts with the case of only vertical tax competition where with linear demand, $\frac{\partial t_i}{\partial T}$ is always negative, and with iso-elastic demand, the sign of $\frac{\partial t_i}{\partial T}$ is ambiguous.

To see this, re-write (3.9) in elasticity form, using (3.7):

$$\frac{\partial t_i}{\partial T} = \frac{x}{qD}[-\varepsilon + \frac{t}{q}(-\varepsilon\eta + 2\sigma\varepsilon)] = \frac{x\varepsilon}{qD}\left(\frac{\sigma - \varepsilon - \eta}{\sigma + \varepsilon}\right), \quad \eta = q\frac{x''}{x'}$$

Then if demand is linear, the sign of the vertical response is determined by $\sigma - \varepsilon$, which can easily be positive e.g. if ρ is large enough. If demand is iso-elastic it is easily calculated that $\eta = -(\varepsilon+1)$, so the sign of the vertical response is determined by $\sigma-\varepsilon-\eta = \sigma+1 > 0$.

The intuition is simple; from (3.3), $\frac{\partial t_i}{\partial T}$ is more likely to be positive, the more positive (or less negative) is the response of the slope of the aggregate demand curve, X_1, to an increase in T. As an increase in T increases both q_1, q_2, this response is $X_{11} + X_{12}$, and can be split into two parts. At the symmetric equilibrium, from (3.6),

$$X_{11} + X_{12} = x'' - 2\rho x x'$$

The first part x'' is due to the possible nonlinearity of individual demand. The second part, $-2\rho x x'$, which is always positive, is due to the *interaction* between vertical and horizontal tax competition. In particular, from inspection of (3.5), X_1, has an additional term $\rho[x(q_i)]^2$ capturing the fact that a small increase in q_i will cause, to first order, a loss of $\rho x(q_i)$ shoppers from region i, each of whom buys $x(q_i)$ units of the good. An increase in T will decrease this loss in demand, as it decreases individual demand $x(q_i)$.

The general conclusion is that there is a *non-trival interaction between horizontal and vertical tax externalities:* the presence of horizontal tax externalities arising from cross-border shopping makes it more likely that the vertical tax response will be positive.

3.3. Smuggling

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[13] as it seems that in the US, this is the main form of smuggling (Fleenor (1998)). In our model, the incentives to smuggle tax-paid cigarettes depend on the relative consumer prices. For example, if $q_1 > q_2$, smugglers can make a profit per pack of $q_1 - q_2$ by smuggling from 1 to 2. So, let the quantity smuggled from state 2 to state 1 be some increasing positive function $s(q_1 - q_2)$, with $s(0) = 0$.

Such a function can easily be generated from more basic assumptions. Suppose for example, there is a measure μ of smugglers, each of whom can transport one unit of the good. There is a distribution of costs of smuggling from state i to j (including any fines, if caught) of F on $[\underline{\kappa}, \overline{\kappa}]$. Then a smuggler with cost κ will be active iff $q_1 - q_2 \geq \kappa$, implying $s(q_1 - q_2) = \mu F(q_1 - q_2)$.

Then, assuming that the smugglers can sell all they wish in the high-price state (for example, the smugglers may shade the price by ε) the tax base in state i becomes

$$X(q_i, q_j) = \begin{cases} (1 + \rho(v(q_i) - v(q_j)))x(q_i) - s(q_i - q_j), & q_i \geq q_j \\ (1 + \rho(v(q_i) - v(q_j)))x(q_i) + s(q_j - q_i) & q_i < q_j \end{cases} \tag{3.10}$$

Using (3.10), it is easily checked that at symmetric equilibrium, the formulae (3.6) are modified as follows. The term $s'(0)$ is subtracted from X_1, and added to X_2, and the term $s''(0)$ is subtracted from X_{11}, and added to X_{12}.

There are then two cases. First, it may be that no smugglers have an incentive to respond to arbitrarily small price differentials, in which case $s'(0) = 0$. In the example above, this occurs when $\underline{\kappa} > 0$. Then, the analysis goes though completely unchanged. This, however, seems an artefact of the symmetry of the model, so the more sensible case to consider is where $s'(0) > 0$. In the example above, this occurs when $\underline{\kappa} = 0$, and $F'(0) > 0$ i.e. there is a positive density of smugglers with zero cost. In this case, the we can say the following. First, the formula (3.7) for the equilibrium tax still applies, but now $\sigma = \rho q x + q s'(0)/x$, capturing the fact that (holding individual purchases constant), smuggling makes the tax base more elastic. Second, assume further that $s''(0) = 0$ - in the

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

example, this requires that the cost distribution of smugglers is uniform. Then, formula (3.8) still applies, although now σ is modified as just described. Finally, the formula (3.9) also still applies. So, the qualitative predictions of the model are much as before.

4. Empirical Specification

Our theory suggests that t_i is a function of 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

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

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

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

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

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

and ω_{ij} are exogenously chosen weights, normalized so that $\sum_{j \neq i} \omega_{ij} = 1$. This is a widely used procedure and there is considerable discussion of the appropriate weights in the literature.[14]

We consider four possible weighting schemes for (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 for this argument are *neighbor weights*

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

[14] See Brueckner (2001) for a survey of empirical techniques.

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. In response, the home state may be more likely to match the cut with a cut in its own tax.

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

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

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[15]. A formal derivation of these weights for a more general version of the model is given in Appendix A.

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: 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' tax setting, then $t_{-i,s}$ is, almost by definition, endogenous. We therefore use an IV approach. We use the weighted average of neighbors' control variables as instruments:

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

The federal tax may also be endogenous. Following Besley and Rosen (1998), we instrument this with the federal deficit to GDP ratio. We test the validity of the instrument set using the Sargan test of overidentifying restrictions. We present standard errors that are robust to heteroskedasticity and serial correlation.

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

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. Abstracting from cross-border effects returns us to the Keen (1998) model, where the sign of γ depends on the curvature of the demand function.

Finally, it is clear from an analysis of the data, given below, that state and federal governments change nominal excise tax rates relatively infrequently. As a central case, we analyse the relationships between real values of the excise tax rates. However, there is clearly a tendency for the real value of these taxes to fall over a period of a few years, until it has reached a low enough level such that the nominal rate is increased. It seems reasonable to suppose that there is some inertia or cost which prevents the tax being raised in each year to compensate for inflation. As a robustness check, we have therefore also investigated the decision to raise excise tax rates. To do this we estimate a probit for each type of excise tax, where the dependent variable takes a value of 1 in cases where the tax rate is raised, and 0 otherwise. (There are no cases in which the nominal excise tax rate is reduced). As in (4.1), we regress this on the weighted average of other states' excise tax rates, the federal tax rates, and the same control variables.

5. Data

We constructed a panel of data from 48 US states over 21 years, 1977-1997 inclusive; i.e. 1008 observations. We do not use the two states which do not share borders with any other states, Alaska and Hawaii. For each 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.[16] (We do not allow for ad valorem taxes, since to incorporate them we would need to have reliable

[16] See www.OTPR.org.

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.

As shown in more detail in Appendix B, 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. Figures 1 and 2 present the federal cigarette and gasoline taxes in both nominal and real terms. This illustrates the nature of the changes to the nominal rates described above.

Of course, 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 and unemployment); the domestic production of the relevant commodity within each state; state economic variables (income per capital, 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 which includes the federal tax, but excludes the average of other states' tax rates. We first estimate by OLS. The control variables are jointly significant. Two stand out as being particularly significant: the proportion of young people in the state has a positive effect, as does the proportion of democrats elected to the House. State income per capita also has a positive effect.

The federal tax rate has a significant and positive impact on the state tax rate. Instrumenting the federal tax in column 2 increases the significance and also the size of the coefficient. The specification passes the Sargan test of overidentifying restrictions. Column 2 implies that a one percentage point in the federal excise tax on cigarettes tends to raise state excise duties on cigarettes on average by around 63 cents. This mirrors the results in Besley and Rosen (1998) in that the federal tax has a positive impact on state taxes. In the context of our model above, and ignoring horizontal effects (see (3.9) with $\rho = 0$), this suggests strong convexity of the demand for cigarettes, so that $x'' > -x'/t$.

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 the three 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 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. In each column, at least some control variables remain significant, although the joint significance of the control variables differs across columns; in columns 3 and 4 the control variables are jointly insignificant. The the Sargan test of overidentifying restrictions is passed in all cases.

Introducing the uniform-weighted average of other states' tax rates substantially reduces the coefficient on the federal tax rate. Its significance also falls, so that it is no longer statistically significant. In fact, moving to neighbor weights and neighbor-density weights substantially reduces the significance still further. It is clear that the federal tax rate plays no role in determining the home state tax rate, conditional on including either the neighbor-weighted or neighbor-density-weighted average of other states tax rates.

In all three cases, however, the weighted average of other states' tax rates is significant. The significance is relatively weak in column 3, but more significant in columns 4 and 5. This is to be expected since in a process of tax competition with cross-border shopping and smuggling, the tax rates of neighbors are likely to be most important. Columns 4 and 5 indicate that a unit (cent, adjusted for inflation) increase in the average of neighboring states' tax rates would induce and increase in state i's tax rate of between 0.5 and 0.75 of a cent.

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 large 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 substantially matches any increases or decreases in other states' taxes.

Before turning to gasoline taxes, we examine the role of cigarette smuggling. As described above, we construct a uniform-weighted average of the very low tax rates in Kentucky, North Carolina and Virginia, and take this to reflect the tax rates at which smugglers can obtain cigarettes. In Table 2, we then examine the role played by this average tax rate on the tax rates sets in the remaining 45 states. To start, we first reproduce column 5 of Table 1, but estimated only over these 45 states. 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 virtually identical to that in Table 1. The federal tax rate remains insignificant. More surprisingly - since the three excluded states are significant producers of tobacco and all have very low tax rates - the control variable indicating whether the state produces tobacco is now significant.

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 coefficient which is significant at the 10% level. 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, however, we include both of these variables reflecting tax rates in other states. The neighbor-density weighted average tax rate remains positive and significant, with a coefficient close to that in column 1. However, the coefficient on the average tax rate in the three low tax states drops sharply and becomes insignificant. In general, then, although there is some evidence that the opportunity for smuggling may play some role in the setting of state tax rates on cigarettes, this is dominated by the role played by cross-border shopping.

In Table 3, we turn to gasoline taxes. The estimation strategy and format of the table is the same as that for Table 1. 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, column 1 is estimated by OLS, and column 2 instruments the federal tax rate with the federal deficit to GDP ratio. The control variables are significant, and the Sargan test is passed in all 5 specifications. In column 1, the coefficient on the federal tax rate is effectively zero, and insignificant. However, when instrumented, the coefficient on the federal tax rate becomes positive and highly significant, with a coefficient of 0.75. This mirrors the equivalent result for taxes on cigarettes in Table 1. But with respect to the federal tax rate, columns 3, 4 and 5 also mirror the results in Table 1. That is, the federal tax rate plays no role in determining the home state's tax rate on gasoline, conditional on a weighted average of other states' tax rates. This is consistent with demand for gasoline being fairly inelastic, as for cigarettes.

The results of including the weighted average of other states' tax rates are similar to the case of cigarettes, with one exception. Including the uniform-weighted average results in a large, positive and very significant effect. In this case, the control variables remain jointly significant. But we have argued above that the use of uniform weights does not adequately account for the effects of cross-border shopping and smuggling. The significance remains in the case of neighbor weights, which is better evidence of competition for cross-border shopping and smuggling. However, the specification with neighbor-density weights leaves the average of other states' tax rates insignificant.

So, overall, there is again no evidence of vertical competition in gasoline taxes, conditional on including the tax rates set in other states. There is some evidence of horizontal tax competition, but this is most persuasive in the case of uniform and neighbor weights. Indeed, it is puzzling that the coefficient, which is large and highly significant in the case of uniform or neighbor weights becomes insignificant when neighbor density weights are used. As argued above, 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. This would suggest that the coefficient should be small and possibly insignificant in all three cases.

One possible explanation of the evidence from Table 3 is that there is a different form of competition between states at work. One possibility is the existence of yardstick competition (Besley and Smart (2003)). Here, state governments may match the tax policy of other states, not to compete over cross-border shopping, but because their voters look to other states to identify what are reasonable tax rates. It is quite possible that the set of "neighbors" may be rather different in this case, and may well not require geographical proximity. Voters in one state may look at the tax rates of comparable states spread across the country, rather than states with a common border.

7. Explaining Tax Changes

One feature of the federal and state nominal excise taxes is that they are changed infrequently. For example, Figure 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 Figure 1. Also, when taxes are changed, they are 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 4 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[17]. The explanatory variables are as follows. First, we include the one-period lagged value of the tax in real terms: all one-period lagged variables are denoted with an "l" prefix. The hypothesis is that if this is high, the government is less likely to adjust. Second, we include either the current or lagged federal tax and weighted average of other states' taxes. Consistent with the approach above, it is probably more natural to consider the current values - on the assumption that the home government adjusts its own tax rate conditional on current, rather than lagged values of the other tax rates. However, since the timing is not clear in theory or in practice, and because the current values may introduce endogeneity, we present both cases. We also include the cumulative inflation since the last tax increase took place (labelled "cumin"). Finally, we include all the controls - including state dummies - already used in the previous regressions.

Columns 1 and 2 present the results for cigarette taxes. Column 1 presents the case in which lagged values of the federal and the neighbor-density weighted average of other states' tax rates are included. Column 2 includes instead contemporaneous values. The lagged home state tax rate is negative and significant in both specifications, as expected: the lower the tax rate, the more likely the state government is to increase it. 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 significant in both specifications - whether lagged (column 1) or contemporaneous (column 2) . 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. More puzzling is the effect of the federal tax rate. In the lagged specification, this has a positive and significant effect. However, in the contemporaneous specification, it is insignificant.

The results for gasoline taxes in columns 3 and 4 are broadly similar. The lagged home

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

state tax rate is again negative and significant, although in this case cumulative inflation is not significant. Amongst the control variables, however, it is interesting to note that state governments are less likely to raise gasoline taxes in an election year (a factor which is not significant for cigarette taxes). For gasoline taxes, the neighbor-weighted average tax rate is significant only in the contemporaneous specification. This weaker effect of other states taxes is again consistent with the results above. In this case, the federal tax plays a negative and significant role in the lagged specification, but, as in the case of cigarette taxes, is insignificant in the contemporaneous specification. A negative effect is of course consistent with the theoretical framework, although it is not observed in the other results.

8. 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 just over 0.5 cents, implying an important effect of cross-border shopping. Although we also find some evidence of a role played by the opportunity for smuggling, this is dominated empirically by the role played by cross-border shopping.

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 2. 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 (although there is some evidence that the tax rates in other states do play a role). In fact, the federal tax is also insignificant, conditional on the tax rates in other states.

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 were broadly consistent with the main results, although there was some greater evidence of a role played by the federal tax.

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A. A Theoretical Justification for Neighbor Weights

The model is a multi-jurisdictional generalization of the model developed in Section 3 above, with unit individual demand for the good. Consumers live in any one of a number of rectangular continuous states $i = 1, ..n$. Any state i has a set N_i of states bordering it. The good is taxed by each government on an origin basis, with t_i being the unit tax in state i; and producer prices are zero. Individual demand $x(q)$ is inelastic: $x(q) = 1$ if $q \leq v$ and $x(q) = 0$ otherwise. So, in any state, we can define the *border region* as comprising that area of the state close enough to the border such that the consumers there would choose to cross-border shop for *some* possible configuration of taxes set by states. Outward cross-border shopping from a state is greatest when that state sets the maximum tax at which consumers will buy i.e. $t_i = v$, and all bordering states set zero taxes. In that case, all consumers within distance $d = v/c$ of the border will choose to cross-border shop.

Within any state, the non-border region has population q_i. Now note that if state i shares a border of length l_{ij} , with state j, each state has a border region with the other of area dl_{ij}. Following Nielsen (2001), we assume that population is uniformly distributed within each of these two contiguous border regions[18] with density δ_{ij}. Total population in each state is therefore

$$p_i = q_i + d \sum_{j \in N_i} \delta_{ij} l_{ij}$$

Consider now a consumer residing in a border region with state j in state i. She can purchase the good in the state she resides, paying t_i, or she can travel to the border of state j and buy the good there, paying $t_j + cs_j$, where s_j is the distance of this consumer from the border in state i. So, this consumer will cross-border shop if $s_j \leq (t_i - t_j)/c$. So, by this argument, $\delta_{ij} l_{ij} (t_i - t_j)/c$ citizens will cross-border shop from i to j when $t_i > t_j$. By the assumption of uniform population density in the border regions, $\delta_{ij} l_{ij} (t_i - t_j)/c$ citizens will cross-border shop from j to i when $t_i < t_j$. So, the tax revenue for state i is

$$R_i(t_i, t_{-i}) = t_i \left(p_i - \sum_{j \in N_i} \frac{(t_i - t_j)}{c} \delta_{ij} l_{ij} \right)$$

where t_{-i} is the vector of all taxes other than $i's$. Maximizing tax revenue with respect

[18] Given this definition of border regions, border regions will overlap i.e. there will be two (or possibly more) border regions co-existing in the square of area d^2 at the corner of each rectangular state. We are not concerned with this, since if d is small, then d^2 is of second-order and so the formulae for states tax revenues and the reaction functions derived from them are good approximations.

to t_i, and solving the first-order condition,

$$t_i = \frac{cp_i}{2\sum_{j\in N_i}\delta_{ij}l_{ij}} + \frac{1}{2}\frac{\sum_{j\in N_i}\delta_{ij}l_{ij}t_j}{\sum_{j\in N_i}\delta_{ij}l_{ij}}$$

So, the slope of the reaction function with respect to t_j is

$$\frac{1}{2}\frac{\delta_{ij}l_{ij}}{\sum_{j\in N_i}\delta_{ij}l_{ij}}$$

Appendix B: Variable Definitions, Sources, and Summary Statistics

Variable Name	Definition	Source	Obs	Mean	Min	Max
Tax variables						
		State level				
Stgastax	State gasoline unit tax, cents per gallon*	www.OTPR.org	1008	0.115	0.024	0.240
Stcigtax	State cigarette unit tax, cents per pack of 20*	www.OTPR.org	1008	0.165	0.014	0.504
		Federal Level				
Fedgastax	Federal unit tax on gasoline, cents per gallon*	www.OTPR.org	1008	0.079	0.04	0.119
Fedcigtax	Federal unit cigarette tax, cents per pack of 20*	www.OTPR.org	1008	0.130	0.08	0.160
Control Variables						
		State level				
Gsptob	Fraction of GSP generated by tobacco production	Bureau of Economic Analysis	1008	0.002	0	0.062
Gspgas	Fraction of GSP generated by gasoline production	Bureau of Economic Analysis	1008	0.004	0	0.046
Stun	State unemployment tax-rate	Bureau of Labor Statistics	1008	0.063	0.022	0.18
Stincpc[1]	State income per capita, $*	Bureau of Economic Analysis	1008	12558.26	8081.29	21634.69
Stdebt	State debt, $m*	Bureau of Economic Analysis	1008	4227.59	70.450	44973.25
Grantpc[2]	Grant per capita, $*	Consolidated Federal Funds Reports program US Census Bureau	1008	459.134	223.396	1022.56
Stpop[3]	State population	US Census	1008	5019343	413354	32182118
Styoung	State population between 5-17 yrs old as fraction of Stpop	US Census	1008	0.121	0.074	0.185
Stold	State population over 65 as fraction of Stpop	US Census	1008	0.197	0.154	0.265
Govtermlimit	Governor incumbent couldn't run by law	Statistical Abstract of the				

[1] The coefficients for this variable are multiplied by 10^5 in table 1 and by 10^4 table 2 regressions.
[2] The coefficients for this variable are multiplied by 10^5 in table 1 and by 10^4 table 2 regressions.
[3] The coefficients for this variable are multiplied by 10^8 in table 1 and table 2 regressions.

	(1=yes; 0=no)	United States	995	0.232	0	1
Demgov[4]	Party of winner governor (1=Dem; 1=Rep; 2=other)	Statistical Abstract of the United States	1007	0.512	0	2
Pdemh	Proportion of state House that is Democratic	Statistical Abstract of the United States	987	0.591	0.157	0.980
Pdems	Proportion of state Senate that is Democratic	Statistical Abstract of the United States	987	0.600	0.142	1
Stelection[5]	Dummy =1 when an election occurs	Statistical Abstract of the United States	1008	0.255	0	1
Inctax	Gross Federal Income Tax	Bureau of Economic Analysis	945	0.112	0.076	0.160
Cuminfl	Cumulative inflation since last rise in nominal gas tax	Our calculations	960	4.711 (cig) 3.45 (gas)	1 (cig and gas)	20 (cig and gas)
			Federal Level			
Gdp[6]	Gross Domestic Product*	OECD-Economic Outlook	1008	4898.69	2031.4	8300.8
Fedunemp	Federal Unemployment Rate	OECD-Economic Outlook	1008	6.69	4.9	9.7
			*- variable is deflated by the CPI (base year 1982)			

[4] The coefficients for this variable are multiplied by 10^3 in table 2 regressions.
[5] The coefficients for this variable are multiplied by 10^3 in table 2 regressions.
[6] The coefficients for this variable are multiplied by 10^3 in table 1 and by 10^4 table 2 regressions.

Table 1- Cigarette Tax Rate

	OLS	IV(1)	IV(2) Uniform Weights	IV(2) Neighbor Weights	IV(2) Neighbor-Density Weights
fedgastax	0.193	0.631	0.150	0.023	-0.020
	[2.27]**	[3.20]***	[1.60]	[0.10]	[0.10]
wstgastax			0.578	0.756	0.518
			[2.08]**	[4.70]***	[2.75]***
gdp	0.034	0.021	0.022	0.016	0.020
	[1.87]*	[1.13]	[1.15]	[0.87]	[1.06]
fedunemp	0.001	-0.002	0.000	0.002	0.001
	[0.28]	[0.72]	[0.07]	[0.41]	[0.31]
stpop	0.670	0.710	0.760	0.660	0.750
	[1.14]	[1.20]	[1.32]	[2.97]***	[2.72]***
stincpc	0.830	0.686	0.436	0.162	0.307
	[1.72]*	[1.37]	[0.75]	[0.28]	[0.50]
stun	0.107	0.190	0.229	-0.051	-0.024
	[0.42]	[0.76]	[1.03]	[0.17]	[0.08]
styoung	1.908	1.816	1.263	0.591	0.886
	[6.36]***	[6.02]***	[2.96]***	[1.48]	[1.89]*
stold	0.467	0.690	0.615	-0.275	-0.042
	[0.53]	[0.79]	[0.68]	[0.38]	[0.06]
gsptob	0.207	0.303	0.341	-1.082	-0.545
	[0.21]	[0.30]	[0.34]	[1.42]	[0.64]
gspgas	0.244	0.498	0.517	0.227	-0.274
	[0.40]	[0.81]	[0.92]	[0.36]	[0.46]
grantpc	-0.035	0.352	-3.555	-2.075	-0.830
	[0.01]	[0.09]	[0.71]	[0.45]	[0.19]
inctax	0.614	1.127	0.713	0.197	0.240
	[1.66]	[2.54]**	[1.97]*	[0.43]	[0.57]
demgov	-0.002	-0.003	-0.002	0.005	0.003
	[0.46]	[0.55]	[0.30]	[0.86]	[0.50]
pdemh	0.086	0.075	0.090	0.031	0.051
	[2.18]**	[1.89]*	[2.24]**	[0.65]	[1.10]
pdems	-0.018	-0.017	-0.012	-0.019	-0.006
	[0.43]	[0.41]	[0.28]	[0.51]	[0.17]
stelection	0.003	0.006	0.002	0.002	0.001
	[1.51]	[2.24]**	[1.01]	[0.80]	[0.65]
govtermlimit	-0.001	-0.003	-0.002	-0.004	-0.001
	[0.22]	[0.57]	[0.30]	[0.58]	[0.16]
Observations	974	974	974	974	974
R-squared	0.75	0.74	0.75	0.75	0.76
F Test statistic: overall significance	12.10	14.93	2.91	2.20	1.71
of control variables. -P- value	[0.00]	[0.00]	[0.002]	[0.019]	[0.079]
Sargan test statistic: validity of instruments		0.00	0.62	0.81	1.45
P- value		[1.00]	[0.77]	[0.61]	[0.19]

Robust t statistics in brackets
State effect included in all regressions
* significant at 10%; ** significant at 5%; *** significant at 1%
(1) Instruments for fedcigtax is deficitgdp
(2) Instruments for fedcigtax and wstcigtax is deficitgdp wstun wgspgas wgsptob wgovterm wstelection wstpop wstold wstyoung

Table 2- Cigarette Tax Rate(+)

	IV(2) Neighbor-Density Weights	IV(1) KNV(3) Weights	IV(2) KNV(3) and Neighbor-Density Weights
fedcigtax	-0.051	0.221	0.038
	[0.22]	[1.06]	[0.22]
wstcigtax	0.529		0.461
	[2.86]***		[2.10]**
smugstcigtax		2.152	1.084
		[1.77]*	[0.74]
gdp	0.000	0.000	0.000
	[1.23]	[2.12]**	[1.20]
fedunemp	0.001	0.000	0.000
	[0.32]	[0.13]	[0.09]
stpop	0.000	0.000	0.000
	[2.54]**	[1.21]	[2.42]**
stincpc	0.000	0.000	0.000
	[0.44]	[0.70]	[0.20]
stun	-0.025	0.260	0.072
	[0.08]	[1.13]	[0.30]
styoung	0.874	1.259	0.682
	[1.87]*	[3.06]***	[1.51]
stold	-0.237	0.437	-0.061
	[0.33]	[0.50]	[0.08]
gsptob	-5.046	-7.009	-5.230
	[1.90]*	[2.18]**	[1.87]*
gspgas	-0.331	0.391	-0.141
	[0.52]	[0.65]	[0.25]
grantpc	0.000	0.000	0.000
	[0.26]	[0.77]	[0.53]
inctax	0.222	0.852	0.430
	[0.50]	[2.26]**	[1.10]
demgov	0.004	-0.001	0.004
	[0.66]	[0.21]	[0.61]
pdemh	0.057	0.092	0.061
	[1.18]	[2.22]**	[1.25]
pdems	-0.015	-0.021	-0.014
	[0.46]	[0.50]	[0.42]
stelection	0.001	0.004	0.002
	[0.63]	[1.71]*	[1.04]
govtermlimit	0.000	-0.001	-0.001
	[0.06]	[0.18]	[0.16]
Observations	911	911	911
R-squared	0.7	0.68	0.7
F Test statistic: overall significance of control variables. -P- value	1.90	6.96	1.55
	[0.04]	[0.00]	[0.12]

Robust t statistics in brackets
State effect included in all regressions
* significant at 10%; ** significant at 5%; *** significant at 1%
(+) Kentucky North Carolina and Virginia are noth included in the regressions
(1) Instruments for fedcigtax is deficitgdp
(2) Instruments for fedcigtax and wstcigtax is deficitgdp wstun wgspgas wgsptob wgovterm wstelection wstpop wstold wstyoung
(3) Average of Kentucky North Carolina and Virginia cigarette tax rates

Table 3- Gasoline Tax Rate

	OLS	IV(1)	IV(2) Uniform Weights	IV(2) Neighbor Weights	IV(3) Neighbor-Density Weights
fedgastax	0.014	0.749	0.010	0.134	0.201
	[0.18]	[3.46]***	[0.09]	[0.54]	[0.64]
wstgastax			0.749	1.460	0.448
			[3.79]***	[3.19]***	[0.72]
gdp	-0.029	-0.364	-0.005	-0.246	-0.175
	[0.26]	[2.51]**	[0.04]	[2.09]**	[1.18]
fedunemp	-0.002	-0.009	-0.002	-0.003	-0.004
	[1.64]	[4.13]***	[1.39]	[0.98]	[1.08]
stpop	-0.030	0.020	-0.060	-0.260	-0.100
	[0.06]	[0.04]	[0.14]	[0.94]	[0.25]
stincpc	0.026	0.014	-0.009	0.036	0.041
	[0.63]	[0.32]	[0.19]	[0.93]	[0.81]
stun	0.069	0.168	0.152	0.153	0.126
	[0.49]	[1.08]	[1.07]	[1.12]	[0.84]
styoung	0.585	0.407	0.296	-0.270	0.332
	[3.27]***	[2.22]**	[1.40]	[0.83]	[1.03]
stold	0.598	0.870	0.469	0.374	0.642
	[1.03]	[1.53]	[0.78]	[0.67]	[1.07]
gsptob	0.147	0.234	0.111	-0.080	0.144
	[0.22]	[0.35]	[0.15]	[0.09]	[0.19]
gspgas	-0.059	0.258	0.035	-0.008	-0.053
	[0.11]	[0.46]	[0.06]	[0.01]	[0.09]
grantpc	-0.251	-0.482	-0.127	0.059	-0.199
	[1.18]	[2.14]**	[0.61]	[0.21]	[0.62]
inctax	-0.742	-0.349	-0.322	0.219	-0.355
	[4.28]***	[1.49]	[1.41]	[0.58]	[0.85]
demgov	-0.848	-1.297	-0.872	0.319	-1.564
	[0.37]	[0.51]	[0.38]	[0.10]	[0.56]
pdemh	0.033	0.031	0.022	-0.009	0.023
	[1.69]*	[1.47]	[1.05]	[0.40]	[1.20]
pdems	-0.021	-0.019	-0.024	-0.019	-0.021
	[1.26]	[1.20]	[1.55]	[1.15]	[1.28]
stelection	-0.853	1.616	-0.739	-0.104	-0.260
	[1.02]	[1.31]	[0.85]	[0.09]	[0.19]
govtermlimit	-0.002	-0.004	-0.002	-0.003	-0.003
	[0.97]	[1.69]*	[0.98]	[1.30]	[1.33]
Observations	974	974	974	974	974
R-squared	0.65	0.59	0.65	0.58	0.66
F Test statistic: overall significanc	9.91	29.81	2.18	1.33	1.27
of control variables. -P- value	[0]	[0]	[0.02]	[0.221]	[0.259]
Sargan test statistic: validity of instruments		0.00	0.35	1.30	1.41
P- value		[1.00]	[0.94]	[0.26]	[0.21]

Robust t statistics in brackets
State effect included in all regressions
* significant at 10%; ** significant at 5%; *** significant at 1%
(1) Instruments for fedgastax is deficitgdp
(2) Instruments for fedgastax and wstgastax are deficitgdp wstun wstincpc wgspgas wgsptob wgovterm wstelection wstpop wstold wstyoung
(3) Instruments for fedgastax and wstgastax are deficitgdp wstun wstincpc wgspgas wgsptob wgovterm wstelection wstpop wstold

Table 4- Probit estimates of cigarettes and gasoline tax changes
(neighbour weights)

	Cigtax(1)	Cigtax(1)	Gastax(1)	Gastax(1)
lstcigtax	-8.133	-9.587		
	[2.44]**	[3.35]***		
lfedcigtax	7.204			
	[2.05]**			
lwstcigtax	8.228			
	[3.53]***			
fedcigtax		2.521		
		[0.72]		
wstcigtax		11.951		
		[4.52]***		
lstgastax			-20.021	-20.477
			[4.63]***	[4.56]***
lfedgastax			-16.202	
			[2.73]***	
lwstgastax			2.064	
			[0.38]	
fedgastax				-4.557
				[0.90]
wstgastax				14.065
				[2.46]**
cuminfl	1.291	1.298	-0.098	-0.081
	[3.09]***	[3.14]***	[0.28]	[0.23]
gdp	0	0	0	-0.001
	[0.37]	[0.07]	[0.11]	[0.90]
fedunemp	0.097	0.025	-0.095	-0.061
	[1.03]	[0.24]	[1.14]	[0.66]
stpop	0	0	0	0
	[1.32]	[1.67]*	[3.66]***	[3.49]***
stincpc	0	0	0	0
	[1.07]	[0.83]	[0.63]	[0.61]
stun	5.035	2.3	14.879	15.777
	[0.90]	[0.39]	[2.49]**	[2.66]***
styoung	0.087	-2.678	5.626	-1.227
	[0.01]	[0.19]	[0.47]	[0.11]
stold	-13.492	-16.913	26.618	29.897
	[0.56]	[0.70]	[1.04]	[1.15]
gsptob	76.427	58.732	28.94	25.405
	[1.20]	[1.08]	[1.03]	[0.80]
gspgas	3.673	-4.509	-39.96	-33.428
	[0.12]	[0.15]	[1.94]*	[1.56]
grantpc	-0.002	-0.002	-0.002	-0.002
	[1.73]*	[1.43]	[1.50]	[1.72]*
inctax	-10.796	-14.941	-27.715	-18.031
	[1.01]	[1.22]	[2.73]***	[2.00]**
demgov	-0.12	-0.091	0.051	0.078
	[0.83]	[0.60]	[0.36]	[0.55]
pdemh	2.656	2.3	1.009	1.125
	[1.74]*	[1.47]	[0.86]	[1.00]
pdems	-0.085	0	-0.814	-0.626
	[0.08]	[0.00]	[1.06]	[0.89]
stelection	0.201	0.231	-0.285	-0.277
	[1.54]	[1.74]*	[2.43]**	[2.34]**
govtermlimit	-0.011	-0.029	-0.16	-0.172
	[0.07]	[0.17]	[0.79]	[0.88]
Observations	920	940	920	940
Chisq Test statistic: overall significance	43.25	31.06	67.16	66.71
of control variables. -P- value	[0.00]	[0.01]	[0.00]	[0.00]

Robust z statistics in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%
(1) State dummies included

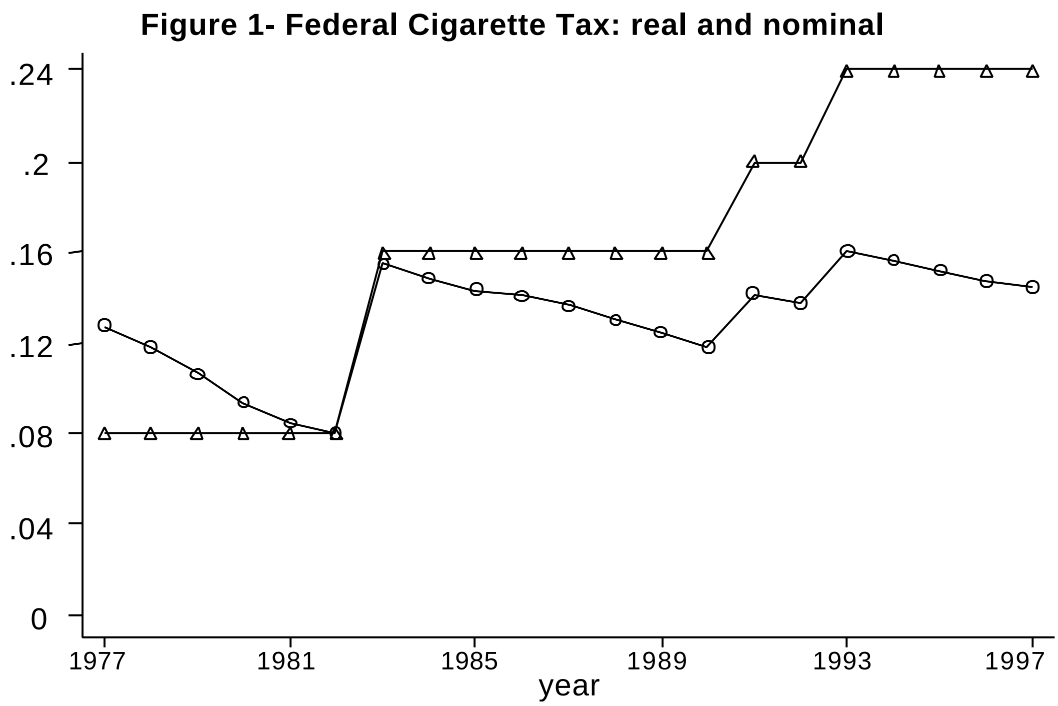
Figure 1- Federal Cigarette Tax: real and nominal
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1977
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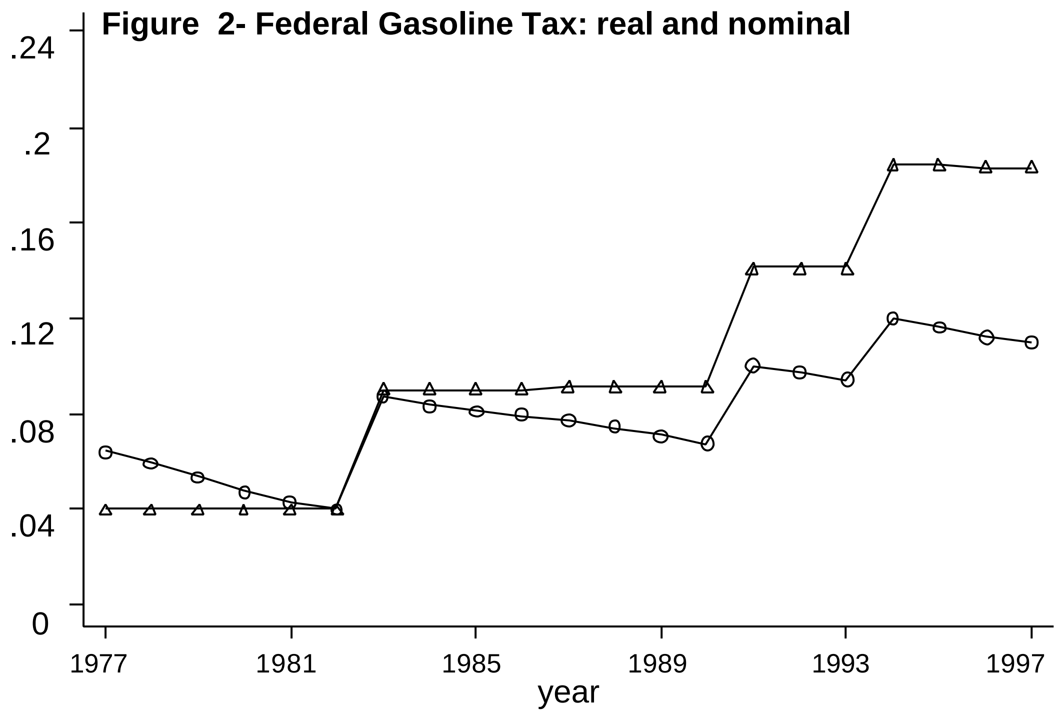
Figure 2- Federal Gasoline Tax: real and nominal
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1977
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year