Tax compliance and fiscal externalities: Evidence from U.S. diesel taxation

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Abstract

Fiscal externalities across jurisdictions can arise from tax evasion and avoidance. While the tax competition literature has generally focused on base shifting and the resulting positive fiscal externalities, we show theoretically and empirically that negative fiscal externalities can dominate when the tax base is apportioned across jurisdictions. This can lead to a negative relationship between jurisdiction size and the desired tax rate. Interstate truckers in the United States owe state diesel taxes based on diesel consumption, which is apportioned based on the miles driven in each state. We find that own-state diesel sales fall when the diesel tax rates of other states rise, suggesting that tax base evasion is the predominant source of externalities. We then estimate a tax reaction specification, finding that the own-state tax rate is negatively correlated with the tax rates set in other states and with state size, both consistent with the sign of the estimated fiscal externality.

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1 Introduction

Tax compliance and enforcement lead to horizontal and vertical fiscal externalities in tax systems. As is widely recognized by academics and policymakers, a tax increase in one jurisdiction can lead shift the tax base to lower tax jurisdictions, creating a positive fiscal externality. Traditional tax evasion, on the other hand, results in a negative fiscal externality if a transaction in one jurisdiction generates a tax liability in other jurisdictions or at other levels of government.

A familiar example illustrating these two opposing externalities is the state corporate income tax, where the tax base is apportioned among states. An increase in a state's corporate income tax can lead a company to shift operations to other states, as well as to underreport corporate income. The former increases tax revenues in other states, while the latter reduces the tax revenues of any state in which the company operates. While the latter type of externality is less emphasized in discussions of horizontal fiscal externalities, it could dominate the positive externality from base shifting if tax evasion is easy or the location of the tax base is inelastic.

In this paper, we study how tax compliance creates fiscal externalities in the context of state diesel taxes in the U.S, and we examine the effect this has on how states set tax rates. Much like how corporate income is apportioned to US states based on a company's location of sales and capital, diesel consumption by truckers is apportioned to states based on the mileage the trucker drives in each state. Apportioning diesel consumption based on state mileage sharply reduces the incentive for truckers to *avoid* taxes by purchasing fuel in low-tax jurisdictions. However, two incentives for tax *evasion* remain, which could lead to either positive or negative externalities. First, base shifting could still arise if truckers over-report the share of miles driven in low-tax states. Second, negative fiscal externalities could arise through the understatement of the tax base. A tax increase in one state may lead to a trucker reporting less diesel purchases overall, hurting revenue in all states to which those purchases are apportioned.

Whether the positive or negative fiscal externalities dominate has important implications for models of tax competition. In contrast to the case of base shifting in which tax rates in neighboring states are strategic complements, tax rates are likely to be strategic substitutes when local taxes exert negative fiscal externalities. This is because an increase in the tax of a competing jurisdiction leads to base erosion via evasion, thereby reducing the marginal revenue of the local tax rate. Furthermore, the important result of Kanbur and Keen (1993) that the desired tax rate increases with jurisdiction size may be overturned in the tax apportionment setting. The logic is as follows. More of the tax base is apportioned to a large jurisdiction, who will consequently internalize to a greater extent the impact its own tax rate has on the tax base.

We begin by estimating how the diesel excise tax rates set by other states affect own-state diesel tax revenues. To do so, we form a theoretically-motivated weighting of other states' diesel taxes that gives greater weight to the tax rates in states located on the truck shipping routes important to the home state. We find that other states' diesel tax rates are negatively correlated with own-state diesel tax revenue, suggesting that any base shifting is dominated by the effects of underreporting gallons consumed. We provide several pieces of evidence in support of this interpretation. First, we show that the negative spillovers result is driven entirely by our truck-route-based measure of competing tax rates and not by the tax rates set in neighboring states or states that are economically linked in other ways. Second, we find that fiscal externalities are less important for larger states and states for which interstate shipments are a smaller share of truck traffic. Third, in states where gallons underreporting is difficult, we see no evidence of spillovers. This bolsters the explanation that these fiscal externalities are driven by the method of taxing interstate truckers rather than other unobserved linkages between states, and that gallons underreporting is the likely explanation.

We then estimate an empirical model of tax setting to determine the sign of states' tax reaction functions, and to investigate the relationship between state size and the desired tax rate. We find that own-state diesel taxes are indeed lower when the tax rates of competing states are high. We also find that smaller states set higher tax rates. Both results are consistent with the theoretical model's predictions when negative fiscal externalities dominate.

Our paper relates to several strands of the tax literature. First, a large literature examines the fiscal externalities and the resulting strategic behavior imposed by interjurisdictional variation in tax rates.[1] Brueckner (2003) provides a excellent overview of both the theoretical literature relating to tax externalities and the empirical literature documenting horizontal tax competition with respect to cigarette, liquor, and sales taxes. Brueckner notes in this review that in a model of competition between jurisdictions where tax revenues fund purchases of public goods, reaction curves can slope either up or down depending on local preferences for public goods. In a seminal paper, Case et al (1993) show that the slope of the reaction function depends on the degree of complementarity between the own-state and other-state strategic variable in the government's objective function. While the objective function they consider is the utility for public goods whose benefits may be shared across jurisdictions, the result parallels our model where the objective function is simply government revenues and the strategic complementarity or substitutability of taxes depends on the cross-derivative of marginal revenue with respect

[1] More broadly, a very large literature examines interjurisdictional competition with respect to regulation, tax policy, and fiscal policy.

to other state taxes. The sign of the reaction curve is relevant for a tax union such as the one we study, as Konrad and Schjelderup (1999) find that when capital tax rates are strategic complements a tax union is welfare maximizing.

A number of papers have tested for both horizontal and vertical fiscal interdependence, including the setting of taxes and spending across jurisdictions. Case et al (1993) consider the reaction of state government expenditures to the spending in other states. Brueckner and Saavedra (2001) examine the strategic setting of property taxes across cities within the Boston metro area. Lockwood and Migali (2009) find evidence of increased excise tax competition for alcohol after the 1993 introduction of the EU single market. Consequently, the tax rates tend to be too low, as local jurisdictions compete over a mobile tax base. Brulhart and Jametti (2006) examine personal and corporate tax rates of Swiss cantons and find evidence that the vertical tax externalities dominate the horizontal ones. Devereux et al (2007) test for evidence of horizontal and vertical tax competition in the context of U.S. state cigarette and gasoline taxes and find that horizontal competition is more important for an easily storable good like cigarettes. Agrawal (2015) examines the sales tax rates set by local jurisdictions near and far from state borders with large state sales tax differentials and finds that local tax rates on the high and low-tax sides of the border smooth the differential in state sales taxes. Waseem (2014) shows evidence of the negative externality of evasion across tax bases, as the evasion of business income in Pakistan leads to a reduction in the VAT tax take. Buettner (2003) estimates the fiscal externalities of business taxation across neighboring German municipalities.

Another set of papers examines the relationship between tax enforcement and collections. Trandel (1992) and Lovely (1994) formalize the welfare effects of evasion and enforcement in a world with interjurisdictional tax differentials and cross-border sales. De Paula and Scheinkman (2010) and Pomeranz (2015) examine the self-enforcing nature of the value-added tax and illustrate how enforcement efforts targeting one point in the supply chain can be have effects on evasion up- and down-stream from the targeted firm. More specific to our particular setting, several papers examine evasion and enforcement in the context of fuel taxes. Marion and Muehlegger (2008) estimate the effect of a a key regulatory innovation, the dyeing of untaxed diesel, on taxed and untaxed diesel sales in the U.S. Agostini and Martinez (2012) examine the effect of audit threats on tax reporting in Chile.

Finally, our paper overlaps with issues in corporate taxation – in particular, the rules used to apportion a firm's profits across the jurisdictions in which it maintains staff, capital and sales. Gordon and Wilson (1986) highlights the implicit tax on capital and labor, the distortion to firm input decisions and the distortions to state fiscal policy created by apportioning profits based on factors that can be reallocated across jurisdictions. A more recent literature (e.g., Shackelford and Slemrod (1998), Goolsbee and Maydew (2000), Devereux and Loretz (2008), Clausing (2009), Hines (2010), and Suarez Serrato and Zidar (2016)) empirically document distortions to firm input decisions, the fiscal externalities, and the attendant effects on state fiscal policy in both the U.S. and E.U. The empirical literature finds evidence that firms set capital and labor strategically in response to the apportionment formula and interjurisdictional differences in corporate tax rates. Business mobility and endogenous allocation of labor create the incentive for states to both lower the overall corporate tax rate and shift away from apportionment based on capital and labor and towards sales. Suarez Serrato and Zidar (2016) find that after accounting for fiscal externalities and apportionment rules, current state corporate taxes are close to revenue-maximizing levels.

While recognizing the theoretical possibility of negatively sloped reaction curves, the existing literature tends to strongly emphasize the positive externalities that local taxes impose on neighboring jurisdictions due to cross-border sales, tax avoidance, or endogenous firm location decisions. This paper presents an alternative source of fiscal externalities, those arising from tax evasion and enforcement, that we demonstrate in the context of diesel fuel taxes lead to negative externalities and suggest that tax rates may be higher than they would be in the absence of the fiscal externality.

We begin by presenting a simple model of firm decisions that illustrate the relevant fiscal externalities. We then present our empirical approach and results. We conclude with a discussion of the implications of our results for other tax policies, such as taxing income from foreign sources, taxing internet transactions, and other excise taxes.

2 Tax evasion, fiscal externalities and strategic taxation

We motivate our empirical analysis by formalizing a model of tax evasion in diesel fuel markets. Importantly, taxation of diesel fuel is based on *point-of-use* – firms are responsible for taxes in the states in which they traveled rather than the states in which they purchased fuel. This sharply reduces the incentive for firms to avoid taxes by selectively purchasing fuel in low-tax jurisdictions. Yet, firms can *evade* taxes either by underreporting the total number of taxed gallons they used or by over-reporting mileage in low-tax jurisdictions. We demonstrate that the sign of the fiscal externality (and tax interaction), depend on which of the two methods of evasion dominates.

We begin by considering a lone trucking firm operating in a high-tax state and a low-tax state. We denote the tax rates as τ_1 and τ_2 and assume that the high-tax state is the first, implying $\tau_1 > \tau_2$. The firm reports two pieces of data to the tax authority: the total number of gallons of fuel purchased and the share of miles driven in the high-tax state. These two pieces of information together determine the firm's tax liability in each state. We assume that total miles driven can be easily verified by examining the odometer and thus is not manipulated by the drivers.[2] We denote the true values of gallons purchased and the share of mileage driven in the high-tax state as G and m respectively, and the amounts reported by the firm to the tax authority as $\hat{G}$ and $\hat{m}$.

The firm chooses $\hat{G}$ and $\hat{m}$ to minimize the value of the tax liability plus the cost of misreporting:

$$T = \hat{m}\hat{G}\tau_1 + (1-\hat{m})\hat{G}\tau_2 + \phi(G-\hat{G}) + \eta(m-\hat{m}) \tag{1}$$

where $\phi(.)$ and $\eta(.)$ represent the increasing, convex costs of understating gallons ($G > \hat{G}$) or underreporting the share of miles driven in the high-tax state ($m - \hat{m}$).[3] Differentiating both sides with respect to the choice variables, we have joint interior first-order conditions:

$$\phi'(G-\hat{G}^*) = \hat{m}^*\tau_1 + (1-\hat{m}^*)\tau_2 \tag{2}$$

$$\eta'(m-\hat{m}^*) = \hat{G}^*(\tau_1 - \tau_2). \tag{3}$$

Equation (2) states that at the optimal $\hat{G}$ the marginal cost of underreporting gallons is set equal to the average tax rate faced by the firm, where the tax rate of each state is weighted by the reported mileage in that state. Equation (3) states that the optimal level of underreporting use in high-tax state equates the marginal cost of mis-reporting and the magnitude of the tax differential. If the two states have identical tax rates, equation (3) implies the firm has no incentive to mis-report the location of use, although it will have an incentive to underreport total gallons.

The two first-order equations reveal that the two forms of evasion are substitutes – if the cost of evasion of a particular channel increases (due to perhaps a change in enforcement), the firm will reduce the amount of evasion occurring through that channel, but increase the amount of evasion through the other channel. Consider equation (2). A decreased ability to

[2] In this model, all fuel purchases are made in bulk with tax not included. In practice, truckers may refuel along the route, with the tax of the state in which the refueling occurs included in the price. The trucker would then receive credit for that amount when submitting the tax return.

[3] The evasion cost function reflects the cost of time and resources required to commit the tax, and the expected fines associated with detected illegal activity, both of which are plausibly increasing and convex in evasion.

misreport where miles were driven increases the weighted average tax rate faced by the firm, implying an increased return to underreporting total gallons by setting lower $\hat{G}$. Similarly, an enforcement action that improves "gallons" compliance and increases $\hat{G}$ in (3) raises the return to underreporting the share of miles traveled in the high tax state, since the effective tax rate is applied to more gallons.

2.1 Evasion and fiscal externalities

Of primary interest in the paper is how the tax base changes due to misreporting when one jurisdiction adjusts its tax rate.[4] The two first-order conditions jointly determine the optimal choices of $\hat{G}^*$ and $\hat{m}^*$, which in turn determine the tax base for each state. Differentiating (2) and (3) with respect to τ_2, we have:

$$\frac{\partial \hat{G}^*}{\partial \tau_2} = -\frac{1}{\phi''}\left[\frac{\partial \hat{m}^*}{\partial \tau_2}(\tau_1 - \tau_2) + (1 - \hat{m}^*)\right], \tag{4}$$

$$\frac{\partial \hat{m}^*}{\partial \tau_2} = -\frac{1}{\eta''}\left[\frac{\partial \hat{G}^*}{\partial \tau_2}(\tau_1 - \tau_2) - \hat{G}^*\right]. \tag{5}$$

Recall that state 1 was assumed to be the high-tax state. An increase in the tax in state 2 reduces reported gallons and increases the mileage reported in state 1. The impact on the tax base in state 1 depends on the relative importance of these two evasion responses. Suppose that firms are unable to misreport where they drive, so that $\hat{m} = m$. The first term in brackets in (4) would be zero, which would then unambiguously yield $\frac{\partial \hat{G}^*}{\partial \tau_2} < 0$. That is, an increase in τ_2 leads to fewer reported gallons and lower tax revenues. Similarly, if firms are unable to misreport gallons consumed, then the first term in brackets in (5) would be zero and $\frac{\partial \hat{m}^*}{\partial \tau_2} > 0$, i.e. an increase in the tax base in state 1.

In our empirical application. we regress the log of local taxed quantities on the log of the average other-state tax rate and the log of a state's own-tax rate. Interpreting the coefficients from the regression as elasticities, it is possible to construct analogues to the coefficients of interest in the theory model.

To do so, we extend the model above to account for firm heterogeneity and index the true and reported values of G and m by firm i. We allow the cost of evasion to differ by firm, since trucking firms may vary in the respect to which they can misreport total quantities and location

[4]We limit states to tax competition. In a related paper, Stowhase and Traxler (2005) consider a model in which states endogenously set audit probabilities and "compete" by offering more lax enforcement.

of use. For example, a local truck that makes irregular trips between two states may find it easier to misreport the location of use than a truck that travels a regular, set cross-country route, for which the state-by-state mileage along the route can be easily calculated during an audit.

The main empirical variable of interest is state-level taxed quantity, $\hat{Q} = \sum_i \hat{G}_i \hat{m}_i$. We can represent the elasticity of local taxed quantities with respect to a state's own tax rate and the tax rates in other states as:

$$\epsilon_{\tau_1}^{\hat{Q}} = \sum_i \frac{\hat{G}_i \hat{m}_i}{\hat{Q}} \left(\epsilon_{\tau_1}^{\hat{G}_i} + \epsilon_{\tau_1}^{\hat{m}_i} \right) \tag{6}$$

$$\epsilon_{\tau_2}^{\hat{Q}} = \sum_i \frac{\hat{G}_i \hat{m}_i}{\hat{Q}} \left(\epsilon_{\tau_2}^{\hat{G}_i} + \epsilon_{\tau_2}^{\hat{m}_i} \right). \tag{7}$$

The expressions are the theory analogues to the coefficients obtained from regressing the log of taxed quantities in a state on the log of a state's own-tax rate and the log of a tax rate in the neighboring state. The coefficients reflect the average of the firm-level responses, weighted by each firm's share of state-level taxed quantity.

Using two benchmarks to interpret the coefficients is instructive. If the only means of evasion is misreporting total quantities (i.e., $\frac{\partial \hat{m}}{\partial \tau_1} = \frac{\partial \hat{m}}{\partial \tau_2} = 0$), then both elasticities should be negative. If firms can only misreport the location of purchase, the elasticity of local quantity with respect to neighboring tax rates (7) is positive. If firms use both methods of evasion, the sign of the fiscal externality depends on which of the two forms of misreporting dominate.

2.2 Evasion and strategic taxation

The sign of fiscal externalities closely relates to whether the tax rates in competing states act as strategic complements or substitutes. We assume that a state sets τ_1 to maximize revenues from a representative firm, $TR_1 = \hat{G}\hat{m}\tau_1$.[5] Following the canonical result in Bulow et al (1985), whether taxes are strategic complements or substitutes depends on the sign of the effect of other states' tax rates on own-state marginal revenue with respect to τ_1. To see the intuition of this result, consider tax revenue $TR_1 = \tau_1 q_1$, where q_1 represents gallons apportioned to state 1. The cross-partial derivative of revenue is given by $\frac{\partial^2 TR_1}{\partial \tau_1 \partial \tau_2} = \partial q_1 / \partial \tau_2 + \tau_1 \partial^2 q_1 / \partial \tau_1 \partial \tau_2$. If the

[5]We think the assumption of revenue maximization not unreasonable in this context given that the fuel tax revenues tend to fund transportation infrastructure. But, states may be motivated by other objectives, such as addressing negative externalities (e.g., road wear, emissions and congestion) associated with truck traffic. If a state sets the tax rate so as to reflect the marginal external cost of truck traffic, the correlation between own-state and other-state taxes depends on whether the marginal external costs rise or fall with changes in truck traffic induced by out-of-state tax rate changes.

first-order effect of higher taxes in state 2 is that fewer gallons are taxed in state 1, this reduces desired tax rate since the revenue impact of an increase in own-state taxes is lower.

We can derive the slope of a state's tax reaction function as a function of the different forms of evasion. Taking the derivative of tax revenues with respect to τ_1 and τ_2, we have:

$$\frac{\partial^2 TR_1}{\partial\tau_1\partial\tau_2} = \frac{\partial^2\hat{G}}{\partial\tau_1\partial\tau_2}\hat{m}\tau_1 + \frac{\partial^2\hat{m}}{\partial\tau_1\partial\tau_2}\hat{G}\tau_1 + \frac{\partial\hat{G}}{\partial\tau_1}\frac{\partial\hat{m}}{\partial\tau_2}\tau_1 + \frac{\partial\hat{m}}{\partial\tau_1}\frac{\partial\hat{G}}{\partial\tau_2}\tau_1 + \frac{\partial\hat{G}}{\partial\tau_2}\hat{m} + \frac{\partial\hat{m}}{\partial\tau_2}\hat{G} \tag{8}$$

Multiplying by $\frac{\tau_2}{\hat{G}\hat{m}}$, we can represent the sign of $\frac{\partial^2 TR_1}{\partial\tau_1\partial\tau_2}$ as:

$$sign(\frac{\partial^2 TR_1}{\partial\tau_1\partial\tau_2}) = sign\left(\frac{\partial^2\hat{G}}{\partial\tau_1\partial\tau_2}\frac{\tau_1\tau_2}{\hat{G}} + \epsilon^G_{\tau_2}\left[1+\epsilon^m_{\tau_1}\right] + \frac{\partial^2\hat{m}}{\partial\tau_1\partial\tau_2}\frac{\tau_1\tau_2}{\hat{m}} + \epsilon^m_{\tau_2}\left[1+\epsilon^G_{\tau_1}\right]\right) \tag{9}$$

where $\epsilon^m_{\tau_k}$ and $\epsilon^G_{\tau_k}$ denote the elasticities of misreporting and underreporting with respect to the tax rate in state k.

The sign of the expression depends on which of the two types of evasion dominate. As before, two benchmarks are particularly instructive. If the technology of evasion only allows firms to misreport the total quantities of diesel ($\hat{G} < G$), the second-order and elasticity terms related to m drop out of equation (9). The remaining expression is negative.[6] In this case, taxes are strategic substitutes and the slope of the reaction function is negative. In contrast, if the technology of evasion only allows firms to misreport the location of use ($\hat{m} \neq m$), taxes are strategic complements and the slope of the reaction function is positive.

2.3 Strategic taxation and jurisdiction size

Whether negative or positive fiscal externalities dominate has important implications for the relationship between tax setting and jurisdiction size. Kanbur and Keen (1993) demonstrate that if taxes are strategic complements, the incentive to undercut a neighbor's tax rate depends on population density. Neilsen (2001) and Trandel (1994) find similar incentives exist when jurisdictions vary by geographic extent or when populations are distributed non-uniformly. Cutting the tax rate has two conflicting effects. On one hand, tax rate cuts increase revenue by attracting cross-border shopping. On the other hand they generate lower tax revenues from domestic consumers. In more populous jurisdictions where the domestic tax base is large (or in jurisdictions where a higher fraction of the population lives far from borders), the latter effect is large relative to the former, reducing the incentive to cut taxes.

[6] If m is fixed, equation (9) simplifies to $\frac{\partial^2\hat{G}}{\partial\tau_1\partial\tau_2}\frac{\tau_1\tau_2}{\hat{G}} + \epsilon^G_{\tau_2}$. Again holding m fixed, both terms are negative. The result for the case in which G is held fixed is derived analogously.

We demonstrate it is possible to reverse the tax setting incentives for large and small jurisdictions, if the only method of evasion is underreporting total gallons. In this setting, a large jurisdiction has an incentive to set a lower tax rate, as its tax rate has a disproportionate effect on the average tax rate faced by firms and therefore the level of evasion.[7]

We analyze how the Nash tax rates vary with the share of miles driven in state 1, m, which is analogous to jurisdiction size. We contrast two scenarios, one in which truckers only engage in mileage shifting and one in which truckers only misreport gallons. For this exercise, we make two simplifications. First, we assume that the cost of evasion function is quadratic, so that $\eta(m - \hat{m}) = \alpha_m(m - \hat{m})^2$ and $\phi(G - \hat{G}) = \alpha_G(G - \hat{G})^2$ where α_m and α_G are cost-of-evasion parameters. The second simplification we make is to normalize true gallons to one. State 1's objective function is

$$R_1 = \tau_1 \hat{m} \hat{G}. \tag{10}$$

2.3.1 Only miles shifting

Under this scenario, we assume that α_G is sufficiently high to prevent underreporting total gallons. Such a scenario might arise for carriers unable to buy fuel pre-tax. When underrerporting the share of miles driven in high-tax states is the only form of evasion, the optimal reported $\hat{m}$ is

$$\hat{m} = m + \frac{\tau_2 - \tau_1}{2\alpha_m} \tag{11}$$

Substituting this for $\hat{m}$ in the government's objective function, equation (10), and solving for the Nash equilibrium tax rates, we have:

$$\tau_1 = \frac{2}{3}\alpha_m(1 + m); \qquad \tau_2 = \frac{2}{3}\alpha_m(2 - m). \tag{12}$$

Similar to the result in Neilsen (2001), smaller states (those with a smaller miles share) wish to set lower taxes. While the mechanism here is slightly different to that in Kanbur and Keen (1993) and Neilsen (2001), it captures a similar idea. A state cutting its tax rate gains revenue from miles shifting, yet its tax base is taxed less heavily. Small and large states gain equally from miles shifting, but due to having a larger tax base, large states lose more by setting low taxes. Therefore, small states have a relatively stronger incentive to set lower tax rates.

[7] Neilsen (2002) also reverses the tax setting incentives for large and small states, by incorporating heterogeneity in the marginal cost of public funds.

2.3.2 Gallons evasion

Now instead assume that underreporting the number of gallons used is the predominant form of evasion, and that α_m is sufficiently high to prevent miles shifting. This would be the case if, for instance, true miles travelled were easily determined by examining a carrier's mileage log and odometer. The optimal reported gallons depends on the miles weighted average tax rate faced by the trucker:

$$\hat{G} = G - \overline{\tau}/\alpha_G \tag{13}$$

where $\overline{\tau} = \tau_1 m + \tau_2(1-m)$.

Substituting this into equation (10), we obtain a negative relationship between jurisdictional size and equilibrium tax rate:

$$\tau_1 = \frac{\alpha_G}{3m}; \qquad \tau_2 = \frac{\alpha_G}{3(1-m)}. \tag{14}$$

Unlike with miles shifting, gallons evasion leads to an equilibrium where the larger state sets lower tax rates. The intuition for this result is that the larger state has a greater impact on the average tax rate, which is internalized when setting the optimal tax rate on diesel.

3 Diesel fuel use and taxation

Our context is the U.S. market for diesel fuel. Diesel taxes are levied on fuel intended for on-highway use by the federal, state, and some local governments. The federal tax is 24.4 cents per gallon. Per-gallon diesel excise taxes vary substantially across states, from a low of 8 cents per gallon to a high of 35.1 cents per gallon in 2011.[8] Marion and Muehlegger (2011) finds that the burden of diesel taxes falls entirely on consumers, in this case, large trucking companies and users of commercial diesel vehicles.

Diesel tax liability for interstate truckers is based on the state of use rather than the state of purchase. Apportioning liability based on location of use offers two advantages attractive to policy makers. First, it connects revenues directly to the policy motivation for the tax, highway funding for road repair and construction associated with road use and wear. Second, it reduces the benefits to truckers of strategically purchasing fuel in low-tax jurisdictions, a likely source

[8] Although most states exempt fuel sales from state sales taxes, a small handful of states (e.g., California) levy sales taxes on diesel rather than relying exclusively on per-gallon excise taxes. State sales taxes are included as part of the IFTA assessments discussed below. Local sales taxes, in states that do not exempt fuel sales from sales taxes, are not included in IFTA assessments.

of positive fiscal externalities of great concern to state policymakers, as large diesel trucks can travel over a thousand miles between fill-ups.

Prior to the mid-1980s, the system of licensing and tax collection was decentralized. Trucks with national routes were required to report to each state individually the number of in-state miles driven and total taxes paid on fuel, and thereby collect tax rebates or pay tax bills on a state-by-state basis if gallons purchased differed from gallons consumed. To ease tax collection and compliance, the tax authorities in the lower 48 states and 10 Canadian border provinces adopted the International Fuel Tax Agreement (IFTA) in the late 1980's.[9] Under IFTA, operators register in a single base jurisdiction, to which they submit a single tax return, reporting fuel taxes paid, total fuel consumed, and road distance traveled in each member jurisdiction covering all vehicles they operate. From this information, the net tax payment due to each state is calculated, and IFTA then facilitates the settlement of tax payments between states.

With perfect compliance, taxing the location of usage rather than sales should significantly mitigate the horizontal externality created by levying local taxes on a mobile tax base.[10] Yet self-reporting mileage and fuel purchases creates two potential strategies for tax evasion by truckers. First, operators could under-report the total number of purchased gallons of diesel fuel. Commercial truckers can purchase bulk fuel pre-tax and legally use it on-highway, so long as they pay the appropriate taxes as part of the quarterly IFTA tax settlement process.[11] Second, an operator could accurately report gallonage, but over-report mileage in low-tax states and underreport mileage in high-tax states, lowering the average tax rate they face.

It is important to note that we focus on a different evasion pathway than the previous literature examining tax evasion in diesel markets. Marion and Muehlegger (2008) and Kopczuk et al. (2016) study tax evasion by the parties in the diesel fuel supply chain responsible for initially remitting on-highway taxes to the federal and state governments. Since diesel used

[9] Denison and Facer (2005) discuss the history of the IFTA in greater detail.

[10] Although truckers can no longer reduce the effective diesel tax they face by timing purchases in low-tax states, there may still be some incentive to alter the location of purchase in response to taxation. Due to the lag between when fuel is purchased and when the tax bill is settled, the present value of taxes owed could be lower. On the other hand, if the tax pass-through rate is less than 100 percent, purchasing in a high tax state may actually be desirable. In addition, a horizontal externality still may exist if long-haul truckers select cross-country routes to minimize tax costs. Given the relative tax rates, we also think this unlikely to meaningfully influence trucker decisions. A 5 cent per gallon average tax differential on a cross-country New York to Los Angeles route translates into roughly twenty dollars (assuming the fleet average of 6.5 miles per gallon) and is likely outweighed by other considerations like minimizing travel time, distance or delays related to weather, terrain, construction or traffic.

[11] Unfortunately, publicly available sources do not track the bulk diesel sales as a fraction of on-highway (taxed) sales. Purchases of bulk fuel are not limited to a firm's home state, although bulk purchases make the most economic sense in locations where a firm has a consistent demand for diesel fuel. The firm needs a physical location at which to store and dispense bulk fuel.

off-highway, such as for farming, home heating, and industry, is exempt from excise taxation, firms supplying diesel to retail stations have the incentive to divert untaxed fuel for taxed use. The previous literature finds evidence of substantial tax evasion, and that government policies that increase the cost of evasion or change the identity of the remitting party reduce tax evasion.

4 Data

We use annual, state-level data on taxed diesel quantities for 1986-2006 from the Federal Highway Statistics Annual, published by the Federal Highway Administration (FHA).[12] The FHA solicits reports from each state that contain the total gallons on which taxes were collected after any rebates, collections, taxation of bulk fuel purchases, and inter-jurisdictional tax transfers as per IFTA. The Highway Statistics Annual also reports state and federal per-gallon taxes over a similar period of time.

Data on diesel prices come from the Energy Information Administration, which provides information on the tax-exclusive price of No. 2 distillate sold to end users through retail outlets for select states from 1983 onward. The states for which diesel prices are collected are mostly located in the Northeast, Mid-Atlantic, Upper Midwest, and a handful of Northwestern states with relatively high use of home heating oil. While this EIA series does not attempt to distinguish between taxed and untaxed uses of diesel, it is likely that most purchases made by end-users through retail outlets are for on-road use, with a smaller portion intended for agriculture. Diesel used for home heating, industrial processes, powering trains, or other common untaxed uses is not sold through retail outlets. Since state-level data is available for only a subset of states, we assign to the state the regional average diesel price.[13] So that all states are treated symmetrically, we do this both for those states where prices are directly observed and for those where prices are not observed. To the extent that true diesel prices vary within region, it is worth noting that this will introduce measurement error. This measurement error is likely to be small. For those states where we have price data, 98.6 percent of the variation in prices is explained by the regional prices. After taking out date-effects, 29 percent of the remaining variation in state prices is explained by variation in prices across regions.

[12] Quantities are available for all fifty states, however we drop Oregon from our sample due to the idiosyncratic way they tax trucking. In Oregon, commercial firms can elect to pay a weight-mile tax that varies with vehicle weight and the number of axles in lieu of per-gallon diesel fuel taxes.

[13] Regional prices are reported for five Petroleum Area Defense Districts that correspond to groups of states with common sources of refined petroleum products. For example, the upper-midwest (PADD 2) obtains refined products from a combination of local refineries and refineries in Texas, Oklahoma and Louisiana that deliver product through dedicated pipelines.

4.1 Weighted average tax in competing states

The standard approach in the literature assesses tax competition by forming a weighted average of other states' tax rates: $\tau_{-i} = \sum_{j \neq i} w_{ij} \tau_j$. A critical step is defining the weights w_{ij}, so that more "relevant" states are given greater weight. From the firm's first-order condition in equation (2), an interstate trucker evades based on the average tax rate faced along the route, weighted by the number of miles driven in each state. State i's tax base will therefore depend on the average of these route-specific tax rates, weighted by the route's importance for truck traffic in state i.

To calculate our proposed measure of τ_{-i}, we first form the average diesel tax rate along every possible trucking route, weighted by the distance in each state and leaving out i's tax rate. We then average these route tax rates across routes on which state i is situated, weighting by the value of shipments along each route. The resulting expression can be re-arranged to form a non-symmetric weighting matrix W with elements

$$w_{ij} = \sum_k I_{i \in k} V_k D_{jk} / (V_i D_k) \tag{15}$$

where k indexes trucking route, V_k is the value of goods shipped along route k, D_{jk} is the distance traveled in state j along route k, and $D_k = \sum_{j \neq i} D_{jk}$ is the total distance along route k excluding the distance in i. The weight w_{ij} is meant to approximate the portion of total miles driven in state j on routes state i is situated. Total miles is approximated by distance in state j times the volume of trade along the route, measured by the dollar value.[14]

We operationalize this approach using shipping information from the Commodity Flow Survey (CFS), which is based on survey data from thousands of firms in mining, manufacturing, wholesale, and select retail industries. Respondents are asked about the weight and value of a sample of outgoing shipments by destination, mode of transportation, and commodity category.[15] We define the set of possible routes K based on all city-pairs provided in the CFS.[16] We then calculate the distance in miles along the shortest possible driving route between the centroids of the endpoint cities.

The value of shipments, V_k, is based on the value of bilateral shipments traveling between

[14]We give further details of the weighting scheme, including the theoretical motivation, in an online appendix available from the authors.

[15]Shipments to and from the fifty US states and the District of Columbia are covered, though shipments passing through the US from a foreign origin and heading to a foreign destination are not included. Industries not covered by the survey include transportation, construction, agriculture, and most retail sectors.

[16]Origins or destinations outside of major cities are referred to in the data as "Rest of state", which we treat as though it were a city.

the endpoint cities by truck from the 2007 CFS.[17] We use a static measure of bilateral truck flows, which will be invariant to changes in state tax rates. Some bilateral flows are not reported in the CFS, most commonly due to sampling error, which usually only occurs for smaller, more distant origin-destination pairs. We therefore set missing values to zero.[18]

We also consider several other possible weighting schemes consistent with the fiscal externalities literature. These include: (1) equally weighting states neighboring i, (2) assigning a weight of one to the neighboring state with the minimum tax rate, (3) weighting neighboring states in proportion to diesel sales, and (4) using a similar approach as in equation (15) using the value of non-truck shipments in place of V_i and V_k. The various measures are highly correlated, though sufficient independent variation remains to establish our preferred measure as the primary driver of fiscal externalities.

4.2 Summary statistics

In Table 1 we present the summary statistics of the data. The average state-year in our data has a tax rate on diesel of 19 cents per gallon. Along with the average federal tax of 21.6 cents per gallon, taxes represent a large portion of the purchase price of diesel, which was 92.3 cents per gallon pre-tax on average in our sample. Own-state shipments constituted the majority of truck shipments. Of the total value of shipments originating in a state, 73 percent is accounted for by own-state destinations. Lastly, for much of the sample, wholesale distributor remittance was most common, as 69 percent of state-years collected the diesel tax at this level of the supply chain. Another 18 percent of state-years experienced diesel tax collection from prime suppliers. Both of those figures mask the gradual shift over time away from collecting from retail stations.

Figure 1 presents three maps illustrating the geographic variation in taxes: at the beginning and end of the sample (Panels A and B), as well as the change in tax over this time (Panel C). Outside of southern states, which tend to have low tax rates and have increased their taxes slowly over the study period, the maps offer little evidence of strong geographic patterns in either the level or change in diesel taxes.

[17] We have also calculated weights from the 2002 CFS, obtaining qualitatively similar results.

[18] The Freight Analysis Framework produced by the Federal Highway Administration imputes the missing values, but we are concerned that variables endogenous to the tax rate are used in the imputation. The FAF estimates from 2007 indicate that the CFS covers 66 percent of truck shipments.

5 Results

5.1 Fiscal externalities

We test for fiscal externalities by examining the relationship between the gallons of diesel on which taxes were collected and the average tax rate in other states. Although in many contexts in which taxes are levied based on the location of purchase (e.g., cigarettes sales), we expect fiscal externalities to be positive, truckers are taxed based on the location of use. Thus, we would not necessarily expect a strong relationship between local quantities and the tax revenues in neighboring states if all truckers were tax-compliant. Yet, fiscal externalities may arise, as the theoretical model notes, if firms engage in tax evasion either by: (1) underreporting total gallons, and (2) misreporting usage in high-tax and low-tax jurisdictions.[19] The first would lead state tax rates to impose negative externalities on neighbors – as a firm's average tax bill rises, it might be inclined to underreport total gallons. The second would lead to positive externalities – similar to cross-border sales, high tax rates in a neighboring jurisdiction would increase reported local miles and local tax revenues.

As a starting point, we consider the following specification, regressing the log taxed quantity on a weighted average of other states' tax rates

$$Log(q_{it}) = \alpha_i + \gamma log(\tau_{-it}) + \beta_1 Log(p_{it}) + \beta_2 Log(1 + \frac{\tau_{it}}{p_{it}}) + \theta X_{it} + \delta_t + \epsilon_{it}. \tag{16}$$

The main coefficient of interest in equation (16) is γ, which captures the effect of other state taxes τ_{-it}. Our primary approach in measuring this variable weights the tax rate of another state based on its share of miles driven in trucking routes passing through state i, as described in Section 4.1. According to our model of tax competition, the sign of the coefficient γ will determine whether other states' tax rates are strategic substitutes or complements for own-state taxes. The intuition is as follows. If higher tax rates in other states reduce the number of own-state taxed gallons, then the marginal revenue from an increase in the own-state tax rate will be lower, thereby reducing the revenue maximizing tax rate.

We split the own-state tax inclusive price into its two components, the log of the pre-tax price (p_{it}) and the log of the own-state tax rate ($1 + \tau_{it}/p_{it}$), and separately estimate coefficients for both terms. Normally, the coefficients β_1 and β_2 are expected to be the same, since they enter

[19]We think it unlikely that drivers would underreport mileage. A vehicle's odometer provides an easy way to verify reported miles travelled. While mileage, if used in conjunction with estimates of a vehicle's unladen fuel economy, might provide a theoretical upper bound of the amount of underreported gallons, actual fuel economy depends heavily on terrain, load, and vehicle operation and is substantially lower than a vehicle's unladen fuel economy, and thus allows a driver ample latitude to underreport fuel purchases.

linearly into the tax-inclusive price $p_{it} + \tau_{it}$. Evasion could create a difference in the response of taxed gallons to prices and taxes.[20] There is no reason for the estimated coefficient γ to be related to either β_1 or β_2 in a similar manner. The variable $log(\tau_{-i})$ is in different units, and furthermore in theory the response to other-state taxes is distinct from own-state taxes. We also include additional explanatory variables related to: (1) local economic conditions (unemployment rate and state GSP), (2) tax administration (the identity of the party responsible for remitting state taxes) and (3) demand for untaxed diesel fuel (heating degree days and heating degree days interacted with the fraction of households using diesel fuel for heat).

Following Buettner (2003), our most rich specification allows for serial correlation in the dependent variable by including the lagged dependent variable as a regressor.[21] As noted by Nickell (1981), the within estimator is inconsistent in a dynamic panel with a relatively small number of time periods, in our case twenty years of annual data. Rather than estimate the within estimator above, we estimate the first-differenced specification

$$\Delta Log(q_{it}) = \gamma \Delta log(\tau_{-it}) + \beta_1 \Delta Log(p_{it}) + \beta_2 \Delta Log(1 + \frac{\tau_{it}}{p_{it}}) + \theta \Delta X_{it} + \nu \Delta Log(q_{i,t-1}) + \delta_t + \epsilon_{it}. \tag{17}$$

Although the first-differenced specification may also be inconsistent, we further estimate the Arellano-Bond GMM estimator (Arellano and Bond (1991)) using three lags and above as instruments and demonstrate our coefficients of interest are not substantially affected.[22]

Table 2 presents our main set of results. Columns (1) through (5) report the estimates from the first-differenced specification (17). Columns (6) through (8) report the Arellano-Bond estimates. Of primary interest is the coefficient on the log of the weighted tax rate in other states. In our base specification, we weight other states' taxes by the value of bilateral shipments between state i and each of its trading partners. We see a negative and statistically significant coefficient on the log of other states' taxes, implying negative fiscal externalities – as other states increase tax rates, own state revenues fall. Interpreting the magnitudes, a one-standard

[20] In Marion and Muehlegger (2008), we demonstrate that in markets with evasion, it is important to allow taxed gallons to respond differently to changes in the pre-tax price and changes in the tax rate. If firms increase evasion in response to a change in the tax rate, we should expect quantities to change more in response to taxes than prices. Salience could similarly drive a wedge between β_1 andβ_2, but since the consumer only sees the price inclusive of the tax, and because truckers are likely to pay more attention to taxes than a typical consumer, salience is unlikely play a role in this marekt.

[21] Buettner (2003) estimates a similar specification, except that own-state and other-state tax rates enter in levels.

[22] As a further check, we also consider IV specifications of Table 2 that use own-state gasoline taxes and similarly weighted averages of other-state gasoline taxes as instruments for diesel taxes. We describe the validity of the IV in section 5.5, below. Our results do not qualitatively change when we instrument in this fashion. We present the results in an online appendix available from the authors. Furthermore, we also consider specifications in which we allow for region-specific trends in taxed gallons to better account for potential spatial correlation in tax rates. We do not find that our results change with the inclusion of region-specific trends.

deviation increase in the other states' taxes (3.0 cpg) is associated with a 6.5 percentage point reduction in a state's taxed gallons. This result remains as additional covariates capturing diesel demand shifters are included in the model and does not substantially change using the consistent Arellano-Bond estimator.

In column (1), we report estimates from a specification omitting the additional explanatory variables related to local economic conditions, tax administration and demand for heating oil. We do not find that the inclusion of these covariates substantially changes the estimated coefficients of interest. Although not dispositive, this suggests that unobserved trends in economic activity are unlikely to be correlated with own-state and neighboring state tax rates.

Since both tax rates and taxed gallons are likely to be serially correlated, in the specification shown in column 3, we include a control for the lag of the dependent variable. The coefficient on the lag of log taxed gallons is -0.35 and statistically significant.[23] The inclusion of this control has little effect the primary coefficient of interest. A one standard deviation increase in in the other states' taxes (0.22 log points, or approximately 4.3 cpg from the mean) is associated with a 8.6 percentage point reduction in a state's taxed gallons.

Our hypothesis is that tax compliance by truckers works through two channels – a positive fiscal externality via misreporting where miles were driven, and a negative fiscal externality from underreporting the number of gallons consumed. We posit that shifting miles should be easier for trucks operating between neighboring states, rather than trucks travelling long distances. In the former case, a trucker need only alter the recorded odometer reading when crossing state lines, or report an alternative route that passes through a lower tax jurisdiction (even if that route was not actually the one taken). In contrast, cross-country routes may follow interstates for which the distance travelled in each state is more easily audited. In column (4), we indirectly examine this hypothesis by including the equally weighted average tax rate of neighboring states in our base specification. Conditional on the τ_{-i} weighted by truck shipments, the tax rates of neighboring states is more likely to show the effect of the positive fiscal externality.

We show the estimates of this specification in column (4) of Table 2. As with the base specification, the truck-shipment weighted tax rate exerts a negative influence on own-state revenue; the magnitude of the coefficient is modestly larger. In contrast, we find evidence that a higher tax rate in neighboring states leads to *higher* own-state revenues conditioning on the the truck-shipment weighted tax rate. The coefficient is positive, relatively precisely estimated, but

[23] Bond (2002) suggests that the within estimator is biased downward when estimated with OLS. However, the estimated negative coefficient on the lagged dependent variable in the first-differenced specification in our case is more likely due to serially correlated reporting errors. Taxed gallons are sometimes unusually smaller or larger than average one year, and this is reversed the next year.

close to zero, and statistically different from the truck-shipment weighted tax rate at a p-value of .102.

The own-state tax rate could affect taxed gallons through a traditional demand response, through forms of evasion discussed in Marion and Muehlegger (2008) and Kopczuk et al (2016), as well as through the misreporting of miles or fuel consumption in the current setting. As own-state taxes rise, trucking companies would both report using fewer gallons and report more of their miles being driven in other states. We find that the coefficient on the log of the local tax rate is of greater magnitude than the coefficient on the log of the pre-tax price. The more negative point estimate on a state's own tax rate suggests that taxed quantities decline more with an increase in taxes than changes in the pre-tax price. The relative magnitudes of the coefficients on taxes and prices are consistent with both types of evasion – as local taxes rise, firms are more likely to both underreport fuel usage as well as misreport local mileage.

Aggregate demand and output in other states is also likely to affect own-state diesel tax revenues, since the economic health of trading partners translates into more trade and therefore more truck shipments. This could bias our estimates of γ if taxes are set endogenously. In column (5) we include the weighted average of other state's Gross State Product (GSP) and unemployment rate, again using the truck route value weighting matrix W used to form the averages of these variables for other states. We see that indeed the GSP of a state's trading partners is positively correlated with own-state diesel tax revenues. The inclusion of these coefficients slightly attenuates the coefficient estimate γ from -0.47 to -0.37, yet the coefficients remain statistically significant.

Columns (6) through (8) present the results from the consistent Arellano-Bond estimator, using three lags and above as instruments. The estimated coefficients of interest do not change substantially from the OLS specifications. The estimates in columns (6) and (7) are virtually identical to the first-difference estimates in (3) and (4) respectively. In the most rich specification (column (8)), the point estimate of γ declines somewhat so as to no longer be statistically significant. The relatively close estimates of the two models suggests that inconsistency of the first-difference estimator in our dynamic panel is not driving our empirical results.

To further establish that the behavior of the trucking sector is likely to be the source of the fiscal externality, we consider several other weighting schemes. These weights will suggest geographic or economic linkages between states, but will not be directly related to the degree of truck traffic. In Table 3, we show estimates of our base specifications under the alternative weighting strategies. In the specifications shown in columns (1)-(5), we include each measure in turn. When considered in isolation, the coefficieints for some of the alternative weighting schemes are negative and statistically significant, proportional to the correlation between the alternative weighting scheme and the truck-shipment weighted tax.[24] The coefficient on the truck shipment-weighted tax rate is -0.39. The alternative measures weighting taxes by (1) a weight of one for the minimum neighboring state, (2) equally-weighting the neighboring states, (3) weighting by the quantity of diesel consumed in each state, and (4) by the value of non-truck shipments have estimated coefficients of -0.11, -0.18, -0.14, and -0.38 respectively.

In columns (6)-(9) we show the effects of including both our preferred weighted tax rate measure and each of the alternatives together and confirm that it is the correlation with the truck-shipment weighted tax rate that drive the signficant coefficients for the alternative weighted schemes when considered in isolation. Despite the different measures of the weighted tax rate being highly correlated, only the preferred measure weighted by truck-route shipments has a statistically significant effect on own-state revenues. This is not due to being less precisely estimated. In each case, the coefficient on the alternative measure is substantially smaller, and in three of four cases has a smaller standard error.

5.2 Estimate by state size and importance of interstate trucking

To bolster our interpretation of the fiscal externality estimates, we allow the effect of other state taxes to depend on two variables that capture how sheltered a particular state might be from the horizontal externalities imposed by neighboring states: state size and the share of a state's shipments that occur within state. For a state that is not on interstate trucking routes or ships all goods internally, we expect that the taxation of diesel in other states will have no impact on own-state diesel tax revenues since none of the miles driven by locally-registered trucks will occur in other states. We can directly measure the value share of own-state shipments using the CFS. State size offers a second proxy for the importance of interstate shipping. Additionally, state size also captures one element of the ease of evasion – a trucker registered in a small state will on average be closer to their home base when travelling outside the state. It is at their home base where they can refuel using pre-tax bulk fuel.[25]

[24]For reference, the correlation between the truck-shipment weighted tax and the alternative weighting schemes is 0.56, 0.87, 0.84 and 0.98 for the minimum neighbor tax, a simple average of neighbor tax rates, a quantity weighted average of neighbor tax rates and non-truck-shipment weighted tax rate.

[25]To provide further evidence in support of this channel, we examined the 2002 Vehicle Inventory and Use Survey, which surveyed truckers regarding a number attributes and characteristics, including where truckers primarily fuel their vehicles, their home state, and the portion of miles driven out-of-state. Using only those who drive diesel fueled vehicles, we split truckers by whether their home-base state is above or below the median in terms of area. Among interstate truckers (those with positive miles driven outside their home-base state), 36 percent reported primarily fueling at their home base in small states compared to 23 percent in large states. Therefore, evasion will be more

In Table 4, we present the results of introducing the interaction of other state taxes τ_{-it} with in-state shipping share and state size. The interaction between state size and τ_{-it} is positive and statistically significant, as predicted. The direct effect of τ_{-it} is -2.11, while the coefficient on the interaction term is 0.17. To interpret the coefficient magnitudes, compare the effect of τ_{-it} for the smallest and largest states in the dataset, with a log area of 7.34 and 12.50 respectively. The effect of τ_{-it} is -0.86 in the smallest state, while virtually zero (-0.015) in the largest state. The results are similarly striking when τ_{-it} is interacted with in-state shipment share. The point estimate of the direct effect of other state taxes is -1.22, while the coefficient on the interaction term is 1.19. Taken together, this estimate implies that diesel revenues in a state with no interstate trucking would be virtually unaffected by the diesel tax rates set in other states.

5.3 Estimate by opportunities to evade

The opportunities for evasion by trucking firms differ when fuel taxes are levied upstream rather than downstream. We use this to provide evidence that the fiscal externalities are a result of evasion by exploiting state-level variation in the point at which taxes are collected. U.S. states choose to collect taxes at one of three different parties in the supply chain: (1) the wholesale terminal operators who store fuel in bulk tanks near most major metropolitan areas, (2) the distributors who trucks the product from the storage terminals to the retail stations, and (3) the retail station operators themselves.[26] If taxes are levied sufficiently downstream, trucking firms may be able to purchase bulk fuel pre-tax, making it easier to underreport gallons and tax liability.

We extend our base specifications above to estimate separate models for each of the three diesel fuel collection regimes. Table 5 presents the results. We find that the fiscal externalities are greater in states that choose to collect from the distributors, precisely the situation in which trucking firms might be able to purchase bulk fuel pre-tax. In contrast, we find little evidence of fiscal externalities when the taxes are collected from wholesale terminal operators. In this case, it is more difficult for trucking firms to purchase bulk fuel at a point in the supply chain before taxes are levied. This supports the explanation that these fiscal externalities are driven by the method of taxing interstate truckers rather than other unobserved linkages between states, and that gallons underreporting is the likely explanation.

feasible for a greater portion of gallons purchased by truckers in small states.

[26] See Kopczuk et al (2013) for more detail about variation in the point of tax collection.

5.4 Falsification check using gasoline

We next conduct a falsification check to support our conclusion that the fiscal externalities in diesel tax collections are driven by tax compliance in interstate trucking. To do so, we estimate the relationship between gasoline tax collections and the gasoline taxes set in other states, using the same weighting matrix used in the baseline specifications. Doing so addresses an alternative explanation that states are economically linked and face common shocks that may influence both tax revenues and the desired tax rate.

Although several papers document that tax avoidance (through cross-border purchases) are relevant for gasoline, we argue, consistent with Devereux et al (2007), that the benefits of and scope for evasion are much greater for diesel fuel. Unlike diesel fuel, retail stations account for almost all of U.S. gasoline sales. Stations sell the vast majority of gasoline to non-commercial vehicles, and sell all gasoline at a tax-inclusive price. Also, cross-border shopping for gasoline is less prevalent, as the typical gasoline consumer crosses state boundaries less frequently than a trucker. Manuszak and Moul (2009), in the context of the Chicagoland area, estimate that consumers are willing to travel to the low-tax side of the border in order to save 6-8 cents per gallon for each mile they must travel. Doyle and Samphantharak (2008) find evidence that avoidance has modest effects on tax pass-through, although the effects diminish quickly with distance from the border. Thus, estimating fiscal externalities for gasoline provides a falsification test for our interpretation of the diesel results. If we find similar fiscal effects for gasoline, where the scope for evasion is significantly less, it would suggest that the fiscal externalities in both markets are due to some characteristics of local fuel taxation rather than diesel tax evasion.

We estimate our base specifications, regressing the change in taxed gasoline volumes on the change in other-state gasoline taxes, and we show the results in Table 6. As before, we separately estimate coefficients for a state's own tax-exclusive price and own tax rate. In addition, all specifications include identical explanatory variables to the main first-differenced specification for diesel. In each of the five columns of this table, we include one of the weighting schemes used in Table 3 for other-state gasoline tax rates. Across all specifications, we find that the estimated effect of other-state gasoline taxes on own-state gasoline tax revenues are precisely estimated, yet statistically indistinguishable from zero.

5.5 Tax Setting

A key question is how the presence of fiscal externalities affects the tax rates chosen in equilibrium. In this section, we provide estimates of the reaction of a state's tax rate to that of its neighbors. As mentioned in the theory section, when tax externalities are positive, the tax reaction curve is upward sloping. That is, when increases in other states' tax rates lead to increases in own-state revenue, there is an incentive to lower taxes in response to lower taxes by competing states.

Estimating the reaction function is complicated by the fact that the observed tax rates are an equilibrium. To identify the slope of the reaction function, one needs some sort of exogenous variation in the tax rates chosen by other states. We take an instrumental variables approach, using the rate of gasoline taxation as an instrument. The gas tax rate is attractive as an instrument for two reasons. First, gasoline taxes and diesel taxes are strongly correlated. In Figure 2, we plot the change in the weighted average diesel tax rates of other states against the similarly weighted average of other states' gasoline taxes. There is a strong, close to linear, relationship between these two variables. Second, the evasion response that is the source of the tax externality in this paper is unlikely to be affected by the gasoline tax. Gasoline is irrelevant for the vast majority of diesel users.[27]

We include the lagged dependent variable (following the approach in Devereux et al (2007)) to account for serial correlation in the dependent variable. Doing so introduces correlation with the fixed effect, and as they do we instrument for the lagged dependent variable using the Arellano-Bond estimator with lags three and up.[28] The equation we estimate is therefore

$$\tau_{i,t} = \beta_0 + \beta_1 \tau_{-i,t} + \beta_2 \tau_{i,t-1} + BX_{it} + \gamma_i + \rho_t + \epsilon_{it} \tag{18}$$

where as before $\tau_{-i,t}$ is the weighted average of other states' tax rates.

In Table 7, we present estimates of equation (18). The first three columns of this table show OLS estimates of own-state diesel tax rates on the weighted average of other states' diesel tax

[27] Gasoline and diesel taxes are both used as sources of revenue for infrastructure projects and are often signed into law as part of state infrastructure legislation. The recent California infrastructure bill provides one example the gasoline excise tax will increase by 12 cents per gallon and the diesel tax will increase by 20 cents per gallon on Nov 1, 2017. But, importantly, our identification strategy largely relies on first-differenced changes in taxes and revenues. Possible confounders (e.g., higher taxes leading to better infrastructure leading to more truck traffic) should change gradually as infrastructure investments are made slowly over time, whereas the gasoline and diesel taxes change abruptly following a change in taxes. Using the California infrastructure bill as an example, the gasoline and diesel excise taxes changed abruptly in 2017, but will fund infrastructure investment over the subsequent decade, one goal set by the highway measure is for 98 percent of highway pavement to be in good or fair condition by 2027. Moreover, although many states earmark gasoline and diesel tax revenue for infrastructure projects, those projects also include subsidies for public transportation, law enforcement and other disbursements that are less likely to affect routing decisions by long-distance truckers.

[28] Revelli (2015) provides an excellent critique of spatial lag models. In particular, it notes that alternative specifications of spatial lag models often rely on very similar functional forms, where the outcome is a function of lagged terms of spatially correlated explanatory variables. As a result, the sign and general strength of the coefficients may be more informative than the point estimate.

rates. Consistent with the predictions of the model of tax setting, we see that other states' tax rates are negatively correlated with the own-state tax rate. A ten-cent increase in other states' tax rates is associated with a 1.8 cent reduction in own-state taxes. In column (3), we present estimates of a specification that also includes the average tax rate of neighboring states. The coefficient on the truck-route weighted average tax rate rises to -0.42. In the taxed gallons specifications, we saw that the average tax rates of neighboring states is positively, but imprecisely, correlated with taxed volumes after conditioning the average tax rate of the state's shipping partners. Consistent with this result, the estimates shown in column (3) indicate that the own-state tax rate responds positively, albeit insignificantly, to the tax rates set in neighboring states.

In columns (4)-(5) we show the corresponding IV estimates. The results are generally similar in sign and remain statistically significant, although they are smaller in magnitude. When both the shipment-weighted and average neighbor tax rates are included, the IV estimates on the shipment-weighted tax rate is negative and statistically significant. The coefficient on the truck-route based competing tax is -0.095, and the coefficient on the average neighbor tax is 0.028. This is consistent with the fiscal externality results, which indicated that own-state revenues were decreasing in the tax rates of other states sharing truck routes and increasing in the tax rates of neighboring taxes. Theory suggests that the former tax rate should therefore be strategic substitutes, while the latter should be strategic complements.

5.6 Tax competition and jurisdiction size

Finally, we examine how jurisdiction size affects the desired tax rate. The sign of the relationship between tax rates and state size depends on the sign of the fiscal externality. In the models of Kanbur and Keen (1993) and Neilsen (2001), the fiscal externality arises from cross-border shopping, which would correspond to the "miles shifting" form of evasion in our setting. In those models, cutting taxes has two opposing effects: a negative mechanical effect, where the domestic tax base is taxed at a lower rate, and a positive behavioral effect where cross-border shopping is induced. In states with a small tax base, the mechanical effect is relatively small compared to the behavioral effect, so in equilibrium small jurisdictions set lower taxes.

Conversely, the sign of the correlation between jurisdiction size and tax rates may flip if, as we find, taxes exert negative externalities on competing jurisdictions. In this case, small jurisdictions can set higher taxes without substantially affecting the average tax rate faced by truckers. Consequently, our model predicts a negative relationship between state size and diesel taxes in the present empirical setting.

To test this, we correlate state taxes with state size. We must adjust our approach to estimating our baseline empirical model of tax setting, since differencing sweeps out state fixed effects, including state size. Rather than estimating (18) in first-differences, here we instead estimate a fixed effects model in levels, and then examine the relationship between the estimated fixed effects and state size. The state fixed effect is the state's average tax rate conditional on covariates. In Figure 3 we plot the state fixed effects against log of state area in square miles. Consistent with the theoretical predictions, we find a negative relationship between state size and fuel taxes. Larger states, that might exert especially large influence on the average fuel price paid by truckers, tend to set lower taxes. The magnitude of this relationship is plausible, as the slope of the linear fit -4.90. This implies that a one standard deviation increase in a state's size (corresponding to 1.04) would be associated with a diesel tax rate 5.1 cents lower.

6 Conclusion

In this paper, we demonstrate a novel source of fiscal externalities that may result from tax evasion. We highlight two forms of tax evasion particularly relevant to diesel fuel markets: (1) truckers may understate the total number of gallons purchased, and (2) truckers may overstate use in low-tax jurisdictions and understate use in high-tax jurisdictions. Interestingly, the fiscal externalities generated by each of these forms of evasion push in opposite directions. While misstating the location of use generates positive fiscal externalities, underreporting of taxes tends to impose negative fiscal externalities on competing jurisdictions. As the average tax paid by a firm increases, the firm underreports to a greater degree which adversely affects both a jurisdiction that changes a tax as well as other relevant jurisdictions. Empirically, we demonstrate evidence consistent with evasion-driven fiscal externalities in the context of diesel fuel markets. We further find evidence of negative fiscal externalities, consistent with underreporting of gallons being the primary form of evasion in which truckers engage. Finally, we find evidence that state diesel taxes exhibit strategic substitutability, consistent with negative fiscal externalities.

Our work has implications for tax competition in other contexts. Of particular relevance is the taxation of internet commerce that faces similar incentives for evasion and tax competition as discussed in Goolsbee (2000, 2001) and Einav et al (2014). Similar issues arise related to the apportionment of corporate income, which requires self-reported information by jurisdiction from firms on payroll, property, and sales. In industries for which misreporting of capital and labor (e.g., resource extraction) are more difficult, our results suggest that firms may shift evasion towards misstating overall profits rather than misreporting inputs and sales by jurisdiction.

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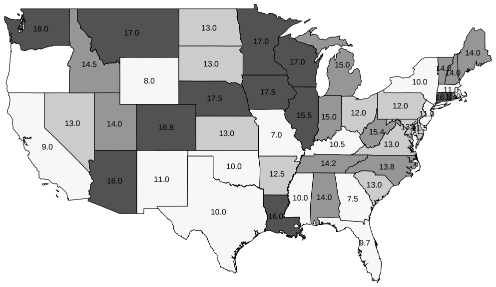
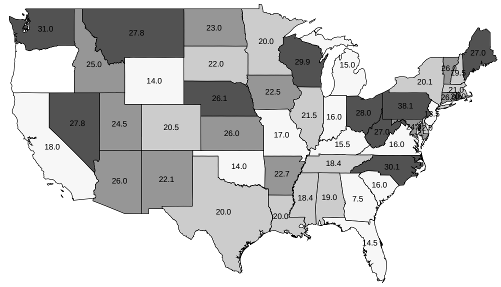
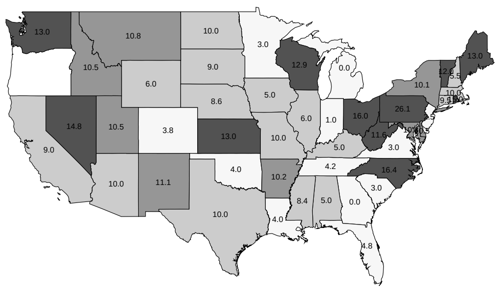
Figure 1: Diesel tax rate per gallon by State



(a) 1986



(b) 2006



(c) Change, 1986-2006

Figure 2: Change in real other states' tax rates, diesel versus gasoline (truck route value weighted)

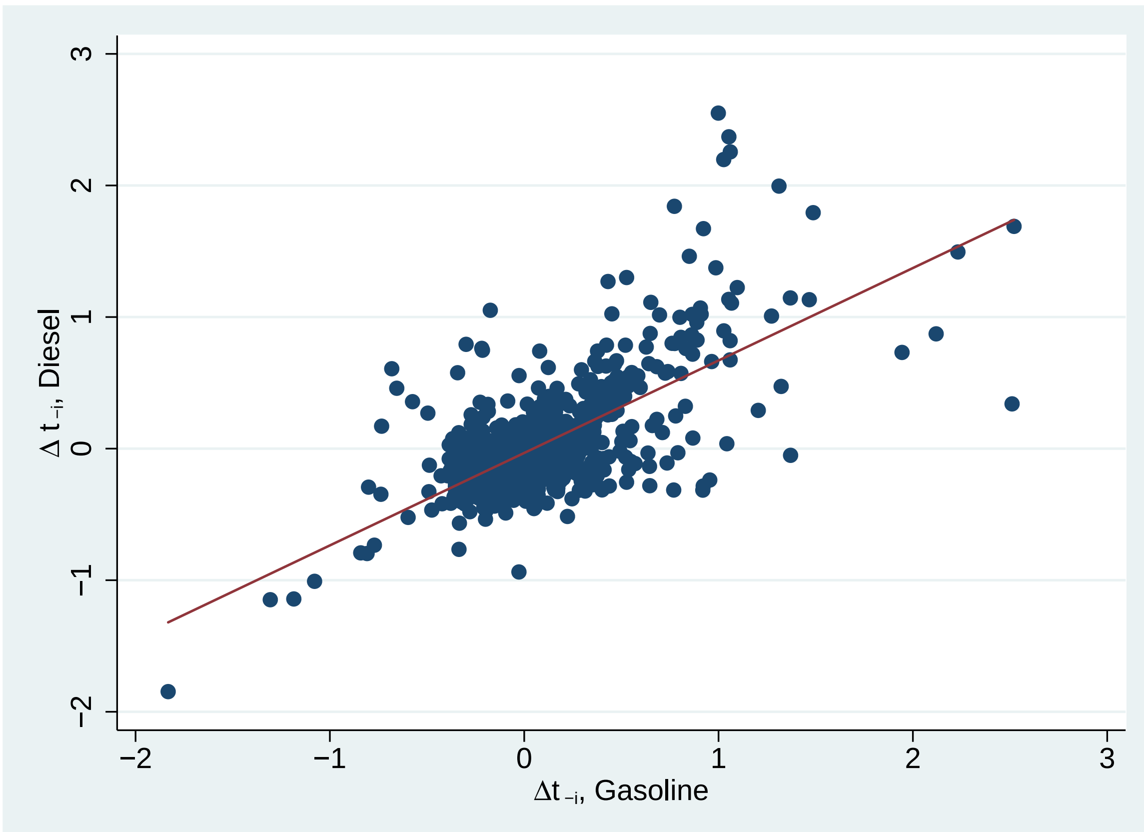


Figure 3: Conditional average tax rate by state and state size

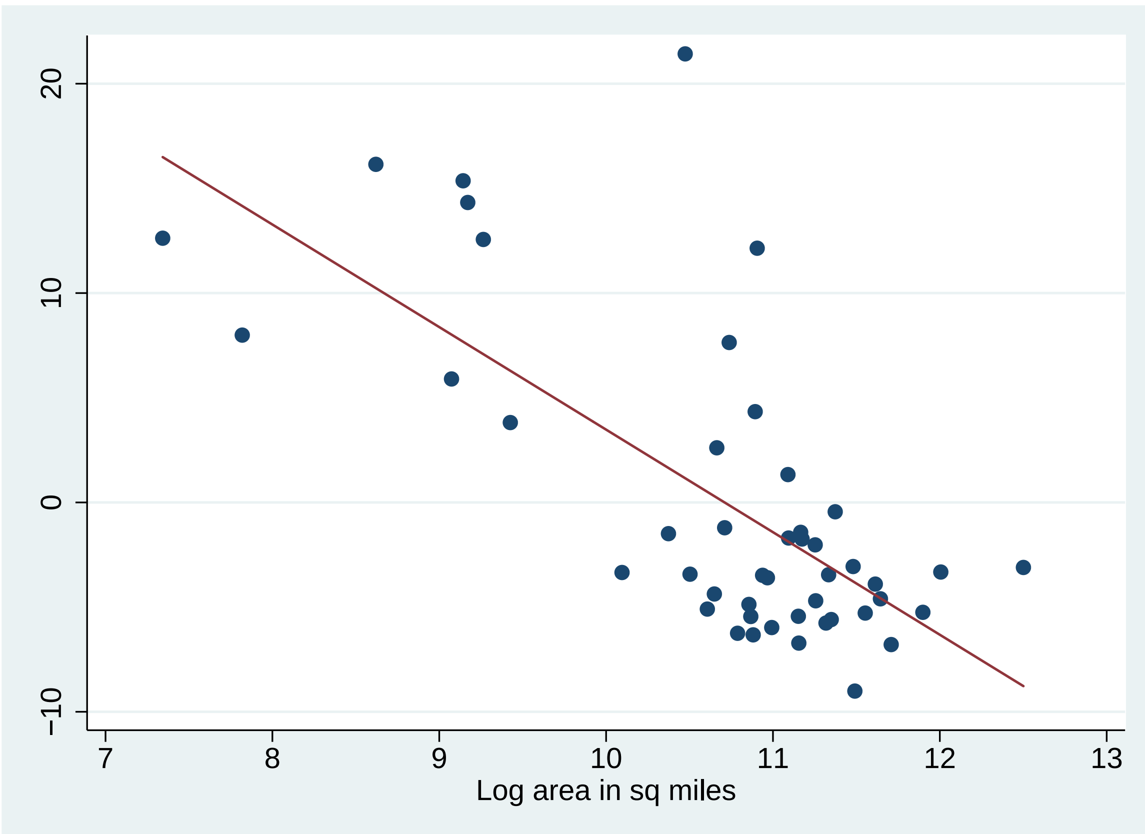


Table 1: Summary Statistics

	mean	sd	min	max
Prime supplier sales (000s gal)	2098.81	2182.51	0.00	16145.20
Taxed diesel sales	1580.48	1402.44	99.08	10950.84
Tax-exclusive diesel price (cpg)	92.30	41.73	55.73	230.91
State diesel tax (cpg)	19.03	4.99	7.00	38.10
Federal diesel tax (cpg)	21.63	3.86	15.00	24.40
State gas tax (cpg)	18.70	4.89	7.00	37.50
Federal gas tax (cpg)	15.63	3.86	9.00	18.40
Minimum neighbor tax	14.05	4.30	7.00	24.25
Mean neighbor tax	18.79	3.42	10.34	26.92
Other state tax, truck value weighted	18.51	3.01	8.93	25.34
Unemployment rate	5.24	1.54	2.24	12.43
Annual degree days	5181.61	2045.78	476.00	10547.00
Fraction In-state shipping	0.73	0.10	0.42	0.92
Supplier-remitted	0.18	0.38	0.00	1.00
Distributor-remitted	0.69	0.46	0.00	1.00
Observations	987			

Table 2: Tax rates of other states and taxed gallons

	First-difference					Arellano-Bond		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log t_{-i}, Truck route value weighted	-0.44*	-0.33*	-0.39***	-0.47**	-0.37*	-0.40***	-0.47**	-0.24
	(0.23)	(0.18)	(0.14)	(0.20)	(0.21)	(0.12)	(0.20)	(0.21)
Log t_{-i}, Neighbors equally weighted				0.06	0.04		0.05	0.01
				(0.12)	(0.12)		(0.12)	(0.12)
Log price	-0.38*	-0.40**	-0.47**	-0.48**	-0.44**	-0.20	-0.20	-0.16
	(0.19)	(0.18)	(0.19)	(0.19)	(0.18)	(0.17)	(0.17)	(0.17)
Log tax rate	-0.56***	-0.53***	-0.71**	-0.72***	-0.67**	-0.41*	-0.42*	-0.38*
	(0.19)	(0.18)	(0.25)	(0.25)	(0.25)	(0.23)	(0.23)	(0.23)
Other states' unemployment rate					-0.02			-0.03**
					(0.02)			(0.01)
Other states' log GSP					0.24			0.30
					(0.47)			(0.19)
Lagged dependent variable			-0.35***	-0.35***	-0.36***	0.31***	0.31***	0.27***
			(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.06)
Other covariates		X	X	X	X	X	X	X
Observations	940	940	940	940	940	940	940	940
R-Squared	0.12	0.14	0.25	0.25	0.25			

Standard errors clustered by year are in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% level, respectively. Columns (1) - (5) report estimates from the first-differenced OLS specification. Columns (6) - (8) report Arellano-Bond estimates using lags three and higher. All specifications include year fixed effects. The other covariates are log GSP, unemployment rate, log degree days, log degree days interacted with household heating oil use, and indicators for the remitting party.

Table 3: Tax rates of other states and taxed gallons

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log t_{-i}, Truck route value weighted	-0.39***					-0.32**	-0.47**	-0.45**	-1.03*
	(0.14)					(0.15)	(0.20)	(0.16)	(0.56)
Log t_{-i}, Minimum neighbor tax		-0.11				-0.06			
		(0.07)				(0.07)			
Log t_{-i}, Neighbors equally weighted			-0.18*				0.06		
			(0.09)				(0.12)		
Log t_{-i}, Neighbor diesel q weighted				-0.14*				0.03	
				(0.07)				(0.07)	
Log t_{-i}, Non-truck ship. weighted					-0.38**				0.77
					(0.14)				(0.60)
Log price	-0.47**	-0.47**	-0.46**	-0.46**	-0.48**	-0.46**	-0.48**	-0.47**	-0.46**
	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)
Log tax rate	-0.71**	-0.63**	-0.65**	-0.63**	-0.70**	-0.69**	-0.72***	-0.72***	-0.71***
	(0.25)	(0.27)	(0.27)	(0.27)	(0.26)	(0.25)	(0.25)	(0.24)	(0.24)
Observations	940	940	940	940	940	940	940	940	940
R-Squared	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Standard errors clustered by year are in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% level, respectively. The dependent variable is the log of taxed gallons of diesel. All specifications include year fixed effects, log GSP, unemployment rate, log degree days, log degree days interacted with household heating oil use, and indicators for the remitting party. All variables are first-differenced.

Table 4: Revenue externality and state size

	(1)	(2)	(3)
Log t_{-i}, Truck route value weighted	-2.11**	-1.22*	-2.11**
	(0.81)	(0.66)	(0.81)
Log t_{-i} X Log state area	0.17**		0.19***
	(0.08)		(0.06)
Log t_{-i} X In-state share shipments		1.19	-0.27
		(0.85)	(0.83)
Log price	-0.50**	-0.48**	-0.50**
	(0.19)	(0.19)	(0.19)
Log tax rate	-0.70**	-0.70**	-0.70**
	(0.25)	(0.26)	(0.25)
Observations	940	940	940
R-Squared	0.26	0.26	0.26

Standard errors clustered by year are in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% level, respectively. The dependent variable is the log of taxed gallons of diesel. All specifications include year fixed effects, log GSP, unemployment rate, log degree days, log degree days interacted with household heating oil use, and indicators for the remitting party. All variables are first-differenced.

Table 5: Revenue externality by tax collection regime

	Retailer		Distributor		Prime Supplier	
	(1)	(2)	(3)	(4)	(5)	(6)
Log t_{-i}, Truck route value weighted	0.26	0.24	-0.49***	-0.70***	-0.35	0.35
	(0.25)	(0.47)	(0.11)	(0.23)	(0.48)	(0.85)
Log t_{-i}, Neighbors equally weighted		-0.12		0.15		-0.57
		(0.32)		(0.15)		(0.42)
Log price	0.35	0.38	-0.37	-0.62*	-0.33	-0.34
	(0.46)	(0.60)	(0.34)	(0.31)	(0.33)	(0.32)
Log tax rate	0.12	0.54	-0.51	-0.79*	-0.97*	-0.92*
	(0.65)	(0.79)	(0.44)	(0.40)	(0.50)	(0.48)
Observations	124	111	675	641	175	175
R-Squared	0.33	0.33	0.25	0.27	0.32	0.33

Standard errors clustered by year are in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% level, respectively. The dependent variable is the log of taxed gallons of diesel. All specifications include year fixed effects, log GSP, unemployment rate, log degree days, log degree days interacted with household heating oil use, and indicators for the remitting party. All variables are first-differenced.

Table 6: Gasoline tax rates and taxed gallons

	(1)	(2)	(3)	(4)	(5)
Log gas price	-0.25**	-0.18*	-0.30***	-0.31***	-0.25**
	(0.10)	(0.09)	(0.08)	(0.08)	(0.10)
Log gas tax rate	-0.36**	-0.28*	-0.48***	-0.48***	-0.36**
	(0.15)	(0.16)	(0.14)	(0.14)	(0.15)
Log t_{-i}, Truck route value weighted	0.01				
	(0.07)				
Log t_{-i}, Minimum neighbor gas tax		-0.03			
		(0.03)			
Log t_{-i}, Neighbors equally weighted			-0.05		
			(0.07)		
Log t_{-i}, Truck value, bilateral				-0.03	
				(0.09)	
Log t_{-i}, Non-truck value, route					0.04
					(0.08)
Lagged dependent variable	-0.07	-0.07	-0.00	-0.00	-0.07
	(0.08)	(0.09)	(0.07)	(0.07)	(0.08)
Observations	1033	892	940	940	1033
R-Squared	0.10	0.10	0.12	0.12	0.10

Standard errors clustered by year are in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% level, respectively. The dependent variable is the log of taxed gallons of gasoline. All specifications include year fixed effects, log GSP, unemployment rate, log degree days, log degree days interacted with household heating oil use, and indicators for the remitting party. All variables are first-differenced.

Table 7: Tax Rate Reaction to Other States' Tax Rates

	First-difference			Arellano-Bond	
	(1)	(2)	(3)	(4)	(5)
t_{-i}, Truck route value weighted	-0.18*	-0.19*	-0.42*	-0.08*	-0.10**
	(0.10)	(0.10)	(0.24)	(0.05)	(0.04)
t_{-i}, Neighbors equally weighted			0.19		0.03
			(0.20)		(0.05)
Real gas tax				0.12	0.12
				(0.09)	(0.09)
Lagged dependent variable		-0.07	-0.07	0.74***	0.74***
		(0.05)	(0.05)	(0.10)	(0.10)
Observations	940	940	940	987	987
R-Squared	0.06	0.06	0.07		

Standard errors clustered by year are in parentheses.
*,**,*** denote significance at the 10%, 5%, and 1% level, respectively. The dependent variable is the state quantity tax on diesel. The other covariates are the lag of the dependent variable, year effects, log GSP, unemployment rate, log degree days, log degree days interacted with household heating oil use, and indicators for the remitting party. All variables are first-differenced. Columns (1) - (3) present the first-differenced OLS estimates. Columns (4) - (5) present estimates from an Arellano-Bond approach using lags three and up. In these specifications, the weighted average of other states' gasoline tax rates is used to instrument for other states' diesel tax rate.

A Online Appendix

A.1 Further details of weighting

Suppose there are K possible interstate trucking routes. Let the distance traveled in state j along route k be D_{jk}. The average tax rate along route k, leaving out state i, is

$$\tau_{ik} = \sum_{k \neq i} D_{jk}\tau_k / D_k \tag{19}$$

where $D_k = \sum_{j \neq i} D_{jk}$ is the total distance along route k excluding the distance in i.

The measure τ_{-i} averages τ_{ik} for routes involving i.

$$\tau_{-i} = \sum_{k} I_{i \in k} V_k \tau_{ik} / V_i \tag{20}$$

where $I_{i \in k}$ is an indicator for state i being on route k, V_k is the value (or tons) of bilateral truck trade along route k, and $V_i = \sum_k I_{i \in k} V_k$ is the sum of the weighting variable, the total value of trade along routes that i is on. We assume that the value of traffic along route k is proportional to the number of trips along the route.

By substituting (19) into (20) and re-ordering the summation, we can get an expression for the weighting matrix:

$$\tau_{-i} = \sum_{j} \tau_j w_{ij} \tag{21}$$

where

$$w_{ij} = \sum_{k} I_{i \in k} V_k D_{jk} / (V_i D_k). \tag{22}$$

A.1.1 Example illustrating weighting approach

Suppose that state 1 is situated on two shipping routes, A and B. The distance along each route is M_A and M_B, of which m_1 is within state 1 for both routes. The true gallons used to make a single trip on route A are $G_A = gM_A$, which are determined by fuel efficiency (gallons-per-mile g) multiplied by the number of miles. Due to evasion, only $\widehat{G_A} = f(\overline{\tau_A})G_A$ gallons are reported, where the function $f(\overline{\tau_A})$ is the fraction reported and depends on the average tax rate $\overline{\tau_A}$ faced by the trucker along the route. To arrive at the total reported gallons from route A across all shippers, multiply the number of gallons used for one trip by the number of shipments: $\widehat{G_A}S_A$, where S_A represents the number of shipments.

Under the apportionment formula, the total tax base in state 1 can therefore be expressed as

$$G_1 = \frac{m_1}{M_A}\widehat{G_A}S_A + \frac{m_1}{M_B}\widehat{G_B}S_B. \tag{23}$$

Substituting for $\widehat{G_A}$ and $\widehat{G_B}$ and rearranging, we obtain

$$G_1 = m_1 g[f(\overline{\tau_A})S_A + f(\overline{\tau_B})S_B]. \tag{24}$$

Take a first-order approximation of $f(.)$ around some level of the tax τ_0: $f(\tau_A) \approx f(\tau_0) + f'(\tau_0)(\tau_A - \tau_0)$. If $\tau_0 = 0$, then $f(0) = 1$ since with no tax all gallons are reported. The approximation of (24) then becomes

$$G_1 \approx m_1 g[S_A + S_B + f'(0)(\tau_A S_A + \tau_B S_B)] \tag{25}$$

Refer to the term $f'(0)$ as γ and factor out $S_A + S_B$:

$$G_1 \approx m_1 g(S_A + S_B)[1 + \gamma\overline{\tau}] \tag{26}$$

where $\overline{\tau} = (\tau_A S_A + \tau_B S_B)/(S_A + S_B)$ is the average tax rate of routes along which state 1 is situated, weighted by the number of shipments along each route. If $\gamma\overline{\tau}$ is small, then after taking logs we have the approximation

$$log(G_1) \approx \beta + \gamma\overline{\tau} \tag{27}$$

where β is a constant. In the empirical calculation of the theoretical $\overline{\tau}$, shipment value is substituted for the number of shipments. This assumes that the number of shipments along a route is proportional to the value of shipments. This assumption would be violated if the value per shipment is not independent of the variables of the model, for instance if it was not economical to ship goods with a low per-unit value long distances. This motivates our robustness check using shipments in tons rather than value to weight the route's average tax rate.

A.2 IV results for fiscal externality

Table A1: Taxed gallons including gasoline tax IV

	First-difference					Arellano-Bond		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log t_{-i}, Truck route value weighted	-0.38*	-0.34	-0.44**	-0.72*	-0.60	-0.41***	-0.49*	-0.092
	(0.19)	(0.25)	(0.16)	(0.36)	(0.44)	(0.14)	(0.27)	(0.29)
Log t_{-i}, Neighbors equally weighted				0.21	0.20		0.054	-0.035
				(0.24)	(0.24)		(0.16)	(0.16)
Log price	-0.47**	-0.53**	-0.55**	-0.58**	-0.54**	-0.21	-0.22	-0.17
	(0.21)	(0.22)	(0.23)	(0.23)	(0.24)	(0.19)	(0.19)	(0.18)
Log tax rate	-1.31**	-0.91	-0.96	-1.03*	-0.96	-0.44	-0.46	-0.40
	(0.52)	(0.59)	(0.57)	(0.58)	(0.59)	(0.30)	(0.30)	(0.29)
Other states' unemployment rate					-0.020			-0.032***
					(0.022)			(0.012)
Other states' log GSP					0.21			0.33*
					(0.44)			(0.19)
Lagged dependent variable			-0.36***	-0.36***	-0.36***	0.32***	0.31***	0.27***
			(0.054)	(0.052)	(0.052)	(0.052)	(0.053)	(0.055)
Other covariates		X	X	X	X	X	X	X
Observations	1080	940	940	940	940	940	940	940
R-Squared	0.11	0.14	0.25	0.25	0.25			

The columns replicate the specifications from Table 2, further instrumenting for own-state and neighboring-state diesel taxes using own-state and neighboring state gasoline taxes (similarly weighted). Standard errors clustered by year are in parentheses.
*,**,*** denote significance at the 10%, 5%, and 1% level, respectively. The dependent variable is the log of taxed gallons of diesel. The other covariates are year and state effects, log GSP, unemployment rate, log degree days, log degree days interacted with household heating oil use, and indicators for the remitting party.