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Tax Evasion and Commodity Tax Incidence: Theory and Evidence from Diesel Fuel Sales

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Abstract

In this paper, we provide new evidence regarding the incidence of diesel taxes on prices. We find that both state and federal diesel taxes are fully and immediately passed on to consumers. We also investigate how incidence depends on tax evasion, the elasticity of residual supply, the capacity utilization of refineries, and inter-jurisdictional purchases. In prior work, we find in Marion and Muehlegger (forthcoming) that diesel tax compliance improved dramatically following the addition of red dye to diesel intended for untaxed uses. In this paper, we show that this improvement in compliance had at most a small effect on tax incidence. We show that this is consistent with the predictions of a tax incidence model in the presence of evasion. We next provide two empirical results relating the elasticity of supply and incidence. First, the elasticity of residual supply of taxed diesel should be greater when untaxed uses of diesel are more important, and consistent with this we provide evidence that tax pass-through is greater in cold months in states that use diesel intensively for home heating, an untaxed use. We also find that only half of the diesel tax is passed on to consumers when U.S. refinery capacity utilization is above 95 percent. Finally, we find that large states have a greater pass-through rates, which is consistent with a model where state size is positively associated with the cost of purchasing across state lines.

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1 Introduction

State and federal diesel taxes combined currently represent over fifty cents per gallon in some states, and over the past twenty years, taxes have on average represented in excess of thirty percent of the retail price of diesel. Understanding how the burden of tax is distributed between consumers and producers of diesel is important for several reasons. Much of the current policy debate regarding fuel taxes centers around the extent to which taxes are passed on to the consumer, and how this pass-through may depend on current capacity utilization. Whether the proposed "gas tax holiday," which would suspend the gasoline tax during the peak driving season, would provide relief to the consumers depends on the extent to which lowering taxes reduces the tax inclusive retail price. Furthermore, recent proposals have made carbon taxes an important part of reducing carbon emissions. The extent to which gasoline and diesel taxes can reduce carbon emissions hinges on the degree to which taxes raise the user cost of fuel.

Despite the central importance of incidence in the current policy debate, there is sparse evidence regarding the extent to which taxes are incorporated into retail prices, as noted by Poterba (1996) and Doyle and Samphantharak (2008). In particular, there is to our knowledge no prior empirical work on the incidence of diesel taxes. In this paper, we examine the incidence of diesel excise taxes using state-level variation in taxes and prices. We then examine how incidence depends on fuel tax evasion, the supply elasticity, refinery capacity utilization, and opportunities for interjurisdictional purchases.

We begin by incorporating tax evasion into the standard specific quantity tax model. Due to the potential for misreporting the sale of gallons intended for on-highway travel, for which diesel taxes are owed, as intended for non-taxed uses such as home heating, there has traditionally been a significant degree of tax evasion in this market. (see Marion and Muehlegger, forthcoming) As Slemrod and Yitzhaki (2000) note, evasion could significantly alter the distributional consequences of a tax. In our model, there is a quantity tax paid by suppliers, who can underreport the amount of taxable gallons sold by incurring an evasion cost. We distinguish firms by their marginal cost of tax evasion. When all firms have the same marginal cost of evasion, the incidence of the tax on the consumer price is identical to the case where evasion is not possible, provided a nonzero amount of taxed gallons are reported. This is because firms evade until the marginal cost of evasion is equal to the tax rate, which indicates that in equilibrium firms' marginal cost is identical with or without evasion. Therefore, evasion merely shifts surplus from the government to producers, leaving consumer surplus unchanged. Conversely, if the cost of evasion is sufficiently disperse, some firms will find it in their interest to report no taxable diesel sales. For these firms, the constraint that they report a nonnegative level of taxed gallons is binding, which drives a wedge between the marginal cost of evasion and the tax rate. The marginal cost of these full-evaders will therefore differ from the no-evasion marginal cost. The degree to which taxes are passed through to consumers will be affected by evasion depending on the prevalence of full-evaders in the market.

In addition, we consider an extension in which both producers and consumers can purchase from lower tax jurisdictions. As an alternative to either evading or complying instate, firms can choose to travel to a nearby location and truck diesel from a lower tax jurisdiction. Like firms choosing to evade taxes, a firm purchasing solely from a lower tax jurisdiction will base her decision on the tax rate in the neighboring jurisdiction rather than the local tax rate. As the size of the jurisdiction decreases, more suppliers will travel to lower tax states. The tax elasticity of supply should be positively correlated with the size of the jurisdiction. At the same time, we allow purchasers of taxed diesel (largely truckers) to choose their state of purchase. As the size of the jurisdiction decreases, consumers' cost of avoidance declines - as a result, the instate demand becomes more elastic with respect to taxes as the size of the jurisdiction declines. Thus, border-crossing by consumers or producers should shift the burden of taxation more heavily towards producers, especially in small jurisdictions where cross-border travel by consumers and producers is less costly.

The empirical component of the paper starts by establishing results regarding the incidence of the diesel tax on the price paid by consumers. We utilize changes within states over time in taxes and prices to identify the effect of taxes on prices. Our findings indicate that the diesel tax is fully passed on to consumers. Increases in state diesel taxes of one cent per gallon lead to an increase in the state retail price of 1.08 cents. Furthermore, the tax is fully realized in the price of diesel in the month of the tax change. This identification strategy will be biased if tax changes are correlated with supply conditions such as capacity utilization. However, we find that these factors are generally unsuccessful at explaining state tax changes.[1]

We then proceed to examine how this incidence coefficient depends on tax evasion, supply conditions, and cross-border smuggling. In October 1993, new regulations were implemented dictating that prime suppliers add a red dye to untaxed forms of diesel to curtail evasion by distinguishing these gallons from gallons intended for taxable on-road use. Marion and Muehlegger (forthcoming) showed that this resulted in a marked improvement in tax compliance, as

[1]Decker and Wohar (2006) also consider factors shaping state diesel taxes. However they do not examine capacity conditions or neighbor's tax rates, two factors of particular interest to our study. Devereux et al (2007) considers the response of state gasoline taxes to the taxes of other states and the federal government, and Besley and Rosen (1998) consider the tax competition between states and the federal government.

sales of taxed gallons immediately rose by 25 percent in the month of the implementation of the program. Here, we show that, consistent with theory, this had only a small and statistically insignificant impact on the incidence of taxation.

We also provide evidence that more of the tax is passed through to consumers when the residual supply elasticity of diesel is greater. Number 2 distillate can either be sold as diesel fuel or as heating oil. When the heating oil demand is high relative to diesel, this increases the residual supply elasticity of diesel. We find that pass-through is greater during times when heating oil demand is higher, such as in cold months in states where a greater fraction of households use heating oil to heat their homes.

Similarly, very high capacity utilization, indicating a reduction in supply elasticity, is associated with less pass-through of diesel taxes. While taxes are fully passed through in months where refinery capacity utilization is below 95 percent, pass-through falls to 58 percent in the highest capacity utilization months. A diesel tax holiday in the high capacity summer months would therefore likely be shared equally by consumers and producers.

We lastly consider how opportunities for inter-jurisdictional purchases, as measured by state size, affect tax incidence. We find a noticeable effect of state size on incidence as a ten percent increase in state size increases the pass-through rate by 0.7 percentage points. Moreover, this effect is entirely concentrated in the post-diesel dye period. After the dye program was implemented, the same ten percent increase in state size increases the pass-through rate by 1.3 percentage points.

Little empirical evidence exists considering the incidence of commodity taxes on prices in general, and specifically in the fuel markets. To our knowledge ours is the first study to consider the incidence of diesel fuel taxes. Chouinard and Perloff (2004,2007), and Alm et al (forthcoming) provide evidence regarding the incidence of gasoline taxes on retail prices. Doyle and Samphantharak (2008) examine the effects of a gas tax moratorium on prices at the gas station level in Illinois and Indiana. More generally Poterba (1996) examines the incidence of retail sales taxes on clothing prices, Besley and Rosen (1999) consider city-level prices across twelve commodities, and Barnett et al (1995) examines the incidence of cigarette excise taxes.

The paper proceeds as follows. Section 2 presents the model and derives the incidence results. Section 3 provides background details regarding the diesel fuel tax and Section 4 describes the data and empirical methods we will use. Section 5 presents the empirical results, and Section 6 concludes.

2 Model

In this model, we consider a quantity tax of t per unit of a good, which is paid by the supplier. A unit mass of firms sell a quantity q of this good to consumers at the tax inclusive price p, which is produced at cost $C(q)$ where $C'(q) > 0$ and $C''(q) > 0$. Consumers have an aggregate demand for the product given by $D(p)$. Firms are able to evade the tax by underreporting the quantity of the taxable good sold to consumers. Denote the level of underreporting by q_u and the amount of good for which the tax is paid by q_t. The misreporting comes at a heteroegenous evasion cost of $C_e(q_u, \gamma)$, which can be thought of as the resource cost to the firm of hiding underreported quantities, as well as penalties the firm incurs in the event it is caught by the tax authorities. Firms differ according to their evasion cost parameter, γ, which is distributed $F(\gamma)$. We assume the cost of evasion is convex and increasing in the amount of misreporting, $\frac{\partial C_e}{\partial q_u} > 0$, $\frac{\partial^2 C_e}{\partial q_u^2} > 0$. Furthermore, we assume that $\frac{\partial^2 C_e}{\partial q_u \partial \gamma} > 0$, the marginal cost of misreporting is increasing in γ.

Firms maximize the profit function

$$p(q_u + q_t) - tq_t - C(q_u + q_t) - C_e(q_u, \gamma) \tag{1}$$

subject to the constraints $q_u, q_t \geq 0$, which have multipliers λ and ζ.

The first-order conditions for a firm's problem are given by

$$p - C'(q_u + q_t) - \frac{\partial C_e}{\partial q_u} - \lambda = 0 \tag{2}$$

and

$$p - t - C'(q_u + q_t) - \zeta = 0. \tag{3}$$

At an interior solution, equation (3) implies that total supply of diesel is given by

$$q_u + q_t = \phi(p - t) \tag{4}$$

where $\phi(p - t) = C'^{-1}(p - t)$, the inverse of the marginal cost function. It is important to note that supply does not depend on the cost of evasion parameter, γ, for those firms at an interior solution. With the assumed increasing marginal cost of evasion, the first-order condition (2) can be solved to yield a unique solution for the level of underreporting, $q_u^*(p, t, \gamma) = {C'}_e^{-1}(t)$.

The necessary condition for non-evasion is given by comparing the profits a firm earns when choosing $q_u^*(p,\gamma)$ and the profit a firm earns when choosing $q_u = 0$,

$$tq_u^*(p,\gamma) \leq C_e(q_u^*(p,\gamma)) - C_e(0) = FC_e + \int_0^{q_u^*} C_e'(q)dq. \tag{5}$$

Absent a fixed cost of evasion (FC_e) or a marginal cost of evasion greater than t for the first incremental unit of evasion, the constraint $q_u \geq 0$ never binds. Without a fixed cost of evasion, if the marginal cost of evasion at $q_u = 0$ is below the strictly positive tax rate, a firm strictly will choose to at least partially evade.[2]

We also define the condition under which $q_t \geq 0$ binds given a positive tax rate. Under reasonable assumptions, firms with a low enough cost of evasion will find it optimal to fully evade. The cutoff value of the evasion parameter, $\hat{\gamma}(p,t)$, is defined by the unique[3] solution to

$$\frac{\partial C_e'(\phi(p-t))}{\partial \gamma} = t. \tag{6}$$

For example, with a quadratic cost of evasion, $C_e(q_u,\gamma) = \gamma q_u^2$, the unique solution for $\hat{\gamma} = \frac{t}{\phi(p-t)}$.

2.1 Concentrated cost of evasion

Under a concentrated evasion cost, all firms share the same γ. In this case, all firms will partially evade or all firms will fully evade. In reality, it would be unlikely that full evasion is an equilibrium outcome, since in this case *any* observed purchase of the good would illegal. As a result, there would be a high return to raising penalties or monitoring intensity.[4]

We therefore assume that in the case of concentrated evasion cost, all firms have an interior solution. With a unitary mass of firms, this indicates that aggregate supply is given by $S(p,t) = \phi(p-t)$. The market equilibrium equates supply and demand, $D(p) = S(p,t)$. To obtain the tax incidence, we perturb this equilibrium:

$$\frac{dp}{dt} = \frac{\phi'(p-t)}{\phi'(p-t) - D'(p)}. \tag{7}$$

Taking the limit as $t \to 0$ and multiplying through by p/Q, this yields the familiar tax incidence result for a quantity tax in a competitive market: $\frac{\eta}{\eta-\epsilon}$, where η and ϵ are the price elasticities of supply and demand, respectively. This expression for the rate of pass-through is a standard

[2] For example, all firms will choose to at least partially evade for quadratic evasion costs given by $C_e(q_u,\gamma) = \gamma q_u^2$.

[3] Uniqueness follows from our assumption that the marginal cost of evasion is strictly increasing in γ.

[4] It is instructive to note that if all firms fully evaded the tax, the price consumers face is unaffected by the tax rate, $\frac{dp}{dt} = 0$. In this case, the incidence of taxation falls entirely on producers.

result in the tax incidence literature, and suggests that incidence on consumers should be greater as supply is more elastic and demand is less elastic. Importantly, allowing for the evasion of taxes by firms has no effect on the rate of pass-through. The intuition for this result is that firms evade up to the point where the marginal cost of evasion equals the tax rate. Therefore, total firm supply is unaffected, with only the composition of supply between taxed and unreported units altered.

2.2 Disperse cost of evasion

In this section, we allow the cost of evasion to vary across firms, with the support for γ being $[0, \infty]$. Let $\widehat{\gamma}(p,t)$ denote the full-evasion cutoff. Any firm with a cost of evasion parameter γ below this cutoff fully evades the tax. To find aggregate supply, we integrate individual firm supply over the support of γ:

$$S(p,t) = \int_0^{\widehat{\gamma}(p,t)} q_u^*(p,\gamma) f(\gamma) d\gamma + (1 - F(\widehat{\gamma}))\phi(p-t). \tag{8}$$

This is simply the supply provided by the full evaders, plus that provided by the partial evaders. The equilibrium condition $D(p) = S(p,t)$ can be perturbed to obtain the incidence of taxes on post-tax prices:

$$\frac{dp}{dt} = \frac{\phi'(p-t)}{\phi'(p-t) - \frac{1}{1-F(\widehat{\gamma}(p,t))}(D'(p) - \zeta)} \tag{9}$$

where $\zeta = \int_0^{\widehat{\gamma}} \frac{dq_u^*}{dp} f(\gamma) d\gamma$. Since ζ is greater than zero, we see that the incidence of taxes are lower with a disperse cost of evasion than in either the no evasion or concentrated evasion cost cases. The reasoning is as follows. Taxes shift the supply curve up by the amount of the tax, t, in the no-evasion and concentrated cost of evasion cases. With a disperse evasion cost, for the full evaders there is a wedge between the marginal cost of evasion and the tax rate. Supply for these firms is greater than for partial evaders. An increase in the tax increases the measure of firms fully evading, which leads the aggregate supply curve to shift less than if evasion were not possible.

The effect of evasion on incidence therefore depends on the importance of non-evaders. As $F(\widehat{\gamma})$ goes to zero, the effects of evasion on incidence disappear. In the empirical section of the paper, we will consider the effects on incidence of a large reduction in the cost of monitoring tax evaders. Reducing monitoring costs, and therefore the likelihood of an evading firm being detected, raises the cost of evasion. Either greater resource costs must be incurred to achieve a given level of evasion, or the expected penalties associated with a given level of evasion are higher. We therefore treat a reduction in the cost of monitoring as a rightward shift in the distribution of the evasion cost parameter, γ. This reduces the measure of firms for whom $\gamma < \widehat{\gamma}$, which moves the tax incidence effects closer to the no evasion case.

2.3 Residual supply elasticity and fuel oil demand

In the standard incidence equation derived above, the rate of pass-through depends on the relative elasticities of supply and demand. Characteristics of the market for diesel allow for an investigation into the impact of supply elasticity on the pass-through of diesel taxes. No. 2 distillate can either be sold as diesel or as heating oil, which suggests that the supply of diesel is the residual of No. 2 distillate supply after subtracting the demand for fuel oil. The residual supply of diesel is therefore given by $S^{diesel}(p) = S(p) - D^{oil}(p)$, where $S(p)$ is the supply of No. 2 distillate. Differentiating with respect to p, we obtain the residual supply elasticity of diesel,[5]

$$\eta^{diesel} = \eta/\sigma - \epsilon_{oil}/\sigma^{o} \tag{10}$$

where η^{diesel} is the residual supply elasticity of diesel, η is the supply elasticity of No. 2 distillate, σ is diesel's share of No. 2 distillate, ϵ_{oil} is the demand elasticity for fuel oil, and σ^{o} is the supply of diesel relative to the supply of fuel oil. The supply elasticity is therefore greater when fuel oil demand is high relative to diesel, and a more elastic supply of diesel should increase the pass-through of the diesel tax to consumers. In the empirical section to follow, we utilize variation in weather and households' use of fuel oil as factors that shift σ and σ^{o}.

2.4 Interjurisdictional Tax Differences

In this section, we consider the effect of differential state taxes on the incidence of taxation. Both producers and consumers can exploit differential tax rates, to avoid paying taxes in the high-tax jurisdiction. Differential state taxes allow firms a second method of evasion by misrepresenting sales. In addition to misrepresenting taxed as untaxed sales, we allow firms to overstate taxed sales in low tax jurisdictions, while understating taxed sales in high tax jurisdictions. While the evasion we consider does not require a firm to move product interjurisdictionally, the impact of evasion requiring physical movement (such as "carousel" evasion of VAT) would follow analogously. Consumers, on the other hand, do purchase interjurisdictionally, shifting purchases from the high-tax jurisdiction to the low-tax jurisdiction. In this section, we first generalize the

[5] Chouinard and Perloff (2004) perform a similar exercise for gasoline, showing how the residual supply elasticity, and therefore pass-through, in a state is higher as its share of national gasoline demand is lower.

model of firm evasion and then consider cross-border consumer purchases.

Extending the previous model for firms, we now allow firms to report out-of-state sales, q_o, in addition to untaxed quantities, q_u, and taxed quantities, q_t.[6] For convenience, we assume that the in-state tax rate t is composed of a federal tax t_f and a a state tax t_i. In addition, we assume that a neighboring jurisdiction exists, with tax rate $t_o < t_i$. As with overreporting untaxed quantities, firms also vary in their cost of overreporting out-of-state sales (related to, for example, the distance to a lower-tax border or the plausibility of out-of-state sales). A firm choosing to overreport out-of-state sales q_o units of diesel fuel incurs cost $C_o(q_o, \rho)$ and maximizes profits given by

$$p(q_u + q_t + q_o) - (t_f + t_i)q_t - (t_f + t_o)q_o - C(q_u + q_t + q_o) - C_e(q_u, \gamma) - C_o(q_o, \rho) \tag{11}$$

subject to the constraints $q_u, q_t, q_o \geq 0$.

Letting ν denote the multiplier on the non-negativity constraint for q_o, the first-order condition for q_o is given by

$$p - (t_f + t_o) - C'(q) - \frac{\partial C_o}{\partial q_o} - \nu = 0. \tag{12}$$

For an interior solution, optimal reporting of taxed, untaxed and out-of-state sales solve

$$\frac{\partial C_e}{\partial q_u} = t, \qquad \frac{\partial C_o}{\partial q_o} = t_i - t_o, \qquad \frac{\partial C_o}{\partial q_o} = \frac{\partial C_e}{\partial q_u} - (t_f + t_o). \tag{13}$$

When the non-negativity constraints do not bind, the firm equates the marginal cost of out-of-state overreporting with the difference between the in-state and out-of-state tax rates (to equate the marginal profits of out-of-state reporting with legal reporting) and the difference between the neighboring tax rate and the marginal cost of reporting untaxed quantities (to equate marginal profits of the two forms of illegal reporting). Although the method of evasion differs, the effect of overreporting out-of-state sales on incidence is similar to that of overreporting untaxed sales. A firm partially evading taxes will purchase a total quantity of diesel fuel identical to that of a firm fully complying with local fuel taxes. If a firm's cost of overreporting either untaxed or out-of-state sales is sufficiently low, the firm will opt to report no instate taxed sales. In this case, the firm's total quantity of diesel will not change in response to a change in instate taxes. As before, a binding non-negativity constraint drives a wedge between the tax rate and the marginal cost overreporting. If firms fully evade in-state taxes, in-state supply becomes more

[6]We exclude the final option - purchasing untaxed diesel in nearby jurisdictions. Assuming that the costs of evasion instate and out of state are equivalent, instate evasion strictly dominates out-of-state evasion.

inelastic. While the size of the state, does not affect untaxed overreporting, it plausibly affects the ease with which a firm can misrepresent in-state sales as out-of-state sales. Specifically, as the size of the home state rises, the costs associated with legal out-of-state sales also rise. As a result, reporting substantial out-of-state sales tends to become less credible and more likely to be scrutinized by regulators. Thus, home state area should be negatively correlated with out-of-state overreporting. Consequently, as state size rises, we should expect in-state supply to become more elastic and the state taxes to be more heavily borne by consumers.

Unlike firms, consumers (specifically, interstate trucking) can legally shift purchases from higher tax to lower tax jurisdictions. Consumers will choose to purchase in lower-tax jurisdiction if the utility they receive from purchasing out of state exceeds the utility associated with purchasing at a higher tax rate instate. Denoting the utility of diesel consumption as $v(p)$, quantity demanded as $q(p)$ and the instate and out-of-state tax-inclusive prices as $p_i = p + t_i$ and $p_o = p + t_o$, a consumer located at location $d \in [0, \bar{\theta}]$ will choose to purchase instate if

$$d > \frac{v(q(p_o)) - q(p_o)p_o - v(q(p_i)) - q(p_i)p_i}{\delta}. \tag{14}$$

where δ denotes the cost of travel. Using $\hat{\theta}$ to denote threshold distance, total instate demand is given by

$$Q_d^i = q(p_o)\int_{\hat{\theta}}^{\bar{\theta}} f(d)\partial d \tag{15}$$

It is straightforward to derive that tax elasticity of demand will fall, as the size of the jurisdiction rises.[7]

Both consumer border-crossing and producer overreporting of out-of-state sales reduce the consumer incidence of fuel taxes. Border-crossing leads demand to be more elastic and supply to be less elastic than otherwise - shifting the burden of taxation towards producers. As the size of the jurisdiction rises, though, firms find it more costly to credibly misrepresent instate taxed sales as out-of-state sales and consumers find it more costly to make cross-border transactions. Thus, as the size of the home jurisdiction rises, we predict that the incidence of taxation will fall more heavily on consumers. [8]

In addition, the first-order conditions for the firm suggest that, overreporting untaxed sales may act as a substitute for overreporting out-of-state sales. If the costs of misrepresenting taxed sales as untaxed and out-of-state are roughly comparable, a firm will likely prefer to report

[7]An alternative specification allows consumers to vary by travel cost - the conclusions are identical.

[8]Interestingly, Chouinard and Perloff (2004) predict that consumer incidence should be negatively correlated with the state's share of national demand. If state size is positively correlated with total in-state demand, our results suggest the opposite relationship.

overreport illegal sales as untaxed, rather than out-of-state. Out-of-state sales are subject to both the federal tax rate, as well as the state tax rate in the neighboring jurisdiction. In our empirical analysis, we consider the introduction of fuel dye - which substantially increased the cost of representing untaxed sales as taxed sales. Interestingly, the introduction of fuel dye did not affect the cost of overreporting out-of-state sales. By paying the federal taxes (even if the firm misrepresents the ultimate destination), the firm receives undyed diesel. Thus, we hypothesize that "out-of-state evasion" may not have been a large source of evasion in the pre-dye period, but may have become a larger source of evasion in the post-dye period.

3 Diesel fuel tax background

The taxation of diesel fuel varies by use. Diesel fuel used on-road is subject to federal highway taxes of 18.4 cents per gallon and state highway taxes ranging from 9 to 32.1 cents per gallon. In addition, environmental regulations limit the amount of allowable sulfur content of on-road diesel fuel.[9] Diesel fuel consumed for farming or off-road travel, or as fuel oil for residential, commercial or industrial boilers do not pay any taxes and does not meet similar sulfur limits.

Variation in taxation and environmental stringency by use create strong incentives for firms to evade taxation. Evaders purchase diesel fuel meant for off-road use and use or resell it for on-road use without paying or collecting the appropriate highway taxes. In the 1980's, the canonical method of evasion was the "daisy chain", in which a licensed company would purchase untaxed diesel fuel and resell the diesel fuel internally or to another company several times to make it more difficult to audit the transaction. Eventually, a distributor would sell the untaxed fuel to retail stations as fuel on which taxes had already been collected.[10] In 1992, the Federal Highway Adminstration estimated the "daisy chain" and other evasion schemes, allowed firms to evade between seven and twelve percent of on-road diesel taxes, approaching $1.2 billion dollars of federal and state tax revenue annually. While evasion has also been documented for other fuels, including gasoline, kerosene and jet fuel, diesel fuel presents a special situation. Both taxable and non-taxable uses consume significant amounts of fuel. In 2004, 59.6 percent of distillate sales to end users were retail sales for on-highway use.[11] This creates both the incentive to develop evasion schemes to avoid taxes on large quantities of on-road diesel fuel, as well as

[9] From October 1993 to August 2006, the allowable sulfur content for on-highway diesel fuel was 500 parts per million. Regulations did not constrain the sulfur content of diesel intended for other uses. Beginning September 1, 2006, diesel sold for on-highway use must meet new Ultra Low Sulfur Diesel Fuel requirements, with sulfur content not exceed 15 ppm.

[10] For documented examples of evasion, see the Federal Highway Administration Tax Evasion Highlights.

[11] Fuel Oil and Kerosene Sales Report, Energy Information Administration, 2004.

provides access to substantial quantities of untaxed diesel fuel.

On October 1, 1993, Environmental Protection Agency (EPA) began requiring that all diesel fuel failing to meet the low-sulfur on-road requirements be dyed to distinguish it from fuel meeting on-road sulfur limits. The IRS regulations, enacted as part of the Omnibus Budget Reconciliation Act of 1993 and put into effect on January 1, 1994, place similar dyeing requirements on diesel fuel on which taxes had not been collected. The regulations require that any untaxed diesel fuel sold from the wholesale terminal be dyed. The federal penalty for consuming or selling dyed fuel ("red diesel") for on-road use is the greater of $10 per gallon of fuel or $1000.[12]

The IRS and EPA regulations have two effects on fuel tax evasion: (1) the regulations reduce the cost of regulatory enforcement, and (2) the regulations increase the cost of common evasion schemes like the "daisy chain." The use of fuel dye primarily decreases the cost of regulatory monitoring. Dyeing diesel fuel for which on-road taxes have not been collected or which fails to meet on-road sulfur requirements allows regulators to more easily monitor and enforce on-road regulations through random testing of trucks. In conjunction with lower enforcement costs, IRS monitoring intensity rose following the introduction of fuel dye into diesel fuel. Baluch (1996) tabulates IRS staff hours related to audits and enforcement of diesel fuel taxes and finds that staff hours rose approximately three and a half times, from 151,190 hours in 1992 to 516,074 hours in 1994.

4 Data and Methods

4.1 Data

The EIA publishes the monthly average price of No. 2 distillate separately by the type of end user for twenty-three states.[13] To measure the price of No. 2 diesel for on-road purposes, we use the price to end users through retail outlets. This price is virtually a perfect match of the low-sulfur diesel price, which is almost exclusively for on-highway use in the post-dye period.

We collect information about the federal and state on-road diesel tax rates from 1981 to 2003 from the Federal Highway Administration Annual Highway Statistics. Federal on-road diesel taxes were four cents per gallon in 1981, rising to the current level of 24.4 cents per gallon in

[12]In addition to penalties for evading federal taxes, individual states penalize firm caught evading state taxes. Denison and Eger (2000) document fuel evasion penalties for a subset of states in 1997.

[13]The EIA surveys prices for states using No. 2 distillate as a "significant heating source." (source: EIA Form 782b explanatory notes) Price data exists for Alaska, Idaho, Illinois, Indiana, Michigan, Minnesota, Ohio, Oregon, Virginia, Washington, West Virginia, Wisconsin and all states in New England (PADD1a) and the Central Atlantic subdististricts (PADD1b).

1993. State on-road diesel taxes rise throughout the period as well, from a weighted average tax rate of 9.2 cents per gallon in 1981 to 19.4 cents per gallon in 2003.[14] Within state variation also rises throughout the period. In 1981, state on-road diesel taxes vary from a low of 0 cents per gallon in Wyoming to 13.9 cents per gallon in Nebraska. In 2003, Alaska imposes the lowest state diesel taxes, at 8 cents per gallon, while Pennsylvania imposed the highest taxes of 30.8 cents per gallon.

To capture the cost of border-crossing, we use the log of total area for each state.[15] As a metric for the strength of incentive, we calculate the difference between a state's diesel tax rate and the average diesel tax rate levied in neighboring states.

In addition, to studying the effects of evasion and smuggling on incidence, also wish to capture market factors that affect the demand and supply of fuel oil. Our demand shifters are primarily related to temperature and prevalence of the use of fuel oil as a home heating source. We obtain data on monthly degree days by state from the National Climate Data Center at the National Oceanic and Atmospheric Administration. The number of degree days in a month is often used to model heating demand, and is a measure of the amount by which temperatures fell below a given level on a particular day, summed across the days of the month. We also measure state heating oil prevalence using the fraction of households in a state reporting to use fuel oil as the primary energy source used for home heating from the 1990 census. In addition, we obtain national, monthly refinery capacity utilization from the EIA for 1990 to 2003. Capacity utilization is defined as the ratio of total crude oil input to the total available distillation capacity - capacity utilization captures both production constraints arising from both high demand and from unanticipated refinery repairs.

Table 1 reports the summary statistics of the each series employed in the regression analysis to follow. To help interpret the results regarding capacity utilization and incidence, the variable means are also reported separately for months with different rates of US refinery capacity utilization. The average tax inclusive retail price is 120.8 cents per gallon over the course of the series. This price is on average highest when capacity utilization is between 90 and 95 percent, though it is in fact lowest at the highest level of capacity utilization.[16] The average state diesel tax rate is 18.2 cents per gallon, compared with the average federal tax of 19.8 cents per gallon. The average month has 5.3 heating degree days. Since cold months tend to have lower demand

[14] Oregon does not tax diesel sold for trucking, instead taxing the number of weight-miles driven in the state. For this reason, we exclude Oregon from the subsequent analysis.

[15] As an alternative, we include the ratio of state area to the length of the state border. Use of this alternative proxy does not affect our conclusions.

[16] Since the capacity utilization series is not available for the entire sample, the means separated by capacity utilization may appear inconsistent with the overall mean.

for gasoline, the average degree days are at there highest when refinery capacity utilization is at its lowest. For the average state, 28 percent of households use fuel oil (diesel) to heat their homes, yet this varies considerably across states as standard deviation of this variable is 0.20. The average capacity utilization is 91 percent. Low capacity utilization months disproportionately occur in the winter and spring, while 78 percent of high capacity utilization months are in the second and third quarters of the year. Finally, tax increases are most likely to come when capacity utilization is low, as there is a 2.7 percent likelihood a state raises its tax in a month with a capacity utilization of less than 85 percent, compared with 1.6 percent overall. This is primarily due to January being a popular month for tax changes. Yet tax increases when capacity utilization is high is not unlikely. States raise taxes in 1.2 percent of months with a capacity utilization above 95 percent, and tax increases are in fact more likely during these months than when capacity utilization is between 85 and 95 percent

To further illustrate the variation used in this paper, Figure 1 shows the average tax rate over time for the 22 states we use in the analysis, and the number of states per year changing taxes. The average tax per state increases steadily over time, with the growth rate of taxes perhaps slowing somewhat beginning in the nineties. Fewer states changed diesel tax rates during the nineties, yet we still see that several states change taxes in each year of the data. The only exception is 2000, when tax rates were stable for all states.

4.2 Methods

The approach taken in this paper is to estimate the effect of federal and state diesel taxes on post-tax (consumer) prices. We assume that the data generating process at the state-month level for prices p_{it} cents per gallon is given by:

$$p_{it} = \beta_0 + \beta_1 T_{it}^S + \beta_2 T_t^F + BX_{it} + \rho_i + \sigma_t + \epsilon_{it} \tag{16}$$

where T_{it}^S and T_t^F are the state and federal tax rates in cents per gallon, X_{it} is a vector of time-varying state level covariates, ρ_i is a state-level fixed effect meant to capture time-invariant local cost shifters, and σ_t time effects. To estimate (16) in the presence of the unobserved state-level heterogeneity described by ρ_i, we will estimate the first-differenced equation

$$\Delta p_{it} = \beta_0 + \beta_1 \Delta T_{it}^S + \beta_2 \Delta T_t^F + B\Delta X_{it} + \sigma_t + \epsilon_{it}. \tag{17}$$

The coefficients β_1 and β_2 are therefore estimated from contemporaneous changes in taxes and prices. To allow for the dynamic adjustment of prices to changes in tax rates, we will also estimate a version of (17) including the lagged value of the tax rate.

Following the theoretical discussion, we wish to examine how incidence depends on the extent of evasion, the elasticity of supply, and the opportunities for cross-border smuggling. To do so, we will extend equation (17) along four dimensions. First, we will allow the parameter β_1 to differ in the pre- and post-diesel dye period to shed light on the effect of evasion on incidence. The compliance effects of the diesel dye program were studied extensively by Marion and Muehlegger (forthcoming), who found a substantial improvement in compliance after the dye program's implementation. It is worth summarizing those results here. Sales of diesel fuel, which is mostly for taxed on-highway purposes, rose by an estimated 26 percent in the month that suppliers were required to begin dyeing. Sales of fuel oil, which is entirely untaxed, fell by a similar amount, leaving overall sales of No. 2 distillate virtually unchanged. The response by state matches economic incentives, as the jump in reported diesel sales was higher in high tax states and states with more legitimate users of fuel oil (and therefore higher costs of monitoring). Furthermore, a greater fraction of fuel oil sales seem to be legitimate in the post-dye period, as seasonal factors, temperature, and the fraction of households using fuel oil to heat their homes explain nearly three times the variation in the post-dye period compared to the pre-dye period. Finally, state fuel oil sales have a significantly positive diesel tax elasticity pre-dye, yet are unresponsive to taxes in the post-dye period. This all points to a significant reduction in firms' ability to evade diesel taxes after the the implementation of the dye program, and in total, the dye program raised federal fuel tax revenue by approximately 1.7 billion dollars per year.

In a second extension of (17), we will include a triple interaction between the state tax rate, the heating degree days in a state-month, and the prevalence of fuel oil's use to heat homes in the state. In cold weather, states with households using fuel oil for home heating experience in increase in demand for fuel oil. As shown in equation 10, this leads to an increase in the residual supply elasticity of taxed diesel in a state. While cold weather may directly influence the price due to delivery cost or cold-weather additives, this specification will control for state degree days directly so that the effect of tax changes in cold weather is compared between states with differing levels of household fuel oil use.

In a third extension of the base empirical specification, we will examine how incidence varies depending on the capacity utilization in US refineries. As refineries are running at full capacity, the elasticity of supply may be reduced, leading to less pass-through of diesel taxes. We will consider an interaction between capacity utilization and the change in the tax rate, and we will separately estimate (17) for months with high and low levels of capacity utilization.

Finally, to estimate the relationship between incidence and interjurisdictional taxes differences, we test two hypotheses from our theoretical model. First, our model predicts that consumer-border crossing and firm misrepresentation of in-state sales as out-of-state sales should decline with state size. As a result, incidence should increase - to test this we interact changes in the state tax rate with the log of state size. In addition, our model predicts that if firms face similar costs of misreporting taxed sales as untaxed and out-of-state, firms attempting to evade taxes will tend to prefer to misreport sales as untaxed. Following the introduction of fuel dye, the cost of this type of evasion increased substantially. If firms substituted away from "untaxed evasion" to "out-of-state" evasion, we would expect to see a relationship between state size and incidence in the post-dye, but not the pre-dye period. Thus, we estimate the coefficient on the interaction term separately during the pre- and post-dye periods.

5 Results

5.1 Basic incidence results

The results of estimating equation (17) are presented in Table 2. The specifications presented in column 1 control for year and month effects, while the specification shown in column 2 also includes state-level controls. By separately controlling for state and month effects, these specifications allow for the identification of the effects of both state and federal fuel taxes. Our findings indicate that a one cent increase in the state tax rate increases the retail price by 1.2 cents, and every one cent increase in federal taxes is estimated increase the consumer price by 0.94 cents. Consistent with prior estimates from gasoline markets, there appears to be a greater degree of pass-through of state taxes than federal taxes. This is consistent with demand being more responsive to state taxes, perhaps through cross-border purchases, than to federal taxes, where cross-border sales are not a way to avoid the tax. Prior theoretical work on incidence suggest that pass-through of greater than 100 percent is possible. (see Katz and Rosen, 1985; Stern 1987, Besley, 1989; Delipalla and Keen, 1992; and Hamilton 1999) While the estimates for the incidence of state taxes suggest more than full pass-through, we cannot reject a null hypothesis of merely full pass-through.

We next account for a richer set of time effects by controlling for year*month effects. Since federal taxes vary only at the year*month level, this precludes the estimation of β_2. Column 3 presents the results. Including the finer time effects has a noticeable effect on the estimates of

β_1. We estimate a pass-through rate for state taxes of 1.08, which as before is not statistically distinguishable from one. The coefficient is also more precisely estimated.

Changes in taxes are not necessarily immediately reflected in the retail price of diesel. Lags in adjustment by both suppliers and demanders could make short-run elasticities differ from longer-horizon elasticities. To account for the dynamic adjustment of taxes into prices, we follow Alm et al (forthcoming) by including the lagged tax rate in the specification shown in column 4 of Table 2. The coefficient on the interaction term is estimated to be 0.071 and statistically insignificant. Therefore, almost the entire effect of changes in tax rates are immediately realized in prices.

We next turn to the effect of increased diesel tax compliance, as induced by the diesel dye program, on tax incidence. Federal taxes were virtually unchanged in the post-dye period[17], so separately estimating β_2 pre- and post-dye is not possible. We therefore extend the full specification including covariates and year*month effects, as shown in column 3 of Table 2 to include an interaction between the state tax rate in cents per gallon and a post-dye indicator. The results are shown in column 4. We estimate a modest increase in pass-through post-dye of 0.092. This is consistent with the model, which suggests an increase in incidence on consumers as the marginal cost of evasion increases if fully evading producers are present, though the estimated effect that we obtain is statistically insignificant.

The last result we present in Table 2 pertains to the effect of the residual supply elasticity of taxed diesel on diesel tax pass-through. As described in Section 2.3, the residual supply elasticity of taxable diesel to a particular state should be greater the greater is that state's demand for diesel for home heating purposes. We test this by considering spikes in fuel oil demand caused by weather, and their interaction with household home heating oil use. We interact the number of degree days in a state-month with the state diesel tax rate to see whether pass-through is greater in cold months. We also consider the triple interaction of degree days, the diesel tax rate, and the fraction of households that use heating oil to heat their homes. The effect of weather on pass-through should be greater in places where fuel oil is more important for home heating, as this suggests a smaller value for σ_o.[18] In column 5 of Table 2 we present the results of this estimation. To make reading the table easier, degree days have been divided by 100.

[17] The federal highway tax on diesel fuel was 24.4 cents per gallon for the entire duration of the post-dye period, with the exception of January 1, 1996 to September 30, 1997. The 0.1 cent per gallon tax for the Leaking Underground Storage Tank Trust Fund expired in January 1996 and was reinstated in October 1997, lowering the federal tax rate during this period to 24.3 cents per gallon.

[18] We choose not to use a direct measure of σ_o for two reasons. First, at least in the pre-dye period, sales of distillate intended for on-highway use comprised a significant share of reported fuel oil sales. Second, the fuel oil series is often missing.

The coefficient on the interaction between degree days/100, the state tax rate, and the fraction of households using fuel oil to heat their homes is 0.053. This implies that a state with a one standard deviation greater fraction of households using heating oil (20 percent), in a month with 1000 degree days (approximately equal to February in Chicago), has a pass-through rate 10.6 percentage points higher than a month with zero degree days.

5.2 PADD-Level Estimates

One drawback to using state-level price data is that the EIA only reports these data for 23 states.[19] It is desirable to provide incidence estimates for the US, as the states for which we have price data may not be representative. The U.S. is divided into five petroleum districts referred to as PADDs and the Northeast states are further divided into three sub-PADDS. The EIA reports a complete monthly retail diesel price series for each PADD. We form series of tax rates for the three northeast sub-PADDs and the four PADDs comprising the rest of the U.S. To do so, we take a weighted average of the state tax rates of the states comprising the PADD, weighted by the average monthly consumption of No. 2 distillate consumed by the state. The series of covariates are similarly formed.

Table 3 reports the results of regressing the PADD price on the weighted average PADD tax rate and covariates. In Columns 1 and 2, we include state and month effects separately to allow for the identification of the effect of the federal tax rate. These results indicate somewhat lower pass-through of taxes. In the specification with PADD-level covariates, we estimate the pass-through rate of the average state tax rate of 0.87, while the pass-through rate of the federal tax rate is 0.86.

The lower pass-through rate of the average state tax in the PADD-level regression appears to be largely accounted for by time controls. In column 3, we display the results of estimating a specification controlling for year*month effects. With the addition of these controls, the estimated pass-through of the average state tax is 1.13, very close to the analogous state-level estimate of 1.08. Finally, we include the lagged value of the state-tax rate, as shown in colum 4. As with the state-level estimates, the effects of prices on taxes seem to be immediately reflected in the retail price of diesel.

[19]This includes Oregon, which we do not include due to a large proportion of its diesel tax revenues derive from a weight-mile tax assessed on diesel trucks.

5.3 Capacity Utilization

Tax changes can have different effects on prices depending on the capacity utilization of refiners. If refiners are operating at full capacity, there is little scope to alter production in the short-run in response to changes in taxes. In this section, we consider how the incidence of diesel taxes differs depending on the prevailing capacity conditions.

First, in Table 4, the change in the diesel tax rate is interacted with the U.S. capacity utilization rate.[20] In the specification displayed in column 1, only the contemporaneous capacity utilization is interacted with the change in the state tax rate. To assist with the interpretation of the direct tax effect, we take the capacity utilization relative to its minimum observed value in the data of 79.3 percent. We estimate virtually no dependence of incidence on the current capacity utilization rate.

Capacity utilization, however, may only affect incidence with a lag. In the second column of Table 4, we instead interact the lag of the capacity utilization with the change in the current tax rate. Here we obtain a coefficient of -0.007, which is significant at the ten percent level. Together with the direct incidence coefficient of 1.116, this implies that each one cent increase in the state tax raises the consumer price by 1.1 cents if lagged capacity utilization is at its minimum and 0.97 cents if it is 100 percent. These estimates suggest that while lagged capacity utilization has a statistically detectable effect on incidence, this effect is modest.

These specifications just described impose a linearity in the effect of capacity utilization on incidence that may be overly restrictive. The supply elasticity may only be constrained for very high levels of capacity utilization. We next allow for this by estimating the incidence parameter separately for months with less than 85 percent capacity utilization, between 85 and 90, between 90 and 95, and above 95 percent. The results are presented in Table 5. We find that there is virtually no difference in incidence between 80 and 95 percent capacity utilization. The incidence parameter for less than 85 percent capacity utilization is estimated to be 1.04, 0.85 for 85-90 percent capacity utilization, and 1.1 for between 90 and 95 percent capacity utilization. None of these coefficients are statistically distinguishable from one. However, there is a noticeable difference in the estimated incidence for tax changes occurring in months with greater than 95 percent capacity utilization. For these months, only 58 percent of the tax is passed through to consumers. Therefore, we find that the effect of capacity utilization on incidence is highly nonlinear, as it is only noticeable for the most capacity constrained months. However, it is

[20]The data provides less opportunity to examine the federal tax rate. Capacity utilization is available from November 1990 onward, during which time there were four federal tax changes, two of which were the 0.1 cpg reduction in January 1996 and the 0.1 cpg increase in October 1997.

worth noting that even in these extreme situations, over half of the tax is born by consumers.

5.4 Border smuggling

To estimate the incidence effect of differences in state taxes, we include the minimum tax rate in neighboring states, and terms interacting the log of state area and the state tax rate as additional explanatory variables in the first-differenced specification (17). We limit our sample to the lower 48 states - this effectively excludes Alaska which is both substantially larger that other states and lacks viable options for cross-border activity. Table 6 presents the results of three specifications. The first specification includes the minimum tax rate in neighboring states and an interaction term between state tax and the log of state area. The second and third estimate the coefficient of the interaction term separately for the pre-dye and post-dye period, with and without state*month fixed effects.

In all three specifications, we estimate a positive and significant coefficient on the minimum tax rate of a state's neighboring jurisdictions - a one-cent tax change in the least-tax neighboring jurisdiction is associated with a 0.7 cent change in the tax-inclusive price.

We also find a positive and significant coefficient on the interaction between the state's tax rate and state size (measured as the log of state area) in specification (1). Consistent with our predictions, we estimate that the incidence of state taxes falls more heavily on consumers in large states and falls more heavily on producers in small states. For the states in our sample, a one standard deviation increase in state size (corresponding roughly to the relative size difference between Massachusetts and Maine) is associated with consumers bearing approximately 8 percent more of the tax. When we separately estimate the coefficient for the interaction term for the pre- and post-dye periods, we find no significant effect of state size in the pre-dye period, and a positive and significant relationship in the post-dye periods. This result is consistent with the hypothesis that misrepresenting in-state, taxed sales as untaxed sales was a more profitable method of evading taxes than misrepresenting in-state, taxed sales as out-of-state sales in the pre-dye period. In the pre-dye period, firms participating in "untaxed evasion" avoid paying both state and federal taxes. After the introduction of fuel dye, though, misrepresenting taxes sales as untaxed became substantially more expensive as it became much easier for retail stations, consumers and regulators to distinguish fuel on which federal tax had been paid from fuel which had not been taxed federally. Our estimates provide suggestive evidence that, in the post-dye period, firms in small states participated in "out-of-state" evasion to a greater degree than firms in large states. In addition, the absence of an effect in the pre-dye period suggests that consumer border-crossing did not have a large effect on incidence.[21]

5.5 Drivers of Fuel Tax Changes

As noted by Doyle and Samphantharak (2008), one concern with regressing price changes on contemporaneous tax changes, as we do in this paper, is the possibility that taxes are set with current demand and supply conditions in mind. If tax changes are more or less likely when prices or capacity utilization are high, then this will tend to bias our estimates of the pass through of diesel taxes.

In this section, we investigate the factors that are correlated with tax changes. We begin by estimating a regression of the change of the state tax rate on a host of covariates, including the federal tax rate, the minimum of the neighboring state's tax rate, recent prices, and current and past capacity utilization. We also consider the effect of these factors on the likelihood that a state raises its tax in a given month.

In Table 7, we present estimates of the determinants of the level of the month-to-month change in the state diesel tax rate. In column 1, we begin by examining the month-to-month changes in the explanatory variables. In general, we have little success in explaining changes in states' tax rates. We see that the change in the federal tax rate and the minimum of the neighbor's tax rate are both negatively correlated with changes in a state's taxes, though neither of these coefficients are statistically significant. Changes in capacity utilization similarly bear little relationship with changes in state tax rates.

Due to policy lags, a contemporaneous correlation is unlikely to exist between explanatory factors and state diesel tax rates. In column 2, we allow for a lagged response to changes in capacity utilization and the minimum of the neighbor's tax. We again see no relationship between lagged capacity utilization and the tax rate, however with this specification, we do observe a significant negative relationship between a state's tax rate and the lagged change in the minimum of the neighboring state's tax rate. It is worth noting that this is the only significant coefficient reported in the entire table.

Finally, in column 3 we allow for the state tax rate to depend not on changes in the covariates but instead on their levels. This may be a more sensible model, since the level of capacity utilization, for instance, may be more relevant than its change. Again, however, we see that no covariate is a statistically significant determinant of the change in the state tax rate. These

[21] Alternatively, the result are also consistent with a change in the responsiveness of trucking to intrastate variation in tax rates in the post-dye period. If, for example new technology made it easier for interstate truckers to avoid purchasing diesel high tax jurisdiction, we would also expect to see a positive coefficient on the post-dye interaction term.

results ameliorate to some degree the concern that important unobserved factors are correlated with both the tax rate and the price.

Specifications involving the change in the tax rate have several disadvantages. In Table 8, we present the results of estimating specifications involving an indicator for whether a state raised its tax rate in a given month as the dependent variable. Whether federal taxes or the minimum tax of neighboring states were raised has no bearing on a state's likelihood of raising the tax in a given period. Similarly, neither current or lagged capacity utilization has an effect on the likelihood of a state raising its taxes. Due to policy lags, the response to actions of other jurisdictions may take time to affect current taxes. We therefore examine tax changes in other jurisdictions occurring within the preceding 12 months. We find that the likelihood a state raises its diesel tax declines both when the federal government has raised its tax in the past 12 months and when the minimum neighboring state's tax rate has increased in the last 12 months.

6 Conclusion

In this paper, we examined the incidence of diesel fuel taxes on retail prices, a previously unexplored topic. We find at least full, and potentially more than full, pass-through of both federal and state diesel taxes to consumers. The pass-through effects are immediately reflected in prices and are amplified in cold months, particularly in states with a high fraction of households using heating oil. Since heating oil and diesel are chemically equivalent, this is consistent with heating oil use raising the residual supply elasticity of diesel. We also provide support for the notion that pass-through is considerably less-than 100 percent if tax changes occur when U.S. refinery capacity utilization is high.

Further, we used a simple competitive model to derive a testable hypothesis regarding the effects of evasion on pass-through. After the implementation of the diesel dye program, which significantly improved tax compliance, we see a small but statistically significant increase in tax incidence. The timing of this increase also roughly corresponds to the implementation of the dye program. This suggests that prior to the dye program, a significant fraction of diesel consumers were fully evading the tax, for whom there is a wedge between the marginal cost of evasion and the tax rate.

Finally, we find evidence that cross-border purchases are important. Prices in a state increase when neighboring state's taxes are raised. Furthermore, a state's size has a noticeable effect on incidence.

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Figure 1: Average State Diesel Tax Rates by Year

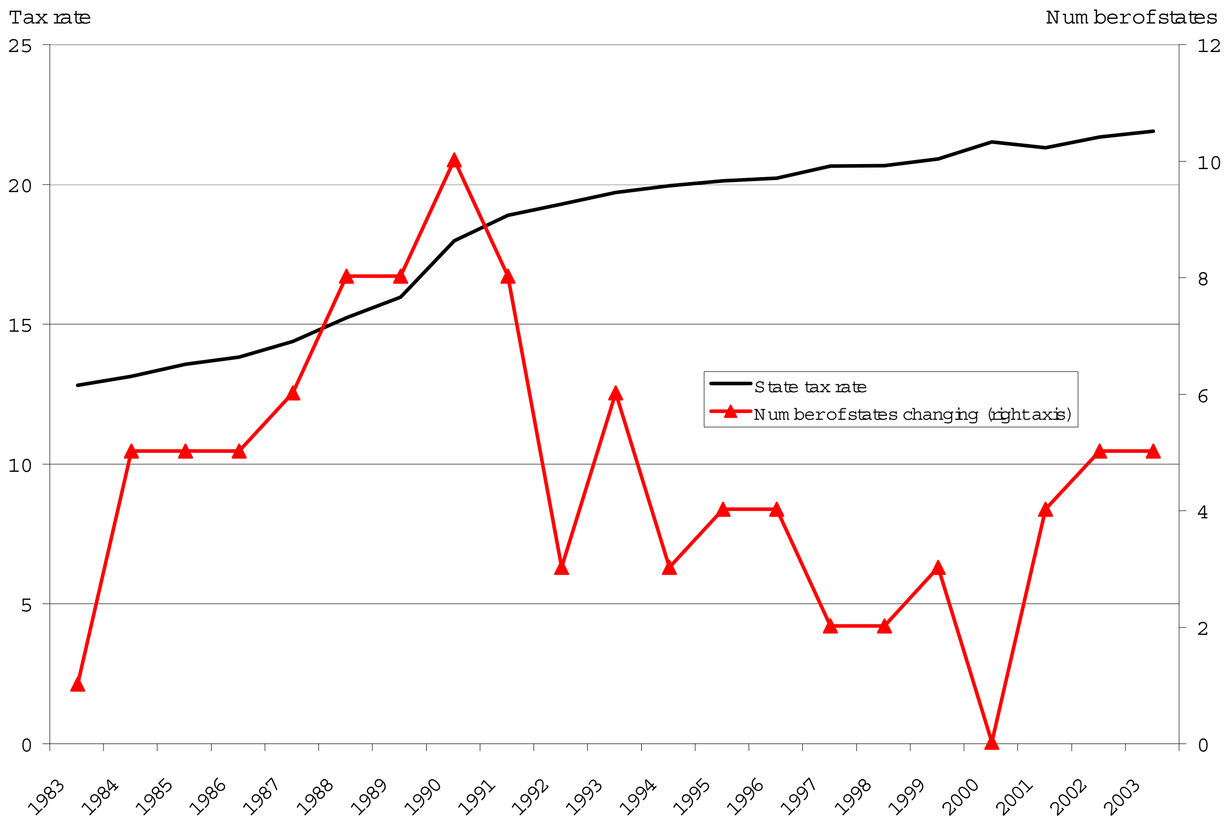

Table 1: Summary Statistics by Capacity Utilization

	(1) Overall	(2) < 85%	(3) 85-90%	(4) 90-95%	(5) >95%
Tax inclusive retail price (c/gall)	120.83	126.21	126.15	129.43	125.76
	(19.31)	(15.12)	(20.10)	(18.68)	(18.00)
State diesel quantity tax (c/gall)	18.22	19.00	20.19	20.72	20.64
	(5.23)	(4.02)	(4.73)	(5.07)	(5.00)
Federal diesel quantity tax (c/gall)	19.79	20.04	22.59	24.00	24.23
	(5.24)	(1.91)	(2.12)	(1.22)	(0.77)
Minimum of nieghboring state's tax	14.27	15.22	16.03	16.39	16.37
	(4.33)	(3.43)	(3.87)	(4.00)	(4.06)
Heating degree days	5.33	8.52	7.48	5.26	1.63
	(4.49)	(3.21)	(4.32)	(4.26)	(2.30)
Fraction of HH using heating oil	0.28				
	(0.20)				
Log state GSP	11.36	11.33	11.50	11.60	11.60
	(1.12)	(1.09)	(1.10)	(1.09)	(1.09)
Unemployment rate	5.71	6.73	5.89	5.06	4.73
	(2.08)	(1.50)	(1.69)	(1.41)	(1.30)
US Refinery capacity utilization	91.36				
	(3.89)				
Tax raised	0.016	0.027	0.007	0.012	0.012
Quarter 1		0.50	0.50	0.18	0
Quarter 2		0.08	0.11	0.27	0.43
Quarter 3		0	0.13	0.24	0.50
Quarter 4		0.42	0.26	0.31	0.07
Number of months		12	38	78	30

Standard errors are in parentheses.
Each row reports the mean of the stated variable separately for months with the U.S. refinery capacity utilization stated in the column heading. The exception is the number of months, which simply reports the number of months that experienced the given capacity utilization.
The samples used to compute the means differ between column 1 and columns 2-5. The former uses the entire series, while the latter is based only on those months for which capacity utilization data is available.

Table 2: Incidence of Diesel Taxes on Prices

	(1)	(2)	(3)	(4)	(5)	(6)
State diesel tax	1.250	1.222	1.084	1.083	1.037	1.071
	(0.195)***	(0.188)***	(0.074)***	(0.073)***	(0.111)***	(0.089)***
Federal diesel tax	0.947	0.944				
	(0.139)***	(0.136)***				
State tax t-1				0.071		
				(0.087)		
Post-dye*State tax					0.092	
					(0.170)	
State tax*deg. days*HH oil frac						0.053
						(0.020)**
Diesel tax * degree days						0.000
						(0.005)
State tax * HH fuel oil frac						0.090
						(0.383)
Minimum neighbor tax		1.259	0.690	0.692	0.690	0.677
		(0.354)***	(0.202)***	(0.203)***	(0.203)***	(0.196)***
Degree days		-0.031	-0.052	-0.044	-0.051	0.216
		(0.044)	(0.022)**	(0.027)	(0.022)**	(0.141)
Degree days * HH Oil Frac.		0.481	0.522	0.516	0.521	-0.449
		(0.054)***	(0.072)***	(0.073)***	(0.072)***	(0.371)
Log state GSP		-5.677	-19.442	-19.557	-19.427	-19.169
		(10.318)	(7.454)**	(7.402)**	(7.429)**	(7.612)**
Unemployment rate		-0.798	0.086	0.087	0.090	0.062
		(0.335)**	(0.400)	(0.401)	(0.397)	(0.404)
Year, month effects	X	X				
Year*month effects			X	X	X	X
Constant	-1.077	-0.891	-5.358	-5.350	5.914	-5.360
	(0.343)***	(0.340)**	(1.129)***	(1.130)***	(1.255)***	(1.120)***
Observations	5297	5156	5156	5067	5156	5156
R-squared	0.18	0.21	0.77	0.77	0.77	0.77

Standard errors clustered by state are in parentheses.
*,**,*** denote significance at the 90%, 95%, and 99% level, respectively.
The dependent variable is the one month change in the tax inclusive retail price of No. 2 diesel. Each independent variable has been first-differenced.

Table 3: Incidence of Diesel Taxes on Prices, PADD level

	(1)	(2)	(3)	(4)
State diesel tax	0.838	0.867	1.131	1.131
	(0.250)***	(0.373)**	(0.145)***	(0.160)***
Federal diesel tax	0.889	0.857		
	(0.814)	(0.813)		
State tax t-1				-0.000
				(0.185)
Covariates		X	X	X
Year, month effects	X	X		
Year*month effects			X	X
Constant	-1.128	-0.164	5.057	5.061
	(0.903)	(2.549)	(1.452)***	(1.447)***
Observations	1741	1692	1692	1677
R-squared	0.21	0.23	0.85	0.85

Standard errors clustered by PADD are in parentheses.
*,**,*** denote significance at the 90%, 95%, and 99% level, respectively.
The dependent variable is the one month change in the PADD-level tax inclusive price. The PADD level tax rate is obtained by taking a weighted average of the tax rates across states within the PADD. The weights used are the average monthly quantity of No. 2 distillate consumed in the state.
Other controls include degree days, degree days interacted with prevalence of household fuel oil use for home heating, log GSP, and the unemployment rate. As with the state tax rate, these controls are obtained by taking a weighted average of the values across states within the PADD. Each independent variable has been first-differenced.

Table 4: Incidence and U.S. Refinery Capacity Utilization

Dependent variable: Change in tax inclusive retail price

	(1)	(2)
State diesel tax	1.041	1.116
	(0.074)***	(0.097)***
State tax*(cap utilization - 79.3)	0.002	0.002
	(0.004)	(0.004)
State tax*(lag cap utilization - 79.3)		-0.007
		(0.004)*
Minimum neighbor tax	0.215	0.214
	(0.195)	(0.194)
Degree days	-0.090	-0.056
	(0.057)	(0.057)
Degree days * HH Oil Frac.	0.634	0.608
	(0.069)***	(0.066)***
Log state GSP	-34.582	-34.916
	(10.785)***	(10.742)***
Unemployment rate	-0.892	-0.921
	(0.517)*	(0.522)*
Constant	-2.117	0.640
	(0.626)***	(0.535)
Year*month effects	X	X
Observations	3205	3158
R-squared	0.80	0.81

Standard errors, clustered at the state-level, are in parentheses.
*,**,*** denote significance at the 90%, 95%, and 99% level, respectively.
Other controls include the minimum of the neighboring states' tax, the number of heating degree days, heating degree days interacted with household use fuel oil for home heating, the log of the state GSP, and the state unemployment rate.

Table 5: Incidence and U.S. Refinery Capacity Utilization

Dependent variable: Change in tax inclusive price

	U.S. Capacity Utilization			
	<85%	85-90%	90-95%	>95%
	(1)	(2)	(3)	(4)
Δ State diesel tax	1.043	0.854	1.096	0.578
	(0.162)***	(0.138)***	(0.072)***	(0.259)**
Year*month effects	X	X	X	X
Observations	263	755	1570	617
R-squared	0.75	0.88	0.74	0.80

Standard errors, clustered at the state-level, are in parentheses.
*,**,*** denote significance at the 90%, 95%, and 99% level, respectively.
Other controls include the minimum of the neighboring states' tax, the number of heating degree days, heating degree days interacted with household use fuel oil for home heating, the log of the state GSP, and the state unemployment rate.

Table 6: Border Crossing and Tax Incidence

Dependent variable: Change in tax inclusive retail price

	(1)	(2)	(3)
State tax (cpg)	0.907	1.129	1.083
	(0.085)***	(0.202)***	(0.166)***
Post-dye*State tax (X100)		-0.344	-0.274
		(0.236)	(0.203)
Degree days (X100)	-0.045	-0.044	-0.051
	(0.031)	(0.031)	(0.086)
Degree days*HH fuel oil use	0.498	0.518	-0.073
	(0.086)***	(0.092)***	(0.236)
Log(GSP)	-5.208	-5.316	-5.804
	(6.422)	(6.405)	(7.621)
Unemp. Rate	0.338	0.308	-0.187
	(0.268)	(0.268)	(0.277)
Min. Neighbor tax (cpg)	0.707	0.702	0.671
	(0.192)***	(0.190)***	(0.180)***
State tax*Log(Area)	0.066	-0.014	-0.016
	(0.035)*	(0.048)	(0.037)
Post-dye*State tax*Log(Area)		0.137	0.131
		(0.038)***	(0.035)***
State*Month effects			x
Year*Month effects	x	x	x
Observations	4991	4991	4991
R-squared	0.79	0.79	0.82

Standard errors, clustered at the state-level, are in parentheses.
*,**,*** denote significance at the 90%, 95%, and 99% level, respectively.
All variables in the regression have been first-differenced. The dependent variable is the change in the tax inclusive retail price of No. 2 diesel.

Table 7: Determinants of diesel tax changes

Dependent variable: Change in state diesel tax

	(1)	(2)	(3)
Change in federal tax	-0.009	-0.011	-0.008
	(0.008)	(0.008)	(0.009)
Change in capacity utilization	-0.001	-0.003	
	(0.004)	(0.005)	
Lagged change in cap. Utilization		-0.007	
		(0.005)	
Change in minimum neighbor's tax	-0.019	-0.021	
	(0.019)	(0.019)	
Lagged change in minimum neighbor's tax		-0.018	
		(0.007)**	
Change in degree days	0.003	-0.000	
	(0.008)	(0.008)	
Change in degree days * HH fuel oil frac	0.015	0.019	
	(0.016)	(0.016)	
Capacity utilization			-0.003
			(0.006)
Lagged capacity utilization			-0.001
			(0.004)
Minimum neighbor's tax			0.000
			(0.002)
Degree days			0.000
			(0.004)
Degree days * HH fuel oil frac			-0.000
			(0.007)
Change in GSP	1.107	1.246	1.013
	(1.224)	(1.267)	(1.229)
Change in unemp. Rate	0.143	0.142	0.137
	(0.096)	(0.094)	(0.093)
Constant	0.014	0.094	0.194
	(0.048)	(0.055)*	(0.537)
Year, month effects	X	X	X
Observations	3267	3231	3289
R-squared	0.02	0.02	0.01

Standard errors, clustered at the state-level, are in parentheses.
*,**,*** denote significance at the 90%, 95%, and 99% level, respectively.

Table 8: Determinants of likelihood of diesel tax increase

Dependent variable: Indicator for increasing state tax rate

	(1)	(2)	(3)	(4)
Federal tax raised	-0.010			
	(0.009)			
Federal tax raised last 12 months		-0.009		
		(0.005)*		
Neighboring state's tax raised	0.006		-0.018	
	(0.032)		(0.033)	
Neighbor raised last 12 months		-0.007		-0.009
		(0.005)		(0.005)*
Log of lagged price	0.021		-0.009	
	(0.016)		(0.017)	
Log average price last 12 months		0.021		0.010
		(0.015)		(0.016)
US Refinery Capacity utilization	-0.000	-0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Lag Capacity utilization	0.001	0.001	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Change in degree days	-0.002	-0.002	-0.002	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Change in degree days*HH fuel oil use	0.007	0.007	0.007	0.007
	(0.003)**	(0.003)**	(0.003)**	(0.003)**
Change in log GSP	0.082	0.084	0.050	0.076
	(0.516)	(0.495)	(0.457)	(0.437)
Change in Unemp. Rate	0.046	0.047	0.090	0.087
	(0.023)**	(0.023)**	(0.050)*	(0.049)*
Year,month effects	X	X		
Month*year effects			X	X
Observations	3232	3290	3232	3290
R-squared	0.03	0.03	0.08	0.08

Standard errors, clustered at the state-level, are in parentheses.
*,**,*** denote significance at the 90%, 95%, and 99% level, respectively.
The reported results are from a linear probability model estimated using OLS, where the dependent variable takes on a value of 1 if the state's diesel tax rate was increased in that particular month.