Measuring Illegal Activity and the Effects of Regulatory Innovation: A Study of Diesel Fuel Tax Evasion

Justin Marion [†]
Erich Muehlegger [‡]

PRELIMINARY AND INCOMPLETE

November 2006

Abstract

The taxation of diesel fuel varies by use. Consumers using diesel fuel on-road must pay state and federal highway taxes while diesel fuel consumed for residential heating, industrial use, farming or off-road travel do not pay taxes. Variation in the taxation of diesel fuel creates the incentive for firms and individuals to evade on-road diesel taxes. Firms evading on-road diesel taxes purchase untaxed diesel fuel and then use or resell it for on-road use.

This paper studies the incentives for tax evasion and the effects of regulatory changes meant to limit evasion of on-road diesel taxes. We propose a model of fuel tax evasion in which firms choose to purchase quantities of taxed and untaxed diesel fuel based on a heterogenous cost of evading and an endogenously set level of regulatory enforcement.

In addition, we empirically study the effects of regulatory innovation in October 1993, including the addition of dye to untaxed diesel fuel, which increase the costs of evasion and lower the costs of regulatory enforcement. We estimate the effect of the regulatory changes on state-level sales of diesel fuel and untaxed heating oil. We find that sales of diesel fuel rose 35 percent following the regulatory change while sales of untaxed heating oil fell by a similar amount. This suggests that the regulatory changes substantially limited the amount of diesel fuel tax evasion. In addition, we exploit differences in state-level on-road diesel taxes as a source of variation in the incentive for evasion. We find evidence consistent with the comparative statics of our model - the change in the sales of diesel fuel following the regulations were greater in areas with higher state on-road diesel taxes.

[*]The authors thank Christopher Synder for helpful comments and conversations.
[†]University of California at Santa Cruz. Marion@ucsc.edu
[‡]John F. Kennedy School of Government, Harvard University. Erich_Muehlegger@ksg.harvard.edu.

1 Introduction

Tax evasion and tax collection are important factors in fiscal policy. According to Slemrod (1996), the resources used in collection potentially represent 10 percent of government revenue. Lack of compliance with tax laws are likely to alter the distortionary costs of raising a given level of government revenue and may affect the distributional consequences of a given tax policy. Furthermore, resources spent evading taxes represent a deadweight loss to the economy.

Despite the central importance of tax evasion in public finance, our understanding of the degree of evasion and its response to the rate of taxation and government enforcement is limited. Theoretically, the response of evasion to tax rates is not clear. Allingham and Sandmo (1972) analyze the evasion decision, finding that evasion is positively related to tax rates. However, theoretical work has since shown that this result depends on the assumptions of the model (see for instance Yitzhaki, 1974).

Detecting tax evasion and testing theoretical predictions regarding how it responds to policy parameters have traditionally been difficult since those engaging in evasion wish to keep this behavior concealed. Furthermore, disentangling the effects of tax rates and audit intensity from other unobserved factors is not straightforward. Audit intensity is likely to be endogenously related to the propensity to evade, as auditors focus collection resources toward groups of taxpayers likely to evade. Also, variation in tax rates across individuals or firms is often correlated with evasion opportunities. For instance, higher income individuals face a higher marginal tax rate and at the same time may have more income from sources that are easier to conceal.

In this paper, we consider the effect of audit probabilities and tax rates on tax evasion in the context of a regulatory innovation that greatly decreased the cost of auditing for the compliance of on-road diesel fuel taxes. In October of 1993, the Federal Highway Administration began adding red dye to diesel sold for non-taxed purposes. The addition of the dye allows inspectors to readily check for the use of untaxed diesel through simple visual inspection, which reduced the cost of auditing and increased the cost of achieving a given level of diesel tax evasion.

The diesel market provides an interesting setting to study tax evasion. The taxation of diesel fuel varies significantly by use. In 2005, consumers using diesel fuel for on-road purposes faced federal quantity taxes of 24.4 cents per gallon in addition to state tax rates that range from 8 to 32.1 cents per gallon. Some localities tax on-road diesel as well, altogether placing the tax burden at over 50 cents per gallon in many states. Despite being virtually identical to the diesel used for on-road purposes, diesel fuel consumed for off-road use such as residential heating, industrial use, farming or off-road travel do not pay any taxes. The drastic differences in tax rates, along with the close substitutability of on-road and off-road diesel, provides strong incentives for firms to evade diesel taxation by purchasing untaxed diesel fuel and using or reselling it for on-road use.

We begin by proposing a model of the incentives for tax evasion and the effects of regulatory innovation meant to limit evasion of on-road diesel taxes. Firms choose to purchase quantities of taxed and untaxed diesel fuel based on a heterogenous cost of evading, a fixed punishment if audited and found to evade, and an endogenously set level of regulatory enforcement. The model separates firms based on their heterogenous cost of evasion into firms which choose to fully evade and purchase only untaxed fuel, firms which choose to partially evade and purchase a mix of taxed and untaxed fuel and firms which fully comply by purchasing only taxed fuel. The comparative statics of the model suggest regulatory innovation lowering the cost of monitoring should increase monitoring intensity and reduce evasion. In addition, tax rates are negatively correlated with consumption of taxed fuel and positively correlated with the measure of firms who choose to fully evade fuel taxes.

We empirically evaluate the model considering the impact of dyeing on the sales of diesel fuel and a close substitute, untaxed heating fuel oil. We find that sales of diesel fuel rose 35 percent following the regulatory change, while sales of untaxed heating oil fell by a similar amount. This suggests that the regulatory changes substantially limited the amount of diesel fuel tax evasion. Next, we exploit variation in state-level on-road diesel taxes to examine how tax rates alter the incentive to evade. Consistent with the model, we find that the change in diesel consumption after the implementation of the dyeing program is highest in states with higher tax rates.

Finally, we observe evidence of a dynamic response of evaders to the dyeing program. Prior to 1993, the elasticity of diesel sales to diesel taxation was 0.28. As obtaining non-taxed substitutes was made more difficult under the dyeing program, the tax elasticity fell to 0.08 for the 1994 to 1998 period. However, after 1998 the tax elasticity observed pre-dyeing reemerged, suggesting firms may have adapted by finding other tax evasion mechanisms.

Several approaches have been taken in prior literature to measure tax evasion. An indirect approach involves observing aggregate quantities such as currency demand or national income and product accounts and inferring evasion from these quantities. For instance, Gutmann (1977) examines the currency to demand deposit ratio, and argues that changes in this ratio reflect changes in underground market activities. Feige (1979) utilizes total dollar transactions relative to GDP, while Pommerehne and Weck-Hannemann (1996) examine the discrepancy between income from tax return data and that from national income accounts across Swiss cantons.

A second approach utilizes cross-sectional variation across taxpayers in observed levels of compliance using the Taxpayer Compliance Monitoring Project (TCMP), which describes the outcome of IRS audits of randomly chosen tax returns. Clotfelter (1983) studies this cross-section of returns, finding a positive relationship between individuals' marginal tax rates and the degree of evasion. One difficulty faced in this study is that marginal tax rates are directly related to income. Feinstein (1991) addresses this problem by pooling two different years of the TCMP, which allows for the comparison of two individuals with the same income but facing different marginal tax rates. In contrast to Cotfelter, Feinstein finds a negative relationship between tax rates and tax evasion. Dubin and Wilde (1988) and Beron, Tauchen, and Witte (1992) use data from the TCMP aggregated to the three digit zip code level to investigate how the enforcement alters tax compliance, finding that increasing a zip codes chances of an IRS audit is associated with higher reported adjusted gross income.

A third approach taken in the literature uses experimental methods to investigate tax compliance and its response to tax rates and enforcement. Slemrod, Blumenthal, and Christian (2001) examine an experiment in Minnesota where randomly selected taxpayers were sent letters warning of close scrutiny of their tax returns. Low and middle income taxpayers responded by reporting higher AGI than the control group, but higher income individuals reported less, highlighting the potential distributional impact of tax evasion. Other studies taking an experimental approach include Wenzel and Taylor (2004) and Alm and McKee (2005).

The approach most closely related to that taken in our paper is that of Fisman and Wei (2004), who examine the misclassification of Chinese imports from Hong Kong. They find that the gap at the detailed good level between reported Chinese imports from Hong Kong and reported exports from Hong Kong to China is largest for goods with high tax and tariff rates.

Section 2 describes a model of the firms' tax evasion decision. Section 3 presents some background related to diesel markets and taxation, and Section 4 describes the data to be used. Section 5 presents the empirical model employed and the empirical results, and Section 6 concludes.

2 A Model of Fuel Tax Evasion

To motivate our empirical model, we consider a model of fuel tax evasion with a measure of firms located on the interval $[0, \theta]$ purchasing diesel fuel for on-road (taxed) use. Firms can choose to comply with regulations by purchasing taxed diesel fuel at price $p + t$ or may choose to evade taxation by purchasing untaxed diesel fuel at price p. Firms choose quantities of untaxed and taxed diesel fuel, q_u and q_t to produce output $x(q_u + q_t)$. If a firm located at $\gamma \in [0, \theta]$ chooses to evade, it pays a heterogeneous cost of evasion which varies with γ. The cost of evasion, $c_e(q_u, \gamma)$, is a potentially non-linear function, weakly increasing function of the quantity of untaxed diesel purchased, q_u, with $\frac{\partial c_e}{\partial q_u} \geq 0$. In addition to paying the cost of evasion, firms face a potential penalty if caught evading taxes. The regulator deters tax evasion by randomly auditing firms with an endogenous probability p_a and assessing a fixed penalty z if $q_u > 0$.

The game proceeds in three steps. First, the regulator observes the punishment associated with evasion, z, the distribution of the cost of evasion, $f(c_e)$, a parameter capturing the cost of auditing, c_a, and relevant market parameters, p and t.[1] The regulator then chooses the probability with which it will audit firms purchasing untaxed fuel, p_a, to maximize the regulatory objective function[2]

$$W = tQ_t - c_a \frac{p_a^2}{2}. \tag{1}$$

where Q_t are the total purchases of the taxed good. In the second step of the game, firms observe p_a, p, t, Q_u^L and, based on their heterogeneous cost of evasion, choose quantities q_u and q_t. In the third step, the regulator randomly audits p_a proportion of the firms and punishes all audited firms choosing $q_u > 0$ with penalty z.

2.1 Discrete Choice of Quantity

First, we consider the model in which all firms purchase one unit of either the taxed or untaxed good and focus specifically on the choice to evade taxation. In particular, assume each firm obtains value $v \geq p + t$ from purchasing one unit of diesel fuel and that a firm with cost of evasion $\gamma \sim U[0, \theta]$ has payoffs given by

$$\Pi(\gamma) = \begin{cases} v - (p+t) \text{ if the firm purchases taxed diesel fuel} \\ v - p - \gamma \text{ if the firm purchases untaxed diesel fuel and is not audited} \\ v - p - \gamma - z \text{ if the firm purchases untaxed diesel fuel and is audited} \end{cases} \tag{2}$$

A firm chooses to evade if and only if

$$E[\Pi_i | \text{ evasion}] \quad \geq \quad E[\Pi_i | \text{ compliance}] \iff$$

[1] If the regulator can choose both p_a and $z(g_u)$, the optimal decision for the regulator is to set extremely high penalties and low enforcement. Since this is inconsistent with the actual penalties for fuel tax evasion, we treat $z(g_u)$ as exogenously given.

[2] We present the model in which fines do not enter into the regulator's objective function. The comparative static results do not substantively change with this inclusion or exclusion of the fines.

$$\gamma \quad \leq \quad t - p_a z. \tag{3}$$

Let $\hat{\gamma} = t - p_a z$ denote the cost of evasion satisfying (3) with equality and let the proportion of firms choosing to evade on-road taxes be $\alpha = F(\hat{\gamma})$. Anticipating the evasion by the firms, the regulator maximizes the objective function

$$W = (1 - F(t - p_a z))t - c_a p_a^2 \tag{4}$$

with respect to $p_a \in$, yielding

$$p_a^* = \begin{cases} p_a^* = \frac{tz}{2\theta c_a} \text{ if } \mathrm{z}^2 \leq 2\theta \mathrm{c_a} \\ p_a^* = \frac{t}{z} \text{ if } \mathrm{z}^2 > 2\theta \mathrm{c_a} \end{cases} \tag{5}$$

Assuming an interior solution, which implies $z^2 \leq 2\theta c_a$, the solution implies comparative statics for p_a^* and c_a

$$\frac{\partial p_a^*}{\partial t} = \frac{z}{2\theta c_a} > 0 \longrightarrow \frac{d\alpha}{dt} = 1 - z\frac{\partial p_a^*}{\partial t} = \frac{1}{\theta} - \frac{z^2}{2\theta^2 c_a} \geq 0 \tag{6}$$

$$\frac{\partial p_a^*}{\partial c_a} = \frac{-tz}{2\theta c_a^2} < 0 \longrightarrow \frac{d\alpha}{dc_a} = \frac{tz^2}{2\theta^2 c_a^2} > 0. \tag{7}$$

An increase in tax rate has a direct and indirect effect on evasion. Holding audit intensity constant, tax rates are correlated with the magnitude of evasion. If audit intensity is allowed to be endogenous, though, a higher tax increases the marginal benefit to regulatory enforcement. The regulator has the incentive to audit more heavily in areas with high taxes and greater incentives for tax evasion. The net effect, in this case, is that evasion rises with tax rate, albeit less than it would with exogenously set audit intensity. An increase in the cost of auditing reduces optimal audit intensity and, as a result, indirectly increases evasion.

2.2 Continuous Choice of Quantity

Now consider a model in which firms choose quantities of taxed and untaxed diesel fuel, q_u and q_t, to maximize expected profits. For convenience, we analyze the equivalent problem in which firms choose total diesel purchases q and the percent of diesel taxes they will evade α, where $q_u = \alpha q$. In addition, we assume that the costs of evasion are quadratic in consumption of untaxed diesel, $c_e = \gamma q_u^2/2$ and $\gamma \sim U[0, \theta]$. Firms choose q and α to maximize expected profits given by

$$E[\Pi] = x(q) - p_a(p\alpha q + c_e(\alpha q, \gamma) + z) - (1 - p_a)(p\alpha q + c_e(\alpha q, \gamma)) - (p + t)(1 - \alpha)q \tag{8}$$

which simplifies to

$$x(q) - p_a z - p\alpha q - \frac{\gamma(\alpha q)^2}{2} - (p + t)(1 - \alpha)q \tag{9}$$

subject to

$$q \geq 0, \alpha \in [0, 1]. \tag{10}$$

Taking the derivatives of expected profit with respect to q and α, we have the first order conditions

$$\frac{\partial \Pi}{\partial q} = x'(q) - p\alpha - \gamma q\alpha^2 - (p + t)(1 - \alpha) = 0 \tag{11}$$

and

$$\frac{\partial \Pi_i}{\partial \alpha} = tq - \alpha\gamma q^2 = 0. \tag{12}$$

which implies, for an interior solution of $\alpha \in (0, 1)$,

$$\alpha^* = \frac{t}{q\gamma}. \tag{13}$$

We group firms into one of three classes based on their heterogenous cost of evasion, γ: full evaders who choose $\alpha^* = 1$, partial evaders who choose an interior solution for $\alpha*$ and, non-evaders who choose $\alpha = 0$. Let $\overline{q}$ denote the quantity of diesel fuel satisfying (11) for partial evaders given by

$$x'(\overline{q}) = p + t. \tag{14}$$

The cutoffs for full evasion and non-evasion are defined by (13) and equating $E[\Pi|\alpha = \frac{t}{q\gamma}]$ and $E[\Pi|\alpha = 0]$, respectively.

$$\hat{\gamma}_{FE} = t/\overline{q}. \tag{15}$$

$$\hat{\gamma}_{NE} = \frac{t^2}{2p_a z}. \tag{16}$$

. Thus, the optimal choice of q and α^* are given by

$$q^* = \begin{cases} x'(q) = p + \gamma q \text{ for } \gamma \in [0, t/\overline{q}] \\ \overline{q} \text{ for } \gamma \in (t/\overline{q}, \frac{t^2}{2p_a z}) \\ \overline{q} \text{ for } \gamma \in [\frac{t^2}{2p_a z}, \theta] \end{cases} \tag{17}$$

and

$$\alpha^* = \begin{cases} 1 \text{ for } \gamma \in [0, t/\overline{q}] \\ \frac{t}{\overline{q}\gamma} \text{ for } \gamma \in (t/\overline{q}, \frac{t^2}{2p_a z}) \\ 0 \text{ for } \gamma \in [\frac{t^2}{2p_a z}, \theta] \end{cases} \tag{18}$$

Given the optimal choices of quantity and evasion by firms, we can express consumption of taxed diesel and untaxed diesel as

$$\begin{aligned} Q_t &= \int_{t/\overline{q}}^{\frac{t^2}{2p_a z}} \overline{q}(1-\alpha) f(\gamma) d\gamma + (1 - F(\frac{t^2}{2p_a z}))\overline{q} \\ &= \overline{q} - \frac{t}{\theta}\left[1 + ln(\frac{t^2}{2p_a z}) - ln(t/\overline{g})\right]. \end{aligned} \tag{19}$$

and

$$\begin{aligned} Q_u &= \int_0^{t/\overline{q}} q^*(\gamma) f(\gamma) d\gamma + \int_{t/\overline{q}}^{\frac{t^2}{2p_a z}} \overline{q}\alpha f(\gamma) d\gamma \\ &= \int_0^{t/\overline{q}} q^*(\gamma) f(\gamma) d\gamma + \frac{t}{\theta}\left[ln(\frac{t^2}{2p_a z}) - ln(t/\overline{g})\right]. \end{aligned} \tag{20}$$

The regulator endogenously chooses p_a to maximize it's objective function, given by

$$W = tQ_t - c_a p_a^2/2. \tag{21}$$

Substituting (19) into the objective function, we have

$$p_a^* = \sqrt{\frac{t}{\theta c_a}} \tag{22}$$

As in the discrete case, the p_a^* increases with t and decreases with c_a. Noting that a change in p_a^* only affects the decision of the marginal firm choosing between partial evasion or non-evasion, $\frac{\partial G_u}{c_a} > 0$ and $\frac{\partial G_t}{c_a} < 0$. The comparative statics with respect to t are more complicated. Unlike c_a which only affects firms through the decision of p_a, t affects p_a, $\overline{g}, \hat{\gamma}_{FE}$ and $\hat{\gamma}_{NE}$.

$$\frac{\partial p_a}{\partial t} > 0, \frac{\overline{g}}{\partial t} < 0, \frac{\partial \hat{\gamma}_{FE}}{\partial t} > 0, and \frac{\partial \hat{\gamma}_{NE}}{\partial t} > 0. \tag{23}$$

While $\frac{\partial G_t}{\partial t} < 0$, it is not possible to sign $\frac{\partial G_u}{\partial t}$ without functional form assumptions on $x'(g)$. That said, t does unambiguously increase the measure of firms who fully evade the regulations.

3 Regulatory Background

The taxation and properties of diesel fuel vary 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-highway diesel fuel.[3] 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.[4] 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.[5] This creates both the incentive to develop evasion schemes to avoid taxes on large quantities of on-road diesel fuel, as well as provides access to substantial quantities of untaxed diesel fuel.

In this paper, we study regulatory innovations by the Internal Revenue Service (IRS) and the Environmental Protection Agency (EPA) meant to decrease the amount of evasion of on-road diesel taxes and environmental regulations. The EPA regulations, introduced October 1, 1993, require that all diesel fuel failing to meet the low-sulfur on-road requirements be dyed, to

[3] 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.

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

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

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. In addition, the IRS regulations move the point at which taxes are collected on the diesel up the supply chain to the the wholesale terminal. The regulations require that any untaxed diesel fuel sold from the wholesale terminal be dyed. The penalty for consuming or selling dyed fuel ("red diesel") for on-road use is the greater of $10 per gallon of fuel or $1000.

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.

Moving the point of taxation up the supply chain to the point of sale from the wholesale terminal serves a dual purpose. Prior to 1994, the government collected fuel taxes from both wholesale terminals and the diesel distributors - firms who transported diesel from the wholesale terminal to the retail station. Moving the point of taxation reduces the number of firms responsible for collection on-road taxes, making it less costly to collect taxes and enforce dyeing of untaxed fuel. In addition, moving the point of taxation increases the costs of evasion for standard "daisy chain" evasion, which relies on being able to purchase untaxed diesel and eventually misrepresenting it as diesel on which taxes have been collected, without collecting the appropriate taxes. Moving the point of taxation, along with dyeing untaxed fuel, substantially increase the cost of evasion for common evasion schemes used prior to the regulations.

In this paper, we are interested in estimating the extent to which fuel tax evasion is correlated with the magnitude of the incentive for evasion, and the extent to which we are able to detect evasion and the incentives for evasion using discrete changes in regulatory enforcement. We exploit variation in state taxes to capture the effect of a common discrete change in regulatory enforcement across areas with different ex-ante incentives for fuel tax evasion. We test for evidence not only of tax evasion, but also that tax evasion fell more in response to the regulatory innovation in areas where the ex-ante incentives for evasion are greater.

4 Data

To estimate fuel tax evasion, we collect state-level data from the Energy Information Administration(EIA) and the Federal Highway Adminstration(FHA) on sales of diesel fuel and No 2 fuel oil and state tax rates over 1983-2003. We collect state-level quantity data from the EIA Petroleum Marketing Monthly. The EIA tracks Prime Supplier Sales, sales by firms to end-users, retail stations, and local distributors, of No. 2 diesel fuel and No. 2 fuel oil by state from 1983 to the present. In addition, from 1994 to the present, the EIA differentiates No. 2 diesel fuel sales by sulfur content. No 2 diesel fuel and No 2 fuel oil are chemically equivalent classifications of No 2 distillate oil. The distinction between the two in the EIA data is one of use. Diesel fuel is defined as No 2 distillate made to be burned in a gasoline engine, while the EIA classifies fuel oil as No 2 distillate to be used in a residential, commercial or industrial boiler. The chemical properties of No. 2 diesel fuel and No. 2 fuel oil are essentially equivalent - the two products can be used interchangeably to power a diesel engine or a burner.

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 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. 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. Figure 1 displays the distribution of state diesel tax rates separately for 1983, 1993, and 2003. In 1983, state tax rates were concentrated between 10 and 15 cents per gallon, with all but seven states having tax rates below 15 cents. During the course of the sample, diesel taxes grew and became more disperse across states. By 2003, 26 percent of states had a diesel tax rates of at least 25 cents per gallon, higher than the federal rate of 24.4 cents per gallon.

To measure heating demand, we also collect data on state temperature levels, as measured by degree days, 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.

5 Empirical Model and Results

To uncover evidence of tax evasion, we estimate a trend-break model at the state level to identify the response of taxed and untaxed diesel sales to the diesel dye program. We account for general trends in demand and supply using a quadratic time trend, which is allowed to differ between the pre-dye and post-dye periods. We estimate an equation of the form

$$lnq_{it} = \beta_0 + \beta_1 post_t + \beta_2 ln\tau_{it} + \beta_3 post_t * ln\tau_{it} + \beta_4 t + \beta_5 t * post_t + \beta_6 t^2 + \beta_7 t^2 * post_t + \Pi X_i + \gamma_i + \epsilon_{it} \tag{24}$$

where lnq_{it} is the log of the quantity of either diesel or fuel oil sold in state i in year t, X_{it} is a vector of state-year covariates, and γ_i represents a state fixed effect. Of primary interest is the trend-break coefficient β_1 on the post-1993 dummy variable. The log of the tax rate applied to on-highway diesel is given by $ln\tau_{it}$. The coefficient, β_2, on the log tax rate represents the tax elasticity, but it is worth noting that this coefficient is not a price elasticity since a quantity tax enters additively into the effective price paid. Finally, we investigate the degree to which tax evasion responds to the tax rate by considering an interaction between the state diesel tax rate and the post-1993 dummy variable. The coefficient β_3 can either be interpreted as the degree to which the response in sales depends on the state tax rate, or alternatively the degree to which the diesel dye program alters the elasticity of sales with respect to the tax rate.

Next, we verify that the timing of the time series break occurs in the year the diesel program was implemented, and we examine how the effect of taxes on sales varies over time. To do so we estimate a specification of the following form:

$$lnq_{it} = \alpha_0 + \alpha_{1t} ln\tau_{it} + \varphi_t + \Gamma X_{it} + \gamma_i + \eta_{it}. \tag{25}$$

Here, we estimate year effects, φ_t, and we allow the coefficient α_{1t} on the log diesel tax rate to vary by year. The parameter γ_i represents state fixed effects. Inspection of the time effects allow for verification that the timing of the break in the quantity series occurs at the time the diesel dye program was implemented. Furthermore, we can examine the dynamics of the response of quantity to the tax rate. Instituting the diesel dye program likely did not eliminate forever firms' ability to evade taxes by using untaxed diesel. Firms may be able to adjust evasion behavior over time due to investments or innovations in evasion technology. Changes in the tax rate elasticity over time could suggest changes in firms' ability to evade.

One concern related to estimating the specification shown in (25) is the possibility that unobserved factors happen to shift either the demand or supply for energy at the time of the implementation of the diesel dye program. We also estimate (25) using other products of the refining process to show that the estimated coefficient is not picking up an unobserved shock to supply.

5.1 Results

The main result of the paper can be seen by examining the monthly time series of sales of U.S. sales of number 2 distillate. In Figure 2, we show the time path of sales of number 2 diesel, number 2 fuel, and total number 2 distillate sales. This figure shows that in the pre-dye period, sales of the two types of number 2 distillate were at similar levels, and both experiencing a fairly flat time trend. In the month of the implementation of the diesel dye program, sales of diesel increased noticeably. In September of 1993, 82.0 million gallons of diesel were sold per day in the United States and this figure increased to 97.4 million gallons per day in October of 1993. Interestingly, this also corresponded to a change in trend for the diesel series, which had previously been flat in the 1983-1993 period. Sales of number 2 fuel oil decline noticeably in the period after the dye program was implemented, even though the discontinuity in the month of implementation is less striking than with diesel due to the seasonality of fuel oil sales. Overall, the increase in diesel is largely cancelled out by the decrease in fuel oil sales, at least in the first year of implementation.

Table 1 displays summary statistics of the data used in the empirical models. The 28 states included in the sample were fairly evenly spread across the Northeast, Midwest, and South, although no states from the west are represented. The average diesel tax rate in these states was 15 cents per gallon in the pre-dye period, and this grew to 19.5 cents afterwards.

Sales of diesel in these states were 1.4 million gallons per day, slightly lower than the 1.7 million gallons of fuel oil sold. Number 2 distillate easily represents the largest portion of the distillate output, as the other forms combined represented 1.5 million gallons per day during this period. After the implementation of the dye program, sales of number 2 diesel grow substantially, while sales of number 2 fuel oil fall. Diesel sales increase by nearly 1 million gallons per day on average to 2.5 million gallons, while fuel oil sales decline by 730 thousand gallons per day.

Table 2 displays the results of estimating (24) for diesel sales. The specification shown in column (1) of this table estimates only the coefficient on the log tax variable, conditional on a quadratic time trend which is allowed to differ in the post-dye period. The elasticity of sales with respect to the tax rate is -0.255, suggesting that a doubling of the diesel tax rate would correspond to a fifty percent reduction in state diesel sales.

In column (2) of Table 2, we include a dummy variable for the post-dye period. The results suggest a trend break coefficient of 0.353, indicating that diesel sales increased approximately 35 percent after dye was added to untaxed diesel. The fit of this specification is illustrated in Panel A of Figure 3. We see that the model is able to fit the pre- and post-levels of diesel sales well, and the large discontinuity in diesel sales around the time of the implementation of the dye program is apparent.

The specification shown in column (3) includes an interaction between the post-dye dummy and the log tax rate. When this interaction is included, the estimated trend break is now 0.118, less than one-third of the value without controlling for the interaction with the log tax rate and statistically insignificant. What this indicates is that for states with a low diesel tax rate, the estimated effect of the dye program is much smaller. A state with a one cent per gallon diesel tax, for instance, would have experienced only an 11.8 percent increase in diesel sales post-dye.

The coefficient on the tax*post-dye variable is estimated to be 0.08, yet is statistically insignificant. However, the fact that it considers of the interaction between the tax rate and the entire post-dye period seems to mask an important dynamic over time. This is illustrated by the results in column (4). In the four years after the implementation of the dye program, the elasticity of diesel sales with respect to the diesel tax rate was lessened considerably. In the pre-dye period, the estimated tax elasticity was -0.28, however this elasticity is reduced by 0.199 to -.081 in the years 1994-1998. The tax elasticity reverts to its pre-dye levels after 1998 however.

This point is illustrated graphically in Panel A of Figure 4. In this figure, we describe the time path of diesel sales by plotting estimates of $\alpha_0 + \alpha_{1t} ln\tau + \varphi_t$ from (25) for different quartiles of the tax rate. In the pre-dye period, higher tax rate states experienced lower diesel sales than higher tax states. After the addition of dyes in 1993, the estimated difference in sales between high tax and low tax states narrows considerably. Beginning in 1999, however, this difference re-emerges. This suggests a dynamic response of evasion, as firms may be able to innovate new tax evasion methods over time.

Table 3 displays similar specifications for log fuel oil sales. In contrast to diesel sales, fuel oil sales are positively related to the log diesel tax rate, however the estimates are insignificant. Interestingly, the number of degree days in the typical month is not a significant predictor of fuel oil sales. While part of this is due to the fact that fuel oil is far less commonly used in the Midwest and South than in the Northeast to heat homes, it is also possible this is due to specification error of the relationship between degree days and fuel oil sales.

From column (2) of Table 3, we see that log fuel oil sales fell by approximately 35 percent in the post-dye period, virtually matching the increase in diesel sales. Panel B of Figure 3 displays the fit of the predicted values of this regression against the average actual values across states. Again, we see that the quadratic specification allowing for differing pre-and post-dye trends, along with the trend break, seems to fit the data well. More importantly, the break in the fuel oil time series is apparent, the timing of which matches exactly the implementation of dyeing.

As with the specification of diesel fuel sales, the specification shown in column (3) suggests that states with low tax rates saw a far lower response to diesel dye. If a state had a one cent per gallon tax rate (and a log tax of zero), it would have seen a decline in fuel oil sales of 19 percent, approximately half of the actual decline witnessed. The interaction between the post-dye dummy variable and the log tax rate is of the predicted sign but is insignificant. As with the diesel fuel sales estimates, this may be somewhat masking the dynamics of the relationship between diesel tax rates and fuel oil sales. In Panel B of Figure 4, we plot the estimated coefficients from (25) for log fuel oil sales at different quartiles of the diesel tax rate. We see that beginning in 1986, a positive relationship between tax rates and fuel oil sales emerges, and the disappearance of this relationship occurs exactly in the post-dye period. From 1994 through 2000, we see essentially no difference between high and low tax states, however this difference reemerges in 2001 and 2002.

It is conceivable that the shifts observed in the diesel and fuel oil series in October of 1993 happen to coincide with shocks to the distillate production process. We explore this possibility by examining how other types of distillates change around the implementation of the diesel dye program. In Figure 5, we plot the predicted values of estimating (24) for number 1 distillate, number 4 distillate, and residual fuel oil. We overlay this against the average actual values for each year. There seems to be no discernable break in any of these series in 1993 or 1994. Changes in these series in these years are well within the typical changes observed in other years. This supports the notion that the observed shifts in the diesel and fuel oil series represent a substitution in classification rather than a shift in production.

6 Conclusion

This paper considers the evasion of diesel taxes, and how it responds to a large shift in the cost of conducting an audit. We find that reducing the cost of audit greatly improves tax compliance, and that diesel tax evasion responds positively to tax rates. However, over time firms may have found new ways to evade diesel taxation, as the significant tax elasticity present before the dye program was implemented returns a few years later.

These results have potential policy implications. Ad valorem taxes are often suggested as an alternative to income taxation due to the low administrative and compliance costs experience by states in implementing retail sales taxes. The results in this paper suggest that direct taxation may also be subject to significant evasion, particularly if taxes are not applied in a uniform manner across goods.

Finally, one factor left for future study is the response of tax policy and administration to the diesel dye program. Alt (1983), Kau and Rubin (1981), and Balke and Gardner (1991) among others point to the importance of tax collection in shaping the tax structure. Given the magnitude of the response of sales of taxable diesel we observet is likely that the federal or state government responds to the diesel dye program by adjusting tax rates.

References

[1] Allingham, Michael G. and Agnar Sandmo. (1972) "Income Tax Evasion: A Theoretical Analysis," *Journal of Public Economics* 1:3-4, p. 323-338.

[2] Alt, James. "The Evolution of Tax Structures," *Public Choice* 41:1, p. 181-222.

[3] Balke, Nathan S. and Grant W. Gardner. (1991) "Tax Collection Costs and the Size of Government," Working paper, Southern Methodist University.

[4] Baluch, Stephen (1996) Revenue Enhancement Through Increased Motor Fuel Tax Enforcement. *Transportation Research Record 1558*

[5] Beron, Kurt J., Helen V. Tauchen, and Ann Dryden Witte. (1992) "The Effect of Audits and Socioeconomic Variables on Compliance," in *Why People Pay Taxes*, edited by Joel Slemrod. Ann Arbor: University of Michigan Press.

[6] Clotfelter, Charles T. (1983) "Tax Evasion and Tax Rates: An Analysis of Individual Returns," *Review of Economics and Statistics* 65:3, p. 363-373.

[7] Dubin, Jeffrey A. and Louis L. Wilde. (1988) "The Empirical Analysis of Federal Income Tax Auditing and Compliance," *National Tax Journal* 41:1, 61-74.

[8] Dubin, Jeffrey A., Michael J. Graetz and Louis L. Wilde. (1990) "The Effect of Audit Rates on the Federal Individual Income Tax, 1977-1986," *National Tax Journal* 43:4, p. 395-409.

[9] Engel, Eduardo M.R.A. and James R. Hines, Jr. (1999) "Understanding Tax Evasion Dynamics," NBER Working Paper #6903.

[10] Federal Highway Administration (1993) Study of the Feasibility and Desirability of Using Motor Fuel Dyes and Markers. Report FHWA-PL-93-022.

[11] Feinstein, Jonathan. (1991) "An Econometric Analysis of Income Tax Evasion and its Detection," *RAND Journal of Economics* 22:1, p. 14-35.

[12] Feige, Edgar L. (1979) "How Big is the Irregular Economy?" Challenge 22:5, p. 5-13.

[13] Gutmann, Peter M. (1977) "The Subtarranean Economy," *Financial Analysts Journal* 33:6, p. 26-34.

[14] Fisman, Raymond and and Shang-Jin Wei. (2004) "Tax Rates and Tax Evasion: Evidence from "Missing Imports" in China," *Journal of Political Economy* 112:2, p. 471-496.

[15] Kau, James B. and Paul H. Rubin. (1981) "The Size of Government," *Public Choice* 37:2, p. 261-274.

[16] Kinsey, Karyl A. (1992) "Deterrence and Alienation Effects of IRS Enforcement: An Analysis of Survey Data," in *Why People Pay Taxes*, edited by Joel Slemrod. Ann Arbor: University of Michigan Press.

[17] Pommerehne, Werner W. and Hannelore Weck-Hannemann. (1996) "Tax rates, tax administration and income tax evasion in Switzerland," *Public Choice* 88, p. 161-170.

[18] Sheffrin, Steven M. and Robert K. Triest (1992) "Can Brute Deterrence Backfire? Perceptions and Attitudes in Taxpayer Compliance," in *Why People Pay Taxes*, edited by Joel Slemrod. Ann Arbor: University of Michigan Press.

[19] Slemrod, Joel, Martha Blumenthal, and Charles Christian (2001) "Taxpayer response to an increased probability of audit: evidence from a controlled experiment in Minnesota," *Journal of Public Economics* 79, p. 455-483.

[20] Slemrod, Joel and Shlomo Yitzhaki. (2000) "Tax Avoidance, Evasion, and Administration," in A. Auerbach and M Feldstein (eds.), *Handbook of Public Economics Volume 3,* North-Holland, p. 1423-1470.

[21] Yitzhaki, Shlomo. (1974) "A Note on 'Income Tax Evasion: A Theoretical Analysis,'" *Journal of Public Economics* 3, p. 201-202.

[22] Weimar, M., Balducci, P., Roop, J., Scott, M., and Hwang, H. (2002) Economic Indicators of Federal Motor Fuel Excise Tax Collections.

[23] Wenzel, Michael and Natalie Taylor. (2004) “An experimental evaluation of tax-reporting schedules: a case of evidence-based tax administration,” *Journal of Public Economics* 88, p. 2785-2799.

Figure 1: Distribution of State Diesel Tax Rates

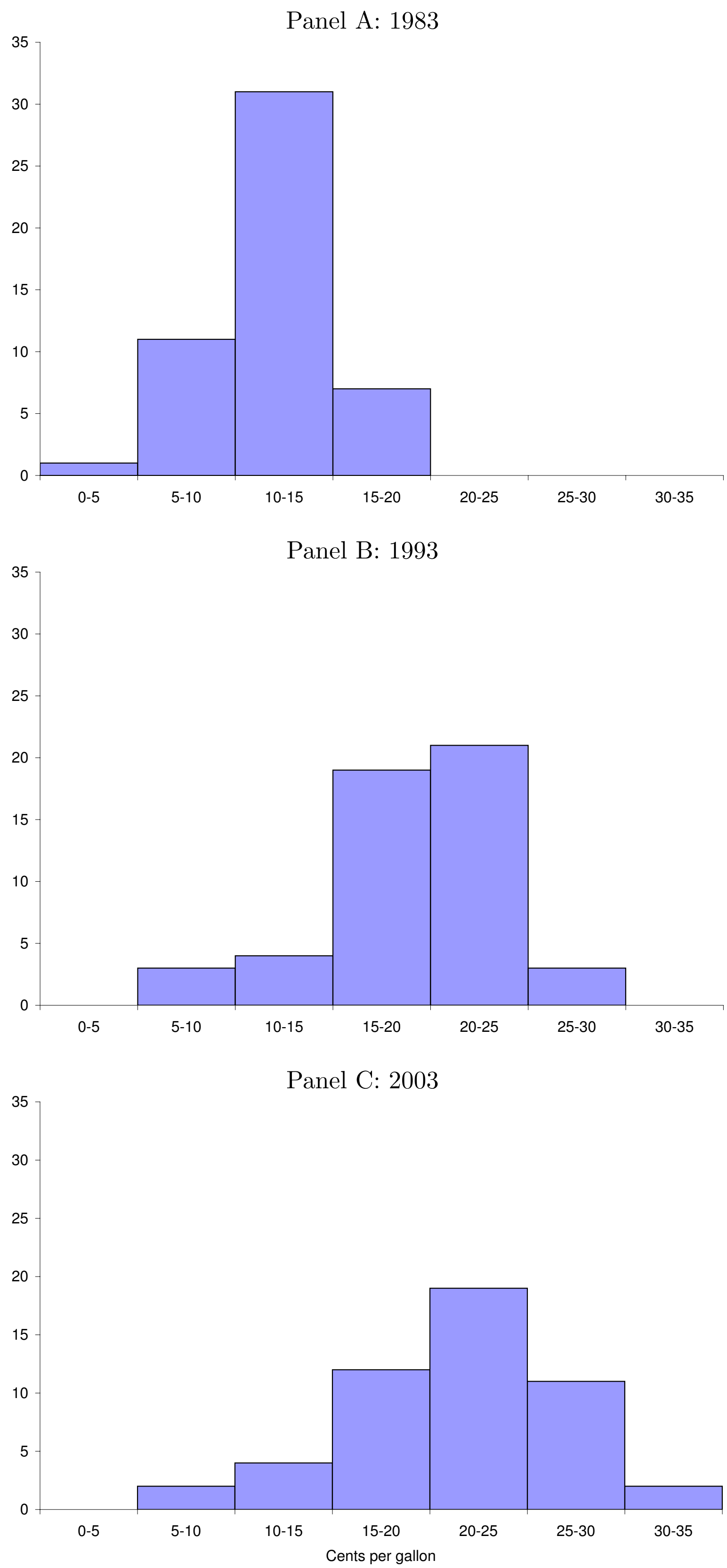


Figure 2: U.S. Sales of No. 2 Distillate

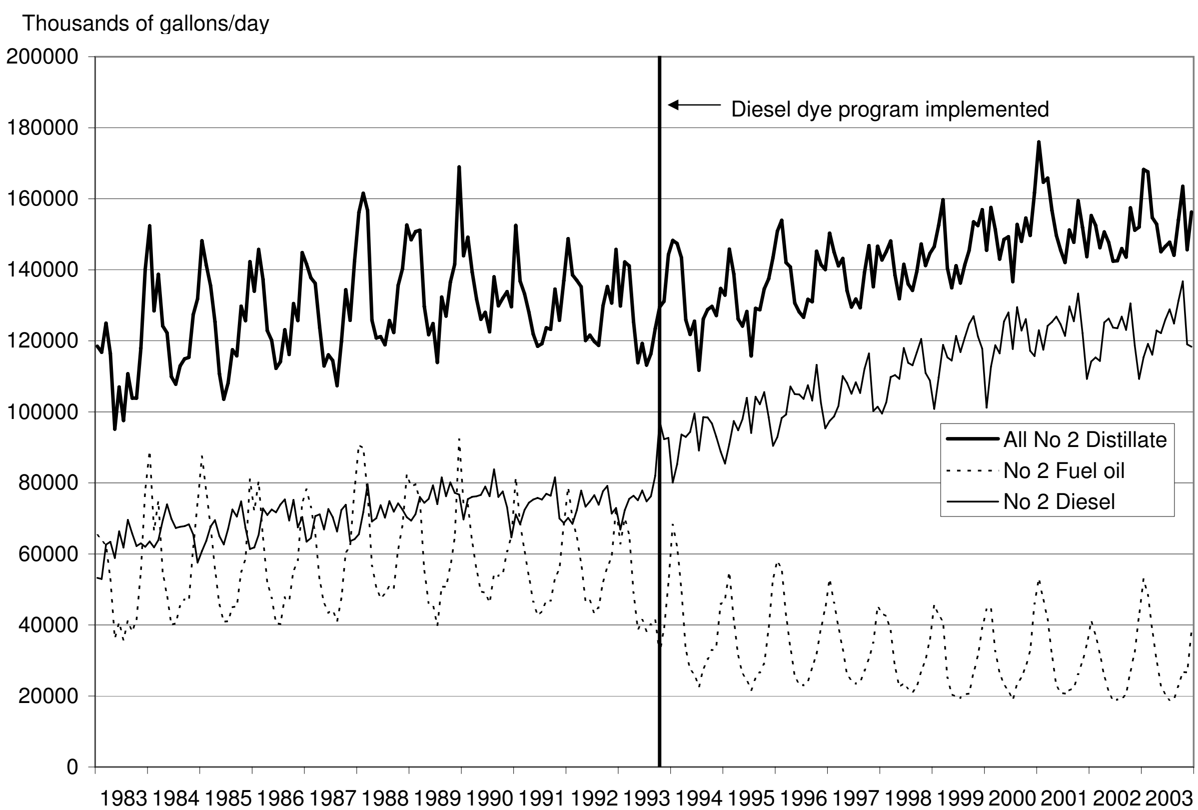
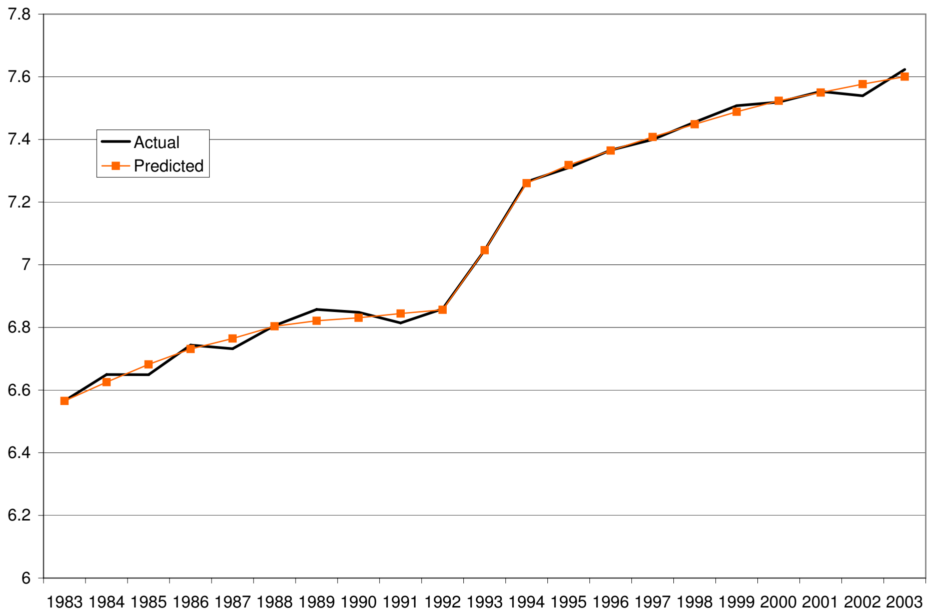


Figure 3: Average Predicted Versus Actual Quantities Sold

Panel A: No. 2 Diesel



Panel B: No. 2 Fuel Oil

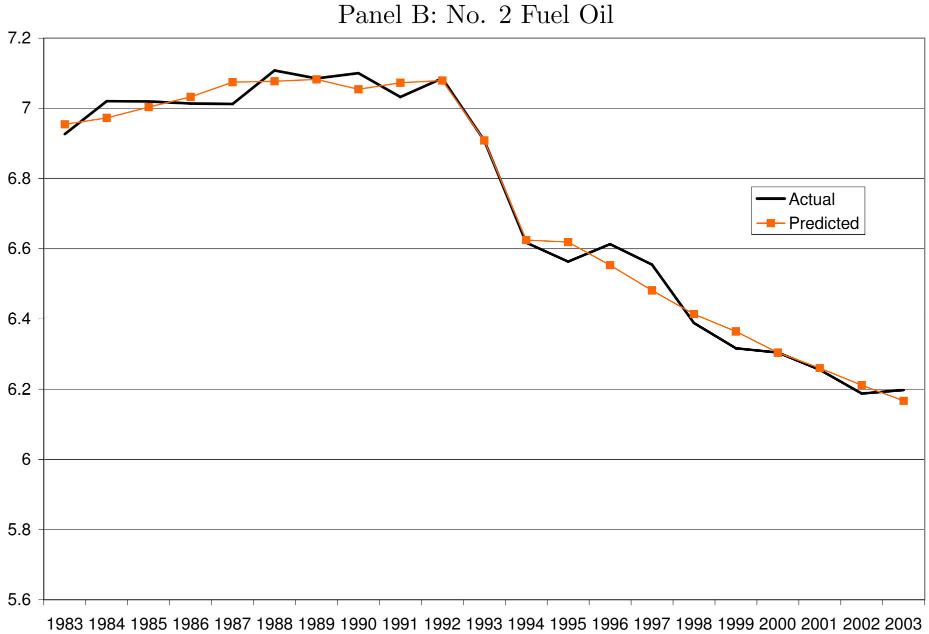
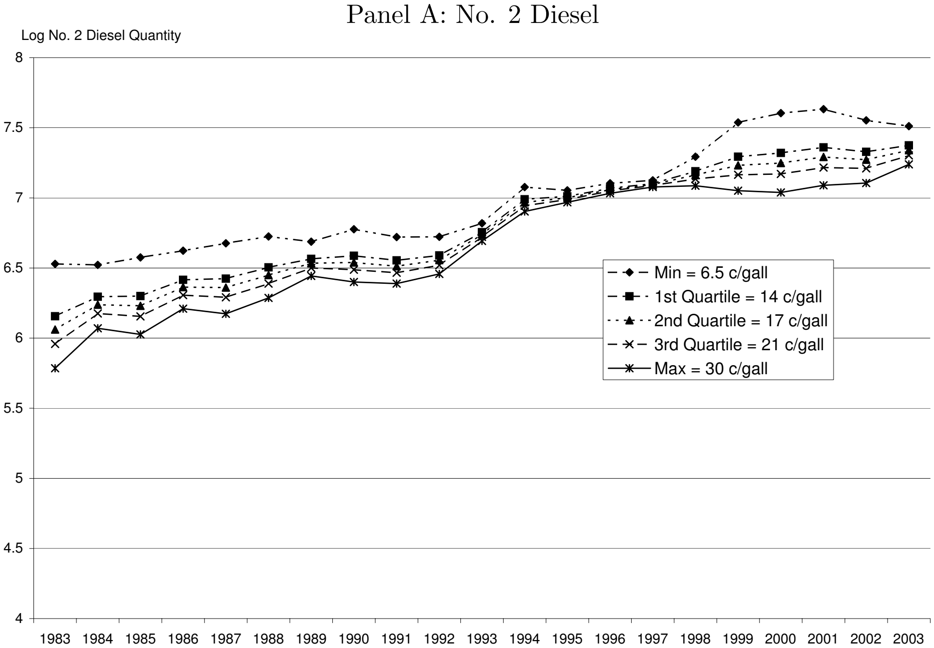


Figure 4: Predicted Quantities Sold By Tax Rate

Panel A: No. 2 Diesel



Panel B: No. 2 Fuel Oil

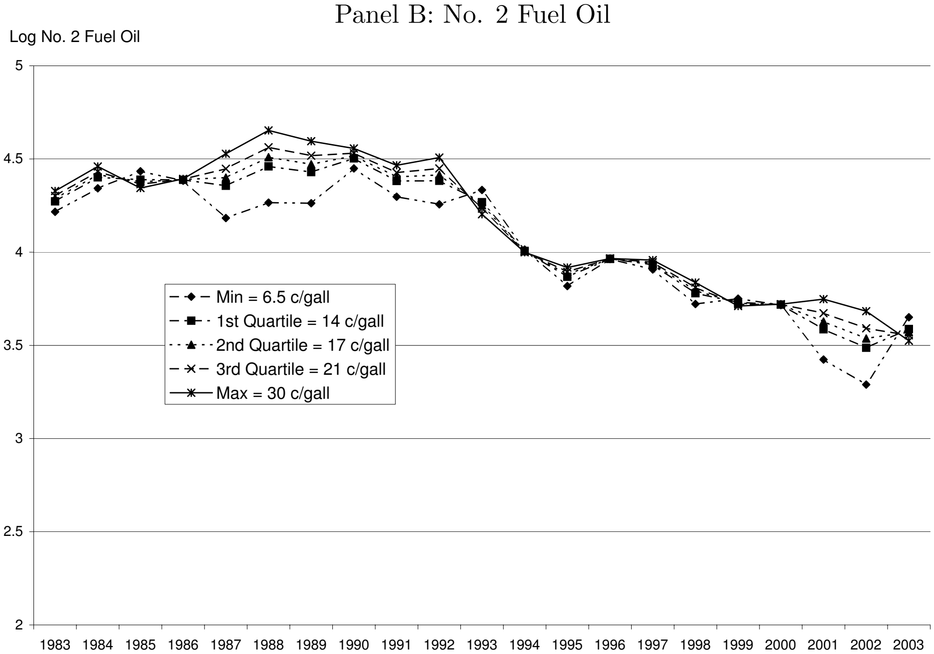


Figure 5: Average Predicted Versus Actual Quantities Sold, Other Distillates

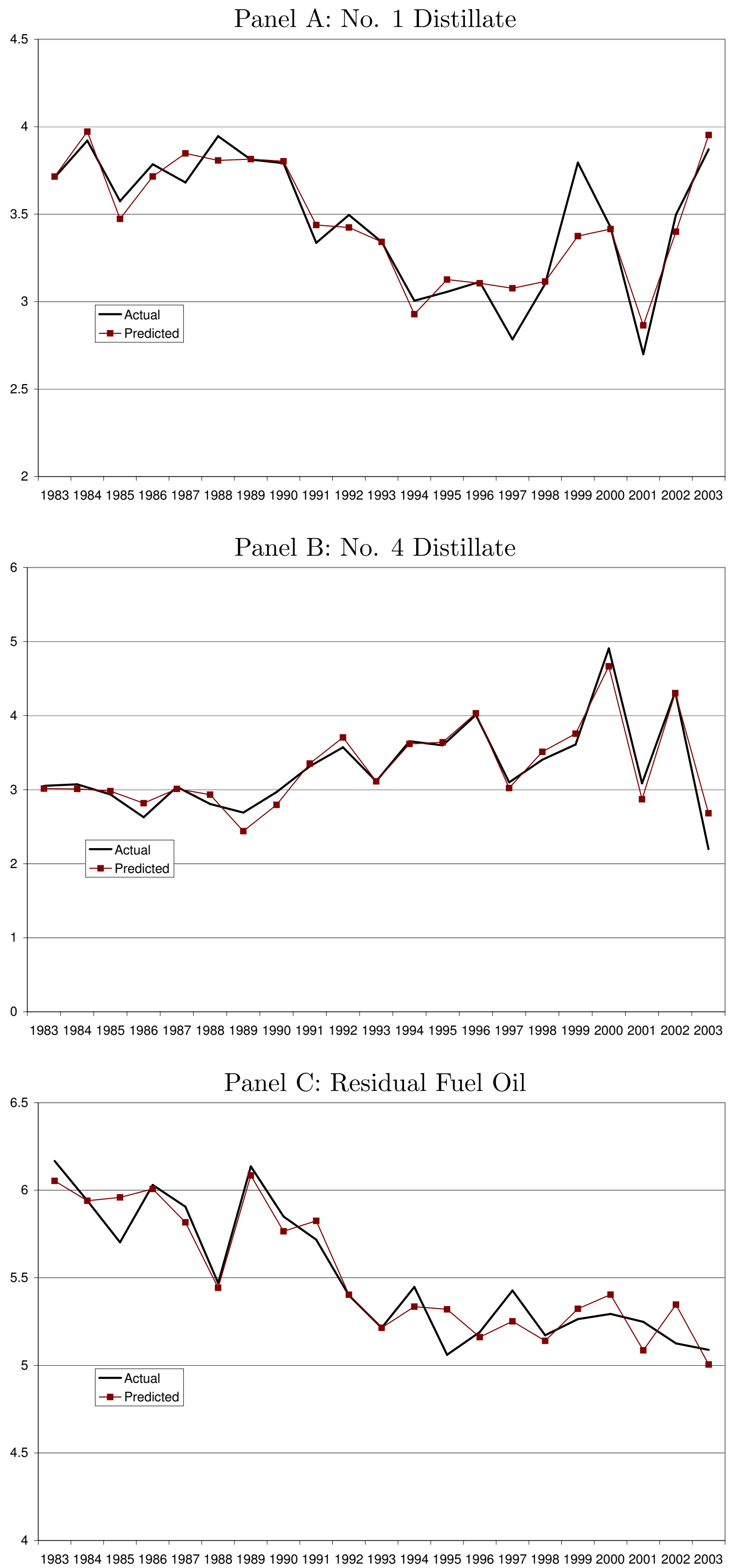


Table 1: Summary Statistics

	Pre-1993 (1)		Post-1993 (2)
State diesel tax	14.97		19.52
	(4.10)		(4.72)
No. 2 Diesel	1409.7		2504.9
	(1790.3)		(2163.8)
No. 2 Low sulfur			2238.1
			(1690.8)
No. 2 High sulfur			452.7
			(530.1)
No. 2 Fuel oil	1655.4		925.1
	(1680.2)		(967.7)
No. 1 Distillate	73.9		69.8
	(71.1)		(66.0)
No. 4 Distillate	89.2		96.3
	(166.7)		(147.8)
Residual Fuel Oil	1304.3		756.7
	(1981.9)		(1204.8)
Average degree days/month	449.9		431.6
	(161.1)		(154.0)
Northeast		0.286	
South		0.357	
Midwest		0.357	
Number of states		28	

Standard errors are in parentheses. Quantity variables are in thousands of gallons per day. The sample excludes 1993, and states with missing values for the No. 2 distillate series have been dropped. The No. 2 low sulfur and high sulfur values added together do not match the total No. 2 diesel value due to missing values.

Table 2: Log No. 2 Diesel Sales

	(1)	(2)	(3)	(4)
Log(Diesel Tax)	-0.255	-0.243	-0.284	-0.280
	(0.055)***	(0.055)***	(0.063)***	(0.063)***
Post-1993		0.353	0.118	
		(0.049)***	(0.162)	
Year 1994-1998				-0.225
				(0.189)
Year 1999-2003				0.433
				(0.193)**
Log(Tax)*Post-1993			0.080	
			(0.052)	
Log(Tax)*(Year 1994-1998)				0.199
				(0.062)***
Log(Tax)*(Year 1999-2003)				-0.025
				(0.061)
Log(Degree days)		0.019	0.023	0.014
		(0.094)	(0.093)	(0.094)
Year	0.073	0.004	0.006	0.006
	(0.012)***	(0.016)	(0.016)	(0.016)
Year^2	0.002	-0.004	-0.004	-0.004
	(0.001)	(0.001)***	(0.001)***	(0.001)**
Post-1993*Year	0.050	0.053	0.051	0.049
	(0.024)**	(0.022)**	(0.022)**	(0.022)**
Post-1993*Year^2	-0.009	0.002	0.002	0.002
	(0.001)***	(0.002)	(0.002)	(0.002)
Constant	7.776	7.448	7.546	7.589
	(0.163)***	(0.580)***	(0.576)***	(0.582)***
Observations	560	560	560	560
R-squared	0.98	0.98	0.98	0.98

Robust standard errors are in parentheses.
*,**,*** denote significance at the 90%, 95%, and 99% level, respectively.
Each specification also includes controls for state fixed effects. The sample excludes 1993.

Table 3: Log No. 2 Fuel Oil Sales

	(1)	(2)	(3)	(4)
Log(Diesel Tax)	0.099	0.089	0.119	0.116
	(0.129)	(0.129)	(0.138)	(0.139)
Post-1993		-0.358	-0.190	
		(0.101)***	(0.396)	
Year 1994-1998				-0.079
				(0.108)
Year 1999-2003				-0.041
				(0.191)
Log(Tax)*Post-1993			-0.057	
			(0.132)	
Log(Tax)*(Year 1994-1998)				-0.079
				(0.108)
Log(Tax)*(Year 1999-2003)				-0.041
				(0.191)
Log(Degree days)		0.288	0.285	0.260
		(0.212)	(0.212)	(0.212)
Year	-0.087	-0.030	-0.031	-0.030
	(0.025)***	(0.031)	(0.032)	(0.032)
$Year^2$	-0.008	-0.004	-0.004	-0.004
	(0.002)***	(0.003)	(0.003)	(0.003)
Post-1993*Year	-0.037	-0.013	-0.012	-0.002
	(0.051)	(0.049)	(0.050)	(0.048)
Post-1993*$Year^2$	0.013	0.003	0.003	0.003
	(0.003)***	(0.005)	(0.005)	(0.005)
Constant	6.592	5.047	4.977	5.137
	(0.379)***	(1.338)***	(1.349)***	(1.348)***
Observations	560	560	560	560
R-squared	0.83	0.83	0.83	0.83

Robust standard errors are in parentheses.
*,**,*** denote significance at the 90%, 95%, and 99% level, respectively.
Each specification also includes controls for state fixed effects. The sample excludes 1993.