

# Capital Flight? Do Airlines Move Fuel-Efficient Planes to High-Fuel-Tax Routes?

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## **Abstract**

This paper shows that airlines operate fuel-efficient planes on routes with high fuel taxes. It builds on a large data-collection effort compiling information on fuel taxes at the airport level, which is used to generate route-level taxes for thousands of nonstop airline routes in the US. The paper extends previous work exploring the connection between fuel prices and airline operations, with a new focus on the taxation of inputs. The results are used to derive the local pollution benefits from a route-specific fuel-tax increase.

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David R. Agrawal and Jan K. Brueckner and Quinton White<sup>†</sup>

## 1. Introduction

Airlines pay a variety of taxes in the course of their operations. These taxes include corporate income taxes, employee payroll taxes, and taxes on the purchase of inputs. The latter tax category includes taxes paid on jet fuel. While fuel taxes are one of many sources of government revenue, such taxes can also incentivize airlines to internalize externalities generated by their operations. Although no specific Pigouvian tax related to congestion or environmental concerns is levied via airline fuel usage in the US, the European Union effectively levies fuel taxes through its Emissions Trading System (ETS), which requires the purchase of emission allowances to match fuel usage.

Given the potential for fuel taxes to serve as a Pigouvian tax, it is important to understand how airlines adjust their operations in response to such taxes. The present paper advances this goal by investigating a particular operational response to fuel-tax differences across airline routes in the US, differences that arise through cross-sectional and intertemporal variation in federal, state, and local jet-fuel taxes across routes. The cross-sectional variation arises because jet fuel is subject to differential state excise taxes and sales taxes (in some states).

In particular, we investigate how airlines adjust their fleet allocations across routes in response to tax differences. Since fuel is an airline's second most costly input after labor services, we would expect the carrier to exhibit substantial sensitivity to fuel-tax liabilities, attempting to reduce fuel-tax payments to the extent possible. If fuel-tax rates were the same everywhere, tax minimization would occur by minimizing the airline's total fuel usage, possible through *real responses* such as purchasing more fuel efficient aircraft. But since fuel-

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tax rates are not uniform across US airline routes, an airline can engage in *tax avoidance* strategies to reduce its tax payments by assigning its most fuel-efficient planes to high-tax routes, which connect airports where fuel taxes are high. While an airline whose fleet consists of identical planes would have nothing to optimize, fleets always exhibit a range of fuel-efficiencies across aircraft as a result of different aircraft vintages, with newer models (incorporating later technologies) being more fuel efficient. Since a fuel-efficient plane will consume less fuel on any route it flies, the effective fuel taxes incurred on a high-tax route will be lower when it is served by such an aircraft instead of a less-efficient plane, leading to lower taxes overall. We demonstrate this latter point formally using a simple model.

We test the prediction that fuel-efficient planes serve high-tax routes using fuel tax data from the 1991-2019 period. The dependent variable in the regression is, for each airline serving a route, the average of an inverse fuel-efficiency measure for the aircraft it uses on that route, which may reflect a mix of plane types. This average is weighted by the annual route passenger volumes for the aircraft types. This inverse measure is the passenger-weighted average of gallons per seat-mile for those aircraft, with more gallons indicating worse fuel efficiency.

The main variables are the fuel-tax rates averaged across the two endpoint airports of the route. These taxes are expressed as ad valorem rates to facilitate the calculation of an elasticity, even though the main fuel taxes are excise taxes per gallon, as discussed below. Recognizing that jet-fuel prices vary regionally within the US, an additional covariate is the fuel price per gallon averaged across route's the endpoint airports. We also include the geometric means of the endpoint populations and incomes, which partly serve as demand indicators. With demand high, we would expect the airline to serve the route with larger planes, which are more fuel efficient, thus again expecting negative coefficients. We include route distance as another control variable. We expect a negative coefficient due to airlines assigning more fuel-efficient planes to longer routes.

The analysis relies on a major data contribution: the collection of fuel-tax rates at the individual airport level. This task is complex because in the US, the taxation of aviation fuel is partly decentralized to state and local governments. In addition to a federal tax, an airline thus pays taxes to the state and sometimes the locality where the aircraft is refueled. The

federal jet-fuel tax is excise tax, but some states levy both excise and sales taxes on fuel, while others levy only one of these taxes. Determining the historical rules that apply in each state requires careful analysis of state tax handbooks, state statutes, and revenue department websites for each state.<sup>1</sup> The result is extensive spatial and temporal variation in fuel-tax rates. We hand-collected all excise tax rates, sales tax rates, and applicable state laws to determine the total tax rate on fuel at every every major airport over a nearly 30 year period. As a contribution of this paper, all tax data will be publicly released for use by other researchers, and it may be useful to public, industrial organization, and environmental economists seeking to study tax-related shocks to the airline industry.

The performance of a basic regression with carrier by year and region pair fixed effects is qualitatively supportive of the hypothesis that higher fuel taxes lower gallons per seat-mile of the aircraft flown on the route. The fuel tax-rate coefficient is negative and statistically significant, indicating that passenger-weighted average gallons per seat-mile is lower (aircraft fuel efficiency is higher) on routes with higher endpoint tax rates. In addition, the coefficient of the average endpoint fuel prices is significantly negative, while the coefficients of distance and the geometric means of population and income are also significantly negative, further conforming to our expectations.

We advance the literature analyzing various aspects of fuel usage by passenger aircraft.<sup>2</sup> The papers by Fukui and Miyoshi (2017) and Brueckner and Abreu (2017) come closest to the present focus by showing that total fuel usage at the airline level falls in response to higher fuel prices. Those results are then used to predict the magnitude of the drop in fuel usage from higher fuel taxes. Both papers conduct their analysis at the airline as opposed to route level, and the airline’s average aircraft vintage is held constant in Brueckner and Abreu (2017), while year fixed effects in Fukui and Miyoshi (2017) also roughly control for aircraft vintages.

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<sup>1</sup> In addition, some states provide tax breaks for fuel sold at particular airports and differ regarding the point of sale where the tax is assessed.

<sup>2</sup> Other papers dealing with aspects of airline fuel usage include Kwan and Rutherford (2015), Zou et al. (2014), Hao et al. (2016), Hao, Hansen and Ryerson (2016), Oliveira et al. (2021). Studies focusing more on airline emissions, which are determined in part by aircraft fuel efficiency, include Scheelhasse and Grimme (2007), Miyoshi and Mason (2009), Morrell (2009), Ryerson et al. (2015), Lee et al. (2021), Brueckner, Kahn and Nickelsburg (2024), and Brueckner and Abreu (2025).

With aircraft fuel efficiency then approximately held fixed, the estimated drop in fuel usage in response to higher prices (or taxes) must arise through fuel-conservation measures such as lower flight speeds, not through changes in aircraft fuel efficiency.<sup>3</sup>

Our analysis captures how an airline’s allocation of its fleet across routes responds to differences in route-level fuel taxes, showing that more fuel-efficient planes are assigned to high-tax routes. We do not observe route-level fuel usage, but our results imply lower usage on high-tax routes due to the presence of more-efficient planes on those routes. Therefore, in contrast to the airline-level fuel-conservation efforts that implicitly underlie the other papers’ results, our conclusions show a different response to taxes: within-airline fleet reallocations whose goal is to reduce fuel usage on high-tax routes.

While this reallocation mechanism appears to generate environmental benefits as more fuel-efficient planes enter a route in response to a tax increase, the effect is purely local since emissions rise on lower-tax routes as less-efficient planes are reallocated to them. A similar phenomenon also arises in the case of cigarette taxes. State-specific cigarette tax increases have been shown to reduce taxable sales of cigarettes in the state but have no effect on cigarette consumption (or its resulting externalities) as individuals simply bootleg or cross-border shop for cigarettes from low-tax jurisdictions (Lovenheim, 2008; Merriman, 2010).

Our paper also advances the literature on avoidance and evasion of gasoline excise taxes (Kopczuk, Marion, Muehlegger and Slemrod, 2016). In the case of diesel taxes, a long-haul trucker’s tax liability to a state is determined by the reported number miles driven in the state, not by the fuel-purchase location. Using a theoretical model, Marion and Muehlegger (2018) show that a higher diesel tax in a state can encourage long-haul truckers to either falsely allocate miles to other low-tax states or to under-report the amount of fuel purchased. Empirically, they find tax burdens are mainly lowered through the second, under-reporting channel. Other studies of the diesel-fuel market have also found that drivers avoid taxes by shifting purchases from taxed diesel fuel toward untaxed fuel intended for usage off-road, for

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<sup>3</sup> In another related paper, Fageda and Teixido (2022) investigate the effect of the European Emission Trading System (ETS) on airline operations. They find that routes covered by the ETS experienced less traffic growth, or were more likely to be dropped by an airline, than exempt routes, confirming indirectly a negative effect of taxes (via the cost of emission allowances) on fuel usage.

example on farms (Marion and Muehlegger, 2008). Such a mechanism is, of course, not feasible in the airline industry. State gasoline taxes also result in capital misallocations by encouraging gas stations to locate on the low-tax sides of state borders (Hurtado, 2023, shows that they have 30% more stations).

The prior literature has shown that decentralized tax policies and place-based policies can generate inefficiencies in the allocation of capital (Fajgelbaum and Gaubert, 2020; Wilson, 1999). Since aircraft with different fuel efficiencies are highly substitutable across routes, it is unlikely that tax differences could cause a significant misallocation of airline capital.<sup>4</sup> But in different settings, the welfare loss from spatial misallocation of capital can be substantial (see Fajgelbaum, Morales, Suárez Serrato and Zidar, 2019). While some models distinguish between “old” and “new” capital, with the latter much more footloose in response to tax differences (Wildasin 2011), the main capital good in the airline case (aircraft) is perfect mobile, although the potential for tax-driven locational inefficiency is limited.<sup>5</sup>

Finally, our paper relates to a recent literature studying the effect of airline ticket taxes on consumer demand, tax incidence, and welfare (Bradley and Feldman 2020; White 2020; White, Agrawal, and Williams 2019). We focus instead on taxes on inputs and study firm responses.

At the end of our analysis, we compute the route-specific gain from cleaner air quality and corresponding tax revenue changes from reduced fuel usage following a 1 standard-deviation increase in the average state fuel tax on a route. To conduct this analysis, following Grobler et al. (2019), we separate the externalities from global versus local pollutants that harm local air quality. When increasing fuel taxes, state officials care about global externalities as well as local pollution from fuel usage affecting their residents, but with global externalities from aviation fuel unaffected by moving planes across routes, local pollution (air quality) becomes the only concern.

While it would be tempting to generalize this calculation to predict the local environmental gain from a tax increase on *all US routes*, that step would be illegitimate. The reason is that

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<sup>4</sup> Conceivably, a fuel-efficient plane that belongs on a long-haul route could instead be assigned to a low-tax shorter-haul route, although this choice seems unlikely.

<sup>5</sup> Inefficiencies from decentralized environmental regulation can also arise, as seen in the work of Sigman (2002) and Lipscomb and Mobarak (2017) on river pollution, where the interests of downstream jurisdictions may not be taken into account.

the lower fuel usage on a high-tax route comes from the reallocation of fuel-efficient planes, which make up only a portion of an airline's fleet. Given this fleet constraint, a general fuel-tax increase cannot lead to higher aircraft fuel efficiency *on all routes*, so that a prediction of a universal increase in fuel efficiency would be incorrect. However, the tax effect on fuel efficiency that we estimate does identify a force that could remake airline fleets in the long run. With a general increase in fuel taxes, airlines would have a greater incentive to replace older planes with new, more fuel-efficient aircraft, eventually leading to lower fuel usage on all routes.

The plan of the paper is as follows. Section 2 presents a simple model showing that fuel-efficient planes should be allocated to high-tax routes. Section 3 discuss the data and regression specifications, and section 4 presents the results. Section 5 computes the change in fuel externalities when the fuel-tax increases, and section 6 offers conclusions.

## 2. Model

Our hypothesis that fuel-efficient planes are assigned to high-fuel-tax routes can be demonstrated in a simple model. Suppose a carrier serves two routes, 1 and 2, providing  $m$  seat-miles (seats times distance) on each route. Route 1 is the high-tax route, with an average tax rate across its endpoint airports of  $t_1$ , while route 2 is the low-tax route, with an average tax rate of  $t_2 < t_1$ . The airline has two aircraft types,  $a$  and  $b$ , each of which can provide a total of  $m$  seat-miles while consuming  $g^a$  and  $g^b$  gallons per seat-mile. The type- $a$  plane is more fuel efficient, with  $g^a < g^b$ .

Let  $m_r^i$  be the seat-miles flown by aircraft type  $i$  on route  $r$ , with  $i = a, b$  and  $r = 1, 2$ . Thus,  $m_1^a$  equals seats flown by aircraft type  $a$  on route 1, etc. Total fuel-tax payments are

$$T = (m_1^a g^a + m_1^b g^b)t_1 + (m_2^a g^a + m_2^b g^b)t_2. \quad (1)$$

Since seats must sum to  $m$  on each route, this expression can be rewritten as

$$T = [m_1^a g^a + (m - m_1^a)g^b]t_1 + [m_2^a g^a + (m - m_2^a)g^b]t_2. \quad (2)$$

Furthermore, since seat-miles for each plane type must sum to  $m$ ,  $m_2^a$  in the last expression

must equal  $m - m_1^a$ . Substituting, (2) reduces to

$$T = [m_1^a g^a + (m - m_1^a) g^b] t_1 + [(m - m_1^a) g^a + m_1^a g^b] t_2. \quad (3)$$

Differentiating this expression with respect to  $m_1^a$  yields  $(g^a - g^b)(t_1 - t_2) < 0$ , indicating that total tax payments are minimized by setting  $m_1^a$  at the largest possible value of  $m$ . Thus, route 1 is served entirely by the more fuel-efficient plane (type  $a$ ), while route 2 is served by entirely by the less fuel-efficient plane. Note that, once the optimality of a corner solution is seen, the choice is whether to use the fuel-efficient plane entirely on the high-tax route or entirely on the low-tax route, with the first choice clearly being the one that minimizes tax payments.

### 3. Data and empirical specifications

#### 3.1. Data sources

In the United States, jet fuel is subject to federal excise taxes, state excise taxes, and (in some states) state and local sales taxes. Excise taxes are levied per gallon of fuel, while sales taxes are levied on the value of the sale. Given this multiplicity of taxes along with the potential that state tax laws allow fuel-tax exemptions for particular airports, the tax treatment of aviation fuel is complex.

As a result, there is no single source of information on jet-fuel taxes. We gather federal excise-tax rates on jet fuel from quarterly federal excise-tax forms. For each state, we hand-collected annual information on jet-fuel excise tax rates, sales tax applicability, exemptions, and points of taxation using an array of sources including CCH annual tax guidebooks for individual states, surveys of state administrators, information from the US Energy Information Administration (EIA), academic articles, news articles, state tax forms, and individual state tax codes. Determining the tax treatment of sales taxes for jet fuel often requires careful historical statutory analysis. Depending on the year, state sales-tax rates were sourced from the Tax Policy Center, the Tax Foundation, or the University of Michigan Office of Tax Policy Research.

Next, we collected annual jet-fuel prices across regions from the EIA, assigning states to regions according to the EIA's PADD regions (Petroleum Administration for Defense Districts).

Given that sales taxes are ad valorem while excise taxes are unit taxes, we express all fuel taxes on an ad valorem basis using the prevailing fuel prices at the route’s endpoints. Conversion to ad valorem form follows the procedure in Chetty, Looney, and Kroft (2009). Use of the ad valorem form is also theoretically preferred as it allows us to apply the log functional form to the after-tax price, with the coefficients yielding elasticities.

We believe that the collection and harmonization of decentralized fuel taxes is a major contribution in its own right. The publication of our tax database will provide opportunities to answer questions in public and environmental economics, while being extremely useful for industrial organization economists who may require exogenous cost shocks in an empirical model.

To compute average aircraft fuel-efficiency by route and airline, we first use the T2 data set of the U.S. Bureau of Transportation Statistics to compute efficiency by aircraft type. This database calculation contains annual fuel consumption and seat-miles flown by each aircraft type and airline. The ratio of fuel consumption to seat-miles gives gallons per seat-mile, an inverse fuel-efficiency measure. An average of this variable (weighted by seat-miles) is computed across airlines and years over the 1991-2019 period to yield the inverse fuel-efficiency measure for each aircraft type.

Next, the Department of Transportation’s T-100 domestic segment database gives the aircraft types and airlines serving individual US nonstop routes, along with passenger counts by aircraft type. Using this information, along with inverse fuel-efficiency by aircraft type, we compute passenger-weighted average gallons per seat-mile on a route across aircraft types for a given airline, our dependent variable.

Bureau of Economic Analysis data give annual populations and per capita incomes for the cities containing the endpoint airports of each route. These variables are used to compute the geometric means of the endpoint populations and incomes. The route distance measure comes from the T-100 database.

### *3.2. Summary statistics and graphs*

Routes are directional, with route from New York’s JFK airport to the LAX airport in Los Angeles distinct from the LAX-to-JFK route. Distinguishing routes by directionality is

appropriate since an airline may fly different planes in each direction. In addition, we only include flights by non-regional carriers, thereby excluding much of the feeder service into hub airports from smaller cities. The number of carriers remaining in the sample is then 19.<sup>6</sup> Finally, we delete route×airline×year observations where total departures in the year across all carriers on the route is very low, in order to exclude seasonal flights or carrier exit/entry from the route. The 25th percentile value for route departures per year is 59, and we keep only observations with higher values of this variable. The median route departures per year is 761, or about 2 flights per day, possibly on more than one carrier.

Summary statistics are shown in Table 1, with the variable names being self-explanatory. The sample contains 151,899 route×airline×year observations across 13,148 directional routes, with each route observed for at least one year. The mean value of the inverse fuel-efficiency measure, *gallons\_seat\_mile*, is 0.0181, with minimum and maximum values of 0.010 and 0.0352, respectively. The average fuel tax per gallon across the two route endpoints, *tax\_per\_gal\_avg*, has a mean \$0.120 per gallon (12 cents per gallon) and its excise component (where any sales tax is removed) has an average of 0.092. While these average rates convert the sales taxes that are sometimes levied on jet fuel into an excise value, the main regressions instead use a tax variable where the excise taxes are converted to ad valorem rates using the annual fuel price, with the rate of the state or local sales tax (if one exists) then added. The average of these rates across the route endpoints is captured by the variable *adv\_fuel\_tax\_avg*, whose mean value is 0.130. This value is close to the excise rate given that the fuel price, denoted *fuel\_price\_avg*, is often near a dollar per gallon in the early part of the sample period. Its mean value across the two route endpoints is \$1.47. The variable *adv\_excise\_tax\_avg* is the ad valorem fuel-tax rate with the sales-tax component removed, and it has a mean of 0.111, slightly less than the *adv\_fuel\_tax\_avg* mean. As can be seen, the sales tax represents a relatively small share both because of its low rate, but also because many states do not include jet fuel in the sales tax base. The average route distance is 930 miles, with a maximum of 5,095 miles,<sup>7</sup> while the

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<sup>6</sup> The carriers are (alphabetically by carrier code) American, Alaska, JetBlue, Continental, Delta, Frontier, AirTran, Allegiant, Hawaiian, America West, Spirit, Northwest, Sun Country, TWA, ATA, United, US Airways, Virgin America, Southwest. A number of these airlines disappeared during the sample period through mergers.

<sup>7</sup> The 11-mile minimum distance is for the route between Oakland and San Francisco, where passengers were

less-interpretable mean values for the geometric-mean variables are also shown.

Figures 1-3 show the time paths of inverse fuel efficiency, the fuel price, and fuel taxes, based on annual averages across the sample routes and airlines. As seen in Figure 1, the log of inverse fuel efficiency falls over the sample period, reflecting the secular improvement in aircraft fuel efficiency over time. Figure 2 shows the variation in the log of the pre-tax fuel price, whose trend is upward over most of the sample period but downward toward the end, with considerable year-to-year variability. Figure 3 shows time path of the log of  $(1 + adv\_fuel\_tax\_avg)$  (excluding the federal excise tax so that the state variation is shown clearly), which shows that a downward trend governed state taxes.

### *3.3. Cross-section vs. intertemporal variability of taxes and inverse fuel efficiency*

It is interesting to contrast the across-route and across-year variability of the fuel-tax rates, expressed in excise form. To gauge across-year variability, we first compute the standard deviation of the average tax rate over the 29 sample years (indexed by  $t$ ) for a particular route  $r$ . This standard deviation is then averaged across routes, yielding a mean across-year tax-variability value of 0.0319. Similarly, to gauge across-route variability, we compute the standard deviation of the average tax rate across routes in a given year, which is then averaged across years. The result is a mean across-route tax-variability value of 0.0505.

Since 0.0505 is almost twice as large as 0.0319, it follows that the across-route variability of fuel-tax rates exceeds the across-year variability of the rates. This conclusion, which shows that cross sectional tax-rate variation in the sample is larger than intertemporal tax-rate variation, makes sense given the likely inertia over time in tax rates for a given route and the scope for variation across routes in the tax rates charged. Because of this relatively low intertemporal tax variation, an event-study analysis gauging the impact of within-route tax changes is likely to be unsuccessful.<sup>8</sup> Thus, our regression results should be interpreted as correlations that arise in equilibrium based on dramatic level differences in taxes across states rather than an effect of small tax changes.

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carried in the early 1990s, presumably as an add-on to an intercontinental flight. The 5,095-mile route is from Boston to Honolulu.

<sup>8</sup> We tried different stacked event-study designs but point estimates were always insignificant and differ dramatically depending on how treatment and comparison groups are defined.

The intertemporal and cross-sectional variations in fuel efficiency can also be gauged by computing the standard deviations across routes and across years of *gallons\_seat\_mile*, following the same procedure used for the tax rates. The results show a value of 0.00298 for the across-year variability of *gallons\_seat\_mile* and a value of 0.00247 for the across-route variability. Therefore, despite the strong downward trend of *gallons\_seat\_mile* over time, the inverse-efficiency measure’s across-route variability is almost as large as its across-year variability. Thus, large differences in aircraft fuel efficiencies exist across routes and time, perhaps partly in response to tax differences.

### 3.4. Presence of different aircraft types

Table 2 presents a final view of the data by showing the aircraft types appearing in the sample along with their *gallons\_seat\_mile* values. The number of routes where each type is present for at least one year is also shown (*#routes*), as is the number of years in which the type appears on at least one route (*#years*). In addition, *#routes*  $\times$  *years* gives the number of route  $\times$  year appearances, which is smaller than the product of *#routes* and *#years* because an aircraft may not be present on the same routes in every year that it appears.<sup>9</sup> Note the wide variation of *gallons\_seat\_mile* across the aircraft types, which range from the high 0.0252-0.0260 values of the old B727-200 and original DC-9 types to the much lower 0.0100-0.0107 values of the new B737 Max 9 and A321-200NEO types.

### 3.5. Regression specifications

Since the fuel price is region-specific, the average fuel price on a route will depend on the “region-pair” pertaining to the route, defined as the ordered pair of origin and destination regions. Let  $p$  denote the region pair,  $r$  denote the route, and  $t$  denote the year. Then, using

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<sup>9</sup> Widebody aircraft are occasionally seen in the T-100 data set operating on the sample routes, all of which are domestic. Some of these appearances are on high-volume routes between an airline’s hubs, where passengers are carried, but other appearances show a passenger count of zero, evidently indicating a repositioning flight for the aircraft after an international trip. With zero passengers, these instances disappear under the passenger-weighting of aircraft fuel efficiencies used to create the dependent variable, and thus can be ignored. The remaining widebody cases are not tabulated in Table 4 since they are fairly rare.

the ad valorem tax rates, the after-tax fuel price (or the “full” price) is given by<sup>10</sup>

$$(1 + \text{adv\_fuel\_tax\_avg}_{rt}) \times \text{fuel\_price\_avg}_{pt}. \quad (5)$$

Our first regression relates the inverse fuel-efficiency measure  $\log(\text{gallons\_seat\_mile})_{cprt}$ , where  $c$  denotes the carrier, to the full price in (5). It also includes the logs of the geometric means of income and population and the log of distance as controls, along with fixed effects defined below. The expectation is that a high full fuel price reduces inverse fuel efficiency, thus raising the fuel efficiency of aircraft serving a route.

A crucial question, though, is whether the fuel-price and tax components of (5) have separate impacts on inverse fuel efficiency, and whether those effects are equal, as they should be given the form of (5). This hypothesis is tested by breaking the log of (5) into two variables:  $\log(1 + \text{adv\_fuel\_tax\_avg}_{rt})$  and  $\log(\text{fuel\_price\_avg}_{pt})$  and estimating the following regression equation:

$$\begin{aligned} \log(\text{gallons\_seat\_mile})_{cprt} = & \alpha + \beta \log(1 + \text{adv\_fuel\_tax\_avg}_{rt}) + \gamma \log(\text{fuel\_price\_avg}_{pt}) \\ & + X_{cprt}\delta + \epsilon_{cprt}, \end{aligned} \quad (6)$$

where  $X_{cprt}$  is the vector of control variables and  $\epsilon_{cprt}$  is the error term. If a test cannot reject equality of the the coefficients  $\beta$  and  $\gamma$ , then the hypothesis of equal effects is upheld. More generally, a statistically significant coefficient for the tax variable indicates that fuel taxes do indeed exert their own effect on the inverse fuel efficiency of aircraft serving a route, independently of a separate effect operating through the fuel price.

While the log-log regression using the ad valorem fuel tax is our preferred specification, we also report the results from an excise-tax version of the regression as a robustness check. The after-tax (full) fuel price with fuel taxes expressed in excise form is  $\text{tax\_per\_gallon\_avg}_{rt} +$

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<sup>10</sup> Strictly speaking, the after-tax fuel cost would be generated by evaluating (5) at each route endpoint, and averaging across the endpoints. However, (5) offers a good approximation to this approach and, critically, allows us to apply the log functional form to separately identify tax and price effects.

$fuel\_price\_avg_{pt}$ . With unlogged  $gallons\_seat\_mile_{cprt}$  as the dependent variable, this full price measure appears on the right-hand side in an initial linear regression along with the controls in linear form. To appraise the separate fuel-price and tax effects, the after-tax cost measure is broken into separate tax and fuel-price variables, with their own coefficients.

The main regressions include two sets of fixed effects, which are part of  $X_{cprt}$ . The first is carrier  $\times$  year fixed effects, an appropriate choice since the makeup of airline fleets differs across carriers, so that some carriers will have more newer, fuel-efficient planes than others in a given year, providing more scope for assigning such planes to high-tax routes. This fleet-composition effect will also vary across years as fleets evolve through retirement and replacement of aircraft.

In addition, the regressions include region-pair fixed effects. Regions are defined as the seven Petroleum Administration for Defense Districts used by the EIA to construct regional fuel prices. For example, a route from Chicago to Los Angeles then contains a fixed effect for the region pair corresponding to Midwest/West Coast. These region-pair fixed effects are similar to route effects, which would be desirable but are unworkable because they eliminate too much of the cross-sectional variation in taxes, whose effect we wish to measure. Allowing for some cross-sectional variation to remain is important because taxes change infrequently and moving planes across routes may not occur immediately due to airport regulations. Letting  $\zeta_{ct}$  and  $\zeta_p$  denote the carrier  $\times$  year and region-pair fixed effects, the  $X_{prt}\delta$  term in (5) expands to

$$X_{prt}\delta = \delta_0 \log(pop\_geomean_{rt}) + \delta_1 \log(income\_geomean_{rt}) + \delta_2 \log(distance_r) + \zeta_{ct} + \zeta_p. \quad (7)$$

The indexing in (6) and (7) makes it clear that the dependent variable varies over carriers while the independent variables do not, with taxes the same for all carriers flying a given route. Furthermore, as routes  $r$  are contained within a particular region pair  $p$ , taxes contain route-level variation while fuel prices are specific to the regions, not states, containing the route endpoints. Standard errors in the main regressions are clustered by carrier  $\times$  year and by nondirectional route, with the latter clustering accounting for possible error correlation across the different flight directions between the two endpoints.

## 4. Regression results

### 4.1. Main results

The results of estimating the regressions with taxes in ad valorem form are shown in Table 3. Given that all variables are in logs, all coefficients can be interpreted as elasticities. Column 1 shows the results using the log of the full after-tax fuel price ( $lfull\_fuel\_price\_avg$ ) as the focal explanatory variable. Its coefficient is negative and strongly statistically significant, showing that airlines operate more fuel-efficient planes on routes where the full price of fuel is higher. The control coefficients are all significant with negative signs, showing that more fuel-efficient planes are operated on high demand routes (with large geometric means of income and population) and on longer-distance routes, as expected.

Instead of using the full price, the regression in column 2 replaces it with the full price's fuel-price component, the log of the route's average pre-tax fuel price ( $lfuel\_price\_avg$ ). The coefficient is again negative and significant, but larger in absolute value than the coefficient in column 1.

The regression in column 3 breaks  $lfull\_fuel\_price\_avg$  into its separate components,  $lfuel\_price\_avg$  and  $\log(1 + adv\_fuel\_tax\_avg)$ . Both the price and tax variables have significant coefficients, but the  $lfuel\_price\_avg$  coefficient is double the size of the tax coefficient in absolute value. However, the null hypothesis that the coefficients are equal cannot be rejected (the  $p$  value is 0.2276). Therefore, higher fuel taxes have a separate negative effect on the inverse fuel-efficiency of the aircraft flown on a route, and the effect is statistically indistinguishable from the effect of the fuel price itself. The slight smaller economic magnitude may be due to reduced salience, possibly a result of the point of collection of taxes differing across states, creating differential evasion strategies (Kopczuk, Marion, Muehlegger, and Slemrod, 2016). The significant negative effect nonetheless supports the hypothesized connection between fuel taxes and aircraft fuel efficiency. Quantitatively, the results, which show elasticities given the log-log form of the regressions, show plausibly moderate quantitative impacts, with the elasticities less than 1 in absolute value.

The regression in column 4 removes the sales tax component from the ad valorem form of the fuel tax, leaving only the federal and state/local excise taxes expressed in ad valorem

form. The resulting variable is called  $\log(1 + adv\_excise\_tax\_avg)$ . Now, the fuel-price and tax effects are very similar in size (and statistically indistinguishable), with the fuel-price effect growing somewhat relative to column 3 and the tax effect growing substantially. Thus, the sales tax component of the ad valorem form of the fuel tax somehow depresses the overall tax effect. The source of this depression can be seen in column 6, where the only tax variable is the sales tax, represented by  $\log(1 + sales\_tax\_avg)$ . As can be seen, the coefficient of this variable is positive instead of negative, helping to explain the larger negative tax effect when it is removed as a component of the ad valorem rate. This peculiar outcome may arise because sales tax is zero for about 60% of origins and destinations, so that the very existence of the tax (representing a tax increase relative to zero-tax routes) could be related in a perverse fashion to unobservable route characteristics that help determine the type of planes flown on the route.

Figures 4-6 illustrate the effects of the full fuel price and fuel taxes on fuel efficiency. Figure 4 is based on separately residualizing inverse fuel efficiency and the full fuel price on the control variables and fixed effects. The negative correlation of these two residuals seen in the figure then yields the negative coefficient in column 1 of Table 3. Similarly, Figure 5 plots a regression where the full-price residuals are replaced by the tax residuals, while Figure 6 plots the regression where the full-price residuals are replaced by the excise-only tax residuals, with both plots showing negative slopes. These binned scatter plots provide a non-parametric way to visualize the estimated effects, indicating that the results are not driven by outliers.

Are these results robust to exploiting different sources of identifying variation? While region-pair fixed effects are natural because they mirror route fixed effects while allowing us to exploit some cross-sectional variation, we can consider different variants. We explored variants of column (4), which focus on the excise fuel taxes, under different fixed-effect assumptions. Analogous to the trade literature, we can replace region-pair fixed effects with separate effects for origin and destination regions in order to more flexibly control for origin and destination-specific factors. Doing so yields a tax coefficient (standard error) of -0.330 (0.058). Analogous to the carrier $\times$ year effects, we can include carrier by region-pair fixed effects to account for regional factors that affects carriers differently, yielding: -0.382 (0.055). Finally, we can include region-pair by year effects, which nonparametrically control for prices, yielding a tax effect of

-0.517 (0.060).

#### 4.2. Results using fuel taxes in excise form

Table 4 presents regression results with fuel taxes expressed in excise form, with the regressions being linear instead of log-log. Since these regressions perform better when the region-pair fixed effects are dropped, the results reflect this change. As can be seen, the full fuel price in column 1 has a significantly negative coefficient, mirroring Table 3, while the control variables again have negative effects, although the *income\_geomean* coefficient loses significance. Column 2 shows the results when the full fuel price is split into its components. Both *fuel\_price\_avg* and *tax\_per\_gal\_avg* have negative coefficients, but the tax coefficient is only significant at the 10% level. In addition the fuel-price coefficient is about ten times as large as the tax coefficient, instead of twice as large, as in Table 3. The regression thus suggests that the effect of a higher fuel price in reducing inverse fuel efficiency on a route is much larger than the effect of higher taxes.

As before, removing the sales tax component from the excise form of the fuel tax reduces the difference between the fuel-price and tax coefficients. As seen in column 3 of Table 4, when the resulting tax variable (*excise\_fuel\_tax\_gal\_avg*) is used instead, the fuel-price and tax coefficients remain negative and are now both significant, but they differ by a factor of 5, a difference that is statistically significant. Nevertheless, it can be shown that the elasticity of *gallons\_seat\_mile* with respect to  $(1 + \textit{excise\_fuel\_tax\_gal\_avg})$  implied by the linear equation is not much smaller than the 0.516 value from the log-log specification (column 3 of Table 3).<sup>11</sup> Overall, the results in Table 4 continue to show that higher taxes reduce the inverse fuel efficiency of the aircraft serving a route, although the identification relies more on cross-sectional variation than in Table 3 due to the lack of route-pair fixed effects.

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<sup>11</sup> Letting  $y$  denote the inverse fuel efficiency and  $t$  the tax variable, the task is to compute the linear  $dy/dT$  estimate's implied value of  $d \log y / d \log(1 + t)$ , which equals

$$\frac{dy/y}{dt/(1+t)} = \frac{dy}{dT} \frac{dT}{dt} \frac{1+t}{y}.$$

Since  $dy/dT = 0.00399$  from the linear model and  $dT/dt = p = 1.47$ , given  $T/p = t$ , the last line becomes  $0.00399 \times 1.47 \times (1+t)/y = 0.00399 \times 1.47 \times 1.11/.0181 = 0.360$  using Table 1, a value that equals 70% of the 0.516 coefficient from Table 3.

## 5. Economic effects of a higher fuel-tax rate

When the fuel taxes on a route are raised, the planes serving it may become more fuel efficient through two different channels: an avoidance response and a real response. First, an airline may shift fuel efficient planes toward the higher-tax route and away from lower-tax routes. Second, an airline may retire fuel-inefficient planes flying that route earlier than expected and replace them with more efficient planes. In the short run, the first mechanism is likely to dominate because replacement of planes is costly and only occurs near the end of a useful life of 25 to 30 years. Finally, individual states are likely to lack enough tax-related market power to induce a real response by an airline. Even if most of the response is through reallocation of aircraft, our results are still useful in quantifying any local benefits from reduced externalities perceived on the route affected by a tax change.

When setting fuel taxes, in addition to tax revenue, officials may care about local pollution from aircraft operations. Average air quality across all routes will not be affected by reallocating planes, but policy makers may value the local pollution reduction from attracting fuel efficient planes to their route, while not caring about offsetting increases elsewhere. We quantify the effects of local pollutants and compare them to the revenue changes from tax increases. To do so, we use the estimates in Gobler et al. (2019) that separate the negative externalities of aviation fuel into those that affect individuals worldwide and those that affect local residents via changes in air quality. They estimate the gain due to improved air quality from a one-metric-ton reduction of fuel consumption on take-off and landing, equal to \$590.

First consider the impact of an increase in route *distance* to gain an appreciation for relevant magnitudes. From column 4 of Table 3, a 1% increase in *distance* leads to a 0.034% reduction in inverse fuel efficiency. Therefore, a one-standard-deviation increase in route distance (665 miles from Table 1) starting from the mean distance of 930, which is a 72% increase, yields a  $72 \times 0.034 = 2.45\%$  reduction in inverse fuel efficiency, a plausible effect.

To gauge the quantitative effects of a higher fuel tax on inverse fuel efficiency, consider the effect of a one-standard-deviation increase in *adv\_excise\_tax\_avg*, which could arise from an increase in state excise taxes on the route. This increase, equal to 0.134 from Table 1, leads to a proportional  $0.134/1.111$  increase in  $1 + adv\_excise\_tax\_avg$  evaluated at the mean tax

of 0.111, equal to 0.121, or 12%. This 12% increase in turn leads to a  $12 \times 0.516 = 6.2\%$  reduction in inverse fuel efficiency, using the coefficient from column 4 of Table 3. Using the mean *gallons\_seat\_mile* value of 0.0181 from Table 1, this decrease amounts to a  $0.062 \times 0.0181 = 0.0011$  reduction.

We wish to value the improvement in local air quality from lower fuel usage due to this improvement in fuel efficiency, which occurs in the two endpoint cities of the affected route. The first step is to compute the change in gallons per route, which equals the change in gallons per seat mile, 0.0011, times average annual seats per route, equal to 139,814, times the average route distance of 930, a product that equals 143,030 gallons. According to Gobler et al. (2019), 10% of fuel consumption on average occurs on takeoff and landing, corresponding to 14303 gallons. Using a value of \$590/mton and noting that one metric ton of fuel consists of 326 gallons, the valuation of improved local air quality associated with the higher tax is then  $14303 \text{ gallons} \times (1 \text{ mton} / 326 \text{ gallons}) \times 590/\text{mton} = \$25,886$ .<sup>12</sup> Therefore, relative to a typical route, a one-standard-deviation higher fuel-tax rate on a route leads to air-quality benefits in the endpoint cities of \$26,000 from use of more fuel-efficient planes.

As noted above, while it would be tempting to aggregate this damage reduction across all the sample routes, doing so would be illegitimate. If the changes are due to shifting behavior rather than an improvement of the fleet, then gains on the route experiencing the tax increase and fuel-efficiency gain are offset by losses on the routes that lose fuel-efficient planes, both for global and local pollutants. The reason is that the fuel-efficient planes on high-tax routes are scarce and not available to serve every route. However, if fuel taxes were higher on all routes, an airline's fleet would become more fuel-efficient in the long run in response as older planes are retired and replaced with new ones. Thus, while our calculation cannot be aggregated, it points in the direction of the ultimate aggregate effects if airline fleets become more fuel efficient.

Finally, we can compare these gains from reduced fuel usage to the fiscal externality, which equals the second-order attenuation of the revenue gained from the tax increase due to

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<sup>12</sup> Grobler et al. (2019) provide confidence intervals on the valuation of air quality improvements that range from \$84 to \$1700 per per metric ton of fuel usage. Using these estimates gives a range for our benefit calculation of \$3685 to \$74,586.

the introduction of more fuel-efficient planes. From Table 1, the average fuel price is \$1.47 and average gallons per seat mile are 0.0181, so that multiplying by average seats per route (139,814) and again by average route distance (930) gives 2,353,489 gallons consumed per route. Thus, absent any adjustment from the airlines, a one standard deviation increase in the tax (0.134 percentage points) would mechanically raise  $0.134 \times \$1.47 \times 2,353,489 = \$463,590$  in additional revenue. However, as airlines change their fleet allocation, the more fuel-efficient planes on the route erode some of this mechanical revenue gain. Thus, the fiscal externality of the tax increase is the lost revenue due to the foregone sales of fuel:  $0.111 \times \$1.47 \times 143,030 = \$23,338$ . Interestingly, this fiscal leakage is slightly smaller than the valuation of the local gain from the fuel-usage reduction.

## 6. Conclusion

This paper has shown that airlines operate fuel-efficient planes on routes with high fuel taxes. It builds on a large data-collection effort compiling information on fuel taxes at the airport level, which is used to generate route-level taxes for thousands of nonstop airline routes in the US. The paper extends previous work exploring the connection between fuel prices and airline operations, with a newer focus on the after-tax fuel price and thus its tax component. We also connect to the literature on fuel-tax avoidance behaviors of firms and individuals. The results are used to show that an appreciable route-level fuel-tax increase yields large benefits on the route, a result of reduced emissions from fuel usage as airlines reallocate their most fuel-efficient planes to the route. However, since this reduction is achieved mostly by shifting planes across routes the reduced fuel usage is offset by increased usage elsewhere. Airlines' reallocation of planes in response to state taxes suggests that universal fuel-tax changes would hasten the replacement of old planes on all routes with more fuel-efficient aircraft.

**Table 1: Summary statistics**

<i>Variable</i>	<i>Mean</i>	<i>Std. Dev.</i>	<i>Min</i>	<i>Max</i>
gallons_seat_mile	.0181	.00417	.010	.0352
tax_per_gallon_avg	.120	.0636	.043	.3684
excise_tax_avg	.092	.064	.043	.368
adv_fuel_tax_avg	.130	.134	.0140	.700
adv_excise_tax_avg	.111	.134	.0138	.700
fuel_price_avg	1.47	.88	.43	3.19
income_geomean	38,821	12,286	13,454	94,110
pop_geomean	3,350,434	2,393,499	79,865	1.63e+07
distance	930	665	11	5095

Observations = 151,899, directional routes = 13,148

**Table 2: Summary statistics for aircraft models**

<i>aircraft type</i>	<i>gallons_seat_mile</i>	<i>#routes</i>	<i>#routes×years</i>	<i>#years</i>
A200-100	0.0145	177	177	1
A-318	0.0182	238	919	11
A300-100/200	0.0184	259	581	6
A310-300	0.0186	57	115	5
A320-100/200	0.0136	6514	44241	29
A320-200NEO	0.0111	1214	1798	2
A321-200NEO	0.0107	354	534	3
A321/LR	0.0122	2773	10792	19
B717-200	0.0223	2258	8411	20
B727-100	0.0315	1819	3330	4
B727-200	0.0252	5964	27228	13
B737-100/200	0.0229	5202	25855	16
B737-300	0.0171	6887	55402	27
B737-400	0.0167	2329	13965	27
B737-500	0.0194	3628	27233	26
B737-700	0.0147	5820	39481	19
B737-800	0.0130	7005	42670	22
B737-900	0.0122	1817	8459	18
B737-900ER	0.0122	2289	5660	6
B757-200	0.0143	5042	41064	29
B757-300	0.0131	1214	5206	19
B737 Max 8	0.0109	1401	2451	2
B737 Max 9	0.0100	138	196	2
Canadair RJ-200	0.0273	36	47	3
Embraer 190	0.0225	1180	5051	15
Embraer 170	0.0239	310	535	3
Fokker 100	0.0259	2800	10657	14
DC-9-10	0.0352	1254	5407	15
DC-9-30	0.0261	4921	23009	20
DC-9-40	0.0266	1296	7425	21
DC-9-50	0.0260	2074	10003	25
MD-81/82/83/88	0.0223	8674	60377	29
MD-90	0.0158	1775	7321	25

*#routes* gives the number of different routes on which an aircraft type is observed in any year; *#years* gives the number of years in which an aircraft type appears on at least one route; *#routes×years* is the number of route×year appearances, which is smaller than the product of *#routes* and *#years* because an aircraft may not be present on the same routes in every year that it appears.

**Table 3: Regressions with fuel taxes in ad-valorem form**

VARIABLES	(1)	(2)	(3)	(4)	(5)
	lgallons_seat_mile	lgallons_seat_mile	lgallons_seat_mile	lgallons_seat_mile	lgallons_seat_mile
lfull_fuel_price_avg	-0.232** (0.0650)	–	–	–	–
lfuel_price_avg		-0.304* (0.139)	-0.367** (0.141)	-0.455** (0.138)	-0.291* (0.139)
log(1 + adv_fuel_tax_avg)	–	–	-0.188** (0.0673)	–	–
log(1 + adv_excise_tax_avg)	–	–	–	-0.516** (0.0803)	–
log(1 + sales_tax_avg)	–	–	–	–	0.499** (0.106)
lincome_geomean	-0.0429* (0.0175)	-0.0438* (0.0174)	-0.0433* (0.0174)	-0.0490** (0.0170)	-0.0502** (0.0172)
lpop_geomean	-0.0251** (0.00287)	-0.0266** (0.00287)	-0.0254** (0.00289)	-0.0258** (0.00278)	-0.0293** (0.00290)
ldistance	-0.0362** (0.00343)	-0.0367** (0.00343)	-0.0362** (0.00343)	-0.0339** (0.00326)	-0.0353** (0.00335)
Constant	-2.904** (0.172)	-2.882** (0.171)	-2.875** (0.172)	-2.778** (0.169)	-2.797** (0.172)
Observations	151,899	151,899	151,899	151,899	151,899
$R^2$	0.681	0.680	0.681	0.682	0.681

Standard errors clustered by carrier-year and nondirectional route in parentheses.

\*\* p<0.01, \* p<0.05

Regressions include carrier-year and region-pair fixed effects.

Table 4: Regressions with fuel taxes in excise form

VARIABLES	(1) gallons_seat_mile	(2) gallons_seat_mile	(3) gallons_seat_mile
full_fuel_price_avg	-0.00675** (0.000884)	–	–
fuel_price_avg	–	-0.0207** (0.00205)	-0.0208** (0.00206)
tax_per_gal_avg	–	-0.00158† (0.000868)	–
excise_fuel_tax_gal_avg	–	–	-0.00399* (0.00162)
income_geomean	-0.734 (0.753)	0.0479 (0.725)	-0.113 (0.728)
pop_geomean	-0.113** (0.0161)	-0.147** (0.0171)	-0.145** (0.0174)
distance	-0.0160** (0.000892)	-0.0155** (0.000859)	-0.0155** (0.000860)
Constant	0.0310** (0.00141)	0.0508** (0.00305)	0.0511** (0.00307)
Observations	151,899	151,899	151,899
$R^2$	0.649	0.654	0.654

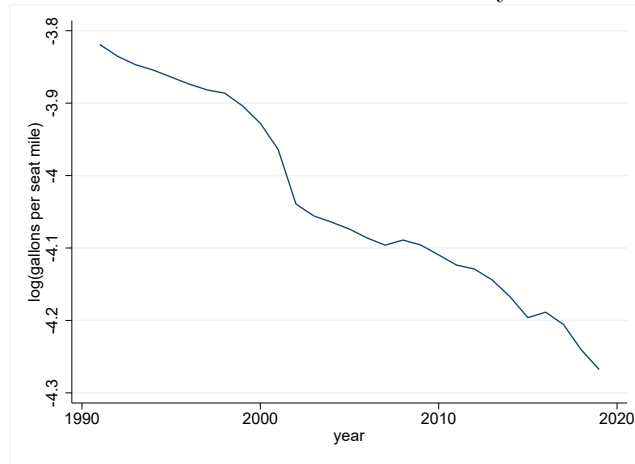
Standard errors clustered by carrier-year and nondirectional route in parentheses.

\*\* p<0.01, \* p<0.05, †p<0.10

Regressions include carrier-year fixed effects.

**Figure 1: Trends**

Panel A: Inverse Fuel Efficiency



Panel B: Pre-tax Fuel Price

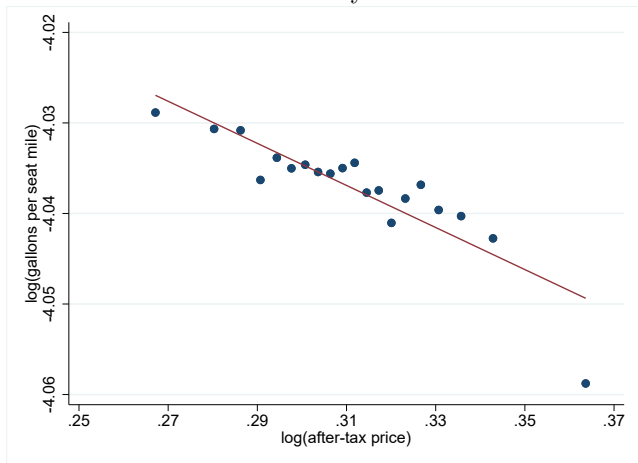


Panel C: Ad Valorem Fuel Taxes

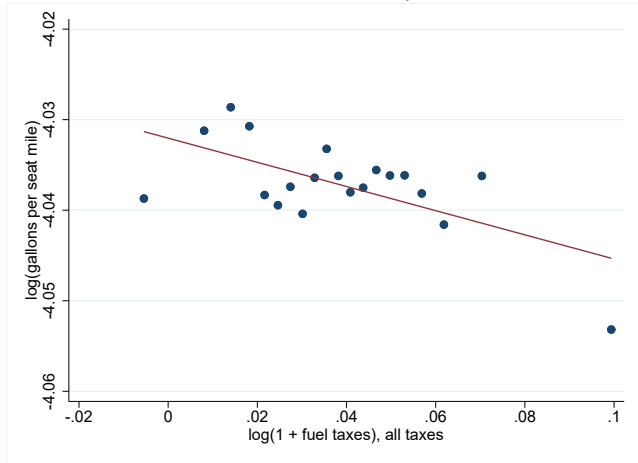


Figure 2: Binned Scatter Plots

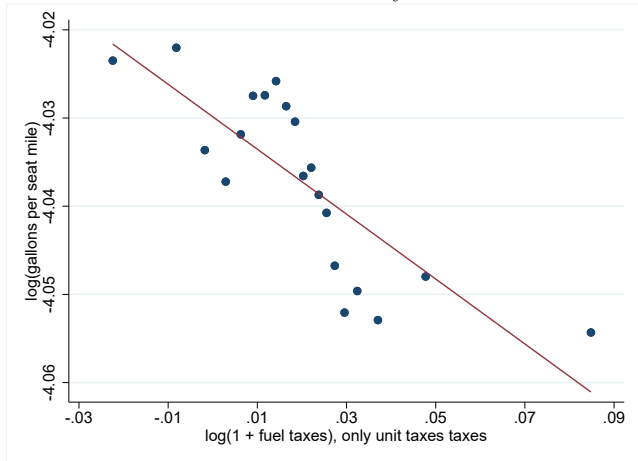
Panel A: Inverse Fuel Efficiency vs. After-tax Fuel Price



Panel B: Inverse Fuel Efficiency vs. Fuel Taxes



Panel C: Inverse Fuel Efficiency vs. Excise Taxes



## References

- BRADLEY, S., FELDMAN, N.E., 2020. Hidden baggage: Behavioral responses to changes in airline ticket tax disclosure. *American Economic Journal: Economic Policy* 12, 58-87.
- BRUECKNER, J.K., ABREU, C., 2017. Airline fuel usage and carbon emissions: Determining factors. *Journal of Air Transport Management* 62, 10-17.
- BRUECKNER, J.K., ABREU, C., 2020. Does the fuel-conservation effect of higher fuel prices appear at both the aircraft-model and aggregate airline levels? *Economics Letters* 197, article 109647.
- BRUECKNER, J.K., KAHN, M.E., NICKELSBURG, J., 2024. How do airlines cut fuel usage, reducing their carbon emissions? *Economics of Transportation* 38, article 100358.
- CHETTY, R., LOONEY, A., KROFT, K., 2009. Salience and taxation: Theory and evidence. *American Economic Review* 99, 1145-1177.
- FAJGELBAUM, P.D. GAUBERT, C., 2020. Optimal spatial policies, geography, and sorting. *Quarterly Journal of Economics* 135, 959-1036.
- FAJGELBAUM, P.D., MORALES, E., SUÁREZ SERRATO, J.C. AND ZIDAR, O., 2019. State taxes and spatial misallocation. *Review of Economic Studies* 86, 333-376.
- FUKUI, H., MIYOSHI, C., 2017. The impact of aviation fuel tax on consumption and carbon emissions: The case of the US airline industry. *Transportation Research Part D* 50, 234-253.
- FAGEDA, X., TEIXIDO, J.J., 2022. Pricing carbon in the aviation sector: Evidence from the European emissions trading system. *Journal of Environmental Economics and Management* 111, article 102591.
- GOBLER, C., WOLFE, P.J., DASADHIKARI, K., DEDOUSSI, I.C., ALLROGGEN, F., SPETH, R., EASTHAM, S.D., AGARWAL, A., STAPLES, M.D., SABNIS, J., BARRETT, S.R.H. , 2019. Marginal climate and air quality costs of aviation emissions. *Environmental Research Letters* 14, article 114031.
- HAO, L., RYERSON, M., KANG, L., HANSEN, M., 2016. Estimating fuel burn impacts of taxi-out delay with implications for gate-hold benefits. *Transportation Research Part C*, in press.
- HAO, L., HANSEN, M., RYERSON, M., 2016. Fueling for contingencies: The hidden cost of unpredictability in the air transportation system. *Transportation Research Part D*, in press.

- HURTADO, C., 2023. Behavioral responses to spatial tax notches in the retail gasoline market. SSRN Working paper 3469900.
- KOPCZUK, W., MARION, J., MUEHLEGGGER, E., SLEMROD, J., 2016. Does tax-collection invariance hold? Evasion and the pass-through of state diesel taxes. *American Economic Journal: Economic Policy* 8, 251-286.
- KWAN, I., RUTHERFORD, D., 2015. Assessment of U.S. domestic airline fuel efficiency since 2010. *Transportation Research Record* 2501, 1-8.
- LEE, J.J., LUKACHKO, S.P., WAITZ, I.A., SCHAFER, A., 2001. Historical and future trends in aircraft performance, cost, and emissions. *Annual Review of Energy Environment* 26, 167-200.
- LIPSCOMB, M., MOBARAK, A.M., 2017. Decentralization and pollution spillovers: Evidence from the re-drawing of county borders in Brazil. *Review of Economic Studies* 84, 464-502.
- LOVENHEIM, M.F., 2008. How far to the border?: The extent and impact of cross-border casual cigarette smuggling. *National Tax Journal* 26, 7-33.
- MARION, J., MUEHLEGGGER, E., 2008. Measuring illegal activity and the effects of regulatory innovation: Tax evasion and the dyeing of untaxed diesel. *Journal of Political Economy* 116, 633-666.
- MARION, J. AND MUEHLEGGGER, E., 2018. Tax compliance and fiscal externalities: Evidence from US diesel taxation. *Journal of Public Economics* 160, 1-13.
- MERRIMAN, D., 2010. The micro-geography of tax avoidance: evidence from littered cigarette packs in Chicago. *American Economic Journal: Economic Policy* 2, 61-84.
- MIYOSHI, C., MASON, K.J., 2009. The carbon emissions of selected airlines and aircraft types in three geographic markets. *Journal of Air Transport Management* 15, 138-147.
- MORRELL, P., 2009. The potential for European aviation CO<sub>2</sub> emissions reduction through the use of larger jet aircraft. *Journal of Air Transport Management* 15, 151-157.
- OGAWA, H. AND WILDASIN, D.E., 2009. Think locally, act locally: Spillovers, spillbacks, and efficient decentralized policymaking. *American Economic Review* 99, 1206-1217.
- OLIVEIRA, A.V.M., NARCIZO, R.R., CALIARI, T., MORALES, A.V.M., PRADO, R., 2021. Estimating fuel-efficiency while accounting for dynamic fleet management: Testing the effects of fuel price signals and fleet rollover. *Transportation Research Part D* 95, article 102820.

- RYERSON, M.S., HANSEN, M., HAO, L., SEELHORTS, M., 2015. Landing on empty: Estimating the benefits from reducing fuel uplift in US civil aviation. *Environmental Research Letters* 10, 094002.
- SCHEELHASSE, J.D. GRIMME, W.G., 2007. Emissions trading for international aviation—An estimation of the economic impact on selected European airlines, *Journal of Air Transport Management* 13, 253-263.
- SIGMAN, H., 2002. International spillovers and water quality in rivers: Do countries free ride? *American Economic Review* 92, 1152-1159.
- WHITE, A.Q., 2020. Taxation of multi-product firms with cost complementarities. In *Proceedings of the Annual Conference on Taxation of the National Tax Association* 113, 1-58.
- WHITE, Q., AGRAWAL, D.R., WILLIAMS, J.W., 2019. Taxation in the aviation industry: Insights and challenges. *Transportation Research Record* , 2673, 666-673.
- WILDASIN, D.E., 2011. Fiscal competition for imperfectly-mobile labor and capital: A comparative dynamic analysis. *Journal of Public Economics* , 95, 1312-1321.
- WILSON, J.D., 1999. Theories of tax competition. *National Tax Journal* 52, 269-304.
- ZOU, B., ELKE, M., HANSEN, M., KAFLE, N., 2014. Evaluating air carrier fuel efficiency in the US airline industry. *Transportation Research Part A* 59, 306-330.