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Abstract

Taxes on gasoline and diesel reduce vehicle travel by making driving more expensive – the price effect. But fuel tax revenue is used to build and widen urban highways, inducing more driving – the capacity effect. We show that in the United States, the capacity effect over the 1981-2021 period was more than five times greater than the price effect. As the rise of electric vehicles forces policymakers to consider replacing or supplementing fuel taxes, our findings highlight the need to decouple the two functions – revenue and environmental – of taxes on driving. The use of gasoline taxes to fund highway capacity expansion undermines their environmental role.

Keywords: gasoline tax, highways, transportation funding, induced demand

Introduction

Planners, policymakers, economists, and environmental advocates often support higher gasoline and other motor fuel taxes as a way to at least partially internalize the external costs of driving such as climate change, air pollution, road safety, and congestion. The gasoline tax approximates a Pigouvian (environmental) tax that incentivizes individuals to drive less and to choose more fuel-efficient cars – the price effect. While the current US gasoline tax is too low to fully account for the externalities from driving (Parry & Small, 2005), it goes some way towards reducing driving and fuel use towards optimal levels.

Motor fuel taxes also function as a user fee that funds roadway construction and maintenance and in turn increases vehicle travel – the capacity effect. Indeed, US states, and later the federal government, enthusiastically adopted motor fuel taxes in the early 20th Century as a means to fund ambitious road construction plans (Lewis, 2013; Rose & Mohl, 2012; Taylor et al., 2023).

In this *Planning Viewpoint,* we show that in the United States, the capacity effect over the 1981-2021 period outweighed the price effect by a factor of 5, meaning that the net impact of fuel taxes was to substantially increase vehicle travel (Figure 1). This is largely because the capacity effect is cumulative as the stock of highways increases each year, while the price effect is transient. Based on a typical price elasticity of –0.22 (Gillingham, 2014), the federal gasoline tax of 18.4 cents per gallon reduced demand for vehicle travel in urban areas by 46 billion vehicle km in 2021. But 144,000 urban highway lane kilometers were added between 1981 and 2021, of which we estimate just over 40% (62,000 km) can be attributed to federal motor fuel taxes. The remaining 60% of the increase is likely primarily explained by the 31% increase in real household incomes and 41% increase in population over the same period. We estimate that this new capacity increased vehicle travel on urban highways in 2021 by 24%, or 246 billion vehicle km per year. The net effect, including both price and capacity effects, was 200 billion vehicle km per year – a 19% increase. Without major shifts in how funds are spent, common approaches to reforming federal highway finance – such as raising revenues through a tax on miles driven – will not address this underlying issue.

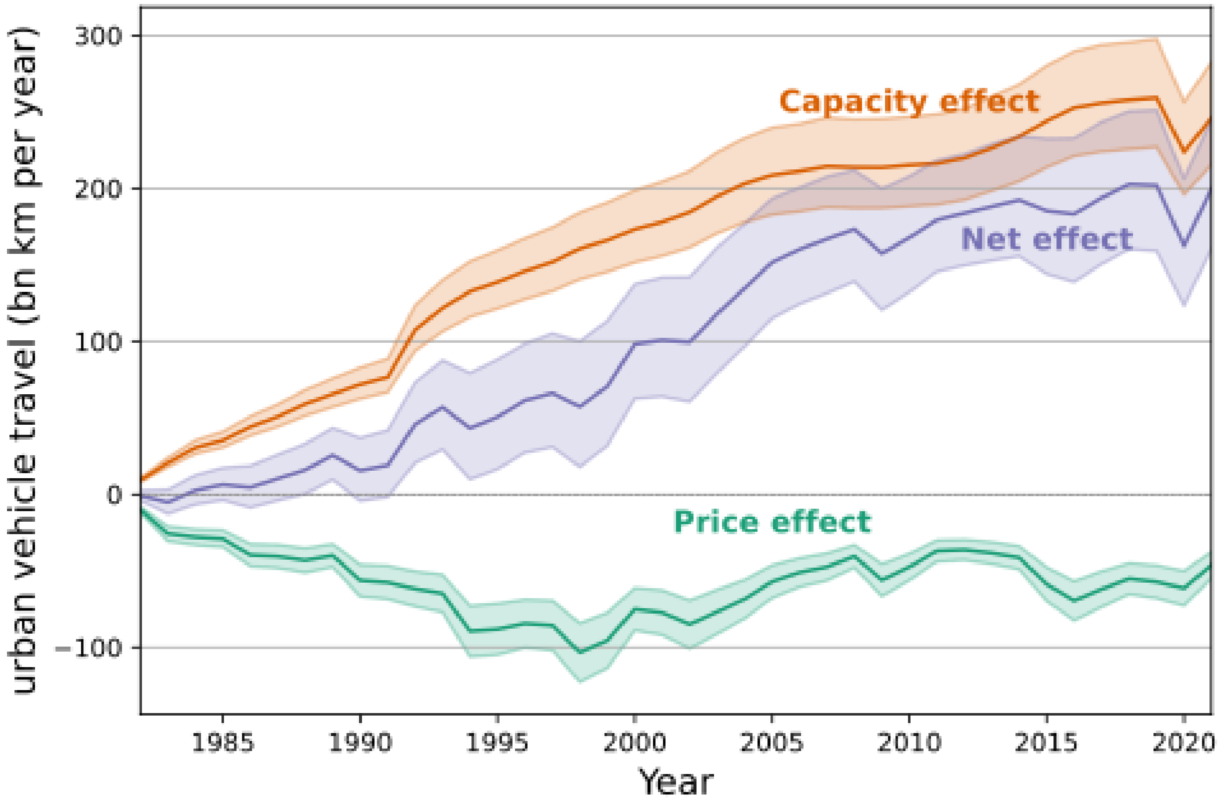

Figure 1 **Change in vehicle travel attributable to federal taxes on motor fuels.**
The shaded area indicates the 95% confidence interval.

Estimating the capacity effect

New roadway capacity induces vehicle travel in the short run through alleviating congestion and increasing travel speeds, which encourages travelers to take more and longer trips and to switch to private cars from other modes. In the medium to long run, roadway capacity further induces travel through promoting automobile-oriented development such as big-box stores at highway interchanges and exurban residential subdivisions (Cervero, 2002; Milam et al., 2017). Numerous studies have quantified induced demand, for example through using matched pairs, simultaneous equations, or instrumental variables to resolve the bidirectional causal relationships between road capacity and driving (Cervero, 2002; Cervero & Hansen, 2002; Duranton & Turner, 2011; Noland, 2001). Our estimates of the capacity effect use an elasticity of vehicle travel with respect to road capacity (lane miles) of 0.78, as in Duranton & Turner (2011). Duranton and Turner's headline elasticity of 1.03 is substantially higher than 0.78, but refers only to Interstate highways in urban areas, while our analysis includes other urban freeways and expressways as well as Interstates. The Appendix provides further discussion of elasticities and comparison to other studies.

Our estimates of the capacity effect are based on the federal contribution towards highway expansion projects, which has declined from 87% in 1981 to 28% in 2021, and the proportion of federal highway funding that comes from federal gasoline and diesel taxes. The 18.4 cent per gallon federal gasoline tax and the 24.4 cent diesel tax generated $32 billion in 2021, accounting for 83% of the Highway Trust Fund's revenue (excluding the portion that is dedicated to public transit). Based on construction cost assumptions detailed in the Appendix, we estimate that 24% of federal gasoline and diesel taxes were devoted to urban highway expansion over the 1981-2021 period, and that 43% of urban highway capacity added over the same period can be attributed to these taxes. While the counterfactual – how much highway capacity would have been added in the absence of federal motor fuel taxes – is fundamentally unknowable, historical research (e.g. Taylor et al., 2023) shows how generous federal matching funds were a key enabler of state highway expansion plans. More suggestively, the US has built far more road capacity than its international peers, in which motor fuel tax revenues are normally not ringfenced for highways.

Note that our results do not include the effect of state-level gasoline taxes on funding highway expansion, which would amplify these figures. We also ignore the capacity effects of federal investments in rural highways and non-highway roadways. Finally, we ignore highway reconstruction that does not add highway lane miles. Reconstruction takes up an increasingly large share of state and federal transportation budgets and also contributes to the capacity effect since the system would otherwise shrink in size over time. Reconstruction also frequently increases capacity without adding travel lanes, by adding wider lanes, wider shoulders, and other modern design standards. For example, the minimum requirements for shoulder widths and curve freeway curve radii increased by 25% to 400% between 1955 and 1985 (Taylor et al., 2023).

Cumulative effects and reinforcing cycles

The cumulative nature of the capacity effect is the key reason why it dominates the price effect. Highway expansions funded with fuel tax revenue today will affect travel decisions decades into the future, and given that road capacity is almost never reduced, the effect is cumulative. Travel decisions today are influenced by the infrastructure that has been funded through nearly a century of motor fuel tax revenues. In contrast, behavioral changes in response to higher fuel prices are reversible over shorter time frames. Higher fuel prices certainly encourage consumers to purchase more efficient cars and choose home and workplace locations accessible by public transportation – both longer-run adaptations. But many decisions on how much to drive are shorter term given that most trips, or at least the choice of destinations, are discretionary in nature – where to shop, where to take part in recreational activities, and so on.

The impact of fuel taxes on vehicle travel also operates in a self-reinforcing cycle (Figure 2). Expanding highways induces more vehicle travel, which increases fuel tax revenue. Much of that revenue is then directed towards further expanding highways. Moreover, while our analysis only considers the effect of federal motor fuel taxes, every state also has a gasoline tax, with the average rate of 27.8 cents per gallon (FHWA, 2022, Table MF-205) exceeding the federal rate. Such taxes are a major source of funding for road construction at the state level.

The capacity effect would be of limited concern if roadway expansion generally resulted in net social benefits – that is, if the gain to drivers outweighed the environmental and social harms. However, in aggregate, urban highway construction may even have been welfare-reducing – the benefits, including employment and land rent, rarely outweigh the costs of construction and maintenance (Duranton & Turner, 2012). The negative effects may be because highway expansion has a minimal effect on travel times, and because "roads are built where land and labor are cheap rather than in the places where they are most needed" (Duranton & Turner, 2012). The economic growth benefits of highways are at best mixed and are often exaggerated for political purposes (Boarnet, 1997; Deng, 2013). Moreover, highways have already largely been built in places with the highest benefits, while costs have increased substantially in recent years (Brooks & Liscow, 2023). Overall, transportation expenditure in general and highway planning specifically have been driven by political considerations — racial animus, pork-barrel projects that help political campaigns, and a blindness to the true costs and benefits of infrastructure projects (e.g. Downs, 2004; Flyvbjerg et al., 2002). US highway expansion has waxed and waned based on the funding available (Taylor et al., 2023), rather than on the costs and benefits of specific projects.

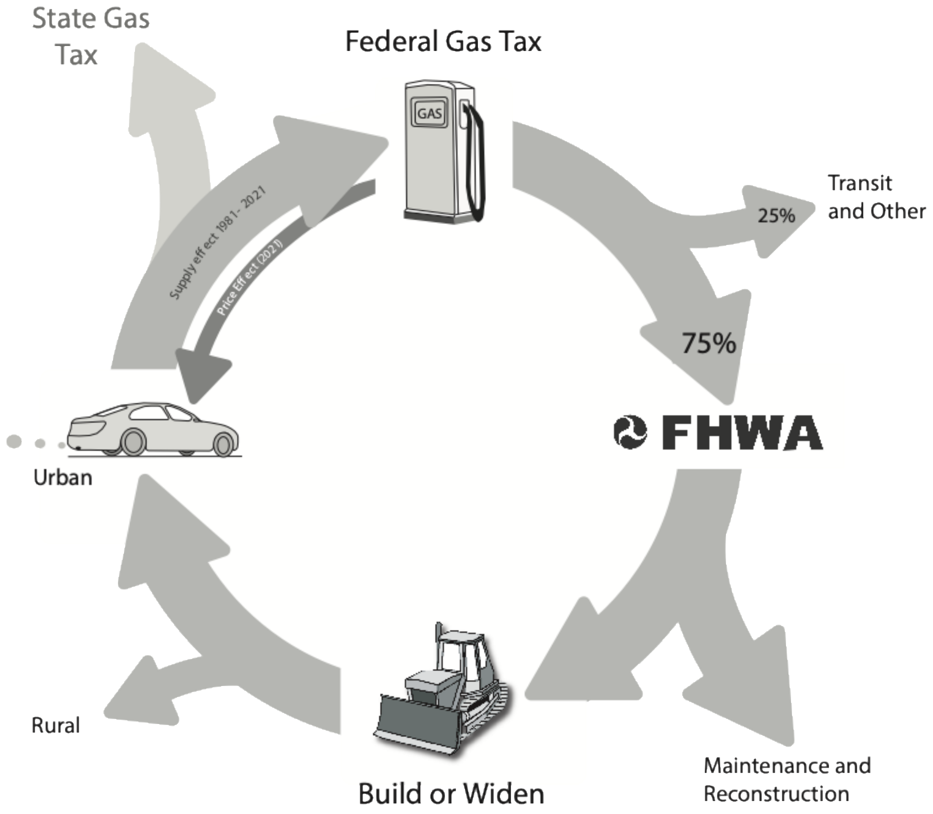

Figure 2 Self-reinforcing impacts of motor fuel taxes

Taxes in a world of electric vehicles

The growing market share of electric vehicles (EVs) means that policymakers will need to rethink transportation taxes in the coming years. One impetus is a decline in forecast gasoline tax revenue that will leave the Highway Trust Fund exhausted by 2028 (CBO, 2023; Karnes, 2009; Taylor et al., 2023). Another impetus relates to externalities from electric vehicles – particularly particulate emissions from tire and brake wear (Fussell et al., 2022), the hazards to other road users from EVs' greater weight (Shaffer et al., 2021), and battery production and disposal (Xia & Li, 2022). As a result, several US states as well as the federal government are exploring taxes levied per mile of vehicle travel, as well as graduated registration fees and other taxes based on vehicle weight.

Our findings here highlight the need to decouple the two functions – revenue and environmental – of any new tax on electric vehicle driving. New per-mile fees would capture revenue from EVs, but if they are used to fund roadway expansion – helping to realize the long wishlist of unfunded highway projects of states and metropolitan regions – air pollution and other externalities would be exacerbated. In contrast, if those taxes were to be directed to other transportation programs such as roadway maintenance or public transit, or to other areas of government spending such as health and education, the environmental benefits would be preserved. Indeed, a key property of Pigouvian taxes is that the revenue is a bonus – the tax would be economically efficient even if the revenue were to be simply burned or discarded. It is possible that the recent escalation in highway construction costs (Brooks & Liscow, 2023), while inefficient in a narrow sense, might be welfare-improving if it restricts the rate at which highways can be expanded.

Our broader point is that the effectiveness of environmental taxes cannot be seen in isolation from the uses of the revenue. This principle is well-documented from a theoretical perspective in the environmental economics literature (Bento et al., 2009; Goulder et al., 1999), but it rarely surfaces in planning and policy discussions over gasoline and other transportation taxes. Just as it would be strange if carbon taxes were used to fund new fossil fuel infrastructure, the use of motor fuel taxes to fund highway capacity expansion undermines their environmental role.

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Should environmentalists support the gasoline tax?

Appendix

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Model Structure

Price effect: We calculate the price effect PE (vehicle km yr^{-1}) for each year as follows:

$$PE = V_a - \frac{V_a\left((p-t)\varepsilon_p + 2p - t - p\varepsilon_p\right)}{-(p-t)\varepsilon_p + 2p - t + p\varepsilon_p} \qquad \text{Eq. (1)}$$

Where V_a is vehicle km yr^{-1} traveled on all roads in urban areas, t is the federal gasoline tax and p the gasoline price (both in cents per gallon), and $\varepsilon_p = -0.22$ is the fuel price elasticity of vehicle travel. For clarity, we omit the year subscripts. Note that we interpret the elasticity as a midpoint elasticity.

Capacity effect: We calculate the capacity effect CE (vehicle km yr^{-1}) for each year as follows:

$$CE = V_h - \frac{V_h\left((L-A)\varepsilon_c + 2L - A - L\varepsilon_c\right)}{-(L-A)\varepsilon_c + 2L - A + L\varepsilon_c} \qquad \text{Eq. (2)}$$

Where V_h is vehicle km yr^{-1} traveled on urban highways (defined below), A is urban highway lane km attributable to federal motor fuel taxes as defined in Eq. 3, L is all urban highway lane km, and $\varepsilon_c = 0.78$ is the elasticity of vehicle travel with respect to road capacity. Again, for clarity we omit the year subscripts. As with the price effect, we interpret the elasticity as a midpoint elasticity, which substantially reduces the estimated capacity effect because the percentage change in capacity is smaller.

We calculate A (lane km attributable to federal motor fuel taxes) as follows for each year y.

$$A_y = \sum_{i=1982}^{y} (L_i - L_{i-1}) s_i f_i \qquad \text{Eq. (3)}$$

Where L_i is all urban highway lane km, s_i the share of Highway Trust Fund income from motor fuel taxes, and f_i the federal share of highway expenditures (the remainder being paid by the states) in year i.

Note that A is cumulative over time. Also note that we apply the price effect to vehicle travel on all roads in urban areas, including local streets, whereas the capacity effect only applies to vehicle travel on urban highways. In practice, urban highway expansion will increase travel on arterials and other local streets as well, but we do not account for this effect. We define urban highways as “Interstates” and “Other freeways and expressways” as reported in *Highway Statistics*.

Our analysis considers on-road vehicle travel in urban areas in all 50 US states plus the District of Columbia, but excludes Puerto Rico and other territories.

Data

Our data on vehicle km come from *Highway Statistics*, published annually by the Federal Highway Administration, the *Transportation Energy Data Book*, published annually by Oak Ridge National Laboratory, and other FHWA web pages. Specifically:

- Vehicle km traveled (V_a and V_h): *Highway Statistics,* Table VM-202
- Federal gasoline tax (t): *Transportation Energy Data Book*, 2022 edition, Table 11.5
- Gasoline price (p): FHWA, *Highway History,* www.fhwa.dot.gov/infrastructure/gastax.cfm
- Urban highway lane km (L): *Highway Statistics,* Table HM-260
- Share of Highway Trust Fund from motor fuel taxes (s): *Highway Statistics,* Table FE-210
- Federal share of urban highway expenditures (f): *Highway Statistics,* Table FA-10

Elasticities

Fuel price (ε_p): A large literature provides estimated elasticities of fuel demand with respect to price. However, our interest here is in the elasticity of vehicle travel, sometimes called the “utilization elasticity.” This is smaller than the elasticity of fuel demand as it does not include the effect of fuel prices on vehicle efficiency.

We use the estimate of −0.22 provided by Gillingham (2014), which he refers to as the “medium-run estimate of the elasticity of vehicle-miles-traveled with respect to gasoline price for new vehicles.” For the uncertainty bounds, we use low (−0.16) and high (−0.28) values of +/- 2x the standard error reported in Gillingham’s preferred specification

An elasticity of −0.22 is consistent with other estimates. For example, Small and van Dender (2007) and Goodwin et al. (2004) report long-run elasticities of −0.22 and –0.29 respectively.

Road capacity (ε_c): Numerous studies have quantified induced demand, for example through using instrumental variables to resolve the bidirectional causal relationships between road capacity and driving, and other causal inference techniques (Cervero, 2002; Cervero & Hansen, 2002; Duranton & Turner, 2011). Duranton and Turner (2011) provide a series of estimates of the elasticity of vehicle travel with respect to road capacity (lane km). We use the midpoint (0.78) of their range (0.67–0.89) for major urban roads. For our lower uncertainty bound, we use the lower (0.67) value of their range. For our upper bound, we use Duranton and Turner’s preferred estimate of 1.03. We do not use 1.03 as our central estimate as it refers only to Interstate highways in urban areas, and our analysis includes other urban freeways and expressways as well as Interstates.

An elasticity of 0.78 is consistent with other estimates. For example, Cervero and Hansen (2002) report a medium-term elasticity of 0.79. This refers to lane miles on state-owned road facilities (generally all highways plus some arterials) in California.

Monte Carlo simulation

We introduce uncertainty into our model through the elasticities. All our results reported in the main text are the means of a Monte Carlo simulation.

To allow for greater uncertainty in different directions around the mean, we use triangular distributions. For the supply effect, we use Duranton and Turner's (2011) mean estimate of 0.78 for highways and arterials. We use the Interstate estimate of 1.03 for the upper bound and 0.67 for the lower bound as noted in the section above. For the price effect, we use a symmetrical -0.16 and -0.28 as the upper and lower bounds around the midpoint of -0.22. These are two standard errors above and below Gillingham's (2014) mean estimate. The final reported findings rely on 10,000 draws from the triangular distribution for the elasticity of car travel with respect to supply and price. We treat each drawn elasticity as consistent for the 40 year simulation, rather than drawing a new elasticity for each year within a simulated 40-year period.

There are also opportunities to introduce uncertainty by varying construction costs, new urban lane miles, and the share of urban highways paid for by the federal government. Since these figures are based on reported historical data, however, we prefer to introduce any additional uncertainty by loosening assumptions about drivers' behavioral responses to price and supply.

Attributing highway expansion to federal taxes

One of our key assumptions relates to the proportion of highway construction and expansion that can be attributed to federal gasoline and diesel taxes. The costs of highways are shared by federal and state governments, with the federal contribution coming from the Highway Trust Fund. This fund is primarily supported by motor fuel taxes, with a smaller share coming from excise duties on tires, heavy vehicles, parts, and so on. The federal contribution to federal-aid highway construction has gradually declined over time, from 80%-90% in the 1980s to 25%-30% since the early 2000s (*Highway Statistics,* Table FA-10). We therefore estimate the number of lane miles attributable to federal motor fuel taxes as in Eq. 3.

We do not have a counterfactual showing how many lane miles would have been built in the absence of motor fuel taxes. However, an extensive historical literature supports our contention that federal funding, in the form of the Highway Trust Fund, was the central driver behind the construction and expansion of the US highway system (Lewis, 2013; Rose & Mohl, 2012; Taylor et al., 2023). For example, the federal Bureau of Public Roads developed extensive plans for a national highway network in 1939 and 1944, but little was built until the Highway Trust Fund was created in 1956, creating a mechanism for the federal government to channel increased fuel tax revenues to highway building and reimbursing states for 90% of the cost (Boarnet, 2014).

As a reasonableness check, we estimate the percentage of the Highway Trust Fund that is devoted to highway construction and expansion, as implied by our estimates. We multiply our estimates of new lane kilometers attributable to federal motor fuel taxes by our estimated construction cost for that year (detailed below), as follows:

$$E = \sum_{i=1982}^{2021} (L_i - L_{i-1})\, s_i\, f_i c_i \,/\, \sum_{i=1982}^{2021} R_i \qquad \text{Eq. 4}$$

Where $(L_i - L_{i-1})\, s_i\, f_i$ is used in Eq. 3 above to indicate the new lane kilometers attributable to federal motor fuel taxes, c_i denotes the cost per lane km of highway expansion, and R_i denotes Highway Trust Fund receipts from motor fuel excise taxes in year i.

Eq. 4 yields an estimate of E of 24%.

Another reasonableness check is based on data on federal expenditures for new construction, relocation, added capacity, and major and minor widenings in urban areas. These are available in *Highway Statistics* Table FA-10 for 1990-2020. Based on our construction cost estimates (see below), the federal government paid for 56% of new urban lane miles in this period.

While the counterfactual of highway capacity in the absence of a federal gas tax is fundamentally unknowable, these reasonableness checks give us confidence in our estimates.

Construction Costs

Our reasonableness checks discussed above require estimates of construction costs for new highways and widenings. We estimate the cost of adding one lane mile using federal data on roadway length and capital expenditures. For each decade (1980-90, 1990-00, 2000-10, 2010-20) we calculate the number of new lane miles of Interstates and other freeways and expressways in urban areas (*Highway Statistics*, Table HM-260), and capital outlays for the same types of roads (*Highway Statistics*, Table SF-12). We convert all costs to 2020 dollars. We then calculate the real compound annual growth rate over the 1980-2020 period (2.82%), and apply this to a base year cost of $4.5 million per lane mile in 1980 to generate a smoothed time series of cost increases, through to $13.6 million in 2020.

Our method is designed to be simple and transparent. It does not consider the heterogeneity in costs between widenings and new alignments and between different urban contexts. Nor does our method consider the lumpiness of capital expenditure, or the lags between expenditures and facility opening, although our use of decadal time periods mitigates these issues. However, our results are similar to other estimates:

- Brooks and Liscow (2023) provide the most comprehensive analysis in matching highway expenditures to specific facilities, but only provide estimates through 1993. They estimate costs (converted to 2020 dollars) of $26.48 million per mile in 1982-87, rising to $36.99 million in 1988-93, which equates to $5.27 million and $7.36 respectively per lane mile. Our estimates for the same periods are $5.2 million and $6.1 million respectively.

- Taylor et al. (2023) (Figure 9.6) estimate that the cost of constructing a lane mile increased by 2.4 times in real terms from 1980 to 2010, which closely matches our estimate of a 2.3-fold increase.
- The Federal Highway Administration (2023) National Highway Construction Cost Index shows a real compounded annual increase of 2.2% from 2003 through 2022 (with a spike in 2023 that reflects more temporary supply chain issues). While this is slightly lower than our estimate (2.8%), the index considers construction only, and does not account for soft costs such as litigation-induced delays.
- The Federal Highway Administration's (2015) Highway Investment Analysis Methodology presents a range of costs per new lane mile, ranging from $3.5 million to $18.5 million for "normal" costs (in 2020 dollars) depending on the size of the urban area and whether the improvement is a new alignment or a widening. Our 2015 estimate of $11.9 million is squarely in the middle of this range.

Share of Construction Costs Attributable to Gas Tax

We estimate the share of construction costs attributable to the federal gas tax as the share of federal obligations for new highways, highway relocation costs, highway widenings, lane additions, and new highway bridges from the Federal-Aid highway program (*Highway Statistics*, Table FA-10). As programs and transportation bills have changed over time, there is no clear and consistent record of funding allocations over time. While the original Interstate program covered 90% of Interstate construction costs, the program and funding mechanisms have shifted substantially with more and more revenues also going to pay for the reconstruction and maintenance of the existing system. While FA-10 was not reported until 1990, it provides the most consistent attribution of federal funding over time. It is also generally consistent with recent years of FA-6A, which provides federal obligations by class and improvement type on and off of the National Highway System.

From 1990 until 2000, the federal government consistently covered an average 83% of construction costs. This drops to 29% from 2002 to 2020, with 53% covered in 2001. To account for lumpiness in allocations, we take a smoothed average from the nearest two years of reported data. This applies the average value from 1990 and 1991 to the 1980s. At 87%, this is close to the maximum share of Interstate highway construction covered by the federal government. Our figures suggest an overall decreasing share of federal highway dollars going to urban capacity increases. In the 1980s, around 43% of funds went to urban capacity increases each year compared to 18% over the past decade. The remainder primarily goes to highway reconstruction, maintenance, and administration.

There are several inconsistencies with the FA-10 data over time. For example, the first few years of data include categories for major and minor road widenings but do not include the category for reconstruction with added capacity. Later years of data drop the widening categories altogether. Despite these differences, the share of spending remains consistent during the years that report widenings and reconstruction with added capacity. More importantly, the roadways that get counted may not always be consistent over time. For example, the Interstate roadway category is not included after 2001 and reenters the database as unused Interstate funds in 2018. Four factors make us comfortable with this larger inconsistency. First, the share of spending is consistent across Interstate and other categories in years where both data exist (including 2001 when the share began dropping). Two, total Federal Aid-Highway obligations are an average of about 80% of total Highway Trust Fund Receipts before and after 2001. Three, the contemporary share of funding is consistent with the total share of roadway expenditures by state and federal governments. Four, investment funds are fungible. Federal funding goes back to states, which allocate highway dollars to projects based on available funding in the different available categories.

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