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Fuel Economy Standards and Public Transport

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Fuel Economy Standards and Public Transport

Abstract

We identify and examine a novel welfare channel of fuel economy standards through the interaction with public transit and households' location choices. A stricter emission standard for cars decreases the marginal cost of driving and triggers a shift in modal choice from public to private transport and a rise in carbon emissions. In the long run, the modal shift exacerbates the increase in the average commute length that results from lower driving costs, as well as traffic congestion. The annual welfare cost for a 50 percent emission reduction goal in a setting calibrated with U.S. data turns out 8 percent (equiv. to 54 USD p.c.) higher than when neglecting public transport. With a larger role of public transport as in Europe, this effect rises to 12 percent (equiv. to 83 USD p.c.). An alternative fuel tax policy, by contrast, induces a modal shift towards public transport and reduces the average commute, urban congestion and the welfare cost of emission reductions.

JEL-Codes: H230, Q480, R130, R480.

Keywords: fuel economy standards, public transport, monocentric city, fuel tax, carbon emissions.

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1 Introduction

Greenhouse gas (GHG) emissions from the transport sector make up a large share of overall emissions in the U.S. and the E.U. and have still been rising in the years leading up to the Covid-19 pandemic.¹ Although Pigovian taxes on the carbon content of fuels are the first-best climate policy instrument from an economic perspective, corporate average fuel economy (CAFE) standards² have been the main environmental policy measure in the U.S. transport sector from the 1970s to the current Biden Administration. They also play a key role as CO_2 efficiency standards in the recent proposal of the European Commission to tighten the emission reduction goal in the E.U. transport sector to 55 percent by 2030 relative to 1990 (EC, 2024).

To design effective and efficient climate policies for the transport sector, it is important to understand the relevant channels of fuel economy standards on welfare and emissions. The main focus in the conventional literature is on the welfare cost of compliance occurring in the automobile market from adjusting engine technology, car features and pricing schedules. However, we identify and examine a new channel of fuel economy standards on welfare and emissions through shifting modal choices from public transport to individual driving and through the interaction of this effect with the corresponding adjustment in the urban form. To this end, we incorporate public transport, modal choice and vehicle choice into a monocentric city model that we calibrate with U.S. data and solve numerically.

On the one hand, fuel economy standards, on average, increase vehicle purchase costs. On the other hand, they reduce the marginal cost of driving and, thus, provide an incentive for households to switch their transport mode choice more often away from public transport to individual driving. This causes additional carbon emissions and requires

¹ Transport causes a large share of 29 percent of total GHG emissions in the U.S. and 23 percent in the E.U. (cf. EPA, 2023, and EEA, 2024).

² A fuel economy standard sets a certain level of fuel efficiency which the whole fleet sold by a car producer in the country in a certain year has to reach on average.

even stricter standards with their costly vehicle-market distortion to still reach climate policy goals. The resulting feedback loop additionally exacerbates the mode switching behavior towards individual driving and the corresponding increase in emissions. Our analysis proceeds in several steps yielding several main results.

First, in a medium run partial-equilibrium perspective, while accounting for adjustments in vehicle choice, modal choice, and congestion, but neglecting adjustments in location choices, the real estate market, and the urban form, the outcomes with and without public transport barely differ. But, in a long-run general-equilibrium perspective, the decrease in marginal driving costs with more fuel efficient vehicles shifts the households' location choices further away from the city center. The resulting long-run expansion of the urban form induces additional welfare costs for reaching certain emission goals that are higher with public transport than in a car-only scenario³. The mode choice shift away from public transport and the urban expansion reinforce each other and additionally increase emissions and the fixed costs of the transit system. Therefore, the fuel economy standard must be tightened further to achieve an emission goal. As a result, the long-run welfare cost for reducing emissions by 50 percent is 8 percent higher with public transport than without. However, if public transport usage is higher, for instance on the level of the E.U. instead of the U.S., then this additional welfare cost due to interactions with public transport rises to 12 percent. This corresponds to additional annual per-capita costs of 54 USD and 83 USD, respectively.

Furthermore, we find that a fuel tax has the opposite effect on commuting distances and welfare costs: marginal driving cost increases. Households shift their mode choice toward public transport and emission reduction targets are reached at a lower welfare cost (13 percent lower for a 50 percent emission reduction). Overall, the resulting gap in welfare costs for reaching emission reduction goals between fuel economy standards and more cost-efficient fuel taxes is substantially exacerbated through our novel public transport channel.

³ The latter is being examined by Marz and Goetzke (2022).

The results for fuel-economy standards are very robust for a wide range of congestion intensities. But the welfare cost reductions through the modal-choice public transit channel for the fuel tax case are larger for more intense traffic congestion. This is because by triggering modal switches away from driving, a fuel tax also creates a larger welfare gain from reducing congestion.

We contribute to the literature on the welfare costs and channels of fuel economy standards. Direct effects of fuel economy standards appear in the vehicle prices and encompass the cost of fuel regulation compliance (Austin and Dinan, 2005; NHTSA, 2010; Anderson and Sallee, 2011; Klier and Linn, 2012; Jacobsen, 2013; Sallee et al., 2016), the opportunity cost of trading off car features against fuel efficiency (Klier and Linn, 2016; West et al., 2017), and the effects on used car values (Jacobsen and van Benthem, 2015). Fuel economy standards also indirectly affect welfare through their impact on externalities, such as local pollution, carbon emissions, traffic fatalities, and congestion (Parry et al. (2007) gives an overview of traffic externalities). Finally, Marz and Goetzke (2022) examine the role of long-run urban-form adjustments and a CAFE-induced distortion of the vehicle market for the welfare consequences of fuel economy standards. However, none of these studies considers the role of public transport and adjustments in mode choice for the welfare balance of fuel economy standards or the interaction of these effects with the urban form. We fill this gap by identifying and examining our novel welfare channel of CAFE standards and its role for a long-run decarbonization of the transport sector.

Our analysis also contributes to the literature that links urban economic modelling with environmental-economic analysis of transport (Brueckner, 2007; Kim, 2012; Borck and Brueckner, 2018; Marz and Şen, 2022). But again, none of these studies accounts for public transport and the mechanisms we examine.

We, finally, contribute to the literature on the economics of public transport in the context of the monocentric city model (e.g., Brown, 1986; Liu et al., 2009; Creutzig, 2014; Tikoudis et al., 2015; Wang and Connors, 2018, among others). Our research

is the first in this area that examines the interaction of public transport systems with fuel economy standards, vehicle choice and location choice and a long-run adjustment of the urban form in an urban economic framework.

The rest of the paper is organized as follows. Section 2 presents the model. We examine the effects of fuel economy standards in Section 3 and the implications of a fuel tax in Section 4. Section 5 discusses the roles of the size of the transit systems and of the intensity of traffic congestion for the magnitude of our new welfare channel. Section 6 concludes.

2 Model

2.1 Households

We develop our framework by building on a monocentric city model in the tradition of Mills (1967), Muth (1969), and Alonso (1977) and abstract from citizens moving in or out, interpreting it as a representative metropolitan area. Commuters travel to the central business district (CBD) over their respective commuting distance x . We go beyond a classic monocentric city model by including a public transport sector and allowing for a modal choice between driving (annual share $0 < \mu < 1$) and public transport (annual share $1 - \mu$). Households at location x maximize Cobb-Douglas utility by choosing their consumption of housing q and of a numeraire composite good c , as well as their vehicle's fuel economy m in miles per gallon.

$$\begin{aligned} \max_{c,q,m} \quad & u(c, q) = c^{1-\alpha} q^\alpha \quad s.t. \\ & c + p(x)q = y - v(m) - T_{mon} - T_{time} \end{aligned} \tag{1}$$

The housing price per unit of floor space is $p(x)$. Household income $y = y_0 + y_{rent} + y_{tax} - y_{sub}$ is uniform over x and consists of an exogenous wage income y_0 , a lump-sum

of recycled excess land rent y_{rent} above the agricultural rent⁴, recycled fuel tax revenues y_{tax} if they occur, and a lump-sum tax to fund the public transit subsidy y_{sub} (cf. Section 2.1.2). The three latter components are all determined in the general market equilibrium (cf. Sections 2.3 and 4 below).

In addition, annual mobility expenditures reduce the part of income available for consumption. They consist of the annual vehicle purchasing cost $v(m)$ (cf. Section 2.1.1) and the monetary cost of travel

$$T_{mon}(x, m) = [\mu(x)t_C(m) + (1 - \mu(x))t_P](x + x_0) \quad (2)$$

with the annual travel cost per meter of daily distance by car $t_C(tec)$ and by public transport (ticket cost post subsidy) t_P . The household also travels a uniform exogenous daily distance x_0 for non-work trips (leisure, shopping, etc.) with the same modal mix $(\mu, 1 - \mu)$ as for commuting.⁵ Moreover, households account for the value of travel time in commuting:

$$T_{time}(x) = [\mu(x)\epsilon_C(x) + (1 - \mu(x))\epsilon_P]x$$

with the cost of travel time by car $\epsilon_C(x)$ and by public transport ϵ_P in Dollars per meter of CBD distance x and year.⁶ While the travel-time cost of public transport ϵ_P is constant, the travel-time cost of commuting by car $\epsilon_C = \epsilon_C(x)$ accounts for the role of endogenous road congestion at different locations (see Section 2.3 for details).

⁴ Only the excess land rent above the agricultural land rent r_A is recycled to account for the opportunity cost of using a unit of land for developments.

⁵ In calibrating x_0 , we account for the different numbers of days for work and for leisure trips.

⁶ We account for the travel-time cost of commuting only (not of non-work trips), as this time is spent in a work- and income-related context.

2.1.1 Commuting by Car

Each household owns a car differentiated by fuel economy m (in miles per gallon), while assuming a uniform average vehicle class (size, convenience, etc.). A higher fuel economy m also implicitly accounts for electric vehicles as "relatively efficient" in terms of gasoline-equivalent carbon emissions of the used electricity. The vehicle production sector is perfectly competitive with zero profits. Therefore, without fuel economy standards, the price of each vehicle equals the exogenous linear technological production cost $v_{tec}(m)$ with intercept $v_{0,tec}$ and slope b_{tec} .⁷

$$v(m) = v_{tec}(m) = v_{0,tec} + b_{tec} \cdot m \quad (3)$$

For the days of car commuting (share $\mu(x)$), annual driving costs per meter of daily distance in the monetary travel cost (Equation (2)) are $t_C(m) = \frac{(p_G + \tau)F}{m} + t_M$ with the gasoline price p_G , a fuel tax per gallon of gas τ (cf. Section 4), maintenance cost per meter and year t_M , and the unit adjustment factor F .⁸ In its choice of fuel economy m , the household faces a trade-off between a higher vehicle price and lower driving costs with a cleaner vehicle while accounting for the modal shares. The first-order condition for m from Equation (1), $b_{tec} - \frac{(p_G + \tau)F\mu(x)}{m^2}(x + x_0) = 0$, yields the optimal choice of fuel efficiency

$$m^*(x) = \sqrt{\frac{(p_G + \tau)F}{b_{tec}}\mu(x)(x + x_0)} \quad (4)$$

Accordingly, $t_C(m)$ changes to

$$t_C(x) = \sqrt{\frac{b_{tec}(p_G + \tau)F}{\mu(x)(x + x_0)}} + t_M \quad (5)$$

and $v(m)$ changes to $v(x) = v_{0,tec} + \sqrt{b_{tec}(p_G + \tau)F\mu(x)(x + x_0)}$.

⁷ We see the vehicle cost curve as capturing the higher cost of more advanced vehicle technology and implicitly also of medium-run R&D efforts. Hence, within the time-scale of our model, a linear functional form seems sufficiently plausible.

⁸ $F = \frac{1}{1.6} \frac{\text{miles}}{\text{km}} \frac{1}{1000} \frac{\text{km}}{\text{m}} \cdot 2 \cdot 250 \frac{\text{roundtrips}}{\text{year}} = 0.3125 \frac{\text{miles}}{\text{m} \cdot \text{year}}$ converts the cost of a single trip in miles into annual expenses in meters.

2.1.2 Public Transport and Modal Choice

Public transport is available within the radius $x \leq \hat{x}_{PT}$ from the CBD. For locations $x > \hat{x}_{PT}$, commuters always drive ($\mu = 1$). For locations covered by the transit system ($\mu \leq \hat{x}_{PT}$), households choose their modal shares $(\mu, 1 - \mu)$. When commuting by public transport (share $(1 - \mu)$), travel costs per meter of distance to the CBD and year are t_P . We assume that the ticket price is set equal to this variable cost of each trip and that the fixed cost of the transit system C_{PT} is fully covered by a public subsidy. This subsidy is funded by the lump-sum per-capita tax y_{sub} . The density, the system cost of the transit network, and the outer transit limit \hat{x}_{PT} all rise proportionally to the average commuting distance x_\emptyset (with all modes) that is determined in the urban economic equilibrium (cf. Section 2.3), so that

$$L \cdot y_{sub} = C_{PT} \cdot \frac{x_\emptyset}{x_{\emptyset,0}} \quad (6)$$

with the population L and the pre-policy mean commute $x_{\emptyset,0}$ holds for the fixed-cost budget of the transit system.

We model the mode choice in commuting as a logit choice probability following Tikoudis et al. (2015). Households at locations $x \leq \hat{x}_{PT}$ evaluate their utility from exclusively commuting by car (i.e., $\mu_C = 1$)

$$u_C(x) = \frac{\alpha^\alpha (1 - \alpha)^{(1-\alpha)}}{p(x, u)^\alpha} [y - v(x) - t_C(x)(x + x_0) - \epsilon_C(x)x] \quad (7)$$

or exclusively commuting by public transport (i.e., $\mu_P = 0$)

$$u_P(x) = \frac{\alpha^\alpha (1 - \alpha)^{(1-\alpha)}}{p(x, u)^\alpha} [y - v(x) - t_P(x + x_0) - \epsilon_P x] \quad (8)$$

In doing so, they continue to act as price takers and do not consider any changes in the vehicle market $v(x)$ or the real estate market $p(x, u)$ that might result from their decision. In the mode consideration they also assume that they keep on using their

vehicle chosen according to Equation (4) (affecting $t_C(x)$, Equation (5)). For $x \leq \hat{x}_{PT}$, this yields the probability to commute by car with Equations 7 and 8 (cf. Tikoudis et al., 2015)

$$\mu(x) = \frac{\exp(u_C(x))}{\exp(u_C(x)) + \exp(u_P(x))} \quad (9)$$

2.2 Housing Market

Given homogeneous utility at any commuting distance x in equilibrium to prevent arbitrage, higher commuting costs are compensated by a lower price for housing $p(x)$. From the first-order conditions for c and q and the budget constraint in (1), we obtain constant expenditure shares $(1 - \alpha)$ for $c(x)$ ⁹ and α for $p(x)q(x)$ ¹⁰, respectively. The housing price function is obtained by substituting both $c(x)$ and $p(x)q(x)$ into the objective function (1) leading to $p(x, u) = \Psi[y - v(x) - T_{mon}(x) - T_{time}(x)]^{\frac{1}{\alpha}} u^{-\frac{1}{\alpha}}$ with $\Psi = \alpha(1 - \alpha)^{\frac{1}{\alpha}-1}$ and u as a parametric utility level. Housing demand is given by $q(x, u) = \Gamma[y - v(x) - T_{mon}(x) - T_{time}(x)]^{1-\frac{1}{\alpha}} u^{\frac{1}{\alpha}}$ with $\Gamma = (1 - \alpha)^{1-\frac{1}{\alpha}}$.

As in Brueckner (2007), land priced at land rent $r(x)$ and housing capital per unit of land S , priced at 1, are inputs for housing production per unit of land, which is given by θS^β with the constant θ . The exponent $\beta < 1$ captures the decreasing returns to scale in building higher. Perfectly competitive developers maximize their (zero) profits at every location x according to

$$\max_S \Pi(S) = p(x)\theta S^\beta - S - r(x) \quad (10)$$

Using the housing price $p(x, u)$ from above yields housing capital demand $S(x, u) = \Lambda[y - v(x) - T_{mon}(x) - T_{time}(x)]^\kappa \cdot u^{-\kappa}$ with $\Lambda = (\theta\beta\Psi)^{\frac{1}{1-\beta}}$ and $\kappa = \frac{1}{\alpha(1-\beta)}$. Substituting

⁹ $c(x) = (1 - \alpha)[y - v(x) - T_{mon}(x) - T_{time}(x)]$ for the composite good.

¹⁰ $p(x)q(x) = \alpha[y - v(x) - T_{mon}(x) - T_{time}(x)]$ for rent expenses.

$S(x, u)$ and $p(x, u)$ with profits $\Pi(S)$ equal to zero, this leads to the land rent function

$$r(x, u) = \Omega[y - v(x) - T_{mon}(x) - T_{time}(x)]^\kappa \cdot u^{-\kappa} \quad (11)$$

with $\Omega = \theta\Psi\Lambda^\beta - \Lambda$.

2.3 General Market Equilibrium

At the city boundary \bar{x} , the land rent $r(x, u)$ in (11) equals the exogenous agricultural land rent r_A :

$$r(\bar{x}, u) = \Omega[y - v(x) - T_{mon}(x) - T_{time}(x)]^\kappa \cdot u^{-\kappa} = r_A \quad (12)$$

To close the model, we determine the population density, i.e. the number of people per unit of land $D(x, u) = \frac{\theta S(x, u)^\beta}{q(x, u)} = \Phi[y - v(x) - T_{mon}(x) - T_{time}(x)]^{\kappa-1} \cdot u^{-\kappa}$ with $\Phi = \frac{\theta\Lambda^\beta}{\Gamma}$.

Its integral over the whole city area must be equal to the city population L .

$$\iint_{city} D(x, u) dA = \int_0^{\bar{x}} D(x, u) 2\pi x dx = L \quad (13)$$

Aggregate excess rent payments (part of land rent $r(x)$ above the agricultural rent r_A) are given back as rent income y_{rent} to the households in a lump-sum fashion (cf. above).

$$y_{rent} = \frac{1}{L} \iint_{city} r(x, u) - r_A dA = \frac{1}{L} \int_0^{\bar{x}} [r(x, u) - r_A] 2\pi x dx \quad (14)$$

The agricultural rent can be seen as the opportunity cost of land while the land within the city is owned collectively by a "city corporation" avoiding further distortions.

Furthermore, the resulting population density profile over the distance x determines the density of vehicles crossing a ring with radius x around the CBD:

$$h_C(x) = \frac{1}{2\pi x} \int_x^{\bar{x}} D(x, u) 2\pi x \mu(x) dx \quad (15)$$

A higher vehicle density leads to more congestion and raises the time cost of driving at that location:

$$\epsilon_C(x) = \epsilon_{C,0} + \epsilon_1 h_C(x)$$

with the travel-time cost of uncongested travel $\epsilon_{C,0}$ and the parameter ϵ_1 capturing the congestion intensity for a given vehicle density.

Bringing together Equations (6), (12), (13), and (14), we can solve the model and determine the city size \bar{x} and the utility level u . The equilibrium also yields aggregate annual carbon emissions E_{CO_2} (cf. Appendix 1). In cases with a fuel tax $\tau > 0$, the aggregate tax revenues are recycled back to the households in a lump-sum fashion $y_{tax} = \frac{1}{L} \int_0^{\bar{x}} D(x, u) 2\pi x \frac{\tau \mu(x) F(x+x_0)}{m^*(x)} dx$.

2.4 Raising Fuel Economy Standards

Sallee et al. (2016) show that households do account for fuel economy in their vehicle choice. Therefore, when the government makes a binding fuel economy standard stricter, then car producers adjust car features, their pricing schedule, and R&D to provide sufficient incentives for customers to buy cleaner cars. Since total vehicle revenues must cover total costs, this implies a cross-subsidy from less fuel-efficient cars to more fuel-efficient ones. We implement this mechanism as a reduction in the slope of the vehicle cost curve (3) from b_{tec} to b_{CAFE} . As a result, households at all locations x choose cleaner cars according to (4):

$$m_{CAFE}(x) = \sqrt{\frac{(p_G + \tau)F}{b_{CAFE}} \mu(x) (x + x_0)} > \sqrt{\frac{(p_G + \tau)F}{b_{tec}} \mu(x) (x + x_0)} \quad (16)$$

An endogenous increase in the intercept of the vehicle cost curve ($v_{0,CAFE} > v_{0,tec}$) ensures full cost coverage and zero profits under perfect competition.

$$\iint_{city} v_{revenues}(b_{CAFE}) dA = \iint_{city} v_{costs}(b_{CAFE}) dA \quad (17)$$

The increase in the intercept of the vehicle cost curve $v_{0,CAFE}$ illustrates the increase in total car production costs for, on average, more fuel efficient vehicles.

3 Analysis of Fuel Economy Standards

In the following, we examine the effects of stricter fuel economy standards in our model. In a first step that captures a medium-run partial-equilibrium (PE) perspective, households adjust their vehicle choices and modal choices. But their location choices, the real estate market, and the urban form remain unchanged and individual utility levels differ. In the second step, we examine the resulting general equilibrium (GE) with additional long-run adjustments of location choices and the urban form and their interactions with modal (and vehicle) choices.

We base the model calibration on the metropolitan statistical area of the median U.S. citizen (Table 1), when ranked by size. See Appendix A.3 for the details of the calibration.

3.1 Partial Equilibrium: Medium Run

In partial equilibrium, the bid-rent curve $p_0(x, u_0)$ and the population density $D_0(x, u_0)$ at all housing locations x , are fixed. Households optimize their choice of travel mode (in $x \leq \hat{x}_{PT}$) and of vehicle fuel economy according to the respective fuel economy standard. The new vehicle cost curve and the corresponding changes in driving costs affect the households' modal choices and their budget constraints. Household utility is

Population	L	900,000
Income p.c.	[\$ p.a.] y_0	57,800
Consumption share of housing	α	0.399
Scaling constant in housing production	θ	0.015
Decrease of production productivity	β	0.902
Value of time travelled (car)	ϵ_C	0.125
Value of time travelled (public transport)	ϵ_P	0.125
Radius of public transport system	\hat{x}_{PT}	3500
Non-work trips	x_0	10,909
Gasoline price	$[\frac{\$}{gal \cdot a}] p_G$	2.75
Agricultural rent	r_A	0.0293
Maintenance cost per meter travelled	t_M	0.03
Conversion factor m/mpg in t_{CO_2}	F_{CO_2}	0.00248
Annual marginal cost of vehicle fuel efficiency	$[\frac{\$}{mpg \cdot a}] b_{tech}$	42
Baseline vehicle cost	$v_{0,tech}$	1700
Fixed cost of public transport	C_{PT}	354,400,000
Ticket price	$[\frac{\$}{m \cdot a}] t_P$	0.104

Table 1: Reference parameter setting

then given by

$$u_{1,CAFE}(x) = \frac{\alpha^\alpha (1 - \alpha)^{(1-\alpha)}}{p_0(x, u_0)^\alpha} [y - v(x) - T_{mon}(x) - T_{time}(x)] \quad (18)$$

We obtain the average utility by integrating $u_{1,CAFE}(x)$ over the whole city, weighted by the population density $D_0(x, u_0)$, and dividing the result by the number of inhabitants L :

$$\overline{u_{1,CAFE}} = \frac{1}{L} \int_0^{\bar{x}} u_{1,CAFE}(x) D_0(x, u_0) 2\pi x dx \quad (19)$$

Introducing CAFE standards to the model provides an incentive for the households to buy more fuel efficient, albeit more expensive, cars. Individual and average carbon emissions and driving costs decrease given the fixed commuting distances (cf. Section 2.4). This benefit is countered by higher vehicle costs and a CAFE-induced distortion of the vehicle market, leading to a decrease in average utility. Furthermore, the reduced marginal driving cost by car makes the use of public transport relatively less attractive, shifting the household's mode choice towards car travel, i.e. increasing μ , and reinforcing the household's need for a more expensive, fuel efficient vehicle. Panel (a) of Figure

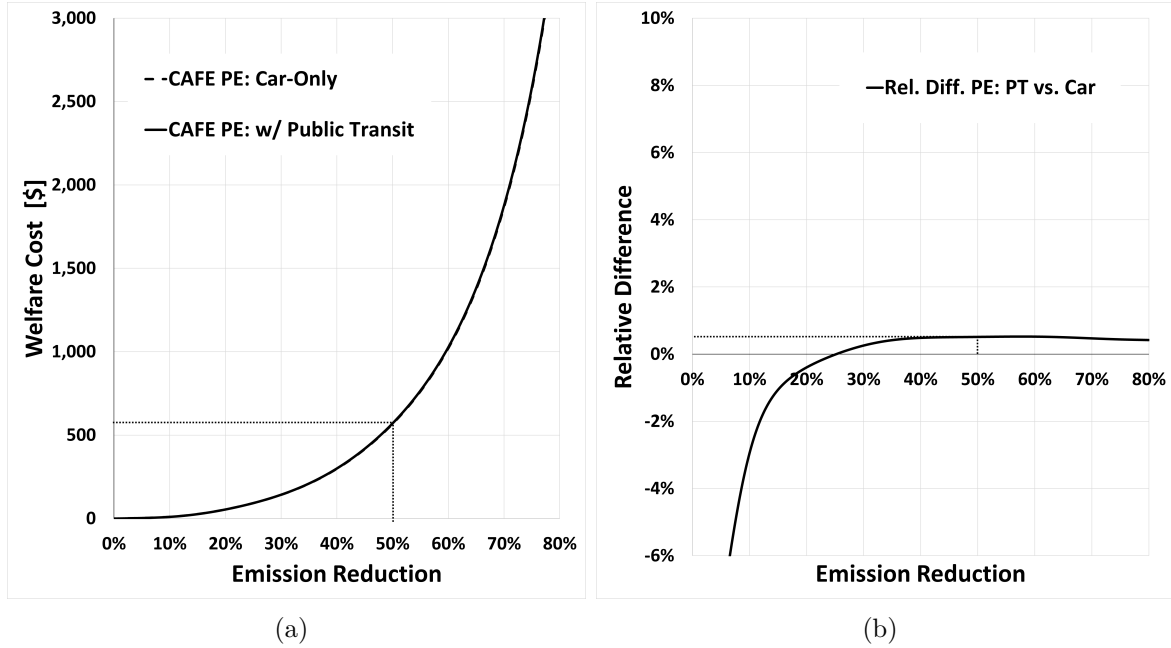


Figure 1: (a) Medium run per-capita welfare costs over emission reduction with (solid) and without (dashed) public transport
 (b) Welfare difference between both scenarios rel. to the scenario without public transport.

1 depicts the per-capita welfare cost over the total emission reduction in percent for a CAFE policy in the medium run (PE) and for a public transit scenario (solid curve) and a car-only scenario (dashed curve; corresponding to the setup of Marz and Goetzke (2022), but, by contrast, accounting for non-work trips x_0 and congestion $h_C(x)$). Both curves are almost identical: Emission reduction costs are low for small reduction goals, but rise convexly for stricter targets. The right-hand panel (b) illustrates the small relative difference (in percent) of the public transport case vs. the car-only case. The marginal driving costs decrease due to the stricter fuel economy standard and trigger modal switching away from emission-free public transit, inducing additional carbon emissions and additional traffic congestion. To reach an emission reduction goal above 25 percent, for instance 50 percent, the fuel economy standard must be tightened more, leading to a stronger vehicle-market distortion and higher costs of 571 USD (transit) instead of 568 USD (car only), 0.5 percent higher. For decarbonization goals below 25 percent, the welfare cost seems to be relatively lower under the public transport

scenario. But for such small emission reductions, absolute costs are tiny and relative differences are not very meaningful and more prone to rounding errors.

3.2 General Equilibrium: Long Run

In the long run, we allow for a general-equilibrium (GE) adjustment of location choices, the housing market, and the urban form in addition to modal and vehicle choices. The lower marginal driving costs with higher fuel efficiency increase commuting trip lengths and lead to additional urban sprawl as households try to benefit from lower real-estate prices in the suburbs, raising carbon emissions. Rents in the CBD decrease and rents in the suburbs increase relative to the pre-policy case. As households simultaneously increase their annual share of car commuting μ , they choose an additionally higher level of fuel economy. Hence, the interaction with modal choice exacerbates urban sprawl, the rise in carbon emissions from modal switching away from transit, and the welfare loss from the distortion of the vehicle market through stricter fuel-economy standards. The increasing commuting trip lengths x further reinforce the feedback between cleaner cars and a modal shift away from public transport until the new equilibrium is reached. At the same time, the size, the fixed costs, and the outer radius of the public transport system rise proportionally to the average commute length. All these effects contribute to larger additional welfare costs from the GE urban adjustment with public transport than without (cf. Figures A.1 and A.2 in Appendix A.2). As a result, reaching emission reduction goals in a public transit scenario is more costly relative to a car-only scenario, as Figure 2 illustrates (panel (a): absolute costs, panel (b) relative difference). For an emission reduction of 50 percent, the modal choice channel increases the welfare cost by an additional 8 percent (720 USD vs. 666 USD, see Figure 2). But the relative difference decreases with more ambitious emission reduction goals.

Figure 3 depicts the changing share of car commuting for an emission reduction of close to 50 percent in the reference scenario. In this setting, we set the average availability of transit to a radius of $x \leq \hat{x}_{PT} = 3,500m$ to reproduce the average VMT share of

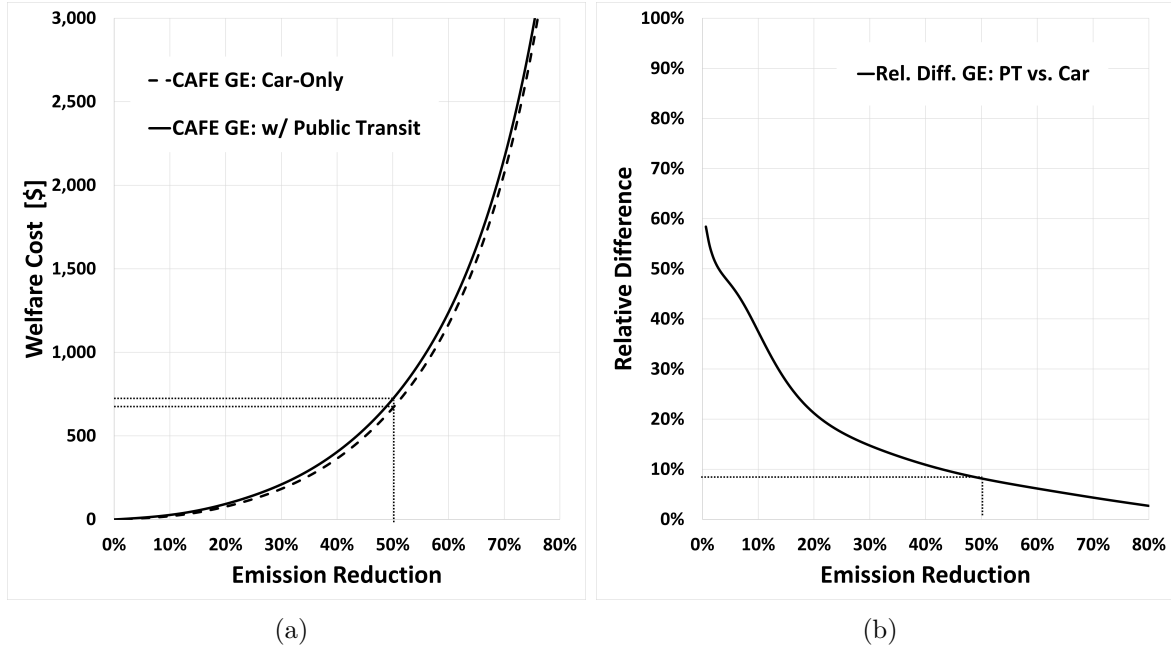


Figure 2: (a) Long run per-capita welfare costs over emission reduction with (solid) and without (dashed) public transport
 (b) Welfare difference between both scenarios rel. to the scenario without public transport.

public transport of 4.23 percent in the U.S. At the CBD, households are virtually indifferent between modes ($\mu \approx 50\%$) due to very short commuting distances. In general, households choose more polluting cars for lower commuting distances. As commute lengths increase, the lower marginal cost of transit tickets compared to driving matter more, increasing the share of transit use. In this reference (pre-policy) setting, the limit $\hat{x}_{PT} = 3,500m$ of the transit system is reached shortly before the effect of improving fuel economy boosting the share of driving starts to dominate for larger commuting distances. After the PE adjustment, the share of driving increases, as discussed above. In the GE adjustment, the outer limit of the transit system expands proportionally to the average commute. Table 2 directly compares the different scenarios quantitatively by welfare costs, city radius, average commuting distance, CO_2 emissions and miles per gallon of the average car.

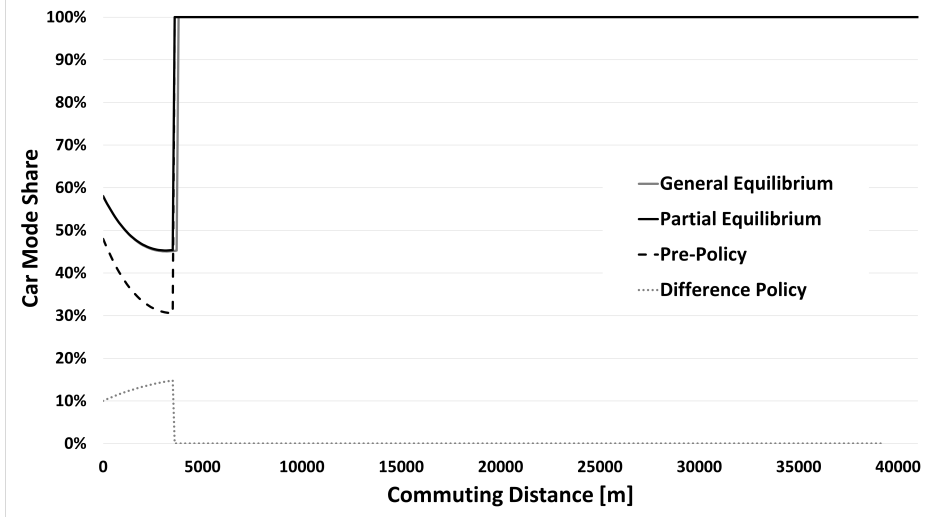


Figure 3: Change of mode choice due to the introduction of a CAFE policy with $b_{CAFE} = 10 \frac{\$}{mpg \cdot a}$

Model outcomes	Pre-Policy	CAFE Policy $m_{CAFE} = 10 \frac{\$}{mpg \cdot a}$		
		PE: Car	PE: PT	GE: PT
City radius \bar{x} [m]		48,202		51,080
Avg. commuting distance [m]		19,771		21,356
CO_2 emissions [tons/a]	2.93	1.45	1.44	1.47
Avg. miles per gallon [mpg]	24.2	50.4	49.7	51.1

Table 2: Model outcomes for different scenarios under CAFE compliance without (PE: Medium Run) and with (GE: Long Run) adjustment of the urban form relative to the pre-policy and the car-only case

4 Fuel Tax

A fuel tax increases the household's incentive to invest in fuel economy. Burke and Nishitateno (2013) and Klier and Linn (2013) show that higher gasoline prices indeed trigger the purchase of more fuel efficient vehicles. Despite the associated increase in miles per gallon, the marginal driving cost overall increases with the fuel tax in contrast to rising fuel economy standards. Also, unlike the CAFE standards scenario, vehicle prices remain equal to production costs in the tax case ($b_{tax} = b_{tec}$). Moreover, rising marginal driving costs create an incentive to switch mode more often to public transport. This reduces road congestion and fosters emission reductions without the distortion of the vehicle market associated with fuel economy standards. In PE before an urban adjustment, therefore, the welfare cost for reaching an emission reduction goal

in the scenario with public transport is again almost identical to a car-only scenario, but slightly lower for emission reductions beyond 19 percent, as Figure 4 (panel (a)) shows. For our example of an emission reduction goal of 50 percent, the welfare cost is 3.4 percent lower for a fuel tax policy than for CAFE standards. In GE, the fuel tax

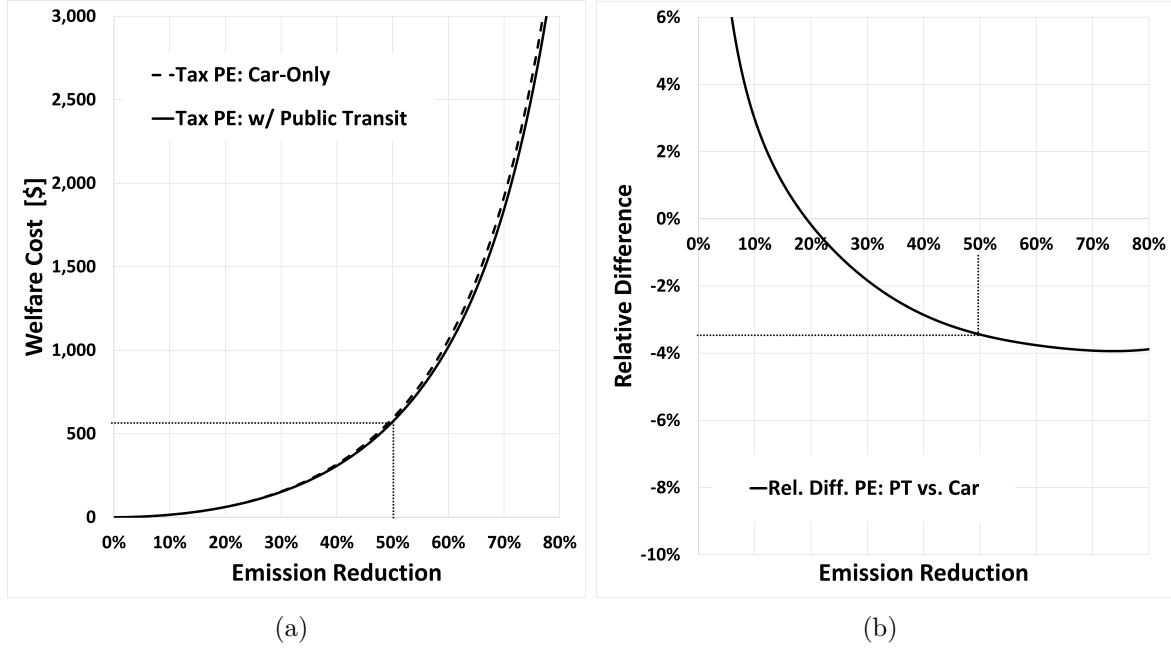


Figure 4: (a) Partial-equilibrium (medium-run) per-capita welfare costs of emission reductions by a fuel tax with (solid) and without (dashed) public transport (b) Welfare difference in percent between both scenarios rel. to the car-only scenario.

also triggers a contraction of the urban form instead of the expansion that takes place for fuel economy standards, because it increases the marginal driving cost instead of reducing it (similarly as in Marz and Goetzke, 2022). The urban contraction reduces average commuting distances, provides an incentive to choose public transit more often and moves more people into the central area $x \leq \hat{x}_{PT}$ where transit is available. All these effects contribute to an additional emission reduction. Consequently, smaller investments into costly fuel economy are sufficient and welfare costs are lower for reaching certain emission targets. An urban contraction due to a higher fuel tax has a similar effect in a car-only scenario (cf. Figure A.3 in Appendix A.2), as Marz and Goetzke (2022) also show. But the urban-contraction-related decrease in welfare costs for reaching an emission-reduction goal is substantially stronger when a public-transit system

is present. The left-hand panel (a) in Figure 5 illustrates how, as a result, the total welfare cost of emission reductions in the long-run GE is lower in the public transit case (solid curve, panel (a)) than in the car-only scenario (dashed curve, panel (a)). Panel (b) of Figure 5 shows the cost difference of the public transit case relative to the car-only case. A 50 percent emission-reduction goal incurs costs of 418 USD with public transport, but 478 USD in a car-only-scenario, a decrease by 13 percent.¹¹

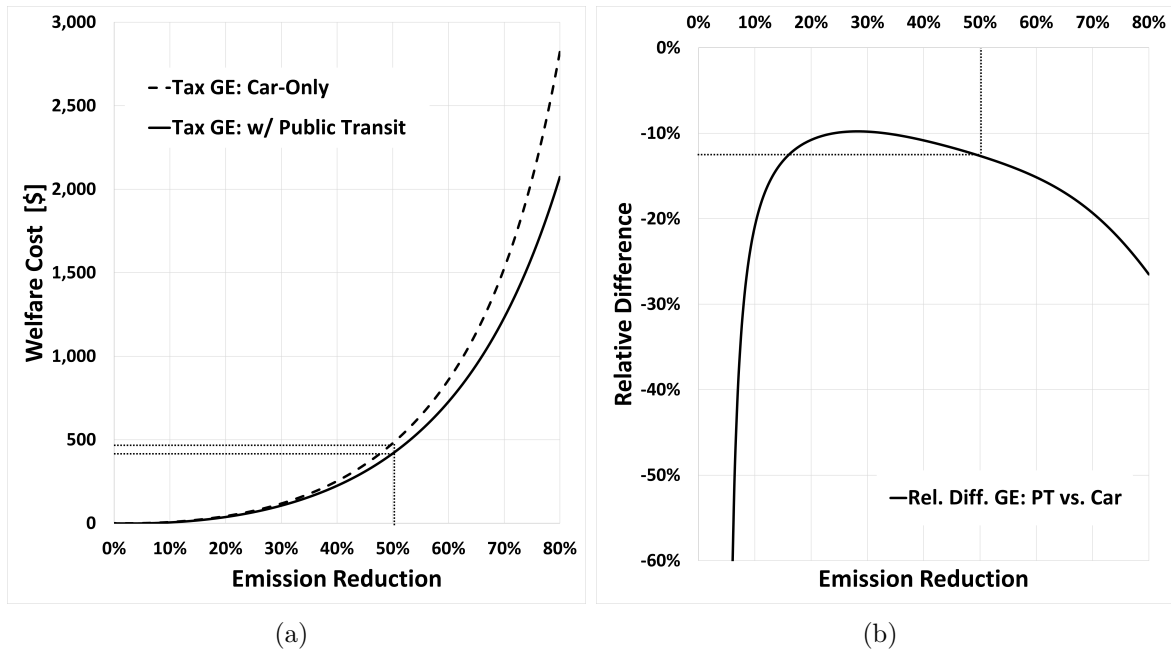


Figure 5: (a) General-equilibrium (long run) per-capita welfare costs of emission reductions by a fuel tax with (solid) and without (dashed) public transport
(b) Welfare difference between both scenarios rel. to the car-only scenario.

The total welfare cost gap between a CAFE policy and a fuel tax with public transport is widened by the welfare implications of the urban adjustment effects of both policies (cf. Figure 6, panel (a)). The dashed curves depict the PE cost trajectories. For emission reduction goals above 50 percent, the cost and emission savings from shrinking commuting distances and the wider usage of public transport under the tax regime more and more dominate the welfare gap. Panel (b) shows that the welfare-cost gap between fuel economy standards and a fuel tax is substantially larger for the public transport

¹¹ Again, for emission reductions below 10 percent, welfare costs are very low and their relative differences are quite meaningless due to dominant rounding errors.

scenario (solid curves) than for a car-only scenario (dashed curves). Thus, a relevant share of the fuel tax’s cost advantage is caused by the interactions of the instruments with the public transport system and the households’ modal choices.

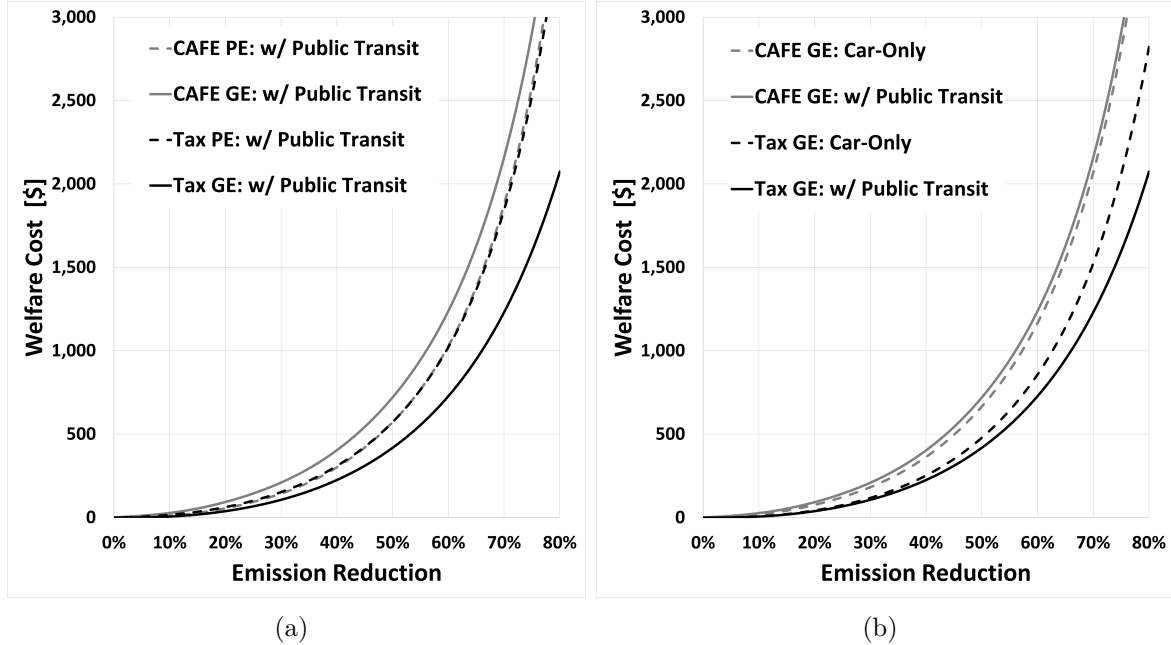


Figure 6: Comparison of CAFE in PE and GE with fuel tax for PT case (panel (a)) and GE comparison of transit case and car-only scenario for CAFE standards and tax policy (panel (b)).

5 Discussion

5.1 The Role of Larger Transit Systems

Public transport systems and their interactions with fuel economy standards and fuel taxes through the households’ modal choices, location choices, and vehicle choices are a relevant driver of differences in welfare costs between the policy instruments. This is the case although the usage of public transport covers only 4.2 percent of total VMT, as currently in the U.S. In this section, we discuss the implications of a larger role of transit systems in a country’s mobility. To examine the welfare effects of the environmental policies in a model calibrated for the U.S., but with a higher share of public transport equal to the 17.5 percent of VMT as in the European Union, we set the outer limit of

the PT system to $\hat{x}_{PT} = 9,500m$ instead of $3,500m$. All other parameters from the U.S. calibration remain unchanged. Figure 7 shows that, for the CAFE policy (panel

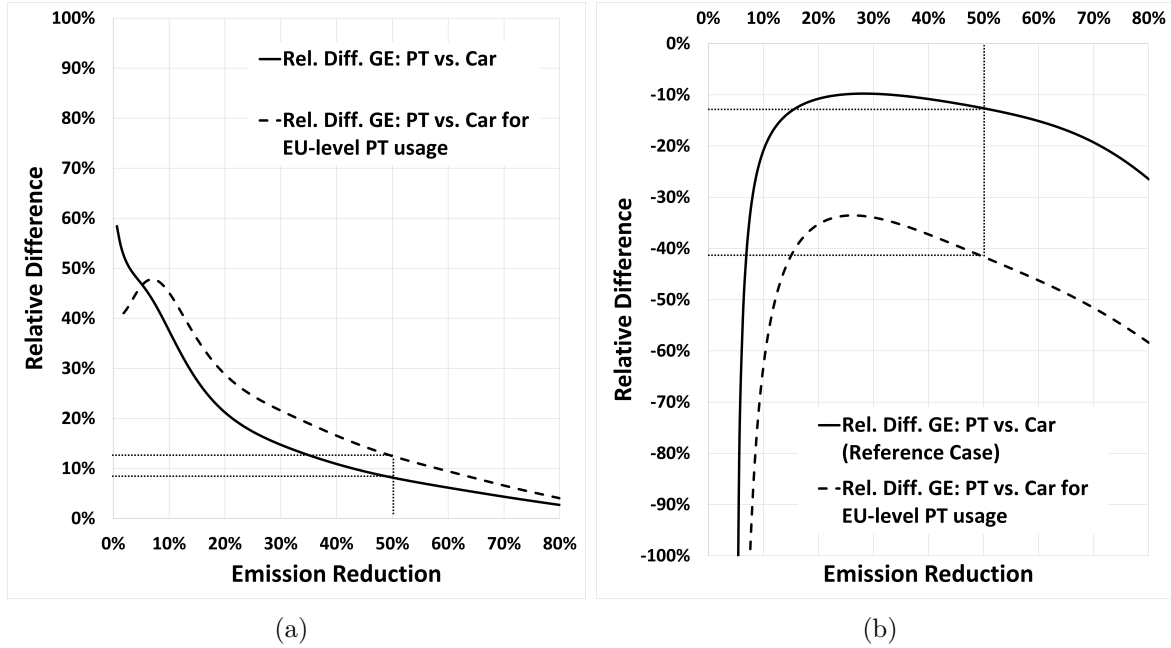


Figure 7: (a) Impact of an E.U.-level role of public transport on the relative welfare-cost difference between the transit scenario and the car-only scenario for the **CAFE policy** (dashed). Solid curve: reference U.S. calibration. (b) Impact of an E.U.-level role of public transport on the relative welfare-cost difference between the transit scenario and the car-only scenario for the **fuel tax policy** (dashed). Solid curve: reference U.S. calibration.

(a)), the additional GE welfare costs of emission reductions due to our novel public transport channel are substantially higher for a larger public transport system that plays a more prominent role in the households' modal choices. Although the level of public transit usage is more than four times as large, the public transport channel adds 12 percent to the costs in a car-only scenario instead of 8 percent, as for the reference U.S. parameter setting. A larger PT system that is available in a larger part of the urban areas, provides more opportunities for people to switch to driving and increases the overall welfare cost. In a similar way, a large availability of the public transport mode provides more opportunities for people to switch away from driving and towards transit when a rising fuel tax increases the marginal driving cost (panel (b)). In the tax case, the impact of a larger transit system is larger than for the CAFE policy: the

transit channel reduces the welfare costs of emission reductions relative to a car-only scenario by 42 percent for an EU-level PT usage compared to 13 percent in the reference setting. This shows that the choice of the more cost-efficient fuel tax instrument instead of the command-and-control tool fuel economy standards is even more important with a more prominent role of public transport.

5.2 The Role of Traffic Congestion

When households shift their commuting mode shares more from public transit to driving due to falling marginal driving costs with fuel economy standards, they contribute to more traffic congestion on the roads. When they shift more often from driving to public transit due to a fuel tax, traffic congestion decreases. Figure 8 illustrates how robust the welfare-cost ratio between the public transit scenario and the car-only scenario from Figures 2 (b) and 5 (b) is to different levels of traffic congestion. For the CAFE policy

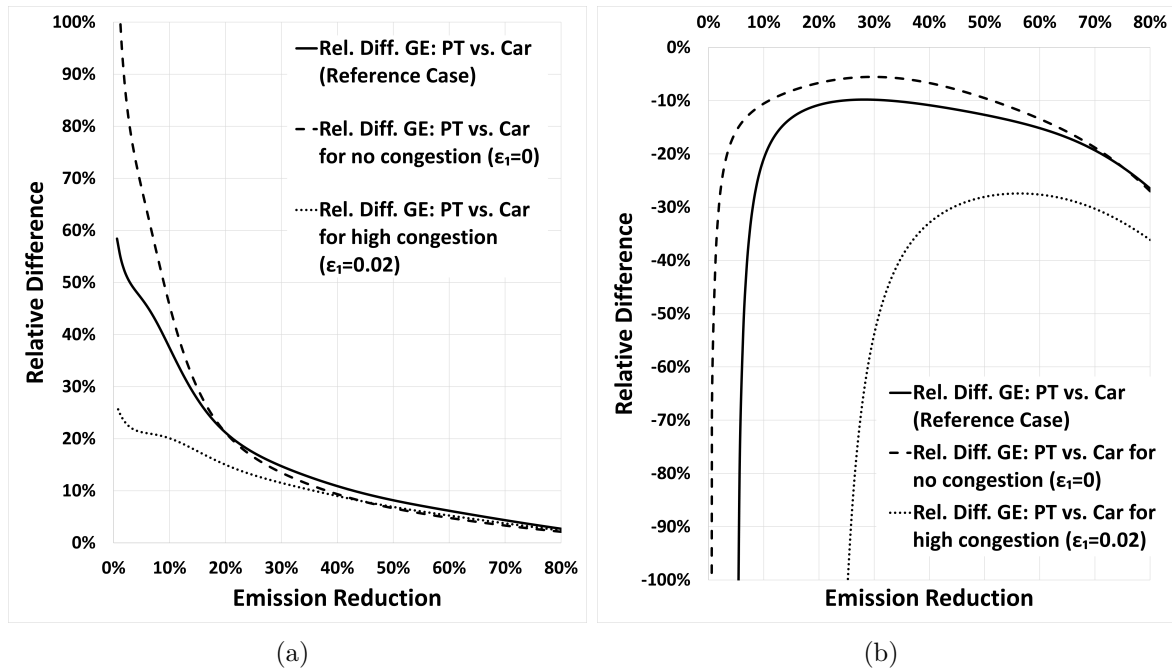


Figure 8: (a) Sensitivity to level of congestion for CAFE policy with public transport
(b) Sensitivity to level of congestion for tax policy with public transport

in panel (a), the intensity of congestion has almost no effect on the additional welfare cost of emission reductions with public transport relative to the car-only scenario. But

for the fuel tax (panel (b)), the decrease in welfare costs from the GE interaction of modal choice, location choice, and vehicle choice is larger for more intense congestion levels. The reason is not only that the tax-driven decrease in commuting trip lengths dampens congestion, but the more frequent choice of the transit mode additionally reduces congestion and the associated welfare costs.

6 Conclusion

We show that fuel economy standards not only trigger the choice of more fuel-efficient vehicles, but also incentivize households to switch more often from commuting by public transport to commuting by car. This channel counteracts the intended reduction in greenhouse gas (GHG) emissions. Furthermore, by decreasing the marginal cost of driving, fuel economy standards induce a long-run expansion of the urban form as households see a stronger incentive to benefit from lower real estate prices in the suburbs. The modal-choice channel reinforces this urban expansion and exacerbates the increase in commuting trip lengths. Thus, the choice of cleaner vehicles, the mode shift away from public transport towards car commuting, and the households' moving away from the CBD reinforce each other and lead to additional GHG emissions. This requires an additional tightening of the fuel economy standard with additional welfare costs from the associated vehicle market distortion to reach certain emission reduction goals. Overall, the examined modal choice channel leads to substantially larger welfare costs in the long run general equilibrium than when the role of public transit is neglected.

By contrast, the described interaction of modal choices, location choices, and vehicle choices also occurs for a carbon tax on gasoline, but with opposite signs: As the fuel tax raises marginal driving costs, households switch more often to public transport, decreasing emissions and welfare costs. The urban form reacts by a long-run contraction that facilitates reaching certain emission reduction goals. The interactions of the discussed environmental policies, modal choice and the urban form, thus, lead to an

even larger gap in total welfare costs between fuel economy standards and a more cost-efficient fuel tax than in a car-only scenario. Moreover, a more prominent role of public transport usage exacerbates the cost-increasing effects of fuel economy standards and the cost-dampening effects of a fuel tax. Finally, we find that the intensity of traffic congestion has almost no effect on our public transport channel under the CAFE policy, but strengthens the cost reductions under a fuel tax. Our analysis shows how interactions of environmental policy instruments in the transport sector with modal choices can substantially affect their welfare balance and that they should be accounted for in policy design.

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Appendix

A Numerical Analysis

A.1 Aggregate Carbon Emissions

Annual carbon emissions E_{CO_2} are calculated based on the total amount of consumed gasoline. The amount of consumed gasoline is calculated by integrating the product of individual driving distances x over the corresponding vehicle fuel economy in Miles per Gallon and the population density $D(x, u)$ over the city area.

$$E_{CO_2} = F_{CO_2} \int_0^{\bar{x}} \frac{x}{tec(x)} D(x, u) 2\pi x dx$$

The factor $F_{CO_2} = 2.48027 \cdot 10^{-3} \frac{tec}{m} \frac{t_{CO_2}}{a}$ transforms gallons of E10 gasoline to tons of CO_2 and meters of distance to the CBD to annual miles driven.¹²

¹² $F_{CO_2} = 7.983226 \frac{kg_{CO_2}}{gallonE10gas} \cdot \frac{500 \frac{one-way\ trips}{a}}{1000 \frac{kg_{CO_2}}{t_{CO_2}} 1000 \frac{m}{km} 1.609344 \frac{km}{Mile}} = 2.48027 \cdot 10^{-3} \frac{mpg}{m} \frac{t_{CO_2}}{a}$ with the CO_2 content of a gallon of E10 gasoline of $7.983226 \frac{kg_{CO_2}}{gallon}$ (U.S. Energy Information Administration (2018)).

A.2 Additional Figures - Reference Case

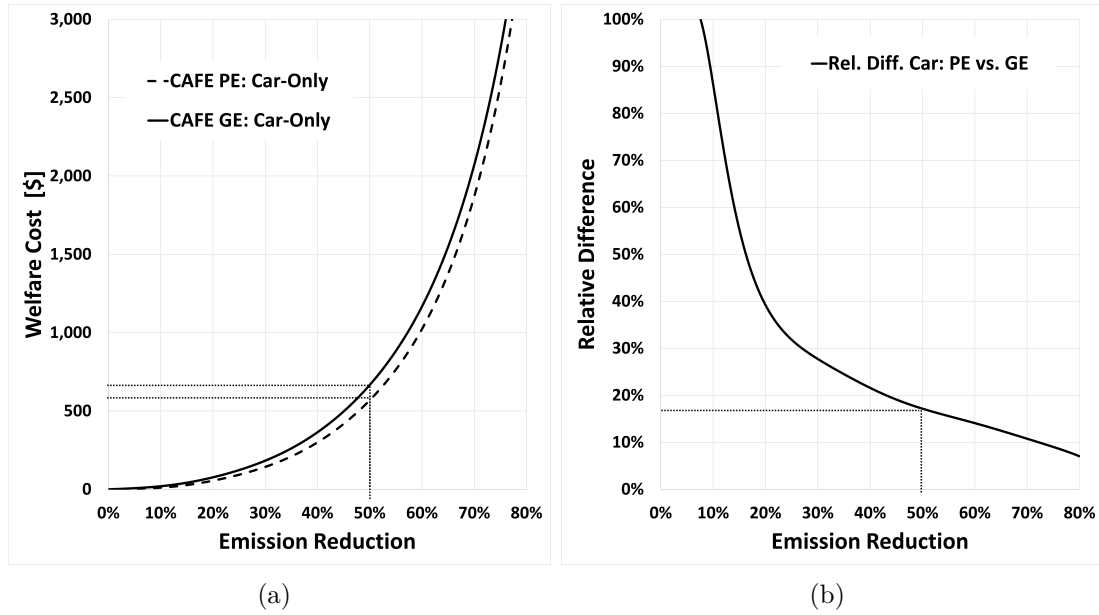


Figure A.1: (a) Welfare costs of emission reductions through fuel economy standards in a **car-only scenario** in partial equilibrium (PE, dashed) and in general equilibrium (GE) with urban adjustment (solid).
 (b) Relative difference of costs from CAFE standards in GE vs. PE in a car-only scenario without public transport.

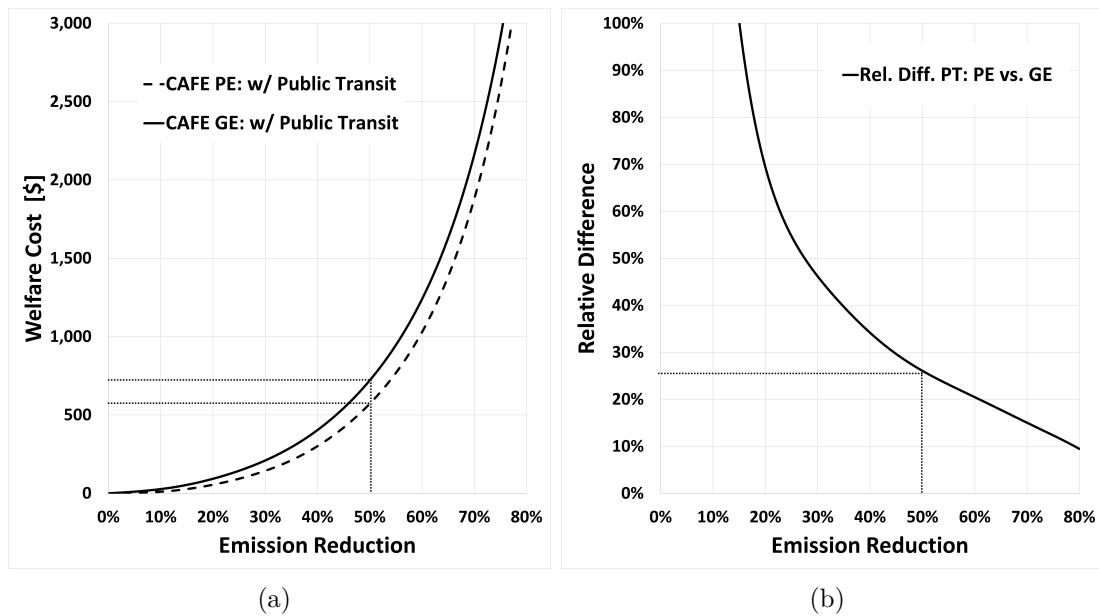


Figure A.2: (a) Welfare costs of emission reductions through fuel economy standards in a **public transport scenario** in partial equilibrium (PE, dashed) and in general equilibrium (GE) with urban adjustment (solid).
 (b) Relative difference of costs from CAFE standards in GE vs. PE in a car-only scenario with public transport.

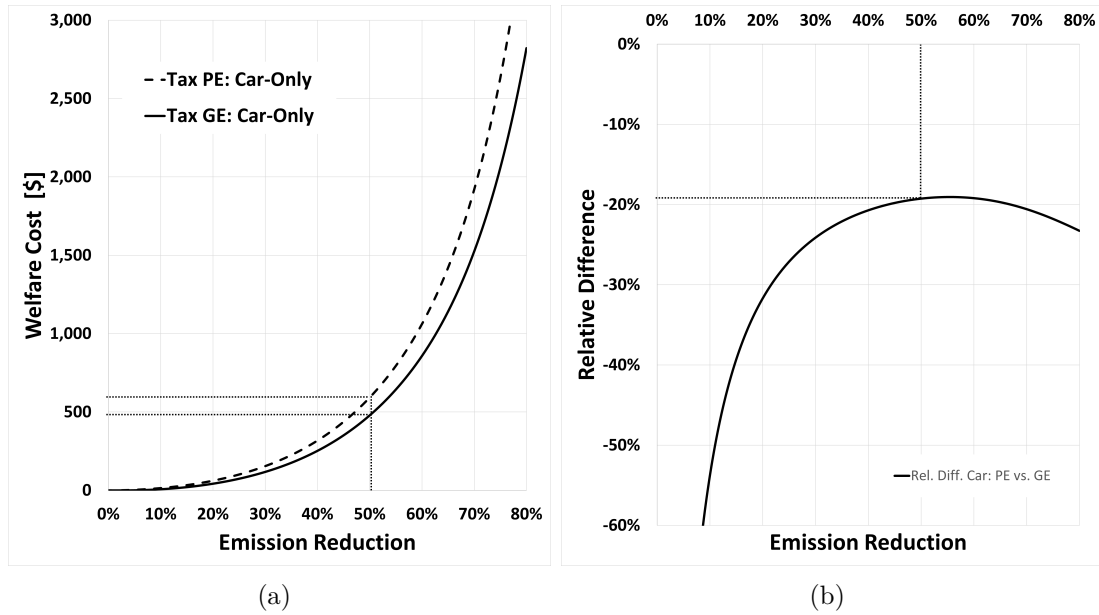


Figure A.3: (a) Welfare costs of emission reductions through a fuel tax in a **car-only scenario** in partial equilibrium (PE, dashed) and in general equilibrium (GE) with urban adjustment (solid). (b) Relative difference of costs from a fuel tax in GE vs. PE in a car-only scenario without public transport.

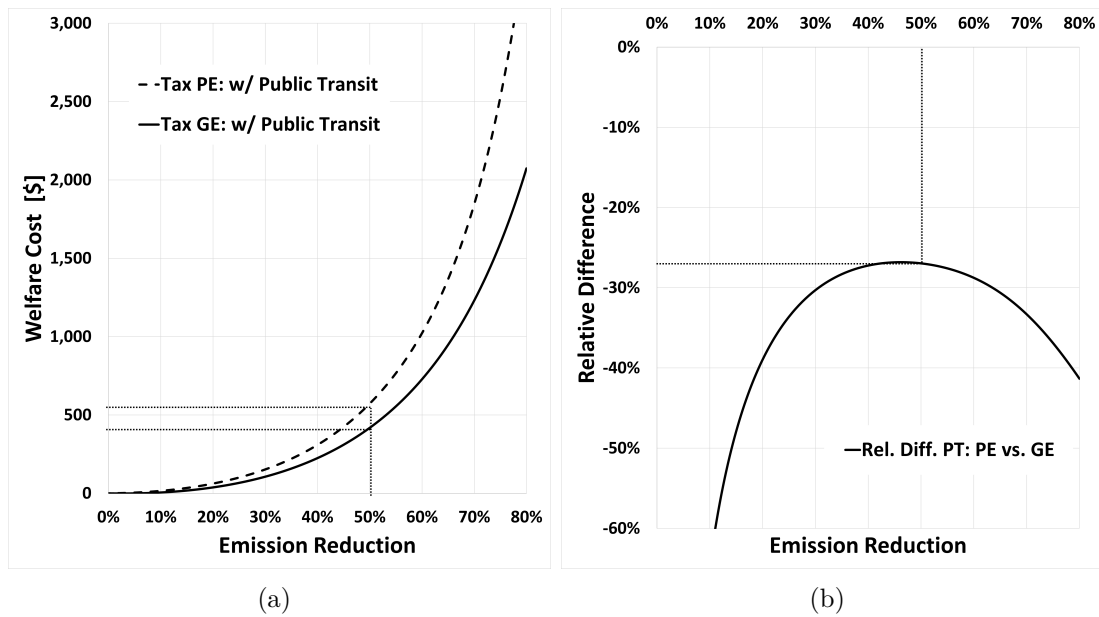


Figure A.4: (a) Welfare costs of emission reductions through a fuel tax in a **public transport scenario** in partial equilibrium (PE, dashed) and in general equilibrium (GE) with urban adjustment (solid). (b) Relative difference of welfare costs from a fuel tax in general equilibrium vs. partial equilibrium in a scenario with public transport.

A.3 Calibration

Our model reference setting is calibrated to the U.S. in the year 2022. We identify the median American citizen to live in a metropolitan statistical area of around 1,675,000 inhabitants (such as Providence, RI) by ranking the metro areas by population size (cf. 2022 data from USCB (2024a)). On average, there are 2.4 people living in a household of which 1.3 are considered earners (cf. BLS, 2024), i.e. the share of earners is approximately 54% in the population. This yields approximately 900,000 earners in this metro area, our commuting population L in the model. In the same way, median income per household of 75,149\$ translates into $y_0 = 57,800\$$ per earner (cf. USCB (2024b)).

The average age of cars in the U.S. was 12.2 years in 2022 (BTS (2023)). The majority of the vehicle fleet currently in operation entered the market accordingly in the past 20 years. Average fuel economy both in our pre-policy equilibrium and in the U.S. car fleet over this time frame is therefore around 24.3mpg (2012 values as a midpoint) according to EPA (2023). This implies a vehicle cost curve with a slope of $b_{tec} = 42\frac{\$}{\text{mpg}\cdot\text{a}}$ for technological improvement costs of fuel efficiency. This is in line with estimations by the National Research Council (2015, p. 270)¹³. Average used car purchasing cost were around 33,500\$ in 2022 (iSeeCars, 2023). Together with the slope of the linear vehicle cost curve $b_{tec} = 42\frac{\$}{\text{mpg}\cdot\text{a}}$, average fuel economy of 24.3mpg and a vehicle lifetime of 12.2 years, this implies an intercept for the annualized vehicle cost curve of $v_{0,tech} = 1700$. According to the AAA (2022), average maintenance and repair costs per mile amount to 0.1064\$. Converted to meters and annualized with 500 one-way commuting trips, we obtain $t_m = 0.03\frac{\$}{\text{m}\cdot\text{a}}$. Finally, the price of gasoline was on average about 2.75\$ per gallon over the years 2002-2022 (cf. EIA, 2022).

For commuting trips, we set the value of travel time (VOTT) to half of the gross hourly wage rate, following Small (2012), Small and Verhoef (2007), and Shires and

¹³A one percent improvement in fuel efficiency increases vehicle production costs by $42\frac{\$}{\text{mpg}\cdot\text{a}} \cdot 10\text{a} \cdot 0.243\text{mpg} = 102.06\$$ for this calibration, an upper estimate in the findings.

de Jong (2009). The median gross hourly wage rate is 22.26\$ in 2022 (BLS, 2023), which translates into a VOTT for commuting of 11.13\$. The average commuting trip in the U.S. is 19.7km (12.22 miles, USDT (2017)) and lasts 26.6 minutes (USDT, 2017), implying a travel speed of 44.44 km/h on average and in extension a value of travel time for 500 one-way trips per year of $\epsilon_c = 0.1252 \frac{\$}{m \cdot a}$ and the same for public transport $\epsilon_p = 0.1252 \frac{\$}{m \cdot a}$. The public transport system is calibrated to reflect the average share of public transport in total trips in the U.S. of 4.23% (USDT, 2022). For a European-style public transport system *ceteris paribus* as highlighted in our discussion, we set the public transport share in total trips to 17.52% (Eurostat, 2024). This reflects the average share over the years 2010-2019 as Covid-19 induced a shock that is not representative of the long-term trend. To reproduce the average commuting distance of 19.7 km and speed of 44.44 km/h in the model, we choose parameter β for the elasticity of housing production w.r.t. capital (decreasing returns in building higher). In the reference calibration, this is achieved at $\beta_c = 0.906$ for the car-only case and $\beta_p = 0.902$ for the case including public transport, respectively. The choices of β are similar to Gillingham and Marz (2024) and Brueckner (2007). Total vehicle miles travelled in the U.S. in 2022 were 3169.4 billion (FHWA, 2023). Given a total population of 333,271,411 for that year (USCB, 2024a) and converted to meters per day, this implies a one-way total distance of 30,609m per person of which 19,700m are commute and $x_0 = 10,909m$ are non-work trips.

According to CRS (2024), total fare revenue of the U.S. public transport system amounts to 18,740 million \$. Given 56.1 billion passenger miles per year (APTA, 2021), this translates into a ticket price of $t_p = 0.1038\$$. In our model, these ticket revenues cover variable costs. The fixed costs, which amount to 354.4 million \$ (CRS, 2024), are covered by federal, state and local subsidies. This setup produces a ratio of 1:2 for variable to fixed costs, which is in the ballpark of observed values. We include a propensity to switch between modes $\rho = 100$. Due to a lack of data, we choose ρ

such that we obtain a plausible modal choice pattern over x and therefore a realistic distribution of μ .

We calculate the agricultural land rent following the approach of Borck and Brueckner (2018) and Bertaud and Brueckner (2005): Average farm real estate value is 3800\$ per acre (4047 m^2) according to USDA (2023). With an interest rate of 0.0312% for 2022 (FRED, 2022), we obtain an annual agricultural land rent of $r_A = 0.029296$ $\$/m^2$. We set the elasticity of consumption w.r.t. housing, equivalent to the income spent on housing under Cobb-Douglas utility, to $\alpha = 0.3991$ (structural estimation by Gillingham and Marz, 2024). The amount of housing production θS^β and equivalently the consumption of housing per land area entering the utility function depends on parameter $\theta = 0.0154$ (structural estimation by Gillingham and Marz, 2024), which in turn does not affect city size, spatial distribution of households or vehicle choice.