

# Demand Side Instruments to Reduce Road Transportation Externalities in the Greater Cairo Metropolitan Area

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## Abstract

Economically efficient prices for the passenger transportation system in the Greater Cairo Metropolitan Area would account for broader societal costs of traffic congestion and accidents, and local and global pollution. A \$2.20 per gallon gasoline tax (2006 US\$) would be economically efficient, compared with the current subsidy of \$1.20 per gallon. Removal of the existing subsidy alone would achieve about three-quarters of the net benefits from subsidy elimination and the tax. Per-mile tolls could target congestion and accident externalities more efficiently than fuel taxes, although they are not practical

at present. A combination of \$0.80 per gallon gasoline tax to address pollution (versus \$2.20 without tolls), and \$0.12 and \$0.19 tolls per vehicle mile on automobiles and minibuses, respectively, to address traffic congestion and accident externalities (versus \$0.22 without fuel taxes) would be most efficient. Current public bus and rail subsidies are relatively close to efficient levels in the absence of such policies; however, if automobile and minibus externalities were fully addressed through more efficient pricing, optimal subsidies to public transit would be smaller than current levels.

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## 1. Introduction

The Greater Cairo Metropolitan Area (GCMA) is one of the largest megacities in the World and is Egypt's largest agglomeration (it is home to 27 percent of Egypt's population). The GCMA is also one of the most polluted and congested urban agglomerations in the world. For example, among the 15 cities illustrated in Figure 1, Cairo has by far the highest atmospheric concentration of total suspended particulates, a proxy for human health risks from air pollution. And it ranks third, behind only Beijing and Jakarta, in terms of congestion among these cities, as measured by the average time it takes to drive a mile by automobile. Pressure on the environment and urban infrastructure will persist in upcoming years with continued expansion in the population of the metropolitan area.

Automobile emissions are a major cause of local air pollution (other emissions sources include industrial operations like lead smelting and cement, chaff from burning of rice straw, trash burning, and desert dust). Moreover, Cairo's climate creates conditions that are especially favorable to poor air quality.<sup>1</sup> Since 1994, several policies have been introduced with the aim of improving air quality in the GCMA including emissions control regulations for industry, a progressive conversion of the fleets of public bus companies from diesel to compressed natural gas, and emissions inspections programs for automobiles.

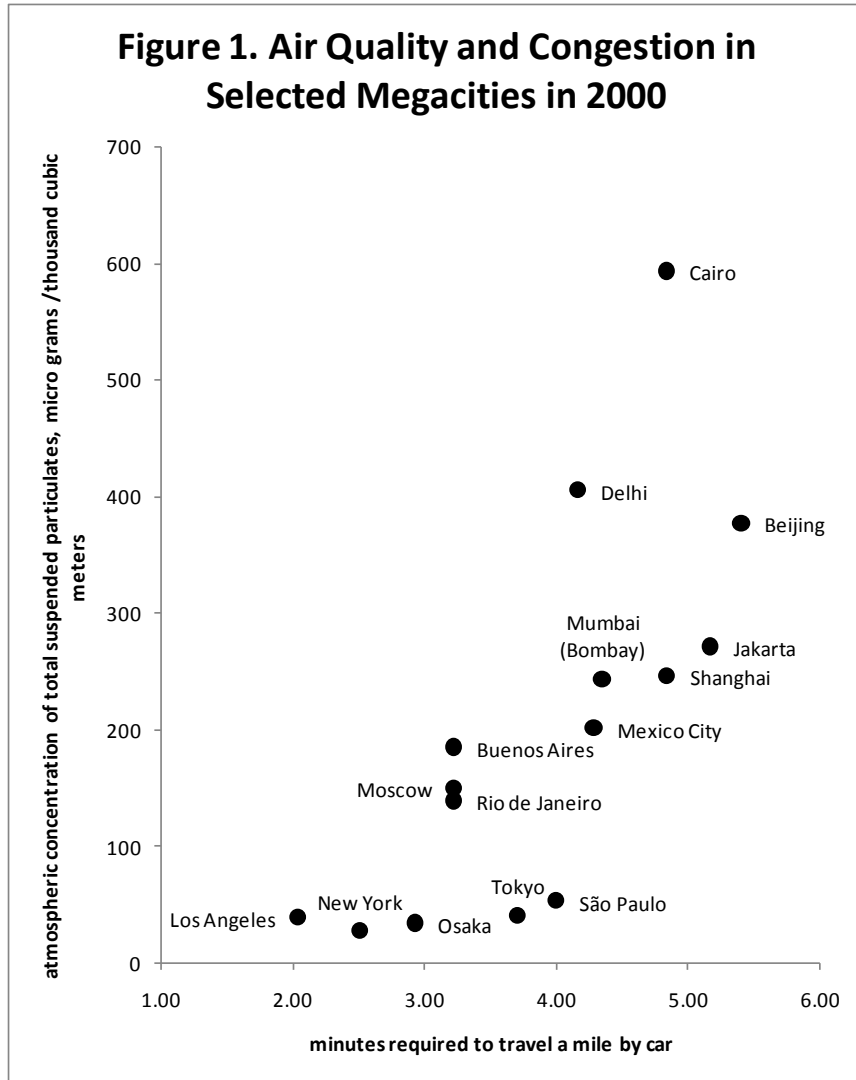
Traffic congestion imposes costs on the economy, particularly from wasted time, and this cost is likely to rise with continued growth in travel demand. Besides pollution and congestion, yet another major adverse side effect of vehicle use is traffic accidents. A large number of people are killed in the GCMA as a result of road accidents, over 700 a year (CAPMAS, 2010).

Traditionally in developing countries, supply-side measures are offered to address traffic congestion problems. These include expansion of road networks and improvement of public transportation systems through the introduction of new, or expansion of existing, light rail transit, bus rapid transit and metro systems. These measures are highly capital intensive and have long

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<sup>1</sup> During the summer, temperatures in Cairo can fluctuate from over 100°F to as low as 50°F during the course of a day. Under these conditions air closer to the ground cools faster than the air above which slows down the ascent of (polluted) surface air, resulting in a very stable atmosphere. This retards the dispersion and dilution of pollutants, keeping them closer to the ground where they pose greater environmental hazards. Moreover, atmospheric stability can lead to temperature inversions when, for part of the day, polluted surface air becomes trapped under a blanket of warmer air, posing acute health risks. High levels of photochemical smog are yet another byproduct of Cairo's hot and sunny climate. Smog develops when sunlight chemically breaks down nitrogen oxides and Volatile Organic Compounds into their constituent parts.

construction phases and are constrained by land availability, particularly in the city core and high density areas. Moreover, supply-side approaches are not enough by themselves. In fact, expanding the road network may be partly self-defeating if it creates ever greater demand for travel.<sup>2</sup> And an expansion of road networks in the city periphery does not reduce environmental emissions (Anas and Timilsina, 2009a).



Note. Suspended Particulates include organic and inorganic particles (e.g., dust, sand, metals, wood particles, smoke), PM-10 (coarse particulates less than 10 micro-meters ( $\mu\text{m}$ ) in diameter), and PM-2.5 (fine particulates less than 2.5 micro-meters in diameter).

Source. Gurjar et al. (2008) and IAPT (2007).

<sup>2</sup> In the United States, for example, Duranton and Turner (2009) find that urban road expansion has had minimal impact on alleviating traffic congestion.

growing interest in using demand side measures, particularly fiscal or pricing reforms, to address the broader societal costs (or negative externalities) of transportation systems.<sup>3</sup> One option is to remove fuel subsidies and impose fuel taxes. In fact, as illustrated for a selection of countries in Figure 2, many developing countries impose high taxes on gasoline, in contrast to Egypt (and some other countries like Algeria, Libya and Venezuela) where fuel is heavily subsidized—to the tune of \$1.20 per gallon in 2006.<sup>4</sup> Another possibility is to lower mass transit fares. A more novel approach is congestion tolls, which economists have long advocated as an effective way of allocating scarce roadway capacity to the highest valued users. The use of congestion pricing in London and Stockholm suggests that public opposition to this approach is not insurmountable though at best, given current technology, such pricing would likely be confined to a small number of limited access roads for the foreseeable future.<sup>5</sup>

Several studies have evaluated demand side instruments for other cities in the developing world.<sup>6</sup> However, no study has been carried out for Cairo. This study attempts to provide, albeit in a highly simplified and preliminary way, some broad sense of how pricing instruments, particularly the replacement of gasoline subsidies with gasoline taxes and the reform of public transit fare systems, might be applied to reduce transportation externalities in the GCMA. We also study a uniform toll on vehicle mileage, though more to provide a metric for the magnitude of congestion and accident externalities, rather than a realistic guide to actual policy options at present.

The paper is organized as follows. The next section provides a brief discussion of the model used for the analysis. Section 3 discusses the estimation of key factors or parameters that feed into the model. Section 4 presents the main findings. Section 5 offers concluding remarks.

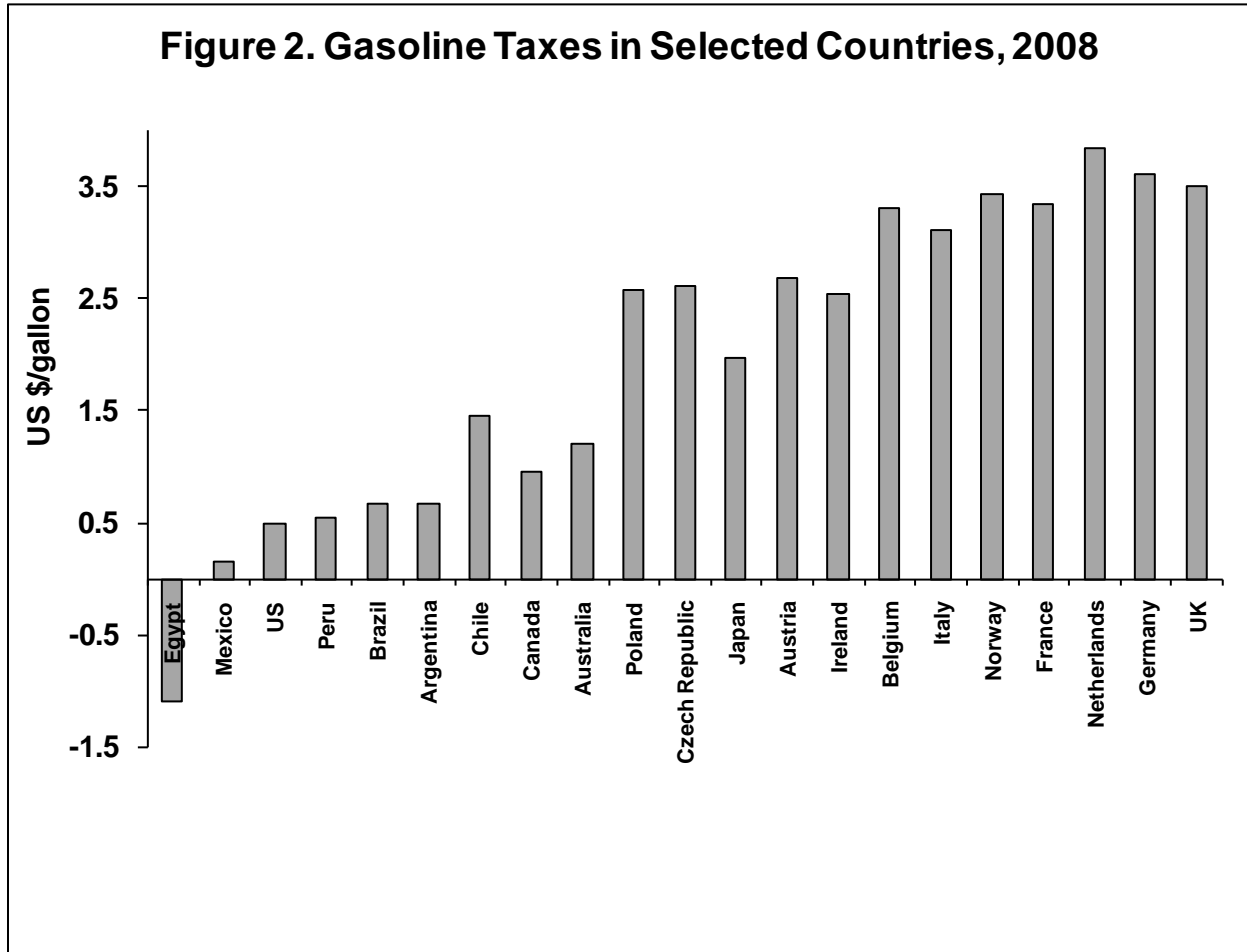
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<sup>3</sup> See Timilsina and Dulal (2008) for an in-depth discussion on fiscal policy instruments to reduce congestion and environmental pollution from urban transportation.

<sup>4</sup> Prices are expressed in US currency to facilitate comparison with other studies. To obtain values in local currency multiply by 5.6. To convert monetary values per gallon to per liter multiply by 0.26 and from per mile to per km multiply by 0.62.

<sup>5</sup> See Santos and Rojey (2004) for an extensive discussion of theory behind congestion tolls and experience with their implementation to date.

<sup>6</sup> See, for example, Anas and Timilsina (2009b), Anas et al. (2009), and Parry and Timilsina (2009) for applications to Sao Paulo, Beijing, and Mexico City, respectively.



Source. IEA (2008) and Parry and Strand (2010).

## 2. Conceptual Framework

This section briefly describes the assumptions underlying our model of passenger transportation for the GCMA, discusses the determination of optimal pricing policies implied by the model, and then comments on some limitations of the analysis.

### Model Description

We assume essentially the same analytical model as that in Parry and Timilsina (2010) that was developed to assess optimal prices for the Mexico City passenger transport system. This model provides a simplified representation of an urban passenger transportation system that is meant to capture, in a parsimonious way, the most important underlying determinants of optimal

transportation prices. The model is static and compares long run equilibrium outcomes to policy changes, after adjustments such as turnover of the vehicle fleet and incorporation of fuel-saving technologies.

In the model, households living in the GCMA choose how much to travel by automobile, (private) microbus, (public) bus, and (public) rail. Auto trips include those in private cars and taxis. Travel involves various monetary costs to households including transit fares, expenditures on automobile fuel, possible congestion tolls levied on auto travel, and the costs of vehicle ownership. Through a budget constraint, more spending on travel implies a tradeoff as households have less money for other goods. Travel by each mode also involves a time cost, which again involves a trade off as this reduces the amount of time people have available for other activities (work or time at home). Travel time per mile differs across mode, and reflects the inverse of the average travel speed for a transportation vehicle. The average occupancy of vehicles is taken as fixed and therefore passenger miles vary in proportion to changes in vehicle miles. Thus, for example, an increase in passenger demand for microbus travel is met by a proportionate increase in the supply of microbus vehicle miles.<sup>7</sup>

Households optimize over travel options to maximize their “utility”, or benefit, from passenger travel by different modes and from other consumption goods, subject to their budget and time constraints. This implies that, aggregated over the GCMA, autos will be driven up to the point where the private benefit to passengers from an extra mile, net of the time costs, equal fuel costs (expressed on a per mile basis) plus any mileage toll. In addition, travel by microbus, bus and rail will be undertaken until the benefit from an additional passenger mile (net of time costs) equals the fare per mile.

Automobiles and microbuses are taken to run on gasoline, while public buses run on compressed natural gas or diesel fuel.<sup>8</sup> In response to higher gasoline taxes, automobile and microbus fuel economy increases (over the long term) through a switch in demand towards vehicles that have greater fuel economy. Ownership or capital costs for these vehicles are greater because, for a given set of other vehicle characteristics, higher fuel economy requires the

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<sup>7</sup> Other travel modes, particularly walking, are implicit in the utility function. Their only role is to affect the price elasticity of demand for driving, microbus, and transit trips.

<sup>8</sup> In contrast in Western European countries, where fuel taxes (especially those in gasoline) are high by international standards, diesel vehicles, which are more fuel efficient than their gasoline counterparts, account for a substantial share of the passenger car fleet.



incorporation of fuel-saving technologies and the costs of these technologies are reflected in higher vehicle prices. Fuel economy is improved over the long run until the (lifetime) fuel saving benefits (valued at retail gasoline prices) equal the extra vehicle capital costs.<sup>9</sup>

For minibuses, public bus, and rail, the operating costs for these vehicles represent fuel costs, vehicle capital costs (which can be varied fairly easily in the medium term through fleet adjustments), manpower needed to drive and maintain vehicles, and possible tolls (for minibuses). Rail provision also involves fixed costs representing manpower needed to operate stations.<sup>10</sup> For automobiles, minibuses, and buses, operating costs are assumed to be proportional to vehicle miles, which is a reasonable approximation (Small and Verhoef 2007, pp. 65). For rail there are economies of scale (operating costs increase by less than in proportion to increases in vehicle miles) due to the fixed costs.

Road congestion, and hence travel time per mile by car and bus, increases with the total amount of cars, minibuses, and large buses relative to the capacity of the road network. An extra *vehicle* mile by a minibus or bus adds more to congestion than an extra car mile, as these vehicles take up more road space and stop frequently. The contribution of an extra vehicle mile by minibus or bus, relative to that from an extra vehicle mile by car, is known as its “passenger car equivalent”. However, because minibuses and buses have much higher passenger occupancy, the addition to congestion per extra *passenger* mile by these vehicles may be less than the additional congestion per extra passenger mile by car. Travel time per mile by rail is taken as constant—that is, additional trains can be run to accommodate policy-induced changes in demand for rail travel, without affecting the speed of other trains in the rail network.

Accident costs depend on the amount of miles driven by road vehicles. It is standard to assume that some of these costs (e.g., injury risks to drivers in single-vehicle crashes) are “internal” or taken into account by households when deciding how much to travel, while other costs (e.g., injury risks to pedestrians) are “external” and not taken into account. As in Parry and

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<sup>9</sup> The model does not account for the possibility that consumers undervalue fuel economy improvements due to myopia, imperfect information, or some other market failure. Optimal fuel taxes would be higher in the presence of such additional market failures (e.g., Parry et al. 2010). However, given the issue is highly unsettled in the empirical literature (e.g., Greene 2010) we abstract from the possibility of these market failures.

<sup>10</sup> Capital infrastructure costs for subways, namely tracks and stations, are excluded from transit agency costs. This is because we follow the usual practice of studying how best to price rail systems given existing infrastructure, without worrying about recovering previously sunk capital investments in current fares.

Small (2009) accident costs for rail are taken to be zero, since they are negligible when expressed on a per passenger mile basis, given the very high occupancy of trains with several cars.

CO<sub>2</sub> and local pollution emissions make households (as a group) worse off through future (global) climate change. CO<sub>2</sub> depends on combustion of gasoline in cars and minibuses, and combustion of diesel fuel and compressed natural gas in public buses.<sup>11</sup>

Local pollution emissions make households worse off through health risks, reduced visibility, and building corrosion. Local pollution is caused by fuel combustion in transport vehicles. For minibuses and buses local emissions are unregulated and are determined by fuel use.

For cars, it is a little tricky to judge the relationship between local emissions, vehicle use, and fuel economy. If auto emissions were unregulated, they would vary in proportion to fuel combustion, that is, long run, policy-induced, changes in fuel economy would affect emissions. At the other extreme, if all autos are subject to the same (binding) emissions per mile standards regardless of their fuel economy, and these emission rates are maintained throughout the vehicle life—that is, repairs are required if pollution control technologies deteriorate—then improvements in fuel economy would have no effect on emissions. Although many vehicles in the GCMA are imported from Europe, where they were subject to emissions per mile standards when first manufactured, typically these vehicles are second-hand when they enter the GCMA. Furthermore, inspection and maintenance programs in the GCMA are not comprehensively enforced implying that any emissions control technology may deteriorate as vehicles age. We therefore think it is reasonable to assume that local emissions vary in proportion to total fuel use (in this regard, our optimal fuel tax estimate could be biased upwards, but any bias is only moderate).

The government in the model is subject to a budget constraint equating spending with revenue from (possible) auto mileage tolls, fuel taxes, and transit fare revenues, less the

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<sup>11</sup> We follow the conventional practice of valuing CO<sub>2</sub> emissions damages for the world as a whole, rather than local impacts (which would be negligible in relative terms).

operating costs of (bus and rail) transit agencies. We assume excess revenues are simply rebated back to households or firms in a lump-sum fashion.<sup>12</sup>

### **Determinants of Optimal Transport Prices**

Here we describe the key factors, or parameters, that determine the optimal pricing policies in the above model. We do not provide the derivation of these formulas here, as they were previously derived in detail in Parry and Timilsina (2009).

*Optimal gasoline tax.* The optimal gasoline tax, in \$/gallon, has three components.

First is the damage (in monetary units) from local pollution emissions, and CO<sub>2</sub> emissions, from combusting an extra gallon of fuel.

Second is the contribution of externalities from traffic congestion and traffic accidents. The external cost of congestion per extra auto mile reflects the increase in travel time to all other road users, as a result of (slightly) greater road congestion, where this loss is converted into a monetary measure using people's valuation of travel time (for rich countries this has been estimated at about half the market wage rate). The external cost of traffic accidents per extra auto mile is the elevated risk to other road users, pedestrians, third parties who bear property damage costs, etc. due to the increased frequency of road accidents when there is more traffic (and less road space between vehicles). If toll per mile on automobiles is in place, this would need to be subtracted from the sum of these externalities, as the toll effectively causes drivers to take into account some of these broader costs when deciding how much to drive.

These external costs, which are estimated in \$/mile, can be converted into \$/gallon by multiplying by average automobile fuel economy (miles per gallon), though we need to take into account that fuel economy is endogenous and rises over the longer term as higher fuel taxes drive up fuel prices. In addition, these automobile costs are scaled back somewhat in computing the optimal fuel tax to account for fact that only a fraction of the tax-induced reduction in gasoline comes from the automobile sector, some comes from reduced use by minibuses. Finally, they are also scaled back because only a fraction of a given, tax-induced reduction in automobile

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<sup>12</sup> More generally, if revenues were used for government spending and the social value per \$1 of spending were greater/less than \$1, then optimal congestion tolls and fuel taxes would be (moderately) higher/lower than estimated below.

gasoline uses is due to reduced driving, some of it instead reflects improved automobile fuel economy.<sup>13</sup>

The final component of the optimal gasoline tax accounts for its effect on reducing the contribution of microbuses to congestion and accidents. As for automobiles, this will depend on how many microbus miles are reduced per gallon reduction in fuel use, which again depends on fuel economy and how much of the fuel reduction comes from reduced mileage as opposed to fuel economy increases.

In assessing optimal fuel and other transportation prices, we ignore some effects of policies on other transport modes which play a very minor role (as demonstrated in Parry and Timilsina 2009). For example, higher gasoline prices will cause some people to shift from cars to public buses, with a resultant increase in congestion, pollution, and accident risk from additional bus mileage. However, this offsetting effect on road transport externalities is very small relative to the reduction in external costs from autos and microbus.

*Optimal mileage toll for autos.* There are three main determinants of the optimal mileage toll for automobiles.

First is the external cost from auto congestion and accidents, as just described, expressed per auto mile.

Second is the reduction in local and global pollution damages per unit reduction in automobile vehicle miles. These damages would be defined net of any prevailing gasoline tax, as that tax serves to raise fuel prices and effectively induce people to consider broader societal costs when making choices that affect fuel consumption. In fact, the opposite occurs at present, given that fuel is currently subsidized in the GCMA, that is, there is a larger gain associated with reductions in fuel use induced by the toll.

On the other hand, the optimal auto toll is lower to the extent this encourages a switch from autos to microbuses as, in turn, this increases congestion, accidents, and pollution associated with those vehicles.

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<sup>13</sup> In fact, if all of the automobile fuel reduction came from improved fuel economy and none from reduced automobile mileage, there would be no congestion and other benefits from mileage-related automobile externalities in the optimal gasoline tax formula.

*Optimum toll for microbus.* The components of the optimal toll for microbuses are analogous to those for the optimal auto toll. That is, the optimal toll depends on the reduced congestion and accident externalities from a unit reduction in microbus vehicle miles, the reduction in local and global pollution damages, and any increase in externalities due to people switching to cars.

*Optimum public bus fare.* The optimal fare, this time expressed per *passenger*-mile for public bus consists of three main components.

First is the cost to bus companies of accommodating an extra passenger mile through increased service, including the (variable) capital, labor, and fuel costs incurred in operating buses. This unit cost is lower the higher is the average passenger occupancy of buses. The second component is the external cost of public bus travel, expressed on a per passenger mile basis. This captures the contribution of additional bus travel (needed to supply more passengers) to road congestion, roadway accident risk, and local pollution emissions from diesel fuel combustion. Finally, there is a downward adjustment to account for the costs of diverting people from buses to cars in response to higher transit fares.

*Optimum rail fare.* The formula for the optimal rail fare per passenger mile is essentially analogous to that for the optimal bus fare. The optimum rail fare is below the cost to the transit agency of accommodating an extra passenger mile on the rail system to the extent this would lead to an increase in automobile externalities.

*Fully optimized transport pricing.* The main difference between the auto and microbus mileage tolls and the gasoline tax is that the mileage tolls target the congestion and accident externalities more directly. This is because all of the behavioral responses to the taxes come from reduced mileage (rather than part of the response coming from improved fuel economy). In contrast, the fuel tax targets the fuel-related externalities more directly as (unlike the mileage tolls) it exploits fuel savings from improved fuel economy. If all these taxes are optimized simultaneously, then each is set equal to the relevant external cost—the gasoline tax equal to the external cost per

gallon of fuel, the auto mileage toll equal to the congestion and accident externalities per vehicle mile, etc. Given this, optimal transit fares would equal the marginal costs of supplying passenger miles, accounting for any externalities from transit vehicles themselves.

### **Some Model Limitations**

While providing a reasonable first-pass understanding of optimal transportation pricing, our analysis is nonetheless simplified in three notable respects.

First, we do not consider policies that vary either by region within the GCMA or by peak versus off-peak travel. Partly, this is because the data required to do this disaggregation, namely sub-region or time-of-day specific congestion costs and the degree of traveler substitution between sub-regions and time of day, are not available. Furthermore, it is still useful to begin with a simple and transparent analysis to fully understand the aggregate impacts of major pricing reform options before studying more refined policies that vary by region and time of day. Moreover, this would require a more detailed, data-intensive transportation network model that is less transparent than our more simplified analysis.

Second, our analysis omits scale economies from expanding transit provision (aside from those arising from fixed costs in the rail system), that is reductions in the average cost to users of transit in larger transit systems. One additional scale economy is the shorter waiting time at transit stops for passengers when there is more frequent rail and bus service. Another is the reduced time costs to people of getting to a transit stop in a larger system with a denser network of bus and rail routes. On the other hand, scale economies can be counteracted by a diseconomy if the occupancy rate of buses and trains rises in a larger system, imposing crowding costs on passengers, and increased delays at transit stops. We lack reliable data to credibly estimate the net impact of these scale economies and diseconomies. Most likely however, accounting for them would imply somewhat lower transit fares than estimated here (Parry and Small 2009).

A final caveat is that we do not analyze the distributional effects of pricing reforms.

### 3. Data and Parameters

While data is available for basic characteristics of the transportation system in the GCMA (e.g., mileage by travel mode and fuel use), it is not directly available for external costs (e.g., pollution and congestion). Therefore, we need to extrapolate evidence from other countries, and make a number of judgment calls. Our benchmark results below should not therefore be taken too literally—instead they should be viewed as a preliminary attempt at obtaining plausible parameters, which can be refined with further study.<sup>14</sup>

Nonetheless, we believe our benchmark results still provide some plausible broad brush sense of optimal transportation pricing and the appropriate direction of pricing reforms. Many assumptions used to assess parameter values may seem somewhat arbitrary, but they have only relatively minor implications for the optimal pricing estimates.

Parameter values are for year 2006 or thereabouts and are summarized in Table 1.<sup>15</sup> All parameters are expressed in US currency and can be converted into Egypt pounds using an exchange rate of USD 1 = EGP 5.2. Below we briefly discuss the parameter assumptions in our benchmark case. An extensive documentation of data sources and computation of parameter values are provided in the appendix.

*Mileage and Fuel Economy.* The average person in the GCMA travels approximately 1,344 miles by vehicle per year. Of these passenger miles, approximately 26 percent are by car (or taxi), 33 percent by microbus, 31 percent by public bus, and 10 percent by rail. Modal shares for vehicle miles travelled, on the other hand, are very different from those for passenger miles. Autos account for 77 percent of vehicle miles, minibuses 17 percent, large buses 5 percent, and rail less than 1 percent. The difference between modal shares by passenger and vehicle miles is easily explained by the dramatically different vehicle occupancy rates, which vary from 2.5

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<sup>14</sup> The spreadsheet calculations that map parameter values into the optimal pricing estimates are available upon request.

<sup>15</sup> Ideally, optimal fuel taxes for some future year, say 2020, rather than a previous year, would be computed. This could be done but would require various parameter updates—for example, pollution damages should be adjusted for growth in income (which affects the valuation of health risks), while congestion costs should be updated for traffic growth and increases in wages (which affect the value of travel time).

people for cars, 14 people for microbus, 45 people for public bus, to 174 people by rail (given that a train pulls several cars).

**Table 1. Selected Parameter Assumptions Used in the Benchmark Simulations**  
(for year 2006 or thereabouts)

	Mileage parameters				Total or average
	Auto	Microbus	Bus	Rail	
Annual passenger miles per capita	353	444	418	130	1,344
Annual vehicle miles per capita	141	32	9	1	183
Average vehicle occupancy	2.5	14	45	174	7.3
Vehicle miles per gallon	19.0	7.8	3.5	na	16.3
Passenger miles per gallon	48	110	160	na	109
Average vehicle speed, miles per hour	14.0	10.1	9.5	na	na
Average travel time cost, cents per passenger mile	5.5	7.7	8.1	na	na
Current fares, cents per passenger mile	na	1.5	0.8	0.9	na
Marginal operating cost, cents per passenger mile	na	1.5	2.6	1.8	na
<i>Marginal external costs</i>					
Cents per vehicle mile					
Congestion	9.7	29.2	48.7	0	15.1
Accidents	8.7	8.7	8.7	8.7	8.7
Local pollution and global pollution (converted to cents per vehicle mile)	4.2	10.3	0.3	0	0
Total	22.7	48.2	57.6	8.7	23.8
Cents per passenger mile--total	9.1	3.4	1.3	0	3.2
<i>Gasoline parameters</i>					
Fuel use, gallons per capita	11.5				
Current fuel subsidy, \$/gal.	1.20				
Retail price of fuel, \$/gal.	1.60				
<i>External cost per gallon</i>					
Local pollution costs attributable to gasoline, cents per gallon	72				
Global pollution, cents per gallon	9				
total	81				
<i>Own-price fuel elasticity</i>					
fraction of elasticity due to changes in auto and microbus miles	0.5				
<i>Mileage elasticities</i>					
own mileage elasticity wrt own fuel price or fare	-0.25				
<i>Behavioral response coefficients</i>					
Reduction in auto vehicle miles per tax-induced gallon reduction in gasoline	6.2				
Reduction in microbus vehicle miles per tax-induced gallon reduction in gasoline	1.4				
Increase in microbus vehicle miles per toll-induced reduction in auto vehicle miles	0.06				
Increase in auto vehicle miles per toll-induced reduction in microbus vehicle miles	1.8				
Increase in auto vehicle miles per fare-induced reduction in public bus passenger mi	0.12				
Increase in auto vehicle miles per fare-induced reduction in rail passenger miles	0.09				

Source. See text and appendix.



Fuel economy also differs a lot across road vehicles. Autos average 19.0 vehicle miles per gallon, minibuses 7.8 miles per gallon, and large buses 3.5 miles per gallon. On a per passenger mile basis, fuel economy rankings are reversed, due to differences in occupancy rates. A gallon of fuel produces 47.6 passenger miles in a car, 109.8 passenger miles in a microbus, and 159.7 passenger miles in a public bus. Due to its relatively high fuel consumption rate, microbus still accounts for 35 percent of gasoline use—autos account for the other 65 percent—even though microbus vehicle miles are 23 percent of those for autos.

*Pollution costs.* There is general agreement among analysts that local pollution damages are overwhelmingly dominated by mortality effects (e.g., Pope et al. 2004, 2006). However, we are unaware of any local study of pollution costs from the transportation sector in the GCMA. Therefore, local pollution costs for the GCMA were extrapolated from damage estimates for Mexico City (where natural conditions also favor pollution formation).

As discussed in the appendix, we adjusted the pollution damage estimate for Mexico City upwards to account for greater population density (and therefore greater exposure to a given volume of polluted air) in the GCMA. And the estimate was adjusted downwards to account for the lower per capita income in Cairo and therefore, presumably, the lower willingness of people in Cairo to pay for reductions in health risks. Automobile emission rates are assumed to be the same in both urban centers. The end result is a local pollution cost of 72 cents per gallon, though this is a very crude estimate given the lack of local evidence on pollution/health effects and people's willingness to pay for risk reductions. For public bus, the external cost is 0.3 cents per passenger mile (costs are expressed on a per mile basis for this case, given that we do not consider taxes on fuel inputs for public buses).

For global pollution we adopt a value of \$10 per ton of CO<sub>2</sub> emissions. This is approximately a lower bound estimate from studies that attempt quantify the discounted value of future worldwide damages from global warming. Given the carbon content of fuels, this implies a further damage of 9 cents per gallon of gasoline combustion and 11 cents per gallon for diesel fuel.

*Congestion.* Marginal congestion costs depend on the added delay to all other road users caused by the additional congestion from an extra vehicle mile, as well as how people value travel time. We employ a widely used function relating travel time to traffic volume in order to obtain marginal delay (see the appendix). The value of travel time is assumed to equal one-half the average gross hourly wage in Cairo, based on US studies of the wage/value of time relationship. This might be viewed as a conservative estimate to the extent that car ownership and use among Cairo residents is concentrated among people with higher than average wage rates.

Overall, the marginal congestion cost for autos is 9.7 cents per *vehicle* mile. We assume the “passenger car equivalent” for a microbus and a public bus vehicle mile are 3 and 5 respectively. Thus, marginal congestion costs for microbuses and buses are 29.2 and 48.7 cents per *vehicle* mile respectively. However, the ranking of marginal congestion costs reverses when expressed on a per passenger mile basis, due to the high occupancy rates of buses. Marginal costs are 2.1 and 1.1 cents per extra passenger mile by microbus and public bus respectively, compared with 3.9 cents per passenger mile for autos.

*Accidents.* External accident costs are driven primarily by fatality risks to pedestrians and cyclists (fatality risk to vehicle occupants is assumed to be internal, though there is some dispute about to what extent risks from multi-vehicle collisions are internal or external). Fatality risks are valued in the same way as pollution/health risks. Based on studies for other countries, other external costs from traffic accidents (e.g., non-fatal injury risk, third party property and medical burdens) are assumed to be 12 percent of those from fatality risk. Overall, external costs are 8.7 cents per vehicle mile for autos—for reasons noted in the appendix costs per vehicle mile are taken to be the same for buses. On a per passenger mile basis, external accident costs are 3.5 cents for autos, 0.6 cents for microbus, and 0.2 cents for public bus.

*Prices and operating costs.* Gasoline is heavily subsidized in the GCMA. As of 2009, the fuel subsidy amounted to \$1.20 per gallon, leaving a retail price of \$1.60 per gallon (compared with a supply cost of \$2.80 per gallon).

The public transit system is also heavily subsidized, as is common in many countries (Kenworthy and Laube 2001). Current fare for public bus average 0.8 cents per passenger mile, only 31 percent of the operating costs per mile to the transit agency. Rail fares are subsidized at 50 percent.

*Behavioral Response Parameters.* Based largely on US evidence, and limited evidence for other countries, we assume the gasoline demand elasticity is -0.5, with reduced vehicle miles of travel and long run improvements in fuel economy each responsible for half of the elasticity. With per mile tolls expressed relative to fuel costs per mile, the own price mileage elasticity for autos and microbus is -0.25. The fuel and mileage price elasticities affect the impact, and net benefit, of pricing reforms though they do not affect optimal transport prices, which depend largely on externalities. However, assumptions about the portion of the long run gasoline demand elasticity that is due to reductions in mileage affect the contribution of mileage-related externalities to the optimal fuel tax.

We assume that 80 percent of the reduction in passenger miles in response to one mode becoming more costly will be diverted onto other travel modes in proportion to their share in total passenger miles (excluding the mode whose price is increased). Taking account of vehicle occupancy rates this means, for example, that microbus vehicle miles increase by 0.06 per unit reduction in auto vehicle miles in response to the auto toll, while auto vehicle miles increase by 1.8 per unit reduction in microbus vehicle miles in response to a microbus toll.

#### **4. Results**

We take each pricing policy option in turn and discuss its optimal level. Fully optimized transportation prices are then discussed. Finally, we briefly comment on how the main results are affected by alternative assumptions about key parameter assumptions.

Yet again we emphasize the tentative nature of the optimal pricing results given the large number of assumptions underlying the parameter values. Another reason to be cautious of these results is that optimal prices are, in some cases, very different from current prices. It is difficult to judge whether parameters that may seem reasonable for the current transportation system will

still be reasonable with a very different price structure—for example, the diversion between public transit and auto is more difficult to project in a situation with much higher fuel prices. Nonetheless, we can have more confidence in the *direction* of pricing reforms suggested by the results. Moreover, we emphasize that partial pricing reforms typically achieve a large portion of the estimated net benefits from full price reform.

## **Gasoline Tax**

Table 2 summarizes determinants of the optimal gasoline tax and the effects of fuel price reform. The optimal tax is \$2.21 per gallon (in years 2006\$), implying a considerable \$3.41 per gallon difference in the optimal retail fuel price compared with the current price (which is subsidized at \$1.20 per gallon). The optimal tax is \$0.51 per gallon smaller than computed for Mexico City by Parry and Timilsina (2010).

Local pollution damages account for 72 cents, or about a third, of the optimal tax. This is in the same ballpark as estimated for Mexico City by Parry and Timilsina (2010). Although per capita income is lower in the GCMA than in Mexico City, implying a lower willingness to pay for reductions in pollution-health risks, a greater number of people are exposed to a given amount of pollution in the GCMA due to its much higher population density.

Global warming damages play a more minor role (relative to local pollution), accounting for 9 cents per gallon, or 4 percent, of the optimal tax. This is simply a reflection of the assumed social cost of carbon dioxide, \$10 per ton, and the emissions produced per gallon of fuel combustion, 0.009 tons. The social cost of carbon dioxide is highly contentious and many analysts would recommend a higher value than used here, implying a significantly greater optimal fuel tax.

Perhaps surprisingly, automobile congestion contributes “only” 32 cents per gallon, or 14.3 percent, to the optimal tax. Note that marginal congestion costs actually fall substantially, from 9.7 cents per auto-vehicle mile at current prices to 3.8 cents per mile, as the quantity of automobile and microbus traffic falls, by about a quarter, as a result of higher fuel prices. Congestion costs play a smaller role in the optimal fuel computed here than in Parry and

Timilsina's (2010) assessment for Mexico City, partly because the wage rate in Cairo, and hence the value people attach to lost time from congestion, is only 40 percent of that in Mexico City.

Traffic accidents are as important as local pollution—they contribute 71 cents per gallon to the optimal fuel tax. This reflects the relatively high rate of fatalities caused by cars and minibuses, given the relatively high ratio of pedestrian to vehicle traffic in Cairo.

Finally, reduced congestion and accident risk from minibuses together contribute 37 cents per gallon (or 17 percent) to the optimal tax or about a third of the amount from the corresponding reduction in automobile externalities. The main reason for this is that, per gallon of fuel reduced, there is a much larger reduction in auto miles than minibus miles, given that autos have a much higher fuel economy.

**Table 2. Optimal Gasoline Tax**  
(in year 2006\$)

Components	Optimal tax \$/gallon	Contribution to optimal tax (%)
Local pollution from autos and minibuses	0.72	32.6
Global pollution	0.09	4.0
Congestion for autos	0.32	14.3
Accidents for autos	0.71	32.2
Congestion/accidents for minibus	0.37	16.8
<b>Total</b>	<b>2.21</b>	<b>100.0</b>
<b>Effects of optimal gasoline tax</b>		
% reduction in gasoline use	43.5	
% reduction in auto and minibus miles	24.8	
auto fuel economy, mpg	25.3	
net benefit, \$ per capita	10.8	
<b>Elimination of fuel subsidy</b>		
% reduction in gasoline use	24.4	
% reduction in auto and minibus miles	13.1	
auto fuel economy, mpg	21.9	
net benefit, \$ per capita	8.0	

Under our assumptions, removing the current fuel subsidy and imposing the optimized fuel tax would reduce gasoline use by 43.5 percent, reduce auto and microbus mileage by about 25 percent, and increase long run auto fuel economy from 19.0 to 25.3 percent. Estimated net benefits of this policy reform would be \$10.8 per capita, or 6.2 cents for each vehicle mile currently driven by car and microbus.

In sum, the current pricing system for gasoline in the GCMA appears to impose a large cost to society as a whole relative to the price that would address externalities associated with use of automobiles and microbuses. The purpose of this analysis is not to recommend a gasoline tax level for the government to implement however, as there are other criteria relevant to this decision that are beyond our scope, such as feasibility and distributional implications. It is highly unlikely that the government would consider such a radical price change as suggested by the above calculations.

A more relevant question from policy perspective might be the implications of less dramatic reforms, like the removal of existing subsidies. In this regard, our analysis suggests that elimination of current gasoline subsidy would cut gasoline demand by about 24 percent and vehicle miles by auto and microbuses by about 13 percent (see Table 2). More interestingly, the net benefit from the elimination of gasoline subsidy is \$8.0 per capita, or 74 percent of the net benefit from implementing the optimized gasoline tax. This follows because the net benefits from successive increases in the fuel tax diminish as the tax approaches its optimal level.

### **Auto Mileage Toll**

Table 3 summarizes results for the optimal toll on automobiles, taking the existing fuel subsidy as given. The fully optimized toll amounts to 21.9 cents per vehicle mile, which would be equivalent, when converted at current automobile miles per gallon, to \$4.18 per gallon.

**Table 3. Optimum Mileage Toll for Autos**  
(in year 2006\$)

Components of tax	Optimal toll cents/vehicle-mi	Optimal gasoline tax equivalent \$/gallon	Contribution to optimal tax %
Local and global pollution from autos (with fuel subsidy)	10.5	2.01	48.0
Congestion for autos	6.1	1.16	27.8
Accidents for autos	8.7	1.65	39.5
Congestion, accidents, and pollution for microbus	-3.4	-0.64	-15.3
<b>Total</b>	<b>21.9</b>	<b>4.18</b>	<b>100.0</b>
<b>Effects of optimal mileage tax</b>			
% reduction in auto miles	27.4		
net benefit, \$ per capita	4.3		
<b>Effect of 5 cent toll per vehicle mile</b>			
% reduction in auto miles	11.0		
net benefit, \$ per capita	3.0		

Local and global pollution from autos contribute most to the optimal toll at 10.5 cents per mile, but note that these externalities are defined with the existing fuel subsidy in place. This greatly magnifies (by 150 percent) the economic efficiency gain from reducing fuel use, given that the subsidy implies a large gap between the costs of additional fuel production and the private benefits to vehicle users. If there were no fuel subsidy, the optimal auto toll would fall to 17.5 cents per mile, with pollution contributing 4.2 cents.

Accident externalities are the next largest factor, contributing 8.7 cents per vehicle mile, or 39.5 percent, to the optimal toll. Congestion contributes 6.1 cents per mile to the optimal toll—again this accounts for the falling marginal congestion costs as tolls deter people from driving. There is a downward adjustment to the optimal toll of 4.4 cents per mile to account for the diversion of people from automobiles onto microbus, which exacerbates pollution, congestion, and accident externalities from those vehicles.

Implementing the optimal toll leads to a large reduction in auto mileage of just over 27.4 percent, moderately higher than under the optimal fuel tax. However, overall road traffic (with minibuses and public buses expressed in terms of their passenger car equivalents) falls by 11 percent under the optimal auto toll and much more, 21 percent, under the fuel tax, which also reduces uses of minibuses. And gasoline use (and hence local and global emissions) falls 25 percent under the optimized auto toll, compared with 43 percent under the optimized fuel tax. The net benefit under the optimal auto toll is \$4.3 per capita. This is considerably smaller than the net benefit from optimizing fuel taxes. One reason is that the auto toll results in an increase, rather than a decrease, in microbus travel. Another is that there are large gains in economic efficiency from eliminating, and then reversing, the fuel subsidy.

Again, a large portion of the net benefit from full price reform could be obtained from a far more moderate policy. For example, an auto toll of 5 cents per vehicle mile reduces auto mileage by 11.0 percent and generates a net benefit of \$3.0 per capita, or 70 percent of that from the optimized toll.

### **Microbus Mileage Toll**

Table 4 summarizes results for the microbus toll. In this case the optimal toll is 7.9 cents per vehicle mile. This is 28 percent smaller than the optimal auto toll. The difference between these two optimized policies is greater still, by far, when expressed on a per passenger mile basis, given their very different vehicle occupancies. In this case the optimal auto toll is 4.4 cents per passenger mile, while that for the microbus is 0.6 cents per passenger mile.



**Table 4. Optimum Mileage Toll for Microbus**  
(in year 2006\$)

Components of tax	Optimal toll cents/vehicle-mi	Optimal gasoline tax equivalent \$/gallon	Contribution to optimal tax %
Local and global pollution from microbus (with fuel subsidy	10.5	0.82	131.8
Congestion for microbus	28.0	2.19	352.6
Accidents for microbus	8.7	0.68	109.4
Congestion, accidents, and pollution for automobiles	-39.2	-3.07	-493.8
<b>Total</b>	<b>7.9</b>	<b>0.62</b>	<b>100.0</b>
<b>Effects of optimal mileage tax</b>			
% reduction in microbus miles	7.9		
net benefit, \$ per capita	0.1		

On a per vehicle mile basis, congestion contributes a lot more to the optimal toll for microbus (28.0 cents). This is because of the higher passenger car microbuses equivalent for microbuses and the much smaller impact of the policy on reducing overall road traffic and hence lowering marginal congestion costs. On the other hand, there is a very large downward adjustment to the optimal microbus toll (39.2 cents per vehicle mile) due to the diversion of passengers onto auto. This reflects the much higher external costs associated with an extra passenger mile by car (9.1 cents) compared with a microbus (3.4 cents).

### **Optimal Transit Fares**

Table 5 presents our calculations of optimal transit fares (given existing fuel prices). Here in particular we caution that the estimates are extremely crude, not least because our analysis omits economies of scale, which are one of the key rationales for transit fare subsidies. The main point here is that, unlike for auto and microbus, current prices for public bus and rail do not appear to be too far out of line compared with optimal prices. Given our model assumptions, efficient transit fares are below marginal operating costs per mile because lower fares entice

people away from automobiles and microbus and hence, indirectly and albeit moderately, they reduce externalities from those vehicles. In this sense, and given the existing pricing structure for automobiles, the current practice of subsidizing transit fares is, directionally at least, correct.

**Table 5. Fares for Public Bus and Rail**  
(in year 2006\$)

	cents per passenger mile	
	Public bus	Rail
<b>Components of optimum fare, cents per passenger mile</b>		
Marginal operating cost	2.6	1.8
Congestion, accident and pollution	1.3	0.0
Increase in auto congestion	-1.2	-0.9
Increase in auto accidents	-1.1	-0.8
Increase in auto pollution (including effect of fuel subsidic	-1.0	-1.0
<b>Total</b>	<b>1.6</b>	<b>0.1</b>
Difference compared with current fare	0.8	-0.8

### Fully Optimized Transportation Prices

Finally, Table 6 summarizes the fully optimized set of transportation prices for each mode and fuel. In this case, the optimal fuel tax is 81 cents per gallon. This is much lower than in Table 2 because in this case the fuel tax addresses only the pollution externalities from fuel combustion. Congestion and accident externalities from autos and microbuses are addresses through tolls per vehicle mile, 12.1 cents for autos and 18.9 cents for microbus. Again, these tolls reflect the much lower marginal costs of traffic congestion at the reduced traffic levels at the optimized prices. Finally, the case for subsidizing public transit fares is eliminated (in our model with no scale economies) when externalities from autos and microbus are fully internalized through other policies. Intermediate cases (i.e., when some subsidy is warranted but not as large as that in Table 5) would apply to cases where fuel subsidies are removed (but no fuel excise tax is imposed) or when the fuel tax is optimized but there is no mileage toll.

**Table 6. Fully Optimized Transportation Prices**  
(in year 2006\$)

Gasoline tax, \$/gallon	0.81
Auto mileage toll, cents/vehicle mile	12.1
Microbus toll, cents/vehicle mile	18.9
Public bus fare, cents/passenger mile	3.8
Rail fare, cents/passenger mile	1.8

## 5. Conclusion and Further Remarks

This study analyzes pricing instruments that could reduce externalities from urban transportation in the Greater Cairo Metropolitan Region using a simple analytical and simulation model. The key demand side instruments focused in the study are gasoline taxes, vehicle mileage tolls for automobiles and microbuses, and price reforms in public transit. The externalities considered in the study are from local air pollution, global warming, road accidents and traffic congestion.

The optimal tax is \$2.21 per gallon, implying a considerable \$3.41 per gallon difference in the optimal retail fuel price compared with the current price (which is subsidized at \$1.20 per gallon). Implementing this optimal tax would reduce gasoline use in the order of 40%.

If an optimal toll on automobiles could be introduced, without imposing a gasoline tax or altering the current fuel subsidy system, it would amount to 21.9 cents per vehicle mile, which would be equivalent to \$4.18 per gallon of gasoline. It would cause higher reduction of auto mileage as compared to the optimal gasoline tax. However, the reduction in overall road traffic (including microbuses and public buses) would be just half of under the fuel tax case.

Implementing mileage tolls is highly challenging at present—the optimal toll analysis presented here is really to provide a metric for the size of congestion and accident externalities, rather than as a guide to actual policy.

One interesting caveat of the study is that even a small level of fuel tax or vehicle toll, could reduce transportation externalities significantly. For example, an auto toll of 5 cents per vehicle mile reduces auto mileage by 11% and generates a net social benefit of \$3.0 per capita, or 70% of that from the optimized toll. Ideally, a portfolio of pricing reforms would be implemented. According to illustrative calculations this would involve a fuel tax of 81 cents per gallon and a per vehicle-mile tolls of 12.1 cents and 18.9 cents for autos and microbuses, respectively.

The study also shows that, unlike for auto and microbus, current prices for public bus and rail do not appear to be too far out of line compared with optimal prices. Efficient transit fares are below marginal operating costs per mile because lower fares entice people away from automobiles and microbus and hence, indirectly and albeit moderately, they reduce externalities from those vehicles which are currently under-taxed. In this sense, and given the existing pricing structure for automobiles, the current practice of subsidizing transit is correct. Although our estimates are rudimentary, this finding is conservative in that we omit economies of scale, which are another key rationale for transit fare subsidies.

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## Appendix. Details on Parameter Calculations and Data Sources

*Mileage.* We consider four modes of passenger transportation in the GCMA: auto (including taxi), private microbus, public bus, and rail. Other modes like minibuses and the Haliopolis tram account for a very small share of passenger mileage and are excluded from our analysis.

According to IAPT (2007) the average person in the GCMA travelled 1,344 miles in 2002, where modal shares were auto (28.1 percent), microbus (32.2 percent), public bus (30.0 percent) and rail (9.7 percent).

We were also able to calculate modal shares for non-rail travel for 2005 based on estimates of the number of vehicles, average daily trips per vehicle, average trip length, and average vehicle occupancy obtained by pooling data from Central Statistical Office ('CAPMAS'), Cairo Transportation Authority, and the Ministry of Finance<sup>16</sup>. Assuming the same share for rail travel as in 2002, this alternative data suggests modal shares for auto (24.4 percent), microbus (33.8 percent), and public bus (32.1 percent). In Table 1, we split the difference between these two estimates, assuming the same overall per capita mileage as in IAPT (2007). The resulting modal shares are also consistent with figures in NKCL and KEI (2008). Vehicle mileage data were estimated using average daily trip per vehicle and average trip length. These information together vehicle occupancy were obtained from NKCL and KEI (2008) and personal communication with Cairo Transportation Authority.

*Fuel economy.* Fuel economy for different vehicle types was taken from the IAPT (2007) database.

*Fuel prices.* The gasoline price and subsidy were obtained from the Ministry of Finance (Personal Communication, April 2010), averaging over octane 80 and 90.

*Transit fares and operating costs.* Personal communication with Cairo Transport Authority.

*Local pollution damages.* We are unaware of any local study of pollution damages from road vehicles in Cairo. We therefore extrapolate damage estimates from Mexico City where, like Cairo, natural factors are especially conducive to pollution formation.

Parry and Timilsina (2010) assumed a pollution damage estimate of 90 cents per gallon of gasoline (in year 2005 dollars) for the Mexico City metropolitan area. This was based on pooling evidence from a local study and an estimate they extrapolated from Los Angeles, after making some

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<sup>16</sup> Most of these data were obtained through personal communication with various officials of these organizations.



adjustments for local factors.<sup>17</sup> We considered three possible adjustments to transfer the Mexico City damage estimate to the GCMA.

First, we double the damage estimate because Cairo has a population density about double that of Mexico City. The GCMA has a population of 17 million living in an area of about 1,660 square miles (Nippon Koei 2010). The greater Mexico City metropolitan region has a population of 19 million in an area of 3,691 square miles.

Second, we made some adjustment for differences in people's valuation of pollution-health risks. These risks are quantified using the value of a statistical life (VSL), which measures people's willingness to pay for reduced mortality risk, expressed per life saved. Parry and Timilsina (2010) implicitly assume a VSL for Mexico City of about \$1.5 million—about one-fourth of that assumed for the United States by its Environmental Protection Agency and Department of Transportation. The VSL is commonly transferred among countries using their relative real per capita income, raised to the power of the income elasticity of the VSL (e.g., Cifuentes et al. 2005, 40-41). Typical estimates for this elasticity vary between about 0.5 and 1.0 (e.g., Viscusi and Aldy 2003, Miller 2000). Real per capita income in Egypt is approximately 40 percent of that in Mexico, where income is measured in terms of purchasing power parity equivalent (IMF 2009, World Bank 2008). Therefore, this range of elasticities suggests the VSL for Egypt should be about 40-60 percent of that in Mexico. We lean on the conservative side by assuming the VSL for Egypt is \$600,000 (or about one-tenth of that for the United States). Thus, we scale back the local damage estimate by 60 percent.

Third, we did not make any adjustment for differences in automobile emissions rates. Our estimates of average miles per gallon for autos and minibuses in the GCMA are almost the same as those for Mexico City in Parry and Timilsina (2010). It is possible that vehicle emissions control equipment, for a given level of fuel economy, differs between the two cities, but we lack the data to reliably estimate the direction, let alone the magnitude, of any difference.

The net impact of the above adjustments is therefore a local pollution damage of 72 cents per gallon of gasoline. Following Parry and Small (2009), for public buses we assume local pollution costs per vehicle mile are three times those for auto.

*Marginal global pollution damages.* Most estimates of the discounted (worldwide) damages from future global warming are in the order of about \$10-\$30 per ton of CO<sub>2</sub>, though studies using below market

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<sup>17</sup> Their estimate is also broadly in line with local pollution damage estimates for Mexico City in World Bank (2002) and also for Santiago discussed in Parry and Strand (2010).

discount rates (based on intergenerational ethical arguments) obtain damages as high as \$85 per ton or more (e.g., Aldy et al. 2010, Newbold et al. 2009, Tol 2009, IWG 2010). Especially contentious is the treatment of extreme catastrophic risks due to the possibility of unstable feedback mechanisms that might cause a runaway warming effect, for example, due to warming-induced releases of underground methane, itself a greenhouse gas. In theory, these risks could imply damages per ton that are arbitrarily large in expectation (Weitzman 2009). However, this consideration does not provide specific guidance on an appropriate value for the social cost of CO<sub>2</sub>. To be conservative, we adopt a benchmark value of \$10 per ton which is an approximate lower bound estimate from the literature.

A gallon of gasoline and a gallon of diesel produce about 0.009 and 0.0011 tons of CO<sub>2</sub> respectively.<sup>18</sup> Thus, our benchmark damage assumption amounts to 9 cents per gallon of gasoline and 22 cents per gallon for diesel.

*Passenger car equivalents.* We adopt the same value for the passenger car equivalent for an extra vehicle mile by a public bus as assumed for London by Parry and Small (2009), namely 5. For minibuses, which have a size about half way between that of a car and a public bus, we assume a passenger car equivalent of 3.

*Marginal congestion costs.* Marginal congestion costs depend on the added to delay to other road users caused by an extra vehicle mile and how motorists value travel time.

We begin with the following commonly used functional form relating travel delay per automobile mile ( $T^A$ ) to road traffic volume ( $V$ ), where the latter includes microbus and bus vehicle miles in passenger car equivalents:

$$(A1) \quad T^A = T_f^A \{1 + \alpha V^\theta\}$$

$\alpha$  and  $\theta$  are parameters and  $T_f^A$  is the time per auto mile when traffic is free flowing. A typical value for the exponent  $\theta$  is 2.5–5.0 for urban centers (Small 1992, pp. 70–71). We assume  $\theta = 4$ , the same assumption as in the Bureau of Public Roads formula, which is widely used in traffic engineering models.

The average delay due to congestion—that is the addition to travel time per mile over time per mile at free flow speeds—is  $T^A - T_f^A = T_f^A \alpha V^\theta$ . From differentiating (A1) with respect to  $V$ , the

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<sup>18</sup> The carbon content of these fuels is from [http://bioenergy.ornl.gov/papers/misc/energy\\_conv.html](http://bioenergy.ornl.gov/papers/misc/energy_conv.html)). One ton of carbon produces 3.67 tons of CO<sub>2</sub>.

marginal delay caused by one extra vehicle is  $\theta T_f^A \alpha V^{\theta-1}$ . Multiplying by  $V$  gives the added delay aggregated over all road mileage. Thus, we can see that the marginal delay is a constant multiple ( $\theta = 4$ ) of the average delay.

We assume a free flow travel speed of 25 miles per hour for cars, which implies a free flow time per mile ( $T_f^A$ ) of 2.4 minutes (Parry and Strand 2010 estimate a free flow speed of 28 miles per hour based on simulating a model of the Santiago road network). And based on averaging over estimates for average auto travel speeds from IAPT (2007), 12.4 miles per hour, and for the representative 6<sup>th</sup> of October road, 15.5 miles per hour, we assume the current auto speed (averaged across the GCMA and time of day) is 14 miles per hour, implying a time per mile ( $T^A$ ) of 4.3. Thus, the average delay is 1.9 minutes per mile and the marginal delay is 7.5 minutes per mile, or 0.13 hours per mile.

The gross hourly wage rate for Cairo is taken to be \$1.55 (IMF 2007). Following US studies (e.g. see the review in Small and Verhoef 2007) we assume the value of travel time is one-half the wage rate, or \$0.78 per hour. Multiplying by the marginal delay per mile gives a marginal congestion cost for autos of 9.7 cents per vehicle mile. Marginal congestion costs for other vehicles are obtained by scaling up according to their passenger car equivalents.

*Accidents.* According to police-reported data, there were 730 road deaths in Cairo in 2006 (CAPMAS 2010).<sup>19</sup> Given the breakdown between pedestrian/cyclist versus vehicle occupant deaths is unavailable, we use the same share of pedestrian/cyclist deaths as reported in Parry and Strand (2010) for Santiago, namely 55 percent. We make the common assumption that all pedestrian/cyclist deaths are external. For single-vehicle accidents we make the usual assumption that fatality risks are internalized. To what extent injuries in multi-vehicle collisions are external is unsettled. All else constant, the presence of an extra vehicle on the road raises the likelihood that other vehicles will be involved in a collision, but a given collision will be less severe if people drive slower or more carefully in heavier traffic. To be conservative, we omit deaths in multi-vehicle collisions from external costs.

Multiplying external deaths (401.5) by the VSL (\$600,000) gives a total cost of \$241 million.<sup>20</sup>

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<sup>19</sup> We do not make any adjustment for possible under-reporting and in this regard are estimate of accident externalities may be conservative.

<sup>20</sup> To be on the conservative side, we assume the same VSL for accident deaths as for local pollution deaths. In contrast, Small and Verhoef (2007) use a higher value for road deaths to account for the lower average age of someone killed by traffic as opposed to pollution (seniors are most at risk from local pollution).

Other external costs of traffic accidents include non-fatal injuries, property damage and medical burdens borne by third parties, and the tax revenue component of productivity losses. However, for lower and middle income countries these additional costs are fairly modest relative to those from fatalities. Following detailed estimates for Chile in Parry and Strand (2010) we scale up external costs by 12 percent to make some adjustment for these broader effects, to leave an overall cost of \$270 million.

Based on Parry and Small (2010) we assume that external accident costs per *vehicle* mile are the same for cars, buses, and minibuses. Buses are larger, and therefore pose greater damage risk in a collision for a given speed. However, offsetting this is that they typically are driven at slower speeds than cars, and crash less often as they are driven by professionals. Dividing the above cost figure by total road vehicle mileage gives an external cost for all vehicles of 8.7 cents per vehicle mile.

*Summary of External Costs.* Relating the above discussion to externalities that determine the optimal transportation prices in (A1)-(A6), we have the following.  $EXT_G = 72 + 9 = 81$  cents per gallon.  $EXT_A = 9.7 + 8.7 = 18.4$  cents per vehicle mile.  $EXT_{MB} = 29.2 + 8.7 = 37.9$  cents per vehicle mile.  $EXT_B^M = 1.3$  and  $EXT_R^M = 0$  cents per passenger mile (after adding external costs per vehicle mile and dividing by occupancy).

*Elasticities.* There is a large empirical literature on gasoline price elasticities for advanced industrial countries, especially the United States. Surveys by Goodwin et al. (2004) and Glaister and Graham (2002) put the long-run elasticity at around  $-0.6$  to  $-0.7$ , while assessments by US DOE (1996) and Small and Van Dender (2006) suggest an elasticity of around  $-0.4$ . Limited evidence for middle and lower income countries is broadly in line with these estimates (e.g., Eskeland and Feyzioglu 1994, Galindo 2005).

The empirical literature also suggests that about a half to two-thirds of the elasticity comes from long-run improvements in vehicle fuel economy, and the remainder from reduced vehicle use. We might expect a somewhat larger mileage–fuel price response for GCMA than in the United States, given the wider availability of transit alternatives to private car use, and the greater feasibility of walking to destinations in the (compact) GCMA.

We assume that mileage–fuel price and fuel economy–fuel price elasticities are the same for autos and minibuses. And we adopt a benchmark value of  $-0.5$  for the gasoline price elasticity, with the assumed response split equally between better fuel economy and reduced mileage.<sup>21</sup>

*Behavioral response coefficients for gasoline tax.* The coefficient  $\rho_{AG}$  in equation (A1) has three components.

First is automobile miles per gallon, which converts costs per vehicle mile into costs per gallon of gasoline. Miles per gallon increases as fuel taxes rise. This is calculated from  $M_A/G_A$  according to equations (A7) and (A8).

Second is the fraction of any given reduction in gasoline consumption that comes from reduced automobile consumption (as opposed to reduced microbus consumption). Given our assumption that fuel use for autos and minibuses fall in the same proportion this fraction is the share of automobiles in gasoline consumption,  $\alpha_A$ , which is 0.65.

The last component of  $\rho_{AG}$  is the portion of the tax-induced reduction in auto gasoline use that comes from reduced driving, as opposed to improvements in fuel economy. This is 0.5 given our above assumption about the decomposition of the gasoline demand elasticity.

The coefficient  $\rho_{MBG}$  in equation (A1) has analogous components. First is miles per gallon for minibuses, calculated from  $M_{MB}/G_{MB}$  according to equations (A7) and (A8), where microbus gasoline consumption falls in the same proportion as total gasoline consumption. Second is the fraction of any given reduction in gasoline consumption that comes from reduced microbus consumption (0.35). Third is the portion of the tax-induced reduction in microbus gasoline use that comes from reduced driving (0.5).

Initially, an incremental tax-induced reduction in gasoline use reduces auto vehicle miles by 6.2 and microbus vehicle miles by 1.4. These coefficients increase somewhat for non-incremental tax increases, as vehicle fuel economy rises.

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<sup>21</sup> There is a potential problem with applying evidence based on nationwide fuel demand responses to a fuel tax increase that is specific to one urban center. If fuel taxes are increased substantially in the GCMA but not in neighboring regions, people might be induced to drive to lower-price regions for refueling (or smuggle gasoline into the GCMA). We do not have evidence on how this effect might increase the overall magnitude of the region-specific fuel price elasticity. This is another reason for being cautious about the welfare effects from the large fuel price increases discussed here.

*Behavioral response coefficient for auto mileage toll.* The coefficient  $\rho_{MBA}$  in equation (A2) is the increase in *vehicle* miles by microbus per unit reduction in *vehicle* miles by auto induced by the auto toll. We assume that 80 percent of the *passenger* mileage diverted from auto in response to an auto toll will go onto other modes and 20 percent will reflect reduced overall travel demand. Of the diverted passengers we assume that they move on to other modes in proportion to the initial share of those other modes in non-auto passenger mileage. This implies that for each passenger mile diverted off auto, microbus will expand by 0.36 passenger miles. Taking account of vehicle occupancies, this means that microbus vehicle miles will expand by  $(2.5/14) 0.36 = 0.064$  per unit reduction in auto vehicle miles.

*Behavioral response coefficient for microbus mileage toll.* The coefficient  $\rho_{AMB}$  in equation (A3) is the increase in *vehicle* miles by auto per unit reduction in *vehicle* miles by microbus induced by the microbus toll. Again, we assume that 80 percent of the *passenger* mileage diverted from microbus in response to the toll will go onto other modes in proportion to their initial shares in non-microbus passenger mileage. This implies that for each passenger mile diverted off microbus, auto will expand by 0.31 passenger miles. Taking account of vehicle occupancies, this means that auto vehicle miles will expand by  $(14/2.5) 0.31 = 1.76$  per unit reduction in auto vehicle miles.

*Behavioral response coefficient for public bus and rail fares.* Coefficients  $\rho_{AB}$  and  $\rho_{AR}$  in (A4) and (A5) were chosen again assuming that 80 percent of people diverted from public transit in response to higher fares would travel by other modes, with passenger miles going to those modes according to their initial shares in passenger miles for modes other than the one whose price is being increased.