PUBLIC TRANSPORT SUBSIDIES AND AFFORDABILITY IN MUMBAI, INDIA

Maureen Cropper*
Soma Bhattacharya

Abstract:

This paper describes the role of public transport and incidence of transport subsidies in Mumbai, India, where public transport is used for over 75% of all motorized trips. On average, expenditure on public transit constitutes a larger share of income for the poor than for the middle class. However, a larger fraction of transit users are middle class. In terms of incidence, the poorest 27% of the population receives only 19% of bus subsidies and 15.5% of rail subsidies. One-quarter of these households do not use rail and 10% do not use bus, implying that they receive no transit subsidies. Improving the welfare of the poor through demand-side subsidies or cash transfer is, however, difficult. We therefore examine the optimal level of transit subsidies, based solely on distributional considerations.

* The findings, interpretations, and views expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the World Bank, its Executive Directors or the countries they represent.

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I. Introduction

Subsidies to public transport are common in developing countries, and are often justified on the grounds that they make transport affordable, rather than on efficiency grounds. Given this justification, it is of interest to know how the benefits from transport subsidies are distributed. As previous analyses have noted (Estupiñán et al., 2008; Gómez-Lobo, 2007), supply-side subsidies—subsidies which make up revenue losses and thus reduce fares by a constant percent—are likely to be regressive or neutral. Although the purpose of such subsidies is not primarily to redistribute income, their incidence should be of interest to policymakers. Policymakers should also care about the level of such subsidies: if the purpose of subsidies is to make transport affordable, the optimal level of subsidy will depend on the source of funds for the subsidy, on the income elasticity of public transport and on the welfare weights that the policymaker attaches to different income classes.

We examine both issues for Mumbai, India. Mumbai has an extensive rail and bus system, and public transport is used for over 75% of all motorized trips in Greater Mumbai. Both rail and bus fares in Mumbai are subsidized: BEST, which operates public buses in Mumbai, is also an electric utility, and subsidizes bus fares from electricity revenues. The Central and Western railways (part of Indian Railways) operate rail services in suburban Mumbai. Although rail fares cover operating costs, they do not fully cover capital costs; hence there is an implicit supply-side subsidy to rail fares in Mumbai.

We analyze the incidence of these subsidies using data from a survey of households in Greater Mumbai that we conducted in the winter of 2003-2004.[1] In Mumbai, as in many other cities, the middle class is more likely to use public transport for travel than the poor. The poor, however, also use public transit, and their expenditure on public transit constitutes, on average, a larger share of their income than it does for the middle class. We use the expenditure data from our survey to analyze the incidence of public transit subsidies in Mumbai. Although 90% of the poor receive bus subsidies and three-quarters receive rail subsidies, an even higher percent of the non-poor receive subsidies, implying that subsidies are not well-targeted. We do not, however, believe that a program of cash transfers to the poor to cover transport costs, or an employer-based system of transport passes, would be easy to implement in Mumbai.

Given that supply-side subsidies are the most feasible option, we ask how large these subsidies should be, on distributional grounds.[2] Dodgson and Topham (1987)

[1] Baker et al., (2005) describes the survey and provides a copy of the questionnaires used.

[2] There is also an economic efficiency argument for subsidies to public transport: If it is infeasible to charge private vehicles for the externalities they cause (e.g., congestion, accidents and pollution), then

determine whether it is appropriate to reduce the price of public transit based on the source of funds for the subsidy and on the welfare weights that a policymaker attaches to the marginal utility of income. If, for example, the revenue for transit subsidies comes from property taxes and the income elasticity of demand for housing is greater than the income elasticity of demand for transit, it is possible that a reduction in the transit fare is optimal. This becomes more likely the faster the social marginal utility of income rises as income declines. Applying their reasoning to bus subsidies in Mumbai suggests that a further decrease in fares might be warranted.

The remainder of the paper is organized as follows. The second section presents an overview of Greater Mumbai and describes the travel patterns of households based on our survey data. In section III we present information on household expenditure on transport and discuss the structure of rail and bus fares. Section IV evaluates the magnitude and incidence of transit subsidies. The optimal transit subsidy is discussed in section V. Section VI concludes.

II. Background: Travel Patterns in Mumbai

Greater Mumbai, the focus of this study, constitutes the core of the Mumbai Metropolitan Region (MMR). Greater Mumbai, with a population of 12.5 million people in 2011, is one of the most densely populated cities in the world. The city faces enormous challenges with shortages of land, housing, infrastructure, and social services that have not kept up with the growing demands of the city. An estimated 50 percent of the city's population lives in slums.

Mumbai's public transport system consists of a suburban rail system and public bus system, as well as private taxis and auto-rickshaws. The suburban rail network carries over 7.33 million passengers every day. Public buses operated by the Brihanmumbai Electric Supply and Transport Undertaking (BEST) carry over 3.67 million passengers each day (MMRDA, 2012)

To better understand travel patterns we conducted a survey of 5,000 randomly sampled households in the Greater Mumbai region in the winter of 2004.[3] The goal of the survey was to characterize the travel patterns of poor and non-poor households, to estimate the time and money costs of travel and to evaluate the impact of various transport policies. A questionnaire was administered to each household and travel diaries were completed by the head of household, a randomly chosen adult over 21 and a randomly chosen household member between 16 and 21.

In Mumbai, as in other developing country cities, the journey to work constitutes the largest fraction of household trips in terms of distance traveled, accounting for

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subsidies to public transit may be justified. Transit subsidies may also be justified by the fact that the marginal cost of providing transit services is less than average cost. Parry and Small (2009) calculate these subsidies for London, Los Angeles, and Washington, DC.

[3] The survey, funded by the World Bank, was designed and supervised by Judy Baker, Rakhi Basu, Maureen Cropper and Somik Lal.

approximately two-thirds of miles traveled. Table 1 describes the main mode used on a typical commute trip. The main mode is defined to be the mode that takes the longest time, with the exception of "on foot" and "bicycle," which are counted as the main mode only if they are the only mode used on the trip. Table 1 indicates that 45% of commuters walk to work, 22% rely on rail or rail+bus as their main mode, while 22% ride a bus to work—either as a main mode (14%) or to connect with rail.[4] The modal shares for private vehicles are much smaller—approximately 3% each for bicycle and car and 8.4% for two-wheelers.[5] Of commuters who take motorized transport to work, 70% take either rail or bus or both.

The respective modal shares are somewhat different for the poorest income group in the survey, defined as households with a monthly income below Rs. 5,000: 63% of the workers in these households walk to work, 6% ride a bicycle, 15% take the train (or train+bus) and 16% ride the bus (either alone or in conjunction with the train). However, of those workers who use motorized transport, 84% take either rail or bus or both.

Table 1. Main Mode to Work

Main Transport Mode	Percentage of All Households	Percentage of Households with Income <Rs. 5k
On foot	45.3	62.7
Bicycle	3.0	6.0
Rail	14.2	10.0
Public Bus	13.9	11.3
Rail + Bus	7.9	5.0
Auto-Rickshaw	1.7	1.3
Taxi	0.1	0.0
Own Two-Wheeler	8.4	0.8
Own Car	2.6	0.1
Other's car	0.2	0.2
Other	2.6	2.8
Sample Size	**5845**	**1270**

Table 2 provides modal splits for all adult trips, by trip purpose.[6] The modal shares of work trips differ slightly from Table 1, as they reflect the work trips of all adults in the household, based on travel diaries. The modal shares for other trips reflect the travel behavior of adults 16 years of age and older.

[4] In Table 2, these shares, based on travel diaries are, respectively, 46% walking, 21% rail and 15% bus.
[5] The shares based on the travel diaries are 3.5% for bicycle, 3.2% for own car and 8.6% for own two-wheeler.
[6] In Table 2 "rail" refers to "rail" and "rail+bus."

Table 2. Percentage Distribution of Trips by Mode, for Each Trip Purpose

Main Transport Mode	Work	School	Entertainment	Health Care	Personal Business	Household Average
On foot + Bicycle	48.6	55.9	51.6	67.7	49.1	54.7
Train	20.9	15.3	3.5	1.2	13.2	15.4
Public Bus	15.1	22.3	16.0	12.8	18.3	14.6
Auto-Rickshaw/ Taxi	2.4	3.4	10.5	16.3	7.5	5.4
Private Motorized Transport	12.2	2.7	18.5	2	12	9.4
Other	0.8	0.3	0	0	0	0.5
TOTAL	100	100	100	100	100	100

The shares of rail and bus in total trips remain high. Train is used for 15% of school trips (for students 16 years of age and older) and also for social visits. Public bus has a significant modal share for school trips and also for personal business, entertainment and social visits.

III. Affordability of Transport

A. Household Expenditure on Transport

The fact that a high percent of trips—including work trips—are made on foot does not imply that expenditures on transport are low, even for households where the primary earner walks to work (see Table 3). As Table 3 indicates, in poor households where the principal wage earner walks to work, 12.5% of family income is spent of transport. The figure is even higher in households where the main earner takes the bus or train to work: in households where the main earner takes the train to work 16.8% of household income is spent on transportation; the percent spent on transport is 19.4% for households where the main earner takes the bus to work.

Table 3. Percent of Household Expenditure on Transportation by Income and Commute Mode of Principal Earner

	Walk	Train	Bus	MTW	Car
<5k	12.5	16.8	19.4	28.5	NA
5-7.5k	8.6	9.3	9.9	19.8	NA
7.5-10k	7.8	8.3	8.7	16.0	NA
10-20k	7.6	9.0	8.4	14.4	20.0
>20k	7.8	6.8	5.8	11.6	14.2

Table 4 shows mean total household expenditure on transport, by category of expenditure. Average household expenditure on rail increases with income; as does average expenditures on buses—until the highest income category, when it decreases slightly. The percent of income spent on public transport is, however, highest for the lowest income group.

The figures in Table 4 foreshadow some results regarding the incidence of transit subsidies. As long as the transit subsidy is a constant percentage of the fare for all income groups, the subsidy in Rs. will increase with household expenditure on transit. Hence, transit subsidies in Rs. will increase with income for rail and also for bus (up to the highest income group). The transit subsidy as a percent of income will, however, be highest for the lowest income group, which spends the highest proportion of income on transit. This is clearly indicated in Table 4 which shows that of all income groups the poor spend the highest percent of their income on bus (6%) and on rail (3.6%).

Table 4. Mean Monthly Household Expenditure (Rs.) on Transportation and Percent of Income Spent on Transit, by Income Group

	<5k	**5k-7.5k**	**7.5k-10k**	**10k-20k**	**>20k**	**Household Average**
Bus	151	195	221	286	275	210
Rail	89	124	165	227	296	152
Taxi	91	121	165	287	397	169
School Bus	3	5	13	50	59	18
Fuel	59	160	200	589	1545	301
Motorized & Non-Motorized Vehicle Maintenance	7	33	41	98	307	56
Total transportation expenditure	**400**	**638**	**805**	**1537**	**2879**	**906**
Share of Income (bus expenditure)	6.0%	3.1%	2.5%	1.9%	1.1%	2.5%
Share of Income (rail expenditure)	3.6%	2.0%	1.9%	1.5%	1.2%	1.8%
Share of Income (total transportation expenditure)	16.0%	10.2%	9.2%	10.2%	11.5%	10.7%

B. Fare Structure

The fact that all but the highest income households spend more per month on bus than on rail (see Table 4) reflects the fact that bus fares are higher, per kilometer traveled, than rail fares. At the time of our survey a person commuting 15 km each way to work by bus paid a fare of Rs. 18 per day or Rs. 450 per month, assuming 25 workdays per month. A person commuting 15 km each way to work by rail paid Rs. 75 for a monthly pass—one-sixth the cost of the bus fare.[7] Bus fares, per km, remain higher than rail fares today, although monthly bus passes are now available.

[7] The cost of travel by rail, per kilometer, is lower than the cost by bus, even if no monthly pass is purchased. See Cropper and Bhattacharya (2007) for details.

IV. Magnitude and Incidence of Transit Subsidies

A. Magnitude of Supply-Side Subsidies

Supply-side subsidies, defined as (Costs/Revenues)-1, are much greater for public buses than for rail. The Transport division of BEST has historically operated at a loss. During the years 2008/09 – 2010/11, the implicit subsidy to bus fares has ranged from 36% to 54%, averaging 45%. Parts of BEST's transport losses are covered by the profits made by its electricity supply division. Over the past 3 years slightly less than half of the deficit from BEST's bus division has been covered by profits from its electricity supply division, with the remainder made up by government subsidies.

The picture is quite different for the suburban rail system. In 2005-06, the most recent year for which we have data, revenues covered operating costs but not depreciation. A 1.2% increase in fares would have been required to cover total costs. The ratio of depreciation to operating costs (0.078) is, however, much lower than the ratio for other rail services around the world, suggesting that reported depreciation understates economic depreciation and hence the subsidy implicit in rail fares (Cropper and Bhattacharya 2007).

B. Incidence of Bus and Rail Subsidies

Because the bus and rail subsidies are a percent of fares, the share of each subsidy going to income group *i* equals the share of income group *i*'s expenditure on bus (rail) in total expenditure on bus (rail) and is thus independent of the percent of the fare that is subsidized. Formally,

$$S_{ij} = \frac{x_{ij} \cdot n_i}{\sum_i x_{ij} \cdot n_i} \qquad (1)$$

where S_{ij} is the share of total subsidy accruing to income group *i* from travel mode *j*, x_{ij} is the average monthly expenditure by a household belonging to income group *i* for travel mode *j* and n_i= fraction of households in income group *i*. The incidence figures in Table 5 thus apply to any level of bus and rail subsidies that are a percent of the fare.

Table 5. Incidence of Bus and Rail Subsidies, by Income Group

Income Group	Percent of Sample	Percent of Total Subsidy Benefits		Percent of Households Who Receive Subsidy	
		Bus	Rail	Bus	Rail
<5K	26.6	19.1	15.5	90.0	73.9
5001-7500	27.8	25.8	22.5	93.6	83.2
7501-10000	21.9	23.1	23.8	94.3	90.8
10001-20000	17.8	24.2	26.5	92.3	87.6
>20K	5.9	7.8	11.6	81.8	79.4

Table 6. Errors of Inclusion and Exclusion of Subsidy

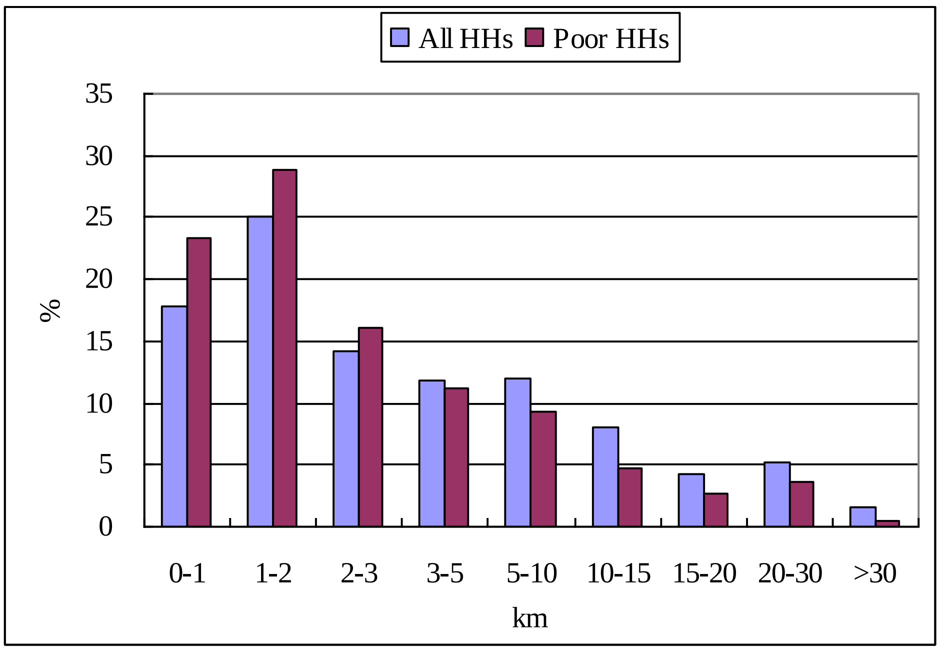
Percentage of Households	Poor (< 5K)	Non-Poor
Receiving Bus Subsidy	90.00	92.55
Not Receiving Bus Subsidy	10.00	7.45
Receiving Rail Subsidy	73.94	86.23
Not Receiving Rail Subsidy	26.06	13.77

An equal distribution of subsidy benefits implies that the percentage of subsidy benefit received by an income category equals its share in the population. Our findings indicate that while the poorest households constitute 27 percent of total households in the sample, they receive only 19 and 15.5 percent, respectively, of bus and rail subsidies. The wealthiest households, who constitute less than 6 percent of the total sample, receive bus subsidies that are about 30 percent larger than their equal share, and about twice the rail subsidy benefits than they would receive under a uniform distribution of the subsidy across income groups. The middle income group, earning 7,500-10,000 Rs. per month receives subsidy benefits from both bus and rail in roughly equal proportion to their share in the population.

If subsidy benefits should be targeted at the poor, then the percentage of the poor not receiving subsidy benefits is an error of exclusion (Foster, 2004) and the percentage of non-poor receiving subsidy benefits would constitute errors of inclusion. For simplicity of calculation, we assume here that all users of public bus and rail receive subsidy benefits. Table 6 shows the errors of inclusion and exclusion for both the rail and bus subsidies. Errors of exclusion are 10 and 26 percent for bus and rail respectively, while errors of inclusion are 93 and 86 percent for bus and rail respectively.

In Mumbai the errors of exclusion for the poor are higher for rail than bus. This reflects the fact that a larger fraction of persons in the lowest income group do not use rail in spite of lower fares for rail. The low usage of rail by the poorest income group is due to the fact that households in the lowest income group live closer to their work than persons in the higher income groups. For all income groups, the percent of commuters using rail increases with commute distance. But, commute distances increase with income. Figure 1 shows the distribution of one-way commute distances for poor workers and for all workers. As Figure 1 illustrates, the distribution of commute distances for workers in the < 5K income group lies to the left of the distribution of commute distances for workers in all households (see Figure 1), implying shorter commutes for the poor. Eighty percent of the poor live 5 km or closer to their work. This may reflect the fact that it is easier for these workers to find jobs close to home and/or to the fact that it is more expensive to live near railway stations; i.e., that proximity to rail is capitalized into land values.

Figure 1. Distribution of One-Way Commute Distances



What is perhaps more troubling from a targeting perspective is the fact a high percent of subsidies go to the non-poor (i.e., that errors of exclusion are high). This could be reduced by providing demand-side subsidies, such as have been instituted in Brazil, or by making direct cash transfers to the poor; however, both options would be difficult to implement in Mumbai. In Brazil, under the Vale Transporte scheme employers provide transit passes to workers, which are partially subsidized by government revenues. Estupiñán et al. (2008) note that the passes are often sold at a discount in the black market, with workers carpooling or walking to work. They suggest that a direct cash transfer would be preferable. There is no direct cash transfer scheme for the poor in Mumbai and, employer-provided transit passes would be difficult to implement in a city with a high percentage of employment in the informal sector. Given these difficulties, supply-side subsidies appear to be the most feasible method of subsidizing public transit in Mumbai. We therefore ask what whether current subsidies should be increased, based on distributional grounds.

V. Optimal Distributional Transit Subsidies

Dodgson and Topham (1987) derive conditions under which a reduction in the price of public transit would be welfare-enhancing, given the distribution of income in a city, the income elasticity of demand for public transport and assumptions about the sources of revenues used to fund the subsidy. In the case they consider, transit fares are subsidized out of property taxes. The goal of a planner, who must fund a fraction (1-g) of the reduction in transit fares from property tax revenues, is to maximize the welfare of households in the city, who differ in income (m) but have identical preferences for goods and services.[8] In maximizing welfare, the planner attaches a weight $\beta'(m)$ to the marginal utility of income received by a household with income m.

As shown in the Appendix, the condition for a reduction in the price of transit to be welfare-maximizing is for

$$\Delta/[1+\tau_1\eta_1] \; > \; (1-g)/[1+\tau_0\eta_0], \qquad (2)$$

where Δ represents the ratio of the "distributional characteristic" of public transit to the taxed good, τ_i denotes the tax or subsidy rate for good i, as a proportion of the price faced by the consumer, and η_i is the price elasticity of demand for good i. We use the subscript "0" to denote the taxed good and "1" to denote public transit 0.[9] Δ, which represents the ratio of welfare-weighted demand for transit relative to the welfare-weighted demand for the taxed good, will be > 1 if the income elasticity of the taxed good is greater than the income elasticity of demand for public transit.

Equation (2) says that a transit subsidy is justified if the marginal cost of public funds (the RHS of (2)) is less than the distributional benefits of the fare reduction (the LHS of (2)). The marginal cost of public funds is smaller the greater the fraction of revenue that the city receives from the federal government (g) and the less price-elastic is the demand for the taxed good.

The distributional benefits of lowering transit fares will be greater the smaller is the current subsidy and the less price-elastic is the demand for transit. They also depend crucially on Δ. The standard approach to computing Δ in the public finance literature (Feldstein 1972) is to assume that income, m, follows a lognormal distribution, that $\beta'(m) = m^{-\delta}$, and that goods 0 and 1 can be described by isoelastic demand functions. Under these assumptions

$$\Delta = \exp[\delta\sigma^2(\theta_0-\theta_1)] \qquad (3)$$

[8] It is assumed that the federal government funds a portion g of the transit subsidy.

[9] Note that this implies $\tau_0 > 0$ and $\tau_1 < 0$.

where σ^2 is the variance of log(m) and θ_i is the income elasticity of good i. A transit subsidy is thus more likely to be justified (a) the higher the social inequality parameter δ; (b) the more unequal the distribution of income (the larger is σ^2), (c) the more income elastic is the taxed good relative to public transit.

We now consider the implications of equations (2) and (3) for bus subsidies in Mumbai. Estimates of the price and income elasticity of demand for bus travel have been estimated by one of us using our Mumbai survey data (Takeuchi, Cropper and Bento 2007). Our estimates suggest that that $\theta_1 = 0.25$ and $\eta_1 = -0.42$. In Mumbai, bus subsidies have been at least partially funded out of electricity revenues, since BEST is also an electric utility. Estimates of the price and income elasticity of demand for electricity in India are provided by Gunimeda and Köhlin (2008). Their elasticities for urban areas in India suggest that $\theta_0 = 0.60$ and $\eta_0 = -0.52$.

Whether an increase in bus subsidies is warranted also depends on the distribution of income in Mumbai and on the income inequality parameter δ. Annez et al. (2010) report mean monthly income in Mumbai to be Rs. 40,000 and median monthly income to be Rs. 21,000.[10] Assuming that income is lognormally distributed, this implies that $\sigma^2 = 1.436$. The value of δ is a subject of much debate. One way to interpret δ is in terms of the maximum sacrifice that a higher income person should be asked to make to increase the income of a poorer person. If δ=1, then a household with 2m of income should be asked to forgo Rs. 2 to provide an additional rupee to a household with 1m of income. If δ=2, the higher income household should be asked to forgo Rs. 4 to provide an additional rupee to a household with 1m of income. Dodgson and Topham cite values of δ=2 for the United Kingdom based on Stern (1977). However, the official value of δ used by the UK government is 1 (H.M. Treasury 2003). A value of δ=1 implies that $\Delta = 1.65$, while a value of δ=2 implies that $\Delta = 2.73$.

Our calculations suggest that an increase in bus subsidies might be warranted on distributional grounds. Evaluating the LHS of (2) at the average subsidy of 45% to bus fares yields a LHS = 1.39 if δ=1. The RHS depends on how much of the subsidy comes from electricity revenues. Even if all of this subsidy were to come from higher electricity prices, the price of electricity would rise by no more than 20%. This would imply that the RHS of (2) = 1.12 and, hence, that an increase in bus subsidies is warranted. This conclusion is, of course, heavily dependent on the choice of δ. Our calculations suggest that if δ=0.5, current subsides are roughly optimal.[11]

VI. Conclusions

Carruthers, Dick and Saurkar (2005) report that Mumbai ranks sixth among 27 cities for which they have calculated indices of public transport affordability. That is,

[10] The income data in Annez et al. (2010) are more detailed than in our survey, which reports only four income categories.

[11] If δ=0.5 then a household with 2m of income should be asked to forgo Rs. 1.41 to provide an additional rupee to a household with 1m of income.

Mumbai is the sixth most expensive city. The figures presented in this paper bear this out. Expenditure on transport accounts for 16% of income in the lowest income category (<5000 Rs./month), with 10% of income, on average, spent on bus and rail fares. This percentage, however, is not evenly distributed: it is much higher than 10% for households in which workers take the bus or train to work, and lower for households in which the main earner walks to work. Even in these households, however, 12.5% of income is spent on transportation.

Expenditure on public transport would be even higher if bus fares in Mumbai were not subsidized. Over the period 2008/09 – 2010/11, transport revenues of BEST fell below total costs by an average of 45%. Rail fares, which are much lower than bus fares per km traveled, officially covered operating costs and almost covered depreciation expenses.

If one asks who benefits from bus subsidies in Mumbai, the answer is clear: Households with incomes below Rs. 5,000 per month, who constitute 27% of the population, receive 19% of bus subsidies while households with incomes above Rs. 10,000 per month, who constitute 24% of the population, receive 31% of bus subsidies. Ten percent of households in the below-Rs. 5,000 group do not use bus services and thus receive no subsidy.

Policymakers concerned about the welfare of poor might argue that it would be more efficient to provide cash transfers to poor households, or, if the goal is to encourage the consumption of transport services, to provide demand-side subsidies, as is done in Brazil (Estupiñán et al. 2008). Neither option, is however, practical in the case of Mumbai: there is no system of cash transfers to the poor and demand-side subsidies of the type used in Brazil are difficult when a large portion of the population works in the informal sector. This leads us to examine the optimal supply subsidy to bus fares.

As Dodgson and Topham (1987) show, the optimal subsidy on distributional grounds depends on the income elasticity of demand for bus transit, the income elasticity of demand for the good that is taxed to provide the subsidy (in this case, electricity) and the distribution of income in the city in question. It also depends on the welfare weights attached to the marginal utility of income. We have provided rough calculations that suggest that a subsidy to bus fares of 50% can very likely be justified on distributional grounds.

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Appendix: Optimal Distributional Subsidies[12]

Suppose that a planner can alter the price of public transportation in a city (q_1). A portion (1-g) of the funds for the subsidy must come out of the source of local tax revenue, a tax on good 0. All households in the city have identical preferences for goods and services but differ in their incomes. Denote the household's indirect utility function $\psi(\mathbf{q},m)$ where m is income and **q** is the vector of prices for all goods and services. The planner's goal is to maximize the sum of utilities of all households in the city, where f(m) is the probability distribution of income and $\beta'(m)$ is the marginal utility that the planner attaches to an additional unit of income for a household with income m. The planner's goal is thus to maximize the social welfare of the population (N)

$$N \int \psi(\mathbf{q},m)\, \beta'(m)\, f(m)\, dm. \tag{A1}$$

A marginal reduction in the transit fare (q_1) and corresponding increase in the price of the taxed good (q_0) will be optimal if

$$-\Delta\, [X_1 dq_1] > X_0 dq_0 \tag{A2}$$

where X_i is the aggregate demand for good i. Equation (A2) says that a fare reduction is warranted if the welfare-weighted reduction in revenues ($-X_1dq_1$) exceeds the tax revenues required to fund the subsidy. Δ represents the ratio of the "distributional characteristic" of public transit to the taxed good, and is discussed further below. Totally differentiating the planner's budget constraint, $t_0X_0 = (1\text{-}g)[C_1(X_1) - q_1X_1]$ where $C(X_1)$ is the cost of public transport, yields

$$-X_1dq_1\, (1\text{-}g)\, [1+\tau_1\eta_1] = X_0dq_0\, [1+\tau_0\eta_0] \tag{A3}$$

where τ_i denotes the tax or subsidy rate for good i, as a proportion of the price (q_i) and η_i is the price elasticity of demand for good i.[13] Substituting (A3) into (A2) implies that a transit subsidy is justified if

$$\Delta/[1+\tau_1\eta_1] \;>\; (1\text{-}g)/[1+\tau_0\eta_0]. \tag{A4}$$

To evaluate this condition requires parameterizing Δ. The standard approach in the public finance literature (Feldstein 1972) is to assume that income, m, follows a

[12] This Appendix follows Dodgson and Topham (1987), with simplifying assumptions.
[13] In other words $q_i \equiv p_i + \tau_i$ where p_i is the producer price of good i [=C (q_1) for transit].

lognormal distribution, that $\beta'(m) = m^{-\delta}$, and that goods 0 and 1 can be described by isoelastic demand functions. Under these assumptions

$$\Delta = \exp[\delta\sigma^2(\theta_0-\theta_1)] \qquad \text{(A5)}$$

where σ^2 is the variance of log(m) and θ_i is the income elasticity of good i.