COMMUTING SUBSIDIES WITH TWO TRANSPORT MODES

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Abstract

We study a simple model of commuting subsidies with two transport modes. City residents choose where to live and which mode to use. When all land is owned by city residents, one group gains from subsidies what the other loses. With absentee landownership, city residents as a group gain at the expense of landowners. Subsidies toward different modes have different effects, however, for instance, in one case, rich automobile drivers suffer from transit subsidies, while poor transit users may benefit from subsidies to automobiles.

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1 Introduction

We study the redistributive effects of commuting subsidies in a monocentric city with two income groups and two transport modes. City residents choose where to live and which transport mode to use. Subsidies then redistribute between city residents living at different distances from the city center, and between city residents and absentee landowners.

The paper uses a simplified version of Borck and Wrede [3], assuming fixed housing consumption. However, we extend the model by allowing for two transport modes. We thus combine the analysis of transport subsidies with the study of transport mode choice as in LeRoy and Sonstelie [9] and Sasaki [10].[1] This extension also allows us to introduce different subsidy rates for the different transport modes.

We find that with resident landownership, subsidies always redistribute between city residents (as long as mode choice is unaffected) and, therefore, one group gains what the other loses. With absentee landownership, city residents as a group generally benefit from commuting subsidies at the expense of landowners. In this case, when both groups use the same mode, they both benefit from subsidies to this mode. When the poor live in the city center and use public transport while the rich live in the suburbs and use cars, we find that subsidies to public transport hurt the rich, while the poor may benefit from subsidies to cars. We also examine a case with three distinct areas, where the rich use public transport in the center and cars in the suburbs, while the poor live between those groups and use public transport. Here, subsidizing public transit more heavily than cars hurts and subsidizing cars more heavily benefits the rich, while the effect on the poor is ambiguous.

In the next section, we introduce our model. We then study three distinct cases of residence patterns and mode choice: In section 3, both groups use public transit, in section 4 the poor use transit and the rich cars, and in section 5, the rich use both modes (transit in the center and cars in the suburbs), while the poor use only transit. The last section concludes the paper.

[1]See also DeSalvo and Huq [7]. Brueckner and Selod [5] study a similar model where the speed of the (unique) transport system in a city is chosen endogenously. For a nontechnical discussion of some of these issues, see Borck [2].

2 The model

We consider a simple model with two groups of individuals living in a monocentric city. The groups are denoted by $i = H, L$, and group i has n_i homogeneous members. We assume that group H has high income and L has low income, i.e. $y_H > y_L$, where y_i is the income of a member of group i. Income consists of two components:

$$y_i = w_i + \theta_i ALR,$$

where w_i is the wage of a group i individual, with $w_H > w_L$, and θ_i is the share of the average land rent ALR accruing to group i members.

Individuals live on plots of land of fixed size. Land consumption by a group i member is q_i with $q_H \geq q_L$, so the rich consume more land than the poor (see, e.g., de Bartolome and Ross [6]). All city residents commute to the CBD for work. There are two transport modes, denoted A and B. For example, A may be the automobile and B the bus or some other form of public transport. Users of mode $j = A, B$ incur a fixed cost of F_j. Further, the variable round trip commuting cost for an individual of type i living at r km from the CBD is $[(1 - s_j)t_j + \phi_j w_i]r$, where t_i is the monetary value of the per-mile-commuting costs of mode j, s_j the subsidy rate towards mode j, and ϕ_j is the time cost (the inverse of travel speed) of mode j.

Hence, the total cost of using mode j at distance r is $F_j + [(1 - s_j)t_j + \phi_j w_i]r$. Mode A has higher fixed cost but lower time costs: $F_A > F_B, \phi_A < \phi_B$. In addition we assume that for both groups, the variable cost of mode A is lower than that of mode B (see Sasaki [10]):

$$t_A + \phi_A w_i < t_B + \phi_B w_i. \tag{1}$$

We then get a group specific cutoff distance, $r_i^*, i = H, L$, where a member of group i is just indifferent between using mode A and B:

$$r_i^* = \frac{F_A - F_B}{(1 - s_B)t_B - (1 - s_A)t_A + (\phi_B - \phi_A)w_i}. \tag{2}$$

Under the assumptions that the automobile has higher fixed costs but lower variable costs for both groups than the bus, $r_i^* > 0, i = H, L$ so that close to the CBD individuals will commute by bus.

Since $w_H > w_L$, $r_H^* < r_L^*$. This implies that if at some distance r, the rich use the bus, so must the poor, and conversely, if at some r the poor commute by car so do the rich.

We assume that housing consumption does not enter utility. Therefore utility of an individual of type i living r km from the CBD if she uses mode j equals consumption

$$c_i^j = y_i - F_j - [(1 - s_j)t_j + \phi_j w_i]r - T - R_i q_i, \quad \text{for } i = H, L \text{ and } j = A, B. \tag{3}$$

where R is land rent and T a lump sum tax.

Since each member of group i must attain the same utility level, (3) implies the bid rent functions (i.e. the maximum rent an individual of group i living at distance r from the CBD who uses mode j would be willing to pay):

$$R_i^j = \frac{y_i - F_j - [(1 - s_j)t_j + \phi_j w_i]r - T - c_i}{q_i}, \quad \text{for } i = H, L \text{ and } j = A, B. \tag{4}$$

The bid rent of group i members is then defined as $R_i(r) = \max\{R_i^A, R_i^B\}$ and land rent at r is $R(r) = \max\{0, R_H(r), R_L(r)\}$.

Suppose that both groups use the same transport mode. Then, the group with the steeper bid rent curve will live closer to the CBD. This implies that the rich live closer to the CBD than the poor if

$$\frac{(1 - s_j)t_j + \phi_j w_H}{q_H} > \frac{(1 - s_j)t_j + \phi_j w_L}{q_L} \quad \text{for } j = A, B. \tag{5}$$

We will assume that this condition holds, which says that the arc income elasticity of housing consumption is less than the arc income elasticity of variable transport costs. See also LeRoy and Sonstelie [9], de Bartolome and Ross [6], and also Glaeser et al. [8] who argue that this is consistent with the available empirical evidence.

The city is linear and extends from the CBD, located at zero, to the urban fringe $\bar{r} = q_H n_H + q_L n_L$. Average land rent is

$$ALR = \frac{1}{n_H + n_L} \int_0^{\bar{r}} R(r) dr. \tag{6}$$

The government budget constraint simply states that total tax revenue must equal total subsidy disbursements, or the lump sum tax equals

$$T = \frac{1}{n_H + n_L} \int_0^{\bar{r}} s^* t^* \frac{r}{q^*} dr, \tag{7}$$

where the * indicates that we consider only the group/mode with the highest bid rent at r.

In equilibrium the city is divided into at most four areas, where each area is populated by members of one group only which all use the same transport mode (see LeRoy and Sonstelie [9] and Sasaki [10]). At one extreme, all rich and all poor use the same mode, while at the other extreme, each mode is used by all groups. In this paper, we will consider three specific examples with two or three different areas where in all examples the poor use the bus.

3 Both groups commute by bus

Suppose first that both groups use the same mode. Since fixed costs are positive, this means both groups commute by bus. The equilibrium in the city is characterized by the following equilibrium conditions:

$$R_H^B(r_1) = R_L^B(r_1), \tag{8}$$

$$R_L^B(\bar{r}) = 0, \tag{9}$$

with $r_1 = n_H q_H$ and $\bar{r} = n_H q_H + n_L q_L$. Equation (9) states that the bid rent of the outermost resident living at $\bar{r}$ just equals the agricultural rent which we normalize to zero. Equation (8) says that at the border between rich and poor, denoted r_1, rich and poor must be willing to pay the same amount per square meter land. Writing out the expression for $R_L(\bar{r})$, using $\bar{r} = n_H q_H + n_L q_L$, gives:

$$R_L(\bar{r}) = \frac{y_L - F_B - [(1-s_B)t_B + \phi_B w_L](n_L q_L + n_H q_H) - T - c_L}{q_L}. \tag{10}$$

Setting $R_L(\bar{r}) = 0$ gives the equilibrium utility of the poor

$$c_L = y_L - F_B - [(1-s_B)t_B + \phi_B w_L](n_L q_L + n_H q_H) - T. \tag{11}$$

Using (11) together with $r_1 = n_H q_H$ in (8) gives:

$$\frac{[(1-s_B)t_B + \phi_B w_L]n_H q_H}{q_L} = \frac{y_H - F_B - [(1-s_B)t_B + \phi_B w_H]n_L q_L - T - c_H}{q_H} \tag{12}$$

Substituting (11) and $r_1 = n_H q_H$ into (4) and solving (12) gives the equilibrium utility level of the rich:

$$c_H = y_H - F_B - [(1-s_B)t_B + \phi_B w_H]n_H q_H - [(1-s_B)t_B + \phi_B w_L]n_L q_H - T. \tag{13}$$

Average variable transport costs net of subsidies are defined as

$$ATC = \frac{1}{n_H + n_L} \int_0^{r_1} \frac{[(1-s_B)t_B + \phi_B w_H]r}{q_H} dr + \int_{r_1}^{\bar{r}} \frac{[(1-s_B)t_B + \phi_B w_L]r}{q_L} dr. \tag{14}$$

Integrating (14) by parts yields

$$ALR = ATC. \tag{15}$$

That is in a linear city with linear transport cost, average land rent equals average total transport costs net of subsidies (Arnott and Stiglitz [1]). This holds regardless of the exact pattern of mode choice and land use.

Using the fact that boundaries are fixed and taking (14), (15) and (7) into account, we find immediately

$$\frac{\partial ALR}{\partial s_j} = -\frac{\partial T}{\partial s_j} < 0. \tag{16}$$

Subsidies reduce average land rent regardless of landownership. Furthermore, the sum of average land rent and lump sum tax is not affected by subsidies.

To see the reason behind this result, we use (11) and (13) in (4) to find

$$R_H(0) = n_L[(1-s_B)t_B + \phi_B w_L] + n_H[(1-s_B)t_B + \phi_B w_H] \tag{17}$$

$$R_L(q_H n_H) = n_L[(1-s_B)t_B + \phi_B w_L]. \tag{18}$$

Thus, increasing s_B decreases land rent both at the CBD and at the rich/poor border. Total land rent therefore falls. Subsidizing transport makes both groups' bid rents flatter. Since housing consumption is fixed and rent at the city border must be zero, this implies that aggregate land rent must fall. This is one of the clues to understanding the political support for commuting subsidies. Since they lead individuals to prefer locations farther from the center, total land rent falls, and rents fall most for those who live closest to the center. These are of course the individuals whom one would expect to lose from subsidies in purely fiscal terms.

Finally, we can calculate the lump sum tax and average land rent explicitly and substitute into (11) and (13). Doing so yields simple expressions for the effect of the subsidy on the utility of the rich and poor:

$$\frac{\partial c_L}{\partial s_B} = \frac{\{[n_H + (1-\theta_L)n_L/2]n_L q_L + [(1-\theta_L)n_H/2 - \theta_L n_L]n_H q_H\}t_B}{n_L + n_H} \tag{19}$$

$$\frac{\partial c_L}{\partial s_B} = \frac{\{(1+\theta_H)n_L^2 q_L - [(1-\theta_H)n_L + (1-\theta_H)n_H/2 + n_L^2/n_H]n_H q_H\}t_B}{n_L + n_H} \tag{20}$$

Note that subsidies have no efficiency effects as long as they leave the type of equilibrium unaltered. The boundary between the rich and poor area is independent of subsidies, and we assume mode choice to be unaffected by the subsidy. Hence, small changes in subsidies only redistribute between both groups of commuters and landowners. Total welfare is

$$W = n_H c_H + n_L c_L + [(1-\theta_H)n_H + (1-\theta_L)n_L]ALR. \tag{21}$$

Hence:

$$\frac{\partial W}{\partial s_B} = n_H \frac{\partial c_H}{\partial s_B} + n_L \frac{\partial c_L}{\partial s_B} + [(1-\theta_H)n_H + (1-\theta_L)n_L]\frac{\partial ALR}{\partial s_B} = 0. \tag{22}$$

Commuters' gains equal landowners' losses. This is natural, for instance, Brueckner [4] found that commuting subsidies in a model like ours but with variable land consumption are inefficient. In our model with fixed land consumption, subsidies simply redistribute between commuters and landowners and have no efficiency consequences as long as mode choice is not affected. Therefore, this result also holds in the next subsection – where rich and poor used different modes – as long as subsidies do not affect mode choice.

We will now consider two polar cases of landownership more explicitly. The first case of interest is that of absentee landownership. Using $\theta_L = \theta_H = 0$ we find

$$\frac{\partial c_L}{\partial s_B} = \frac{[n_H^2 q_H/2 + (n_H + n_L/2)n_L q_L]t_B}{n_L + n_H} \tag{23}$$

$$\frac{\partial c_H}{\partial s_B} = \frac{\{[n_L(n_L + n_H) + n_H^2/2]q_H - n_L^2 q_L\}t_B}{n_L + n_H} \tag{24}$$

Since $q_H \geq q_L$, we have:

Proposition 1 *Suppose that rich and poor commute by bus and land is owned by absentee landowners. Then, both rich and poor benefit from a subsidy to public transport. The total gain to city residents equals the total loss to landowners.*

Equations (23) and (24) show that both groups gain from the introduction of commuting subsidies. The poor have longer commutes and therefore benefit from commuting subsidies financed by head taxes in purely fiscal terms, while the rich pay more than they receive in subsidies. However, the rich incur a larger fall in land rent and the net effect on utility is therefore qualitatively the same for both groups.

We now consider resident landownership. In particular, suppose that both rich and poor receive an equal share of aggregate land rent, i.e. $\theta_L = \theta_H = 1$. (22) shows that subsidies will either have no effect on utility or it will benefit one group of citizens at the expense of the other group. Residents as a group cannot gain from subsidies. This is shown also by Borck and Wrede [3] in the case with variable land consumption when the initial subsidy rate is zero. Here, it holds more generally. Simplifying (19) and (20), we get explicitly:

$$\frac{\partial c_L}{\partial s_B} = -\frac{n_H}{n_L}\frac{\partial c_H}{\partial s_B} = \frac{(q_L - q_H)n_L n_H t_B}{n_L + n_H}. \tag{25}$$

Therefore, we have the following result:

Proposition 2 *Suppose that rich and poor commute by bus and land is owned by city residents in equal proportions. Suppose further that the rich consume more land than the poor. Then, increasing the level of subsidies benefits the rich at the expense of the poor.*

4 Poor commute by bus, rich by car

The second case we consider is that where the poor live in the center and commute by bus, while the rich live in the suburbs and commute by car. LeRoy and Sonstelie [9] and Glaeser et al. [8] argue that the availability of fast but expensive transport modes was responsible for the suburbanization of wealthy city residents in the US.

At the border between the poor and rich, the poor bid rent function when they commute by bus must be steeper than the rich bid rent function when those use the car:

$$\frac{(1-s_B)t_B + \phi_B w_L}{q_L} > \frac{(1-s_A)t_A + \phi_A w_H}{q_H}. \tag{26}$$

We proceed like in the previous section, leaving out much of the detail, however. The equilibrium conditions are now

$$R_L^B(r_1) = R_H^A(r_1), \quad \text{and} \quad R_H^A(\bar{r}) = 0. \tag{27}$$

Solving for the equilibrium utility of poor and rich gives:

$$c_L = y_L - F_B - [(1-s_B)t_B + \phi_B w_L]n_L q_L - [(1-s_A)t_A + \phi_A w_H]n_H q_L - T \tag{28}$$
$$c_H = y_H - F_A - [(1-s_A)t_A + \phi_A w_H](n_L q_L + n_H q_H) - T. \tag{29}$$

The head tax which satisfies the government budget is now

$$T = \frac{s_B t_B n_L^2 q_L/2 + s_A t_A n_H(n_L q_L + n_H q_H/2)}{n_L + n_H} \tag{30}$$

and average land rent

$$ALR = \frac{[(1-s_B)t_B + \phi_B w_L]n_L^2 q_L/2 + [(1-s_A)t_A + \phi_A w_H]n_H(n_H q_H + n_L q_L/2)}{n_L + n_H}. \quad (31)$$

Using (30) and (31) in (28) and (29) gives expressions for the utility levels as functions of the subsidy rates s_A, s_B.

Consider again the case of absentee landownership. We find

$$\frac{\partial c_L}{\partial s_A} = \frac{(q_L - q_H/2)n_H^2 t_A}{n_L + n_H} \quad (32)$$

$$\frac{\partial c_L}{\partial s_B} = \frac{(n_L/2 + n_H)n_L q_L t_B}{n_L + n_H} \quad (33)$$

$$\frac{\partial c_H}{\partial s_A} = \frac{(n_L^2 q_L + (n_L + n_H/2)n_H q_H)t_A}{n_L + n_H} \quad (34)$$

$$\frac{\partial c_H}{\partial s_B} = -\frac{n_L^2 q_L/2t_B}{n_L + n_H} \quad (35)$$

This is summarized as:

Proposition 3 *Suppose that the poor live in the center and commute by bus, while the rich live in the suburbs and commute by car. If land ownership is absentee, subsidizing buses will benefit the poor and harm the rich, while subsidizing cars will benefit the rich. The poor benefit from subsidies to cars iff $q_L > q_H/2$.*

Each group benefits from a subsidy to its own mode, which is cross-subsidized by the other group. However, the proposition shows an asymmetry: the rich who live in the suburbs dislike subsidies to public transport, while the poor city residents may like subsidies to suburbian automobile users. This is because housing market pressure is relieved for the poor when the mode used by the rich is subsidized. When rich housing (and thus commuting distances) is not too large relative to the poor, this effect is large enough to compensate for the fiscal loss of the poor.

Second, we consider again full resident landownership. Again, subsidies redistribute between the rich and poor:

$$\frac{\partial c_L}{\partial s_A} = \frac{n_H[(n_L - n_H)q_L + n_H q_H]t_A}{n_L + n_H} = -\frac{n_H}{n_L}\frac{\partial c_H}{\partial s_A} \quad (36)$$

$$\frac{\partial c_L}{\partial s_B} = \frac{n_L n_H q_L t_B}{n_L + n_H} = -\frac{n_H}{n_L}\frac{\partial c_H}{\partial s_B} \quad (37)$$

Thus, we have shown:

Proposition 4 *Suppose that the poor live in the center and commute by bus, while the rich live in the suburbs and commute by car. If land is owned by all city residents in equal proportions, subsidizing buses will benefit the poor and hurt the rich, while subsidizing cars will benefit the rich and hurt the poor.*

5 Poor bus users surrounded by rich commuters

From the possible equilibria with three different areas we choose one where rich car drivers live in the outskirts of town. From our assumption (5) follows that the rich live close to the CBD where they use the bus and that the poor also drive by bus and live in the middle. In contrast to equilibria with only two areas, subsidies now have efficiency effects, since they affect modal choices and the residence patterns. For the sake of simplification, we assume equal lot sizes in this section, namely that $q_H = q_L = 1$. Hence, only the efficient use of transport modes is at stake. The equilibrium is determined by

$$R_H^B(r_1) = R_L^B(r_1), \quad R_L^B(r_2) = R_H^A(r_2), \quad \text{and} \quad R_H^A(\bar{r}) = 0, \tag{38}$$

where r_1 is the boundary between rich and poor bus users, r_2 separates poor bus users and rich car drivers, and $\bar{r} = n_H q_H + n_L q_L$ is still the urban fringe. From these equilibrium conditions we immediately obtain the equilibrium utility for the rich:

$$c_H = w_H + \theta_H ALR - T - F_A - [(1 - s_A)t_A + \phi_A w_H](n_H q_H + n_L q_L). \tag{39}$$

Using (39), in equilibrium the bid rent function of the rich for mode $j = A, B$ can be written as

$$R_H^j(r) = \frac{F_A - F_j + [(1 - s_A)t_A + \phi_A w_H](n_H q_H + n_L q_L) - [(1 - s_j)t_j + \phi_j w_H]r}{q_H}. \tag{40}$$

Equation (39) allows to decompose the impact on utility of the rich when subsidies are altered. While a change in car subsidies alters utility according to

$$\frac{\partial c_H}{\partial s_A} = \theta_H \frac{\partial ALR}{\partial s_A} - \frac{\partial T}{\partial s_A} + (n_H q_H + n_L q_L)t_A, \tag{41}$$

a change in the subsidy for public transport leads to

$$\frac{\partial c_H}{\partial s_B} = \theta_H \frac{\partial ALR}{\partial s_B} - \frac{\partial T}{\partial s_B}. \tag{42}$$

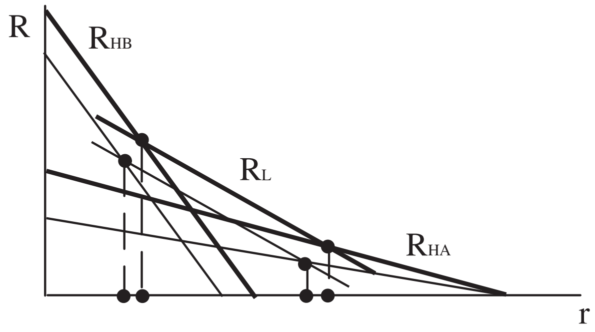

Figure 1: Higher subsidies for cars

Subsidies affect utility of this group only via the lump sum tax, via average land rent and – possibly – via monetary commuting costs at the urban fringe.

Finally, we can use equations (4), (38) and (40) to calculate the equilibrium bid rent of the poor

$$R_L^B(r) = \frac{(1-s_A)t_A + \phi_A w_H}{q_H}(n_H q_H + n_L q_L - r_2) - \frac{(1-s_B)t_B + \phi_B w_L}{q_L}(r - r_2). \quad (43)$$

Since housing is fixed, subsidies do not change the size of the low-income area. They move both boundaries of the low-income area by the same amount either outwards or inwards. Using (40) and (43) we can calculate the impact of subsidy changes on bid rent curves. Consider first subsidies for cars going to the rich in the outermost area. From (40) follows that the bid rent function of rich car drivers becomes flatter and the bid rent function of rich bus drivers shifts downwards. (43) implies, that car subsidies do not affect the slope of poor citizens' bid rent curve. Taking into account that the size of the middle area does not change, the bid rent curve of poor residents shifts downwards (see figure 1). Since all bid rent curves move downwards, average land rent unambiguously falls. Car subsidies clearly hurt landowners, since lot sizes are fixed. It seems natural to think that the poor move inwards, more high income individuals use the car and less the bus. Indeed, this is what analytical results show:

$$\frac{\partial n_H^1}{\partial s_A} = \frac{t_A[F_B - F_A + \phi_B n_L(w_L - w_H)]}{[(1-s_A)t_A + \phi_A w_H - (1-s_B)t_B - \phi_B w_H]^2} < 0, \quad (44)$$

where n_H^1 denotes the number of rich commuters living in the inner area.

In order to analyze subsidies for buses, we proceed like before. As can be seen from (40), subsidies for buses do not change the bid rent curve of rich car drivers, but flatten the

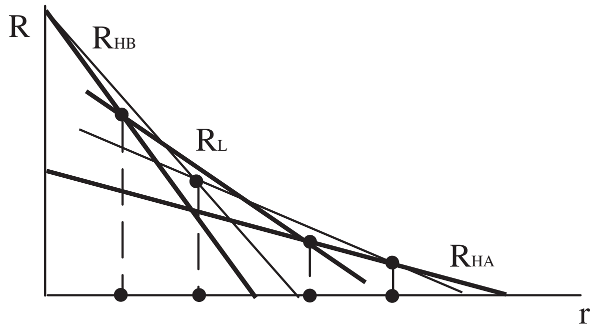

Figure 2: Higher subsidies for buses

bid rent curve of rich bus users. Bus subsidies change the position of the bid rent curve of poor commuters and also flatten the curve (see (43)). Again, we can use the fixed size of the middle area to conclude that poor residents move outwards in equilibrium (see figure 2). Less high income individuals live in the outer area and drive by car, some move to the central area and use the bus. The impact on average land rent and, thus, on landowners, is a priori unclear: while land rent in the inner central area and in the outer part of the middle area increase, land rent may decrease around the boundary between the inner and the middle area.

Next, we calculate how subsidies affect total welfare W (of citizens and landowners):

$$\frac{\partial W}{\partial s_j} = \frac{t_j(s_j t_j - s_k t_k)[F_B - F_A + \phi_B n_L(w_L - w_H)]^2}{[(1-s_A)t_A + \phi_A w_H - (1-s_B)t_B - \phi_B w_H]^3}, \quad \text{for } j,k = A,B, k \neq j. \tag{45}$$

Due to our assumption (1) the denominator is negative when subsidies are sufficiently similar and do not reverse the order of variable transport costs. Independent of landownership, an increase in subsidy rate s_j raises welfare if $s_j t_j < s_k t_k$. In order to rule out a distortion of transport mode choice, total subsidies per km should be equalized. Hence, we have shown:

Proposition 5 *Suppose that the poor live in the middle area and commute by bus, while the rich live either in the suburbs and commute by car or close to the center and commute by bus. Suppose further that subsidies do not alter the relative size of variable transport costs. Then, narrowing the range of subsidies per km raises welfare.*

Since our focus is on the distributional impact of commuting subsidies, we will rule out efficiency effects by analyzing small subsidy changes starting at $s_B t_B = s_A t_A$. Again we will consider two polar cases of landownership: absentee landowners ($\theta_H = \theta_L = 0$) and equal resident landownership ($\theta_H = \theta_L = 1$).

With absentee landownership subsidies have ambiguous effects.

$$\frac{\partial c_L}{\partial s_B} = \frac{t_B[F_B - F_A + \phi_B n_L(w_L - w_H)][F_A - F_B + \phi_B(n_L + 2n_H)(w_L - w_H)]}{2(n_H + n_L)[t_B + \phi_B w_H - t_A - \phi_A w_H]^2}, \quad (46)$$

$$\frac{\partial c_H}{\partial s_B} = \frac{t_B[F_B - F_A + \phi_B n_L(w_L - w_H)]^2}{2(n_H + n_L)[t_B + \phi_B w_H - t_A - \phi_A w_H]^2} < 0. \quad (47)$$

We skip analytical results for car subsidies, since the terms are rather cumbersome. Since efficiency effects are excluded by the starting condition $s_B t_B = s_A t_A$, which means that small subsidy changes leave welfare unaltered, in total residents gain from car subsidies at the expense of landowners (who – as we have shown before – are clearly hurt). Additional subsidies for cars increase taxes, but reduce land prices. However, (39) implies that the rich gain since transport costs for the outermost car driver are higher than average transport costs. Thus we have shown:

Proposition 6 *Suppose that the poor live in the middle area and commute by bus, while the rich live either in the suburbs and commute by car or in the center and commute by bus. If landowners are absentee, subsidizing buses more heavily than cars will hurt the rich and subsidizing cars more heavily than buses will benefit the rich. The effects of subsidies on the poor are ambiguous.*

Although some high income earners use buses, the rich are hurt by higher subsidies for public transport which lead to larger subsidy payments for more people with longer commutes. Hence, those high income commuters who still drive by car suffer from higher taxes without any benefit (as follows from (39)), since land rents are unaffected (see figure 2). The poor, however, gain from subsidies but suffer from higher taxes.

With resident landownership one income class wins exactly what the other loses (still assuming that initially $s_A t_A = s_B t_B$):

$$\frac{\partial c_L}{\partial s_A} = \frac{n_H \phi_B t_A (w_H - w_L)[F_B - F_A + \phi_B n_L(w_L - w_H)]}{(n_H + n_L)[t_B + \phi_B w_H - t_A - \phi_A w_H]^2} = -\frac{n_H}{n_L}\frac{\partial c_H}{\partial s_A} < 0, \quad (48)$$

$$\frac{\partial c_L}{\partial s_B} = -\frac{t_B}{t_A}\frac{\partial c_L}{\partial s_A} = -\frac{n_H}{n_L}\frac{\partial c_H}{\partial s_B} > 0. \quad (49)$$

Thus, we have shown:

Proposition 7 *Suppose that the poor live in the middle area and commute by bus, while the rich live either in the suburbs and commute by car or in the center and commute by bus. If land is owned by all city residents in equal proportions, subsidizing buses more heavily than cars will benefit the poor at the expense of the rich, while subsidizing cars more heavily than buses will benefit the rich at the expense of the poor.*

Since welfare remains unchanged, the opposing interests of landowning residents follows immediately from (22). Furthermore, it is not surprising that subsidizing cars benefits the rich, since the poor use only public transport.

6 Conclusion

The paper has studied the incidence of subsidies to urban public and private transport in a setting with two income groups and endogenous mode choice. As shown by, e.g., LeRoy and Sonstelie [9] and Sasaki [10], there are many possible equilibrium patterns, and we have only used three of them to illustrate the possibilities here. In a more general model with variable housing consumption, the analysis would get much more complicated but also more realistic. We believe that the approach should be fruitful to examine urban transport policies in a unified framework, where mode choice and residence patterns are determined simultaneously.

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