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ABSTRACT

The Political Economy of Urban Transport System Choice

This Paper analyses the political economy of transport system choice, with the goal of gaining an understanding of the forces involved in this important urban public policy decision. Transport systems pose a continuous trade-off between time and money cost, so that a city can choose a fast system with a high money cost per mile or a slower, cheaper system. The Paper compares the socially optimal transport system to the one chosen under the voting process, focusing on both homogeneous and heterogeneous cities, while considering different landownership arrangements. The analysis identifies a bias toward over-investment in transport quality in heterogeneous cities.

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The Political Economy of Urban Transport-System Choice

by

Jan K. Brueckner and Harris Selod*

1. Introduction

A frequently heard criticism of local public policy in the US concerns the choice of transport systems. In particular, environmentalists and other activist groups often argue that US cities have overinvested in road transportation at the expense of public transit. They argue that urban residents would be better off if past transport investment had favored rail and bus systems, with less money spent on freeways. This argument has gained force recently with the emergence of urban sprawl as a policy issue. Critics argue that freeway investment has encouraged excessive spatial growth of US cities.[1]

Unfortunately, urban public economics provides almost no insight into the issues surrounding the choice of an urban transport system. Transport costs are viewed as exogenous in the typical urban model rather than being the result of a prior policy decision regarding the nature of the transport system. As a result, the above criticism of transport investment patterns is difficult to evaluate using existing models. To remedy this deficiency, the present paper proposes and analyzes a model where the transport system is chosen endogenously, with the choice carried out in the context of a simple urban general equilibrium framework. The goal of the analysis is to compare the socially optimal transport system to the one selected under the public-choice process.

While transport costs impose a direct burden on consumers, these costs also affect land rents in a general equilibrium model by determining the value of access to the city center. This land-rent impact creates several paths by which the transport system affects consumption. When land rent flows to absentee landowners living outside the city, a transport-induced change in rent affects just the cost of living for consumers. But when consumers are resident landowners, earning as income a share of the city's total land rent, transport-induced rent changes affect both living costs and incomes. Recognizing these differences, one goal of the analysis is to explore how landownership arrangements affect choice of the transport system.

Transport costs in the model have two components: money cost and time cost. The money cost per mile of travel, denoted t, captures the costs of road construction and automobile operation under a freeway system while representing the analogous construction and operating costs under a public transit system. Time cost, on the other hand, captures the value of the time spent in travel. It depends on the inverse of the transport system's speed, denoted ϕ, being equal to ϕ multiplied by the wage rate. The analysis rests on the fundamental assumption that ϕ is a decreasing function of t, so that the city faces a trade-off between time and money cost in choosing the transport system. To facilitate the analysis, this trade-off is viewed as continuous, with a continuum of transport systems corresponding to different combinations of t and ϕ available to the city. While this assumption is obviously unrealistic, it allows the choice between an expensive, fast freeway system and a cheap, slow bus system to be couched within a continuous optimization problem.

The discussion begins by analyzing transport-system choice in the benchmark case where city residents are homogeneous in their skill levels, thus earning uniform incomes. The analysis shows that the socially optimal system minimizes total transport cost (including time cost). The discussion then demonstrates that the political equilibrium coincides with the social optimum regardless of landownership arrangements. Under the political process, only the urban residents themselves have the right to vote, with absentee landowners (if they exist) having no voice in the city's transport decision.

With no divergence between the equilibrium and the optimum found in the homogeneous case, the analysis turns to the more realistic and complex case of a city with heterogeneous skills. Consumers (represented by a continuum) earn different incomes and thus have different time costs, which means that they have divergent interests in the choice of the transport system. The analysis again shows that the socially optimal system minimizes total transport cost. But consumer heterogeneity eliminates the previous equivalence between the social optimum and the political equilibrium. The analysis shows that, unless the distribution of skills is strongly skewed in the direction of high skills, the transport system chosen under the voting process is more expensive and faster than the socially optimal system. Thus, the paper identifies a bias toward transport overinvestment that matches the allegations of the above critics, who claim that the US has overinvested in freeways. This bias is shown to arise regardless of landownership arrangements, although the analysis demonstrates that, when overinvestment occurs, its extent is larger under resident landownership.

The overinvestment result is intimately tied to the model's explicit spatial structure, which is an appropriate feature of any model of transportation investment. That structure generates a demand function for transport "quality" that is concave in the skill level of the individual, and the analysis shows that this concavity in turn leads to an overinvestment bias.

While the analysis sketched above assumes that the city builds a single transport system, divergence of consumer interests in the heterogeneous case means that construction of several different systems may be welfare-improving. Through numerical examples, the discussion in the last section of the paper shows that two systems should be built when consumer heterogeneity is substantial or when the fixed cost of system construction is low.

Although the analysis in the paper provides the first full exploration of the political economy of transport-system choice, the model has several limitations that may reduce the general applicability of the results to real-world cities. First, the key simplification of fixed and uniform land consumption by consumers generates a location pattern in the heterogeneous model that does not match the US case. In particular, individuals with high skills (and thus high incomes) live close to the city center in the model, in contrast to the typical suburban location of high-income households in the US. Since the city under analysis thus bears a closer resemblance to a European city such as Paris than to the US case, using the results to validate criticisms of US investment transport patterns may not be entirely appropriate. As is well known, a US-style location pattern can be generated in a model with endogenous land consumption, where a high demand for land pulls high-income consumers toward the suburbs, where land is cheap. However, adding this endogeneity proved to be infeasible under the continuum structure of the heterogeneous model. Nevertheless, future work (perhaps numerical in nature) could attempt to analyze such a model.

A second limitation of the model is that the key result of transport overinvestment can be overturned under exactly the kind of skill (and hence income) distribution that characterizes real cities: one that is strongly skewed in the direction of high skills. However, given the highly stylized nature of the model, which involves a host of severe simplifications, focusing on this one issue of realism may involve misplaced emphasis. Rather, the results should be viewed as logically establishing the likelihood of transport overinvestment under a wide variety of skill distributions.

Before proceeding to the analysis, some discussion of the antecedents of this paper is useful. The idea of transport-system choice in the face of a continuous trade-off between time and money costs was first introduced and briefly analyzed by Brueckner (2003). Brueckner's paper in turn builds on the earlier work of LeRoy and Sonstelie (1983), who analyze an urban model where residents choose between two exogenously specified transport systems, one with a high money cost and low time cost, and another with the reverse characteristics. Starting from a situation where the city has just one transport system, LeRoy and Sonstelie's analysis shows that introduction of a more-expensive, faster system, which is adopted by high-income households but not by the poor, can lead to reversal in the city's pattern of location by income, with the rich relocating to the suburbs. The present analysis relies on LeRoy and Sonstelie's idea of money and time cost differences across transport systems, but it makes use of this trade-off in the choice of an optimal system.[2]

Like LeRoy and Sonstelie (1983), Sasaki (1989) shows how coexistence of two transport systems affects urban structure, although he assumes a homogeneous city. With the systems differentiated by fixed cost and variable cost per mile (the latter a composite of money and time costs), Sasaki shows that suburban residents favor the high-fixed-cost/low-variable-cost system, while their shorter commutes lead central-city residents to favor the system with the reverse characteristics. By contrast, Sasaki (1990) considers a city with two income groups and allows transport systems to be differentiated by variable money and time costs as well as by fixed costs. He carries out a comparative-static analysis to explore the effect on urban structure of changes in these parameters, but the problem of choosing an optimal transport system is not considered.

The plan of the paper is as follows. Section 2 analyzes the benchmark model with homogeneous urban residents. Section 3 analyzes the heterogenous model, while Section 4 analyzes the choice of two transport systems in the heterogeneous case. Section 5 offers conclusions.

2. The Benchmark Model

2.1. The setup and the social optimum

The analysis focuses on a linear city of unit width with an employment center (the CBD) at one end. Distance from the CBD is denoted by x. The city is inhabited by N identical residents, each of whom consumes a fixed land area, normalized at unity. With population and land consumption fixed, the area of the city is also fixed, with its edge located at distance N. The rent earned by the nonurban land is set equal to zero for simplicity.

In addition to land, urban residents consume a composite non-land good, denoted c, which is produced at the CBD by a constant-returns technology that uses labor as an input. Letting L denote the aggregate labor input (in effective units), the city's output equals yL, where $y > 0$. The labor market is competitive, so that the wage (per effective labor unit) is equal to y. The impact of the alternate assumption of decreasing returns in CBD production is considered below.

In the benchmark model, consumers have homogeneous skills, with each offering an effective labor input of e units (skill heterogeneity is introduced below). While a consumer would earn an income equal to ey in the absence of commuting, the time spent commuting to the CBD reduces actual income below this "full" income level. In the model, this reduction is achieved in the simplest possible way via the assumption that leisure time is fixed, so that an extra minute of commute time reduces work time by one minute.

To see how time cost is generated via this assumption, recall that since ϕ is the inverse speed of the transport system, a commute trip of x miles requires a time expenditure of ϕx minutes. Thus, with the total time available for work normalized at unity, work time for this commuter equals $1-\phi x$, and income equals $ey(1-\phi x) = ey - ey\phi x$. The last expression equals full income ey minus the value of time lost to commuting, $ey\phi x$, which represents time cost. Recognizing the potential work hours that are lost to commuting, the total labor input at the CBD equals the integral of $e(1 - \phi x)$ across the city's range of x values, as explained further below.

To finish the characterization of transport costs, recall that t equals the money cost of transport per mile. Since a commute trip of x miles thus entails a money cost of tx, total transport cost inclusive of time cost equals $(ey\phi + t)x$. Disposable income net of transport costs is thus given by $ey - (ey\phi + t)x$.

As made clear in the introduction, the purpose of the paper is to analyze choice of the transport system, taking the trade-off between time and money cost into account. Formally, this trade-off means that ϕ is a decreasing function of t, written $\phi(t)$. Thus, time cost falls as money cost rises, a consequence of the higher speed of a more-costly transport system. The inequalities $\phi' < 0$ and $\phi'' > 0$ then hold, with the latter condition implying that time cost decreases at a decreasing rate as t increases.

To begin the analysis, consider the choice faced by a planner in choosing the socially optimal transport system. Note first that the city's aggregate labor input is given by

$$L \;=\; \int_0^N e(1-\phi(t)x)dx \;=\; e(N \;-\; \phi(t)N^2/2). \tag{1}$$

In (1), recall that the edge of the city is located at $x = N$, that the city is one unit wide, and that population density is unity given unitary land consumption. The planner's goal is to choose the transport system to maximize the city's surplus S, which equals output yL minus aggregate money transport cost. This latter cost equals $\int_0^N txdx = tN^2/2$, or average money transport cost $(tN/2)$ times population. Thus, surplus is given by

$$\begin{aligned} S \;&=\; y[e(N-\phi(t)N^2/2)] \;-\; tN^2/2 \\ &=\; yeN \;-\; [ey\phi(t)+t]N^2/2. \end{aligned} \tag{2}$$

Note that the second line of (2) shows that surplus equals full output minus aggregate transport cost, including time cost.

To see that (2) is the correct welfare measure, recall that the opportunity cost of urban land equals zero. Therefore, the only resource cost incurred in generating the city's output is the money cost of transport, which must be subtracted from output to get surplus. In the equilibrium analysis below, it will be seen that S equals total urban consumption plus aggregate land rent, which further confirms the appropriateness of (2) as the welfare measure.

The socially optimal t, denoted t^*, maximizes surplus. But from (2), this goal is achieved by choosing t to minimize transport cost per mile, $ey\phi(t)+t$. The relevant first-order condition is $ey\phi'(t)+1=0$, and $\phi''>0$ ensures that the second-order condition is satisfied. Recalling that $\phi'<0$, the first-order condition can be usefully rewritten as

$$-ey\phi'(t) \quad = \quad 1, \tag{3}$$

which indicates that the marginal benefit from an increase in t, given by the LHS, equals its unitary cost. Indeed, the LHS of (3) can be viewed as the downward-sloping social demand curve for transport-system "quality," as measured by money cost. The optimal t is characterized by the intersection of this social demand curve with a horizontal line at height one, as shown by the upper curve in Figure 1 (e is set at a value e_m for comparison with later results).

The goal of the analysis is to compare the transport system chosen under a public-choice process to the socially optimal system characterized by (3). Before proceeding to this task, however, several general observations and qualifications regarding the model are useful. First, the money cost of transport should be interpreted in the broadest possible sense. For example, in the case of freeway travel, t should be viewed as including automobile operating costs along with the commuter's share of the annualized construction and maintenance costs of the roads used. For rail transit, t should be viewed as including the cost of train operations as well as the annualized construction costs of railroad tracks. For bus transit, t would include the cost of bus operations and an appropriate share of roadway costs.[3]

Another question concerns the presence of fixed costs. The above framework implicitly assumes that these costs are absent, with the total resource costs of the transport system equal to t times total passenger miles of travel, $\int_0^N x dx$. Alternatively, the transport system might involve a fixed cost of k for each mile of the network, with the variable costs that depend on total passenger miles representing a separate expenditure. The ensuing analysis is consistent with this alternate view under a particular assumption: the fixed cost k must be independent of t and thus independent of where the system lies along the money-cost/time-cost continuum. In this case, given that the transport system has a fixed length N, fixed costs represent a lump-sum amount kN that can be ignored in the choice of t. It should be noted, however, that fixed costs play a role in the problem considered in section 4, where the city is allowed to build two separate transport networks to serve a heterogeneous population. The question is then whether a second fixed cost is worth incurring.

2.2. The land-market equilibrium and the choice of t with absentee landownership

Having characterized the social optimum, the next step is to analyze the city's land-market equilibrium, with the goal of finding the t value selected by public-choice process. The initial focus is on the absentee-landowner case, where landowners live outside the city.

Letting $r(x)$ denote land rent at distance x, the consumer budget constraint is written

$$c \ + \ r(x) \quad = \quad ey \ - \ (ey\phi + t)x, \tag{4}$$

where the assumption of unitary land consumption is used (recall that c is nonland consumption). Since locational equilibrium requires that c be the same for all residents, it follows that land rent r must vary with location to offset differences in transport costs, implying that the relationship $r(x) - r(N) = (ey\phi + t)(N - x)$ must hold. But since $r(N)$, land rent at the edge of the city, must equal land's zero opportunity cost, it follows that

$$r(x) \quad = \quad (ey\phi + t)(N - x). \tag{5}$$

Land rent thus declines with x, offsetting the higher transport costs from more distant locations. Substituting (5) into (4), the equilibrium consumption level in the city equals

$$c \quad = \quad ey \ - \ (ey\phi(t) + t)N. \tag{6}$$

Thus, consumption equals disposable income of the city's edge resident.

As explained in the introduction, consumers dominate the public-choice process that determines the nature of the city's transport system. With population homogeneity, consumer interests in this process are identical, and they call for maximization of the consumption expression in (6). But this maximization requires choosing t to minimize transport cost per mile, $ey\phi(t)+t$, just as in the planner's problem. Therefore, with absentee landownership, the outcome of the political equilibrium is socially optimal, with t set at t^*.

2.4. The resident-landowner case

Aggregate land rent in the city, denoted R, is equal to

$$R \;=\; \int_0^N (ey\phi+t)(N-x)dx \;=\; (ey\phi+t)N^2/2, \tag{7}$$

where (5) is used. A key observation is that R is also equal to aggregate transport cost, which is given by

$$T \;\equiv\; \int_0^N (ey\phi+t)xdx. \tag{8}$$

This connection between land rent and transport cost reflects a general property of urban models first noted by Arnott and Stiglitz (1979).[4]

When landowners are absentee, a comparison of (6) and (7) reveals that their interests are diametrically opposed to those of consumers. While consumers, seeking maximal consumption, prefer the system that minimizes transport cost per mile, the resulting system minimizes the rental income of absentee landowners, thus constituting the worst possible outcome from their point of view. Instead, to raise the value of access to the CBD, absentee landowners want a high $ey\phi+t$ and hence an inefficient transport system, with t far away from the value that minimizes cost. Indeed, since R is an inverted U-shaped function, absentee landowners benefit from either high or low values of t. These preferences, however, are not registered in the political process, which is dominated by consumers.

This divergence of interests collapses when the city's land is owned by the residents themselves. Assuming that each individual earns a $1/N$ share of total land rent, the term R/N is then added to the consumption expression in (6). Using (7), this expression then reduces to

$$\widetilde{c} \;=\; ey \;-\; (ey\phi(t) + t)N/2. \tag{9}$$

The key implication of (9) is that consumers, acting as resident landowners, again choose t to minimize aggregate transport cost, so that the public-choice outcome again matches the social optimum. In this case, however, the equivalence is due to the exact coincidence of objectives. In particular, total consumption in the resident-landowner case, given by $N\widetilde{c}$ from (9), equals the surplus measure in (2), so that the objective function of resident landowners exactly matches that of the planner.

While this conclusion is natural, the optimality of equilibrium in the absentee landowner case is more noteworthy. In this case, (6) and (7) yield $S = Nc + R$, so that surplus equals total consumption plus aggregate land rent, as noted above. The objective functions of consumers (c, or Nc) and the planner (S) thus differ in this case, with the difference equal to aggregate land rent. Nevertheless, it is easy to see that, because consumer and landowner interests are diametrically opposed, c and S are both maximized at t^*.[5]

Summarizing the preceding discussion yields

Proposition 1. *In the homogeneous model, the political equilibrium is socially optimal under both absentee and resident landownership, with t chosen to minimize commuting cost per mile.*

3. A Model with Consumer Heterogeneity

3.1. The setup and the social optimum

With no divergence between the equilibrium and optimum found in a homogeneous city, the analysis now turns to a more-complex model where consumers are heterogeneous in their e values, exhibiting a distribution of labor skills. This model may offer a better representation of real-world cities, and in addition, it generates a new source of divergent interests in the choice of t. In particular, since skill differences generate income differences among consumers and hence differences in the time cost of transport, consumers themselves disagree over the characteristics of the preferred transport system.

As before, the first step in the analysis is to characterize the socially optimal transport system, taking consumer heterogeneity into account. To begin, let the support of the skill distribution be given by the interval $[\underline{e}, \overline{e}]$, and let $g(e)$ and $G(e)$ denote the density and cumulative distribution functions, respectively. Then, consider the assignment of consumers to locations within the city, which must be chosen optimally along with the transport system. The principle that emerges is as follows: residential distance should be inversely related to a consumer's skill, with high-e consumers located close to the CBD and low-e consumers located at greater distances. To establish this principle, suppose that some pair of consumers violates it, with consumer 1, who has a skill of e_1, located at x_1 and consumer 2, with a skill of $e_2 > e_1$, located at $x_2 > x_1$. The combined labor input from these two consumers equals $e_1(1 - \phi x_1) + e_2(1 - \phi x_2)$. However, if the locations of the consumers were switched, their combined labor input would be $e_1(1 - \phi x_2) + e_2(1 - \phi x_1)$, and the change would equal $\phi(e_2 - e_1)(x_2 - x_1) > 0$. The resulting labor-input gain indicates the suboptimality of the initial assignment, establishing that e and x must be inversely related. In effect, maximizing output at the CBD requires limiting the commute time of high-skill consumers.

This residential pattern also emerges in the equilibrium analyzed below, where the consumers with the highest skills and thus highest incomes live closest to the CBD. As is well known, this pattern can be overturned when land consumption is endogenous, with the high demand for land of high-income residents then pulling them toward suburban locations, where land is cheap. However, while endogenous land consumption would allow the emergence of this potentially more realistic location pattern, this modification makes analysis of the heterogeneous model infeasible (the consumer continuum is the source of the trouble). In any event, it can be argued that the pattern where high-income consumers live near the CBD is indeed realistic for some cities, with examples being Paris and some other cities in Europe.

With the most-skilled consumers living closest to CBD, the residential distance of a consumer with skill e, denoted $x(e)$, is given by

$$x(e) \quad = \quad N\int_{e}^{\overline{e}} g(v)dv \quad = \quad N(1 - G(e)), \tag{10}$$

which equals the number of people with skills greater than e. The labor supply of a type-e consumer is then $e[1 - \phi x(e)]$, so that the city's total labor input is given by

$$\begin{aligned} L \quad = \quad N\int_{\underline{e}}^{\overline{e}} e[1 - \phi x(e)]g(e)de \quad &= \quad e_m N - \phi N^2 \int_{\underline{e}}^{\overline{e}} e[1 - G(e)]g(e)de \\ &= \quad e_m N \ - \ \phi N^2 J, \end{aligned} \tag{11}$$

where (10) is used, $e_m = \int_{\underline{e}}^{\overline{e}} eg(e)de$ is the mean of e, and $J > 0$ represents the last integral in (11). Note that since $\phi N^2 J \equiv N\int_{\underline{e}}^{\overline{e}} e\phi x(e)g(e)de$ represents the potential labor input lost in transport time, the aggregate time cost of transport is equal to $y\phi N^2 J$.

Surplus is again equal to yL minus the total money cost of transport, which still equals $tN^2/2$. Thus, using (11)

$$S \quad = \quad ye_m N \ - \ [2Jy\phi(t) \ + \ t]N^2/2, \tag{12}$$

which equals full income minus aggregate transport cost, including time cost, as in (2).[6] As a result, maximizing S again requires minimizing aggregate transport cost, and the appropriate condition is

$$-2Jy\phi'(t) \quad = \quad 1. \tag{13}$$

Note that society's demand curve for transport quality, as represented by the LHS of (13), involves a different skill term ($2J$) than in the homogeneous case (compare (3)). It is thus interesting to compare the resulting t^* values for the two cases, assuming that the common skill level in the homogeneous city equals e_m, the heterogeneous mean. Since the appendix shows that $2J < e_m$, it follows that the social demand curve for transport quality is lower in a heterogeneous city than in a homogeneous city where skills equal the heterogeneous mean (the latter curve is $-e_m y\phi'(t)$). The result is a smaller t^* value in the heterogeneous city, as illustrated in Figure 1. The intuitive reason is that the short commutes of high-skill consumers reduce the need to conserve on time costs in the heterogeneous city, yielding a transport system that is cheaper and slower than in the homogeneous city.

3.2. Characterizing the land-market equilibrium

Having analyzed the social optimum, the next step is to characterize the land-market equilibrium of the heterogeneous city, a task that is more involved than in the homogeneous case. The central idea, following the approach of Brueckner, Thisse and Zenou (2002) and Selod and Zenou (2003), is that consumption levels must vary with e in such a way that the individual with a particular e value offers the highest bid for the land at $x(e)$, where he must reside. The initial analysis focuses on the absentee-landowner case.

Letting $c(e)$ denote the consumption level for an individual with a given e value, the land rent he offers at location x is given by (see (5))

$$r(x, e) \;=\; ey \;-\; (ey\phi + t)x \;-\; c(e). \qquad (14)$$

Note first that, for a given e, this land rent function is linear in x and has slope equal to $-(ey\phi + t)$, indicating that the curve's slope is steeper (more negative) the larger is e. It follows that, if a particular high-e individual is the highest bidder for a plot of land, that land must be located at a low x value, and conversely for a low-skill individual. If their locations were reversed, the high-skill individual could outbid the low-skill person for his land and vice versa. The location pattern that must prevail in equilibrium thus matches the social optimum, with the type-e individual living at $x(e)$.

In order for this pattern to emerge, however, the individual with a given e must actually bid more for the land at $x(e)$ than anyone else. This requirement means that, holding x fixed at $x(e)$, the maximum of $r(x(e), e')$ must be reached at $e' = e$. Thus, $\partial r(x, e)/\partial e$ evaluated at $x = x(e)$ must equal zero, and differentiating (14), it follows that

$$y \;-\; y\phi x(e) \;-\; c'(e) \;=\; 0 \qquad (15)$$

must hold. Eq. (15) is a differential equation involving the unknown function $c(e)$. Rewriting (15) as $c'(e) = y - y\phi x(e) = y - y\phi N(1 - G(e))$ and integrating yields

$$c(e) \;=\; ey(1-\phi N) \;+\; y\phi N\int_{\underline{e}}^{e} G(v)dv \;+\; b, \tag{16}$$

where b is a constant.

The constant b is determined by the requirement that land rent at the edge of the city equals zero. Substituting (16) into (14), setting $x = N$ and $e = \underline{e}$ (the skill level of the edge resident), and equating (14) to zero yields $b = -tN$. Therefore, after rearranging (16),

$$c(e) \;=\; ey \;-\; (ey\phi + t)N \;+\; H(e)y\phi N, \tag{17}$$

where

$$H(e) \;=\; \int_{\underline{e}}^{e} G(v)dv. \tag{18}$$

Note that (17) equals the consumption expression for the homogeneous city plus an extra term involving the distribution of skills. Observe also that consumption is increasing in the skill level e, and that $c(e)$ is a strictly convex function. The latter fact follows from strict convexity of $H(e)$, which yields $c''(e) = y\phi NH''(e) = y\phi Ng(e) > 0$.

Convexity of $c(e)$ is a key consequence of the model's spatial structure, in particular, the short commutes of high-skill consumers. While disposable income (and hence consumption) rises linearly with e holding residential location fixed, the fact that $x(e)$ declines with e means that consumption rises with e at an increasing rate.[7]

3.3. Preferred t values

The analysis in section 2 showed that, when consumers are homogeneous, their preferred t minimizes the common transport cost per mile, $ey\phi(t) + t$. How does the outcome differ in a heterogeneous city with absentee landowners? Differentiation of (17) shows that the preferred t of a consumer with skill level e satisfies

$$-[e - H(e)]y\phi'(t) \;=\; 1, \tag{19}$$

with the LHS expression giving the individual demand curve for transport quality. Note that $e - H(e)$ is positive, a consequence of the facts that the expression equals $\underline{e} > 0$ for $e = \underline{e}$ and is increasing, with derivative $1 - G(e) \geq 0$.

The demand function in (19) exhibits two key features. First, since $H''(e) > 0$, $e - H(e)$ is strictly concave, so that, for a given t, demand is a strictly concave function of e. This feature mirrors the convexity of $c(e)$, which is in turn due to the model's spatial structure.

The second key feature comes from noting that $[e - H(e)]y$ is less than ey for $e > \underline{e}$. Since a consumer seeking to minimize his own transport cost would choose t to satisfy $-ey\phi'(t) = 1$, (19) yields

Proposition 2. *The preferred transport system of an interior resident in a heterogeneous city has a lower t than the one that minimizes his own transport cost.*

The source of this result lies in the operation of the land market. To understand this point, note first that the land rent function for the city is the convex upper envelope of the continuum of linear land rent curves of the various residents, as should be clear from the derivation above.[8] The land rent paid by a resident living at location $x' < N$ then depends on the average slope of this convex envelope curve as it rises away from zero at the city's edge, approaching his interior residential location. A steep average slope, resulting from steep individual slopes for the underlying linear curves of the residents living outside x', yields a high land rent for the x' resident. But the steepness of these individual curves depends positively on the outer residents' transport costs, which are in turn determined by t (recall that the land-rent slope equals $-(ey\phi(t) + t)$ for a type-e individual). To moderate the land rent that he pays, the x' resident would thus like to limit these outer costs, while still paying attention to his own transport cost. But, given their lower e's, the outer residents have cost-minimizing t's lower than that of the x' resident. Therefore, with an eye on the outer costs, the x' resident chooses a t smaller than the one that minimizes his own transport cost.

Note that this logic does not apply to the city's edge resident, who has no one living outside him. The edge resident's preferred t should thus reflect only his own income, a conclusion that can be verified in (19) by noting that $H(\underline{e}) = 0$. Note also that, since $H(e)$ is increasing in

e, the "wedge" between ey and the corresponding term in (19) rises as e increases, reflecting the fact that high-e residents (who live near the center) have many outsiders whose transport costs affect the land rent they pay.

3.4. Comparing the voting equilibrium to the social optimum

Because $e - H(e)$ is increasing in e, it follows from (19) that an individual's preferred t rises with his skill level. Thus, consumers have divergent interests in the choice of the transport system, which must be resolved through a majority-voting process.

As is well known, voting equilibria with heterogeneous consumers need not yield a socially optimal outcome, and the goal of the ensuing analysis is to investigate this potential for inefficiency in the present model. The first step is to identify the median voter. Since a consumer's preferred t rises with e, the median voter is the individual with the median skill level, denoted $\widehat{e}$. The median voter's preferred t, denoted $\widehat{t}$, thus satisfies

$$-[\widehat{e} - H(\widehat{e})]y\phi'(t) \quad = \quad 1. \tag{20}$$

To evaluate the optimality of the voting equilibrium, the $\widehat{t}$ given by (20) must be compared to the socially optimal value t^*, which satisfies $-2Jy\phi'(t) = 1$ from (13). This comparison is eased by writing the social optimality condition in a different form, using the fact (established below) that the social optimum in the absentee landowner case maximizes the total consumption of urban residents, just as in the homogeneous model. Given this fact, the heterogeneous social optimum maximizes total consumption, given by $N(e_m y \; - \; (e_m y\phi + t)N \; + y\phi N \int_{\underline{e}}^{\overline{e}} H(e)g(e)de)$ using (17) (recall that e_m is the mean skill level). The first-order condition for choice of t^* can then be written

$$-\left[e_m - \int_{\underline{e}}^{\overline{e}} H(e)g(e)de\right] y\phi'(t) \quad = \quad 1, \tag{21}$$

where the LHS expression represents an alternate representation of the social demand for transport quality. Because the term multiplying $y\phi'(t)$ can be shown to equal $-2J$, as shown in the appendix, (21) is the same as the social optimality condition $-2Jy\phi'(t) = 1$.

The fact that (20) and (21) both involve the function H facilitates a comparison of $\widehat{t}$ and t^*. To proceed, recall that $e - H(e)$ is a strictly concave function, making the individual demand function for transport quality concave in e. Using Jensen's inequality, it then follows that $e_m - H(e_m) > e_m - \int_{\underline{e}}^{\overline{e}} H(e)g(e)de$. Moreover, since $e - H(e)$ is increasing, $\widehat{e} - H(\widehat{e}) \geq e_m - H(e_m)$ holds provided that $\widehat{e} \geq e_m$. Thus, $\widehat{e} - H(\widehat{e}) > e_m - \int_{\underline{e}}^{\overline{e}} H(e)g(e)de$ holds when $\widehat{e} \geq e_m$, yielding

Proposition 3. *If the median $\widehat{e}$ of the city's skill distribution is at least as large as the mean e_m, then the voting equilibrium in the absentee-landowner case yields a value of t larger than the socially optimal value. Thus, the city's chosen transport system is more expensive and faster than the socially optimal one.*

A review of the steps leading to Proposition 3 shows that the comparison of $\widehat{t}$ and t^* is ambiguous when $\widehat{e} < e_m$. However, the inequality $\widehat{e} - H(\widehat{e}) > e_m - \int_{\underline{e}}^{\overline{e}} H(e)g(e)de$ will continue to hold, and the conclusion of Proposition 3 will remain valid, for skill distributions where $\widehat{e}$ does not lie too far below e_m. Thus, as long as the skill distribution is not excessively skewed in the direction of high skills, overinvestment in transport-system quality seems likely to occur. This conclusion is documented below using some numerical examples.

By showing that $\widehat{t} > t^*$ holds when $\widehat{e} \geq e_m$ and that the inequality may also hold in cases where $\widehat{e} < e_m$, the analysis effectively identifies a bias toward overinvestment in transport quality. This conclusion matches the allegations of critics who argue that the US has overinvested in freeways at the expense of public transit. It is important, however, to identify the intuitive basis for this bias, and the following discussion may be useful in this regard.

Consider first an alternative heterogeneous model where commute distance is the same for all consumers (everyone may live, for example, in a compact suburb remote from the employment center). In such a model, which is effectively nonspatial in nature, the socially optimal t would be chosen to minimize mean commuting cost per mile, satisfying $-e_m y\phi'(t) = 1$, while the t chosen in the voting equilibrium would satisfy $-\widehat{e}y\phi'(t) = 1$. In this case, $t^* > (<)\, \widehat{t}$ would hold when $e_m > (<)\, \widehat{e}$, with $t^* = \widehat{t}$ holding when $e_m = \widehat{e}$. Thus, the chosen t would be too small (too large) when the skill distribution is skewed toward high (low) skills, a conclusion that mirrors textbook discussions of how over or underprovision of a public good depends on the skewness of the demand distribution.

This standard conclusion arises because, in this alternate model, the individual demand for transport quality, captured in the demand curve $-ey\phi'(t)$, is a linear function of e. The key difference in the present model, however, is that individual demand, given by $-[e-H(e)]y\phi'(t)$, is a concave function of e. As noted above, this feature reflects the convexity of the function $c(e)$, which is a consequence of the model's spatial structure (in particular, the short commutes of high-skill workers). With concave individual demands, the social demand curve for transport quality, given by the mean demand curve $-[e_m - \int_{\underline{e}}^{\overline{e}} H(e)g(e)de]y\phi'(t)$, lies below the demand curve of the consumer with mean skills, $-[e_m - H(e_m)]y\phi'(t)$, as demonstrated earlier. This outcome, which is shown in Figure 2, constrasts with the alternate case above, where these two demand curves coincide.

Given the divergence shown in Figure 2, the case where the median demand curve lies above the mean-voter's curve (a consequence of $\widehat{e} > e_m$) clearly leads to overinvestment in transport quality ($\widehat{t} > t^*$), as seen in the figure. The crucial observation, though, is that this same outcome can occur in cases where the skill distribution has $\widehat{e} < e_m$ but is not excessively skewed in the direction of high skills. Such a case leads to a median-voter demand curve that lies *between* the mean-voter's curve and the social demand curve in Figure 2. In this case, overinvestment in transport quality occurs even though the skill distribution exhibits high-skill skewness.

To explore such cases, numerical examples based on the gamma and lognormal distributions were generated. While the lognormal distribution is always skewed in the direction of high skills, the gamma distribution exhibits such skewness when its two parameters are chosen appropriately. Calculations showed that for all the chosen gamma parameter combinations leading to high-skill skewness, the median demand curve in Figure 2 remained above the social demand curve, leading to $\widehat{t} > t^*$ and overinvestment in transport quality. By contrast, for all lognormal parameter combinations, the median curve was lower than the social curve, leading to $\widehat{t} < t^*$ and underinvestment in transport quality. However, since the lognormal density tends to be more skewed than the gamma density (an example is shown in Figure 3), this outcome matches the above claim that transport overinvestment occurs unless the skill distribution is strongly skewed in the direction of high skills.

3.5. The effect of resident landownership

The next step in the analysis is to investigate how switching from absentee to resident landownership affects the previous results. Accordingly, suppose that a type-e individual owns an exogenous share $s(e) < 1$ of the city's land area, with $N\int_{\underline{e}}^{\overline{e}} s(e)g(e)de = 1$. It easily shown that, with resident landownership, the only change in the model is the addition of rental income, given by $s(e)R$, to the consumption expression in (17). As before, R is equal to aggregate transport cost, which is represented by the second term in the surplus expression (12). Thus,

$$R \quad = \quad (2Jy\phi(t) + t)N^2/2. \tag{22}$$

Since consumption from (17) is a concave function of t while R in (22) is convex, the curvature of the consumption expression that includes $s(e)R$ is ambiguous. However, provided $s(e)$ is small for all e, a natural assumption, the concavity of (17) will dominate, making the new consumption expression a strictly concave function of t. The first-order condition for choice of t then identifies the preferred value for a type-e individual, and it is given by

$$-[e - H(e)]y\phi'(t) \quad + \quad s(e)(2Jy\phi'(t) \ + \ 1)(N/2) \quad = \quad 1, \tag{23}$$

where the first expression is the previous demand for transport quality and the second expression is the derivative of rental income with respect to t.

If $s'(e) = 0$, so that the urban residents own equal shares of the city's land, then differentiation of (23) shows that the preferred t rises with e, implying that the median voter has $e = \widehat{e}$, as before. However, for any other pattern of landownership, the identity of the new median voter is ambiguous.

Despite this limitation, useful information can be inferred from (23), as follows. Consider an individual whose preferred t in the absentee-landowner model was above t^*. Recognizing that the second expression in (23) is positive above t^* (see (13)), it follows that, when the LHS of (23) is evaluated at the individual's old preferred t, where the first term equals zero, the expression is positive. As a result, each individual whose preferred t exceeded t^* under absentee landownership prefers a larger t under resident landownership. Conversely, each individual whose preferred t lay below t^* in the absentee case now prefers a smaller t. Summarizing yields

Proposition 4. *Resident landownership increases the dispersion around t^* of consumers' preferred t values, relative to the absentee case.*

Recognizing that rental income, which now accrues to consumers, rises as t moves away in either direction from the social optimum, the proposition makes intuitive sense. Each consumer's incentive to increase rental income pushes his preferred t away from t^*.

To develop the implications of this conclusion, let $\breve{t}$ denote the median preferred t under resident landownership, which is the level chosen in the resulting voting equilibrium. Then Proposition 4 yields

Corollary. *If $\widehat{t}$ exceeds t^*, then $\breve{t}$ satisfies $t^* < \widehat{t} < \breve{t}$. If $\widehat{t} < t^*$ holds, on the other hand, then $\breve{t} < \widehat{t} < t^*$.*

This result implies that, if the median preferred t exceeds (falls short of) t^* under absentee landownership, then the same conclusion holds under resident landownership. Moreover, resident landownership amplifies any difference between the voting equilibrium and the social optimum. To establish the first part of the corollary, suppose that $\widehat{t} > t^*$. Then note that, since all the preferred t's lying above t^* rise in moving from absentee to resident landownership given Proposition 4, more than half of the population now has its preferred t above $\widehat{t}$. As a result, the new median preferred t is larger than $\widehat{t}$ and thus larger than t^*. The same argument establishes the second part of the corollary.

Recalling from Proposition 3 that $\widehat{t} > t^*$ holds when $\widehat{e} \geq e_m$, and that $\breve{t} > \widehat{t} > t^*$ in this case, the following conclusion emerges:

Proposition 5. *If consumers are resident landowners and $\widehat{e} \geq e_m$, then $\breve{t}$ exceeds t^*. The chosen transport system under resident landownership is then faster and more expensive than the optimal one. Moreover, overinvestment in transport quality is more pronounced than under absentee landownership, with the chosen t lying farther above t^* than the absentee case.*

As before, this conclusion is likely to hold when $\widehat{e} < e_m$ provided that $\widehat{e}$ does not lie too far below e_m.

Proposition 5 shows that the conclusions of Proposition 3 continue to hold under resident landownership. Thus, regardless of landownership arrangements, a bias toward overinvestment in transport quality arises, with the chosen t exceeding t^*, unless the skill distribution is strongly skewed in the direction of high skills. In addition, Proposition 5 establishes that the impact of this overinvestment bias is more severe under resident landownership.

4. Building Two Transport Systems

Consumers in the heterogeneous model have divergent interests, with the various skill types wanting different combinations of time and money cost in the transport system. By assuming that the city has just one system, the analysis has ruled out a possible means of addressing this diversity: construction of multiple transport systems. Several systems do indeed coexist in most cities, with extensive public transit systems often complementing freeway networks. As a result, it is of interest to investigate the system-choice problem when multiple transport systems are allowed.

The fixed cost of the transport system was suppressed in the preceding analysis, a permissible step under the assumption that any fixed costs are independent of t and ϕ. However, when multiple transport systems are allowed, consideration of fixed costs is crucial. The key question is then whether a better tailoring of system characteristics to consumer preferences, made possible by construction of multiple transport systems, is worth the additional fixed costs involved.

To investigate this trade-off, suppose that construction of any transport system requires a fixed cost of k per mile. Thus, the single transport system in the previous model, which extends to the edge of the city, requires a fixed cost of kN. Suppose in addition that the city contemplates building two transport systems. One system serves the low-skill individuals living in the outer part of the city, and as a result, it must extend from the CBD all the way to the city's edge, at a cost of kN. The other system serves the city's high-skill residents, and it extends from the CBD to some intermediate distance $\widetilde{x}$, at a cost of $k\widetilde{x}$. The analysis takes the perspective of a planner, asking what configuration of transport systems is socially optimal. Possible equilibrium outcomes are briefly considered below.[9]

The planner's goal is to minimize aggregate transport cost. To write the appropriate cost expression, let $e(x)$ denote the skill level of the individuals living at x. This function is the inverse of $x(e)$ in (10), being given by $e(x) \equiv G^{-1}(1-x/N)$. Letting the two transport systems be denoted by 0 and 1, aggregate transport cost equals

$$\int_0^{\widetilde{x}} (e(x)y\phi(t_0)+t_0)xdx \ + \ \int_{\widetilde{x}}^{N} (e(x)y\phi(t_1)+t_1)xdx \ + \ k\widetilde{x} \ + \ kN. \tag{24}$$

The first-order conditions for t_0 and t_1 are

$$\int_0^{\widetilde{x}} (e(x)y\phi'(t_0)+1)xdx \ = \ 0 \tag{25}$$

$$\int_{\widetilde{x}}^{N} (e(x)y\phi'(t_1)+1)xdx \ = \ 0, \tag{26}$$

which can be reduced to a form analogous to (13) with suitable manipulation. Given $e'(x) < 0$, it can be shown using (25) and (26) that $t_0 > t_1$ must hold at the optimum.[10] Therefore, the transport system in the center is a costly, fast system while the one extending to the city's edge is cheaper and slower. While this pattern is not realistic for US cities, it does match the existing transport investments in cities elsewhere, notably Paris.[11]

The first-order condition for choice of $\widetilde{x}$ is

$$(e(\widetilde{x})y\phi(t_0) \ + \ t_0)\widetilde{x} \ - \ (e(\widetilde{x})y\phi(t_1) \ + \ t_1)\widetilde{x} \ + \ k \ = \ 0. \tag{27}$$

This condition states that $\widetilde{x}$ is optimal when the saving in transport cost from switching the individual at $\widetilde{x}$ to system 0 from system 1 (the negative of the first two terms) equals the cost k of the required marginal extension of system 0.

Insight into the nature of the solution to this choice problem comes from noting that the LHS of (27) is positive at $\widetilde{x} = 0$, being equal to k. Therefore, as system 0 is initially extended away from the CBD, aggregate transport cost rises. If construction of system 0 is ever to be optimal, aggregate cost must eventually start to fall with further extension of the system, ultimately dropping below the cost level at $\widetilde{x} = 0$ (where only system 1 exists). Therefore, system 0 must be extended an appreciable distance in order for its construction to be desirable.

Given this feature of the objective function for the system-choice problem, generation of additional insights must rely on simulation analysis. Accordingly, suppose that $\phi(t) = t^{-2}$, that skills are uniformly distributed, with $\underline{e} = 1$ and $\overline{e} = 5$, and that $y = 10$, $k = 0.1$, and $N = 1$. Using these assumptions, (25) and (26) are solved for t_0 and t_1 as functions of $\widetilde{x}$, and the results are substituted into the aggregate transport cost expression in (24). The graph of the resulting expression, which is a function of $\widetilde{x}$, is shown in Figure 1. As can be seen, construction of system 0 is not warranted under the given parameter values, with transport costs rising monotonically as $\widetilde{x}$ increases.

Since divergence of consumer transport preferences provides the rationale for construction of a second system, an increase in this divergence may overturn the negative verdict of Figure 4. This conjecture is confirmed in Figure 5, which shows aggregate transport cost when $\overline{e}$ is raised from 5 to 20. As can be seen, construction of system 0 is now desirable, with its optimal length being 0.69 (the system thus extends over 69 percent of the city). Since $t_0/t_1 = 1.44$, system zero has a money cost 44 percent greater than that of system 1. However, the system is more than twice as fast, with $\phi(t_0)^{-1}/\phi(t_1)^{-1} = 2.07$.

A reduction in fixed cost can also overturn the verdict of Figure 4. When $\overline{e}$ is set at its original value of 5 but k is reduced from 0.1 to 0.04, construction of system 0 is again optimal, as can be seen from a figure that looks very similar to Figure 5. The optimal $\widetilde{x}$ equals 0.59, $t_0/t_1 = 1.25$, and system 0 is 57 percent faster than system 1.

While these results demonstrate the potential desirability of multiple transport systems, it is interesting to consider some equilibrium issues. The first observation is that, in order to support the optimum, the marginal user of system 0 must pay a user fee of k, which makes him indifferent between the transport systems. Without such a payment, consumers will not split between the systems in the manner intended by the planner.[12]

The second observation concerns a realistic scenario for construction of a second transport system, which might proceed as follows. A single system might be built first, with the choice process as described in section 3. Then, the high-skill individuals may decide to "opt out," building a system to serve themselves. With the marginal individual paying a user cost of k, the first-order condition would be the same as (27), but t_1 would now represent the t value of the pre-existing system, which was designed to serve the entire population. Obviously, the resulting outcome is not optimal.

5. Conclusion

This paper has analyzed the political economy of transport-system choice, with the goal of gaining an understanding of the forces involved in this important urban public policy decision. The analysis shows that, when the city is homogeneous, the chosen transport system is socially optimal regardless of landownership arrangements. The equivalence disappears, however, in a skill-heterogeneous city, with the chosen transport system being more expensive and faster than the optimal system as long as the skill distribution is not strongly skewed in the direction of high skills. While this conclusion holds regardless of landownership arrangements, transport overinvestment (when it occurs) is more pronounced under resident landownership.

These results are intimately tied to the heterogeneous model's spatial structure. In particular, the central location of high-skill individuals implies that the individual demand for transport quality is concave in skills, a property that in turn leads to an overinvestment bias.

Since the models analyzed in the paper are highly stylized, the conclusions reached are at best suggestive. However, the analysis provides a starting point for more realistic treatments of the transport-choice problem. As discussed above, one improvement would be to relax the assumption that land consumption is fixed and uniform across consumers, which could potentially generate a US-style location pattern rather than the European pattern that emerges from the model. Brueckner (2003) has made some progress in this direction by analyzing a system-choice model with two income groups, but the assumption of Leontief preferences is needed to make the analysis tractable. As explained earlier, adding endogenous land consumption to a model with a skill continuum appears to be analytically infeasible, although a numerical approach may be possible.

Another improvement would involve relaxation of the model's fixed-leisure assumption, allowing time costs to be generated as a byproduct of an endogenous labor-leisure choice. It can be shown that when consumers have Cobb-Douglas preferences over consumption and leisure, the equilibrium utility in the heterogeneous model equals the previous consumption expression (17) divided by $(ey)^{\lambda}$, where λ is the leisure exponent in the Cobb-Douglas function. As a result, some of the conclusions of section 3 will continue to hold when leisure is endogenous.

Finally, relaxation of the assumption of constant returns in the CBD production process creates a new stakeholder group: firm owners. While profits were previously zero, profits under decreasing returns are positive and increasing in total labor supply. As a result, firm owners (who were previously indifferent to the magnitude of t) now benefit from the fastest possible transport system, which delivers the largest labor supply to the CBD. In addition, knowing that a slower, cheaper system raises the wage by depressing CBD labor supply, consumers now prefer a smaller t than before. These effects are straightforward to analyze in the homogeneous model.

Further work on such extensions of the model would be useful. Generally, any additional research that provides insight into the important and understudied problem of transport-system choice would be worthwhile.

Appendix

Proof of the equivalence of (21) and (13)

Equality of the bracketed term in (21) and $2J$ requires

$$e_m \;-\; \int_{\underline{e}}^{\overline{e}} H(e)g(e)de \;\;=\;\; 2J \;\;=\;\; 2e_m \;-\; 2\int_{\underline{e}}^{\overline{e}} eg(e)G(e)de. \qquad (a1)$$

Using integration by parts to simplify the integral on the RHS of $(a1)$ yields

$$2\int_{\underline{e}}^{\overline{e}} eg(e)G(e)de \;\;=\;\; \overline{e} \;-\; \int_{\underline{e}}^{\overline{e}} G(e)^2 de. \qquad (a2)$$

As a result, $(a1)$ requires

$$-\int_{\underline{e}}^{\overline{e}} H(e)g(e)de \;\;=\;\; e_m \;-\; \overline{e} \;+\; \int_{\underline{e}}^{\overline{e}} G(e)^2 de. \qquad (a3)$$

Integrating by parts, the LHS of $(a3)$ equals

$$-H(\overline{e}) + \int_{\underline{e}}^{\overline{e}} G(e)^2 de, \qquad (a6)$$

and integration by parts shows that $H(\overline{e}) = \int_{\underline{e}}^{\overline{e}} G(e)de = \overline{e} - e_m$, establishing $(a3)$. Note finally that $(a1)$ yields $2J < e_m$.

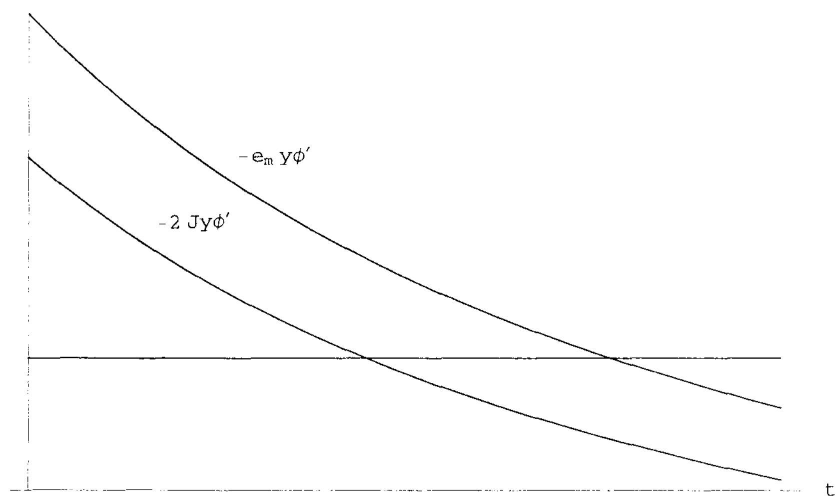

Figure 1 : Social Demand Curves for Transport Quality

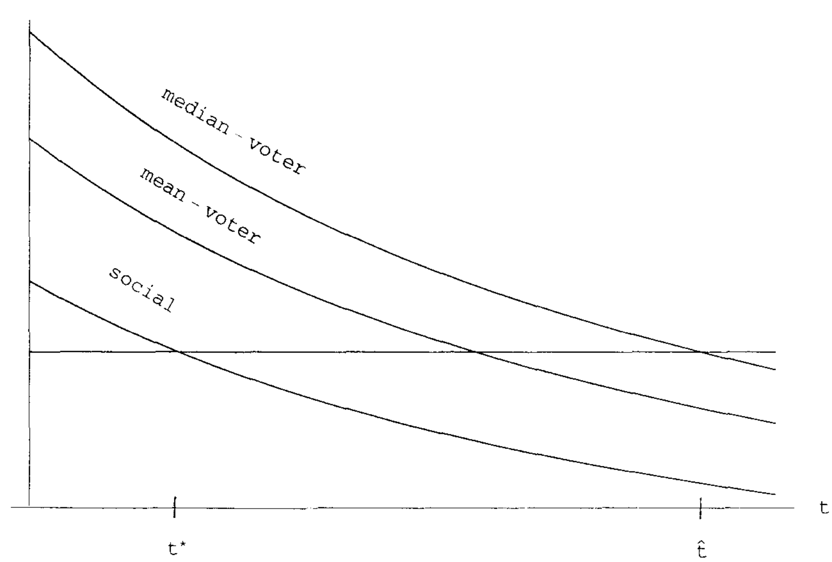

Figure 2 : Voting Equilibrium

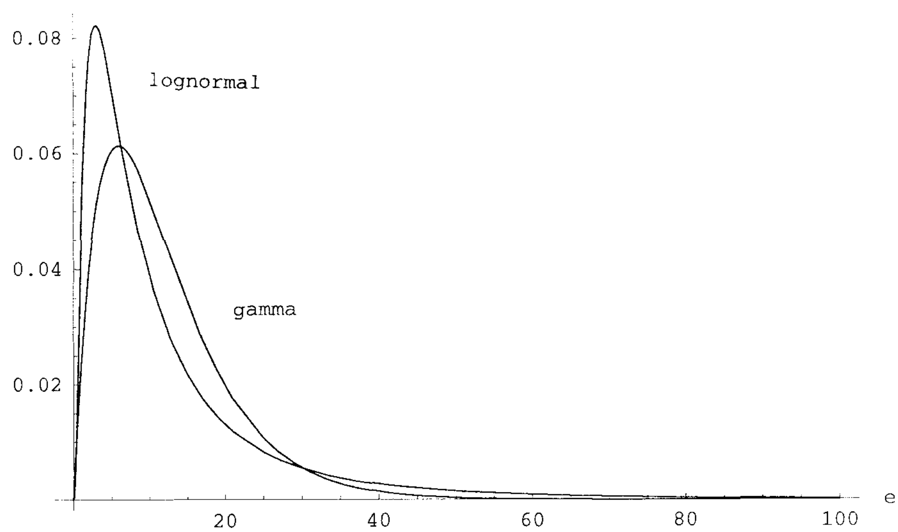

Figure 3 : Gamma and Lognormal Distributions

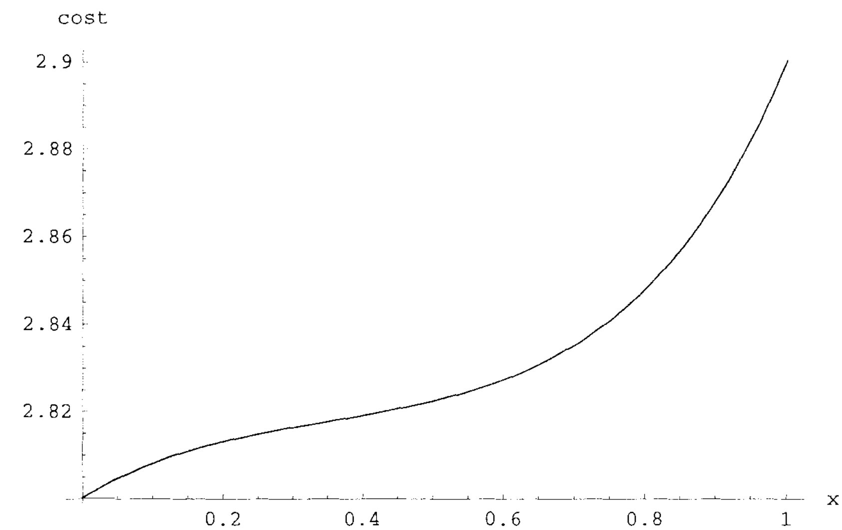

Figure 4 : Low Skill Dispersion, High Fixed Cost

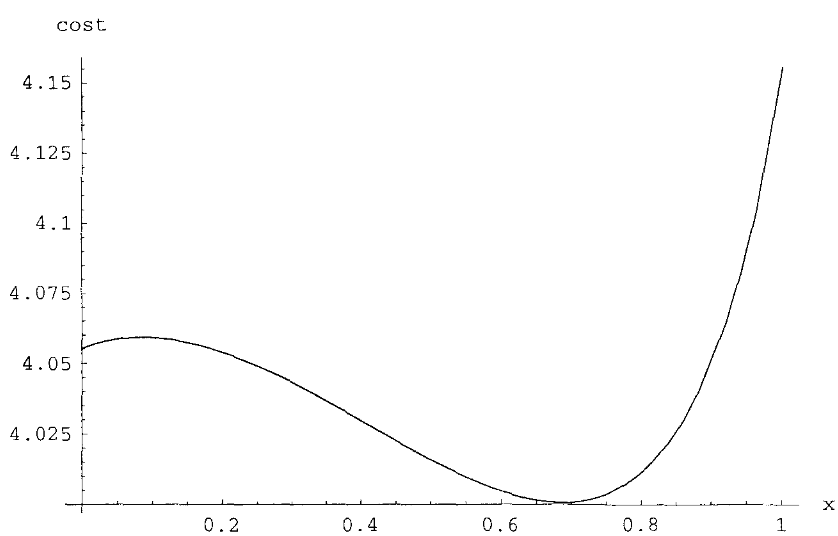

Figure 5 : High Skill Dispersion, High Fixed Cost

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Footnotes

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[1]For an excellent overview of the debate on sprawl, where such ideas can be found, see the urban sprawl symposium in the Fall 1998 issue of the *Brookings Review*.

[2]DeSalvo and Huq (1996) analyze a model where a transport mode's money cost effectively depends on its speed, as in the present analysis (their presentation, however, makes this similarity hard to see). Their analysis focuses solely on the mode choice question, without putting the problem into a spatial setting.

[3]In order for all of these costs to be incorporated in t, the transport network must levy user fees that fully cover its true resource costs. In reality, of course, this assumption is not fulfilled, with public transit fares covering only a share of system costs and gasoline taxes failing to cover the full cost of roads. The resulting transport subsidies must be financed from general tax revenue, which would require subtraction of an additional lump sum amount, representing a tax liability, to get the appropriate disposable income expression above. Since Brueckner (2003) has already analyzed the impact of transport subsidies in a related model, this issue is skirted in the present analysis by assuming that the user fees embodied in t fully reflect the resource costs of the transport system. However, subsidies could be incorporated in the present analysis without much difficulty.

[4]In a circular city, however, R equals one-half aggregate transport cost.

[5]In the absentee landowner case, the dominant role of consumer interests in determining the behavior of surplus can be seen as follows. From the consumer budget constraint, total consumption is equal to total full income minus aggregate transport cost (including time cost) minus aggregate land rent. Since aggregate land rent equals aggregate transport cost, total consumption then equals total full income minus *twice* aggregate transport cost, so that the consumer goal is to minimize the latter. Surplus, which is found by adding aggregate land rent (and hence aggregate transport cost) to total consumption, thus equals total full income minus aggregate transport cost. Society's goal is thus to minimize the latter quantity, matching the goal of consumers.

[6]As in the benchmark model, it can be shown that this surplus measure equals total consumption plus aggregate land rent, as derived below.

[7] To see this point more clearly, rearrange (14) to yield $c(e) = ey - (ey\phi + t)x(e) - r(x(e), e)$, so that differentiation gives $c'(e) = y(1-\phi)x(e) - x'(e)(ey\phi + t + \partial r/\partial x) - \partial r/\partial e$. Since the term multiplying $x'(e)$ is zero, as is $\partial r/\partial e$, $c'(e)$ reduces to the first term. Thus, because of the operation of the land market, $c'(e)$ equals the derivative of disposable income with x held fixed. As a result, $c''(e) = -y\phi x'(e) > 0$, so that convexity of c follows from the fact that $x(e)$ is decreasing. Note, by the way, that positivity of $c''(e)$ ensures that the first-order condition in (15) yields a maximum (with x held fixed).

[8] To establish the convexity of land rent, note that equilibrium rent as a function of x is given by $r(x, e(x))$ using (14), where $e(x)$ is the inverse function of $x(e)$. The derivative of r with respect to x then equals $\partial r/\partial x + (\partial r/\partial e)e'(x)$. Since the second term is zero from above, this derivative reduces to the first term, which equals $-(e(x)y\phi + t)$. Thus, land rent's second derivative with respect to x equals $-e'(x)y\phi > 0$, where the inequality follows from $e'(x) < 0$. Land rent is therefore a convex function of x.

[9] Note that commute trips are made on a single transport system, without switching from one to the other.

[10] To establish this point, note that since $e'(x) < 0$, the terms $e(x)y\phi'(t_i) + 1$ are increasing in x for $i = 0, 1$ (recall $\phi' < 0$). As a result, for (25) and (26) to hold, $e(\widetilde{x})y\phi'(t_0) + 1 > 0$ and $e(\widetilde{x})y\phi'(t_1) + 1 < 0$ must be satisfied. Since $\phi'' > 0$, these inequalities require $t_0 > t_1$.

[11] Central Paris, whose residents have relatively high incomes, relies on convenient and frequent service by the Metro system, while the lower-income Paris suburbs rely on less-frequent suburban train service.

[12] The user-fee scheme required to support the optimum is not straightforward. To induce consumers to split properly across the two systems, it is easy to see that each consumer must pay for system 1 regardless of which transport system is used. An individual fee of k paid by each of the city's N residents would cover system 1's fixed costs. A scheme that charges k to each of the $\widetilde{x}$ users of system 0 would similarly cover its costs. But in order to ensure that all consumers living inside $\widetilde{x}$ use system 0, as intended, individuals living close to the CBD must pay a fee less than k. To see this point, replace $\widetilde{x}$ on the LHS of (27) by x, and note that this expression must be negative in order for an individual living at the given x to use system 0, assuming a user fee of k. Then, note that the slopes of the curves in Figures 4 and 5 equal the LHS of (27), and that these slopes are positive for small values of $\widetilde{x}$ (and thus small values of x). The implication is that if consumers living near the CBD were charged a user fee of k, the LHS of (27) would be positive at their locations, indicating a preference for system 1. Thus, the user fee must be reduced for these consumers, and to cover costs, it must be raised above k at those x values where (27) is negative. On the other hand, a different fee scheme for system 0 would charge a user living at x an amount $kx/\widetilde{x}$. This scheme ensures that the marginal individual pays k, and it can be shown that it induces

the choice of system 0 by all residents inside $\widetilde{x}$, as desired. However, since the scheme does not raise enough revenue, covering only half of system 0's cost, the balance would have to come from general tax revenue.