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Real Costs of Transportation and Influence of Pricing Policies

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The University of California Transportation Center
University of California at Berkeley

REAL COSTS OF TRANSPORTATION AND INFLUENCE OF PRICING POLICIES

Sustainability of transportation depends on both behavior and technology. Behavior determines how much of various activities are undertaken; technology determines whether they are harmful to the environment. Policies can influence both: they provide behavioral incentives, and they affect technological choices and guide technological change.

In looking ten or fifty years to the future, analyses of behavior and of technology begin to merge. Behavior can be defined and understood only within some assumed technological setting. But technological choices and change cannot be predicted so far ahead — indeed in fields such as information and communications, projecting even three to five years seems risky; therefore the analysis of possible technological frontiers must be supplemented by analysis of the behavioral processes defining innovation, dissemination, and adoption of technologies.

Costs and pricing play a key role linking technology and behavior. In this lecture I attempt to describe that role and its policy implications for transportation. To make my task more manageable, I will limit my purview to automobile transportation. That seems reasonable as automobiles are thought to pose the greatest danger, among the transportation modes, to the environment. Also, it enables me to attempt a closely targeted argument that illustrates some principles that could be applied to other modes of transportation as well.

To anticipate: I shall provide a definition and rough tally of the "real costs" of automobile transportation. I shall point out five elements of real costs —— infrastructure, parking, accidents, congestion, and air pollution —— that are not "self-contained", in the sense of being purely private on the part of the user, and that therefore pose interesting and potentially significant issues for public policy. For two of these, congestion and air pollution, I shall consider the implications for policies toward pricing and technology in road transportation.

I. WHAT ARE "REAL COSTS"?

Economists define real costs within some framework of alternatives. The cost of an activity, such as a particular form of transportation, is what must be given up to undertake it. To make costs commensurable, the things given up ("inputs") are valued at market prices if appropriate, or, if not, at imputed prices called "shadow prices." These shadow prices are derived from some implicit or explicit optimization model showing what consumption must ultimately be foregone if the corresponding inputs are provided to the transportation sector. More precisely, each shadow price is either a partial derivative of some objective function or a Lagrange Multiplier of some constraint.

For most questions, the incremental method implicit in such differentiation is practical and informative. Even what we think of as a big change, such as replacing all cars in Southern California by electric vehicles, usually produces only small changes in key variables of interest, such as illnesses attributable to poor air quality. For example, California's controversial electric-vehicle requirements require only 2% of sales to be all-electric in 1998, 5% in 2001, and 10% in 2003; and of course the total fleet would turn over much more slowly than that. Similarly, the effects of policy changes toward road safety, congestion, or infrastructure are usually small over a horizon for which any confidence can attach to quantitative measurements. So it is feasible to analyze such policies in terms of the aggregate costs of making small changes in the economy. In our context, such costs are known as marginal costs.

II. AUTOMOBILE COSTS: Main Categories

In a recent survey of urban transportation economics, I reviewed our knowledge about the main elements of automobile costs in urban areas (Small, 1992, pp. 75-85). Here are some highlights:

Running and vehicle costs: These are the largest component, perhaps $0.15/km, if we include interest and depreciation on the car itself. It is paid by users and there are few direct spillovers except for the environmental and foreign policy effects of petroleum production. So these costs are of limited policy interest. (This is not to say that policy interest should not adhere to the oil industry, as of course it does: just that I believe when you trace the responsibility for oil-industry-related problems back to an anonymous citizen driving his or her car, it will not amount to very much. I realize that I am only asserting, not proving, this point.)

Infrastructure: In many countries, the capital costs of infrastructure are financed in large part through dedicated user taxes, notably fuel taxes. In the U.S., such user taxes cover about 2/3 of total expenditures on streets, roads, and highways. Averaged over all the miles driven, expenditures on highway infrastructure came to about $0.06/km in 1990.

The portion of this not covered by user taxes is a subsidy to automobile drivers as a group. Its size is not trivial, but it is a relatively small part of total automobile costs; so probably its existence has little effect on the amount of driving. Furthermore, the subsidy might be justified on the grounds of increasing returns to scale in highway building; but I will not pursue that here.

Of far greater significance is the subsidy from off-peak users to peak users of urban highways. This comes about because a large portion of infrastructure expenditure in urban areas is to provide capacity, and that is needed only for peak flows. This subsidy is implicitly analyzed below in considering congestion costs.

Parking: Parking costs averaged over all trips are not very large, but those for trips to central cities are: around $0.08/km for a typical-length commute to the edge of a large central business district. This cost is highly subsidized by employers, with disastrous effects for the goal of reducing the number of cars being driven to work. These effects, and some very simple remedies, have been well documented by Donald Shoup and several of his colleagues (Willson and Shoup, 1990).

Accidents: What are the "real costs" of accidents? This is a conceptually and empirically difficult question, and involves measuring the value people place on small increases in their risk of injury and death. (Please note: I did not say placing a value on a person's life.) Some rough attempts at measurement are contained in reviews of urban road costs by David Newbery of Cambridge University (Newbery, 1988, pp. 169-174) and by myself (Small, 1992, pp. 78-81). They suggest that average cost is quite high — on the order of $0.11/km — and, more significantly for public policy, that there are considerable spillovers, both among automobile users (as you know if anyone has ever hit your car) and from automobile users to others (e.g. pedestrians, public medical care programs).

Again, I won't pursue it here, partly because it is so poorly understood, partly because it would get us deeply into tort law, medical insurance, and other issues tangential to this conference.

Congestion: The value people place on time spent traveling has been quite thoroughly studied. The concept is well understood and measurements are abundant and well grounded in statistical methodology. This is not to say the phenomenon itself is simple: the alternative uses for people's time are highly varied, depending upon such factors as income, trip purpose, and activity schedules; furthermore, people find time spent standing at a cold bus stop more onerous than time spent in a limousine. Nevertheless, we can say with some confidence that on average, time spent commuting is valued at around half the wage rate (Small, 1992, pp. 43-45).

This permits us to value congestion of a known severity. For example, suppose an urban arterial with a normal speed of 50 km/hr is slowed by congestion to 25 km/hr. At average U.S. wage rates, this delay of 1.2 minutes per kilometer has a value of about $0.11/km.

But this is not the end of the story. Although this average time cost is "paid for" by the user, total time cost rises nonlinearly with the number of peak users because of congestion. That is, marginal cost (the derivative of the total cost function) is much larger than average cost. This is a potent source of market failure because a given individual's decision of how and when to travel takes into account only this average cost, which greatly understates the real cost to all users of the road of that one individual's decision.

So far, I have described a standard "congestion externality" — direct impacts imposed by users on each other and not mediated through market transactions. Such externalities are well known to cause inefficiencies in the absence of government intervention. But the chain of results goes even further. People take various avoidance measures in response to increased congestion: they may take inconvenient routes or modes, or travel at inconvenient times, or rearrange trips in an awkward sequence. This inconvenience has a cost, which often can be measured. An example at the frontier of current travel-demand research is the cost of inconvenient schedules. This has recently been measured for commuters, as the value of what has come to be called "schedule delay": arriving at work earlier or later than the time work officially begins. Based on data from the San Francisco Bay Area, it appears that a typical commuter to the central city incurs schedule delay which he deems equivalent to 7 minutes of extra travel time (Small, 1992, p. 78). Applying the same valuation as before, this carries an average cost of about $0.05/km for a typical U.S. commute of 14 km.

Another major cost of congestion is the unreliability it causes in travel schedules. Unfortunately this cost has not been measured accurately, but many researchers think it is comparable to travel-time itself in importance.

Air Emissions: There are extraordinary difficulties in determining what it "really" costs to allow people to emit pollutants into the atmosphere. The conceptual problems are bad enough: How do we value lives shortened by lung cancer? How do we measure the value of reduced visibility? How do we value the very uncertain effects of a very uncertain global temperature rise on generations in the very far future? Are there ethical values that transcend these economic costs?

These, at least, are questions that social scientists are trained to address. But the technical problems are even worse. How does a gram of pollutant emitted translate into changes in ambient air quality at each of the many places where people are breathing? What if that pollutant is nitric oxide, which "scavenges" ozone locally so as to temporarily reduce its ambient level, only to create more ozone far downwind after several hours (depending on the amounts of sunlight and wind)? And how exactly do the physiological effects of pollutants such as ozone translate into tangible deterioration of quality of life, especially if there is little or no direct evidence of long-term health damage?

On top of this, some new evidence from tunnels and from remote sensing devices has recently suggested that we don't even know how much is emitted from cars in the first place. About all we really know is what comes out of brand new prototype vehicles in an artificial dynamometer testing cycle.

Despite these barriers to analysis, a few researchers have made plausible attempts to quantify at least some of the relevant phenomena. For the United States, estimates of aggregate costs from the pollution caused by automobiles are on the order of $20-40 billion per year.[1] This translates into about $1000-$2000 over the life of each car.[2] If these

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[1]This is my assessment of the most reasonable range for damages resulting from all emissions of carbon monoxide, hydrocarbons, and nitrogen oxides (including secondary products such as ozone), which may be taken as roughly representing the problems caused by automobiles. Of course other sources contribute to these emissions, especially to nitrogen oxides, but automobiles are dominant; contrariwise automobiles emit other pollutants, but account for only a small fraction of them. The figures given are roughly the central values found in a variety of often conflicting studies. For example, Small (1977, p. 121) estimates 1970 U.S. costs from these pollutants at $5.38 billion, but uses a value of life substantially lower than current estimates based on labor-market behavior toward risk (Small, 1992, p. 83). U.S. Federal Highway Administration (1982, p. E-47) uses estimates, derived from Haugaard (1981), that sum to $25 billion for 1981. The Los Angeles region, where ozone is the worst automotive-related air-quality problem, typically accounts for a substantial fraction of such estimates; a recent estimate of the health costs of exceeding the federal ozone standards in the Los Angeles region is $2.7 billion (Brajer *et al.*, 1991), a figure believed too high by Krupnick and Portney (1991) but raised to $10 billion in a follow-up report by Hall et al. (1992).

estimates are of the correct order of magnitude, they support two conclusions. First, pollution costs are large, a substantial fraction of the purchase price of a vehicle. Second, pollution costs are not nearly so large as the total costs of driving, especially if we include the value of people's time. This suggests that the air-pollution problem is one of vast numbers of vehicle trips, not of an enormous external cost to each trip.

Furthermore, it is now known that a high proportion of air pollutant emissions is accounted for by a small proportion of cars: namely, those whose emission-control mechanisms are missing or malfunctioning. This suggests that progress might be made by targeting policies on this comparatively small subset of vehicles.

Consideration of global warming, while subject to even greater uncertainties, does not appear to alter this conclusion (Small, 1991). Although the consequences of greenhouse-gas emissions are too uncertain to warrant estimating their value, one can estimate the aggregate cost of meeting various targets that have been suggested in political negotiations. Nordhaus (1991) has reviewed such estimates and finds that even a policy to reduce carbon-dioxide emissions by 50 percent from their projected base path, a policy about as draconian as any seriously considered, would cost in the neighborhood of \$0.13 per kilogram of carbon atoms removed. This is equivalent to \$0.084 per liter of gasoline, well within the range of cost increases with which we have experience. If such policies were efficiently designed, they would not impose restrictions on automobile use greater than what would occur from a fuel tax of this magnitude. The response would be predominately technological, not behavioral.

III. POLICIES TOWARD CONGESTION

In the remaining time, I want to explore in more detail two of these cost categories: congestion and air pollution. It happens that these two phenomena are related in interesting ways, leading to some interesting proposals for packages of policies dealing with both of them (Bay Area Economic Forum, 1990; Cameron, 1991). But in one respect the

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[2](...continued)
[2]Based on the approximation of 200 million cars, each lasting 10 years. Cameron (1991, p. 21), using a rather generous allocation of responsibility for health effects to automobiles, estimates their costs in Southern California at \$0.04 per kilometer, or about \$6,000 over the life of a car.

two phenomena are fundamentally different: congestion is highly localized in time and space, whereas air emissions (except for carbon monoxide) are widely dispersed.

Latent Demand and Endogenous Trip Scheduling

I mentioned that congestion tends to induce avoidance behavior on the part of people experiencing it. People's travel decisions involve a complex array of inter-related decisions on route, mode, schedule, sequence, frequency, and destination, among other things. This provides quite a menu of options for someone who finds the current degree of congestion too costly. Perhaps this is why people tolerate so much congestion; but it also presents problems for policy.

Most policies toward congestion have been thwarted because a given policy aims to encourage just one or a few of these options. A multi-billion-dollar subway system may induce some mode shifting, while the establishment of outlying telecommuting centers alters some commuters' destinations. But with so many potential peak-hour trips already being diverted to a wide variety of alternatives, any initial success on the part of such a policy unleashes the reverse of the behavioral changes that congestion itself produced. One way of describing this is to say that there is a large reservoir of latent demand for peak-hour travel: people who do not now travel by car during peak periods, but who will do so as soon as conditions are eased.

Latent demand is largely responsible for the less than fully satisfactory results of expanding capacity. When congestion is moderate, expanding capacity is effective. But when congestion is severe, causing the reservoir of latent demand to exceed the magnitude of any feasible capacity expansion, expanding highways tends to "create its own demand" by attracting this latent demand. This phenomenon is known to traffic engineers as "the fundamental law of traffic congestion," and has been captured in rigorous models by Anthony Downs (1962), J.M. Thomson (1977), and others (Holden, 1989).

Some of the most interesting work shows how capacity expansion, or other policies aimed at controlling congestion, interact with people's trip scheduling. Models of congestion buildup in which scheduling choices are treated as endogenous have been postulated by William Vickrey (1969), a recent President of the American Economic Association; and by J. Vernon Henderson (1981). These models have been refined and explored by an interesting combination of engineers and economists including Chris Hendrickson and George Kocur (1981), Paul-Henri Fargier (1983), Moshe Ben-Akiva and a variety of colleagues (e.g. Ben-Akiva et al., 1984), and Richard Arnott, André de Palma, and Robin Lindsey (1988). Most recent is a foray by a graduate student in economics at Irvine, Xuehao Chu (1993).

In one particularly simple example of such a model, attributable to Vickrey and applicable to morning work trips, travel time is valued at a flat hourly rate α; schedule delay, defined as the difference between the actual and the most preferred arrival time at work, is valued at rate β for early arrivals and γ for late arrivals. Earlier work of mine (Small, 1982) provides empirical estimates of ratios β/α and γ/α. People's desired times of arrivals are distributed uniformly over a period of fixed duration. Congestion builds up in a deterministic queue behind a point bottleneck. The resulting pattern has an astonishing property: total user costs (consisting of approximately equal doses of travel-time costs and schedule delay costs) depend only on parameters β and γ, and not at all on α (which is the conventional "value of time" and the basis for all conventional calculations of congestion costs).

This particular result is unique to this model, but it illustrates how the strong interaction between travel delay and scheduling considerations can greatly alter the nature of equilibrium. The engineering and economics professions are just beginning to incorporate this insight into more practical models for predicting what happens on real congested networks (Ben-Akiva et al., 1986; Vythoulkas, 1991).

Congestion Pricing

Economists have recognized since the early part of this century that standard principles of marginal-cost pricing apply to the analysis of congestion externalities. Put simply, the user is charged the difference between the "real" (i.e. marginal) cost of his decision to drive a car and the portion of that cost he already pays (including travel time, schedule delay, etc.). This induces behavioral shifts to all of the many alternatives to peak-period driving, while continuing to deter people in the latent-demand reservoir. Result: genuine congestion relief, accompanied by large and unpopular monetary transfers from individuals to government authorities.

Serious practical proposals for applying these principles to congested roads began with William Vickrey (1955, 1965). Nothing happened for decades, except in Singapore which adopted such a policy in 1975. But recently a pervasive despair with other policies has created a new surge of interest, this time among transportation planning professionals (e.g.

U.S. Federal Highway Administration, 1992a, 1992b). Singapore's Area License Scheme has now been joined by the Autoroute A1, north of Paris, as genuine implementations. Meanwhile, the transportation profession is watching with intense interest some urban toll rings in Norway, a planned toll ring in Stockholm, and some more elaborate pricing schemes being studied in the Netherlands and Great Britain. In the U.S., recent highway legislation authorizes $150 million for five demonstration projects of congestion pricing; and a private toll road which will apply the concept began construction in California in July 1993.

This interest is fostered not only by discouraging results from other policies such as mass transit subsidies. In addition, technological developments in electronic toll collection have greatly improved the feasibility of implementation, making quite sophisticated pricing schemes easy for the user (May, 1993). Furthermore, financial stringencies have resulted in a new wave of conventional toll roads, most of which are adopting electronic collection and therefore are amenable to varying the toll by time of day. Once the concepts of toll roads and of electronic collection are accepted, the step to congestion pricing appears far less drastic, as is demonstrated by both the California and the Paris applications.

On a more abstract level, the effects of fine-tuned pricing schemes on endogenous scheduling behavior are now quite fully explored through models such as the one by Vickrey I just described. In this model, the optimal price varies continuously over the peak period so as to precisely substitute for travel-time delay in its behavioral effects on users. As a result, they all choose to arrive at work at exactly the same times as before, but they can do so with zero congestion. Total travel cost as perceived by the individual is unchanged: toll payments are simply substituted for time delay. But the toll payments are transfers, not real costs; in aggregate, real travel costs are halved: the cost of travel-time delay is eliminated, and only the cost of schedule delay remains.

Technology is now available for electronic collection of such tolls. Interestingly, that technology is closely related to developments in "smart highways", through such initiatives as Intelligent Vehicle-Highway Systems (IVHS) in the U.S. and the various DRIVE projects in Europe. Ultimately, IVHS technology could increase the capacity of a given road by permitting closer vehicle spacing. Present indications are that such improvements will come at a very high development cost, so at this point it does not fundamentally alter the financial constraints that prevent us from "building our way out of congestion".

IV. POLICIES TOWARD ENVIRONMENTAL EFFECTS

Environmental effects are not nearly as localized as congestion. As a result, policies to eliminate them through shifts in travel behavior will require very widespread reductions in motor-vehicle use. This means the menu of alternatives facing the user is narrower than the menu of alternatives to peak-period driving. Furthermore, a pricing policy strong enough to reduce vehicle use substantially would create very large aggregate transfers and therefore could raise strong political opposition.

Policies attempting to reduce aggregate motor-vehicle use run counter to some very strong trends in automobile ownership and use. Between 1970 and 1987, for example, the per-capita stock of motor vehicles rose by 39 percent in the U.S., 88 percent in twelve nations of Western Europe, and 141 percent in Japan. Per-capita vehicular travel (vehicle-kilometers per person) grew as well: 41 percent in the U.S., 69 percent in Europe, and 84 percent in Japan.[3] These increases have taken place despite strong attempts to curtail automobiles, especially through financial support of public transit and, in Europe, through high use and ownership taxes (Pucher, 1988). Thus, it appears that even when transit service is convenient and inexpensive, people increasingly prefer the greater flexibility of traveling in their own vehicles.

Looking more broadly, this kind of flexible transportation may be what allows a city to operate as an integrated whole. Without it, the economies of scale that seem to operate across industries to power a large urban area — known as "agglomeration economies" — cannot be achieved. The flexibility and individual control of travel in individual vehicles seem to mesh with the activities that are crucial to the most rapidly growing and dynamic service sectors of urban economies: acquisition of information, coordination, flexible decision making, adaptation to rapid change, decentralized but highly inter-dependent patterns of production. An example of the importance of these activities is provided by the increasingly vertically disintegrated production patterns, with their specialized and flexible labor markets, observed and documented by Scott (1988) in the Los Angeles region.

Are environmental effects so severe that we should simply accept this cost and impose draconian limitations on motor-vehicle use? Not from the estimates provided earlier. People have demonstrated through their behavior that they place considerably more value

[3]These data are from "Motor Vehicle Use Statistics, Selected OECD Countries, 1970-1987," obtained from the Royal Commission on National Passenger Transportation (Canada), Ottawa.

on the ability to use this flexible means of transportation than on its air-pollution side effects.

I have suggested that the measurable costs of air pollution are probably on the order of $1,000 to $2,000 over the lifetime of a car. It is no surprise, then, that people have supported technological solutions, which have proven highly effective at costs within that range or less. The passage of recent federal and state legislation in the U.S. suggests that people continue to support this approach, and are willing to extend the technological requirements from the vehicles themselves to the chemical formulation of gasoline.

But by the same reasoning, people will not support policies that they consider far more onerous than this cost. Major behavioral shifts to substantially reduce automobile use are exactly this kind of policy. The upper cost estimate just stated ($2,000 per car) amounts to approximately $0.013 per vehicle-kilometer. Cost differences far exceeding this amount have already been encountered in recent years, both among countries (especially U.S. versus Europe) and over time (especially pre-1972 versus 1980). Yet the effects of these cost differences on automobile use are very modest, especially once differences in land-use patterns are accounted for; and there appear to be no effects at all on the upward trends in automobile use. Instead, these cost differences have produced technological changes in vehicle size and fuel economy.

Two other policies proposed for pollution control are better maintenance and inspection of motor-vehicle engines, especially the pollution-control devices; and the use of alternative fuels such as methanol. Maintenance and inspection has long been supported by professionals as a low-cost and effective policy, and seems a likely candidate for strengthening in the near future; although it requires some modest behavioral changes, it is primarily a fine-tuning of policies designed around improved technology. Alternative fuels are also more technological than behavioral, and in any event appear likely to raise costs by more than $0.013 per vehicle-kilometer; hence they are of doubtful attractiveness as a widespread strategy for reducing air pollution.

I conclude that major behavioral changes in response to automotive air pollution are unlikely. People value personal mobility too highly, and satisfactory measures are likely to be found through improved technology.

V. CONCLUSIONS

Because congestion is localized in time and space, and increasing capacity in built-up areas is very expensive, the solution to it appears to be inducing behavioral changes. The only effective means known to do this are pricing measures. These have great political barriers, but recent events are somewhat encouraging for our ability to implement limited innovations that may in time develop into genuine congestion pricing. There is hope, supplemented by some survey evidence (Jones, 1991), that people will accept such measures provided they can see where the money is going. If they do, it will be because the behavioral changes they are asked to make (reduce peak-period driving) is a limited one and a large number of alternatives are available.

Effective environmental policy, in contrast, will require primarily technological solutions. People will not be willing to curtail their flexible individualized mobility to an extent that would significantly reduce harmful air emissions. But they can be persuaded to support cost-effective technological measures to reduce those emissions.

Technological solutions, however, are promising only so long as they are implemented through policies that can adapt as new scientific findings and experience with costs come into play. No one in 1993 can forecast what automotive technology will be best in the year 2013, much less 2043. Instead, we need policies that put in place incentives to guide the considerable technological power of our market systems toward an efficient solution. Examples are emissions fees, as proposed in California by both a business organization (Bay Area Economic Forum, 1990) and an environmental group (Cameron, 1991); and tradeable pollution permits, such as are now being introduced in a limited way in Southern California. By contrast, letting a few highly placed policy bureaucrats decide on the "right" technology will probably lead to costly solutions of questionable effectiveness.

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