THREE ASPECTS OF HIGHWAY EFFICIENCY: AMOUNT, QUALITY AND PRICE

By Kenneth D. Goldin

Highway efficiency involves efficient pricing (a short-run problem) of an efficient amount of highway (a long-run problem) to achieve efficient quality of service. The quality aspect (i.e., user costs including travel time) affects the efficiency both of pricing of existing highways and of investment in new ones. This paper attempts to integrate the efficiency analyses of price, amount and quality. Existing literature is generally limited to partial efficiency analyses. There have been many discussions in recent years of peak-load pricing to improve quality (i.e. to reduce congestion) on given highways; and many new highways have been subject to cost-benefit studies in the context of given prices. But the essence of economic analysis is to consider efficient pricing and efficient amount simultaneously. Economists have traditionally escaped the problem of quality by labelling each quality a separate product. But in highways there is rarely scope for multiple qualities; quality efficiency must be added to price and amount efficiency. This article constitutes an application of microeconomic theory to a major segment of public finance. In addition to its theoretical interest, the analysis should help in the formulation of highway improvements. Although a fully efficient system may be unlikely, understanding may lead to something better than the present one.

Section I deals with only two parameters: amount and pricing. Since highways and electricity have some common characteristics, use is made of O. E. Williamson’s recent analysis of electricity efficiency [13]. Section II introduces the problem of quality. A money value can be assigned to highway users’ time, implying an efficient quality for new highways. It also implies that it is efficient to reduce quality during peak periods, and vice versa. Section III presents suggestive data on the present financing of highways.

The method of analysis can be described as the partial equilibrium analysis, when income distribution is acceptable, of a basically private economic product. Three aspects of this method require comment.

Second Best Solutions. First, a partial equilibrium analysis of efficiency for one product may have little significance if the remainder of the economy is inefficiently organised. This is the “second best” problem emphasized by Lipsey and Lancaster. But the characteristics of efficient highways may be of interest even if there are

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1In the United States, government expenditures on highways are exceeded only by those on education and defence.

2Vickrey has urged economists to note changing technology. Efficient pricing does not mean a toll booth on every street corner. The problem of charging each user for his many and diverse uses of the highway would seem to be of the same order of difficulty as the current operations of telephone companies. A variety of new charging methods is discussed in the Smeed Report [13].
"second best" problems. Winch argues at some length [14, Appendix] that the efficiency solution need not be rejected for highways.

Income Distribution. Secondly, efficiency criteria require comparison of individual (and aggregated) marginal cost and marginal benefit curves. An individual's marginal benefit (or demand) curve depends on his budget constraint, i.e., on the distribution of income. Thus the efficient solution is usually considered significant only if the income distribution on which it is based is acceptable. But highway efficiency and income distribution can be treated as independent problems. 3

A Private Good. Thirdly, highways are treated as a basically private good, rather than as a "collective", "social" or "public" good. A characteristic of private goods is appropriability, defined as that property which makes it possible, at the margin, for private economic units to price (or appropriate) the full social benefits (and to be priced, or charged, the full social costs). Conversely, the supplier of a public good cannot appropriate (price) the benefits. 4 It is well known that few (if any) goods are purely private or purely public. Rather, most goods will have some non-appropriable benefits or costs. Where the non-appropriabilities are minor, it is convenient to use the private goods framework, modified as necessary. We argue here that most of the benefits and costs related to highways are appropriable.

The "product" which is supplied and demanded is "units of highway capacity". Clearly, it is possible for the supplier to be charged the major costs: right-of-way, construction and maintenance. (Highway suppliers are not always charged the full costs of rights-of-way through parks or scenic areas, yet it is possible so to charge them.) Similarly, it is possible for the supplier to appropriate (price) the major benefits. The major benefits of highways accrue, initially, to highway users, 5 and it is always possible to charge each and every highway user. (Highway suppliers appropriate some benefits from every highway user, through fuel taxes and other fees per mile. If highway suppliers do not fully charge users for benefits received, it remains possible so to charge them.)

Highways are not "pure" private goods, because there are also non-appropriable costs and benefits. These non-appropriabilities accrue mainly to residents living near a highway. They may suffer noise, smoke, etc., and it is not possible, through ordinary private pricing, for the highway supplier to be charged for such costs. These same residents may receive non-appropriable benefits, if they like to watch the world go by, etc. The highway supplier cannot appropriate (charge for) such benefits. (Non-appropriable benefits must be benefits which do not accrue via high-

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3"Were it generally agreed that changes in the existing distribution would be desirable, these would be brought about by normal budgetary procedures. There is certainly no reason for using the planning and financing of one particular economic activity, such as highway construction, to redress any remaining inequities in the distribution of income" [14, p. 38].

4Page 406 in the article by J. G. Head [1]. This is an excellent review of modern public finance.

5The benefits of highways to defence, police, fire, medical and postal services all accrue, initially, to highway users and can be appropriated by the highway supplier. That the final product may be public is irrelevant to the nature of the product supplied by the highway supplier. Similarly, highways are of benefit to farmers (who can send crops to distant markets) and to consumers (who can buy crops at a distance from farms.) This simply indicates that highways are of benefit to truckers, and that truckers perform an economically useful service. The benefit of the highway in this process can be appropriated by the highway supplier.
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way usage, since any benefits due to highway usage can be charged for. The net non-appropriable costs to nearby residents would seem minor, compared to the appropriable costs and benefits. Yet highways are often analyzed as public goods. The observed zero marginal cost on many highways has caused some of the confusion. But for highways, the zero marginal cost is due to excess supply, not to any "publicness" inherent in the product.6

I. HIGHWAY CAPACITY

To construct an efficient highway plant requires determination of the efficient amount of highway capacity. The efficient use of a highway plant, once built, requires efficient prices. This section analyses the efficient amount and pricing of highway capacity, at a given quality. A number of special characteristics make this a non-trivial application of microeconomic theory. The demand for highway capacity is both peaked and stochastic. These demand characteristics would cause no problem if supply could be adjusted rapidly to changes in demand (through inventories or changes in the rate of production). But the supply of highway capacity (of a specified quality) cannot be adjusted to hourly and daily variations in demand. To further complicate the analysis, the supply involves durable goods characterised by substantial indivisibilities. The industry characteristics are also unusual. Since costs do not decrease over the entire relevant range, highways cannot be analysed as a decreasing-cost industry in which one plant is always efficient. But neither can we use the analysis of many-plant industries, in which it is assumed that each plant always operates at its minimum average cost. Rather, the analysis must deal with an industry in which the efficient number of plants (highways between two points) is generally a small number, such as one or two. After a discussion of general characteristics, the analysis treats in turn the cases of uniform, time-peaked and stochastic demands.

General Characteristics

Costs. Highway costs are mostly related to time. They include the opportunity cost of the right of way, items of construction which deteriorate with time, and most maintenance items, e.g., snow removal, sign painting, etc. (In this discussion the unit of length will generally be unstated where no confusion will result.) Given the lives of the various items and an interest rate, the sum of these costs can be expressed as a cost per hour. In addition to this time-related cost, there are costs which vary with the amount of highway use; but they are often cited as being relatively small and

6Market failure arises when there are any non-appropriable benefits or costs at the margin. The extreme case (pure public goods) arises when all benefits are non-appropriable, and when the benefits are jointly available to everyone. This implies that the marginal cost of supplying an additional person is zero. But zero marginal cost can also be an indication of private goods in excess supply. In addition, there is the argument that availability, or "option demand", must be considered in addition to the actual, revealed demand. But the debate in the literature seems to conclude that this would constitute double counting. See B. A. Weisbrod, "Collective-Consumption Services of Individual-Consumption Goods", Quarterly Journal of Economics, Aug. 1964, 78:471-77, and M. F. Long's "Comment" in the same Journal, May 1967, 81:351-52.
will therefore be assumed to be zero. Their inclusion in the analysis, if required, would be straightforward.

The next step is to find the average cost of highway capacity, which will depend on the amount of highway capacity produced. Both cost and capacity produced are time-related; the capacity of a road of given quality is expressed in units per hour. We define the average cost of production (AC) of a unit of highway capacity as

\[
AC = \frac{\text{total cost (cents per hour)}}{\text{total capacity produced (units per hour)}}
\]

so that AC is measured in cents per unit of highway capacity.\(^7\)

In expanding a highway plant (of a given quality), it is feasible to build only full lanes. At first, additional lanes may show decreasing costs, but eventually increasing costs are experienced. To further expand the amount of highway capacity between two points, it may become efficient to have two or more plants (highways). Thus long-run average cost, LAC, will be a step function, falling and rising one or more times in the relevant range. If there are very long-run constant returns, marginal lanes will have the same costs on additional highways. If long-run marginal cost, LMC, is defined as the average cost on marginal lanes, then its integral (from zero to a feasible capacity) will equal the total cost of that capacity. One possible shape for the LMC curve is drawn in Figure 1, where feasible amounts of capacity are shown as \(k, 2k, 3k, \text{etc.} \) Very long-run increasing or decreasing returns to scale would cause the LMC curve to rise or fall, and would add the usual complications.

In the short run, output of a product can usually be increased by adding more variable factors to a fixed plant. But for highway capacity (of a given quality) there are no variable factors which can be added to a fixed plant to increase output. (Nor are there any variable factors which can be subtracted to produce a smaller output.) Thus short-run marginal cost, MC, is zero up to the capacity of the highway plant, and infinite thereafter. The usual representation of such MC functions is as a vertical line at the available amount of capacity.\(^8\)

**Benefits.** In a given hour, an individual user’s demand for a unit of highway capacity will generally be a step function. In most (but not all) cases, his demand will be zero or one, depending on the price. (That is, the marginal benefit from the first unit will be equal to or greater than zero, and from additional units will generally equal zero.) Summed horizontally, the individual demand curves yield a market demand curve. Since the individual demand curves will have “steps” of different heights, the market demand curve will generally be a smooth curve.\(^9\)

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\(^7\)The separation of supply and demand is essential in economic analysis. Although the market equilibrium depends on the interaction of supply and demand, the supply and demand curves are independent. Calculation of the various cost (supply) curves must be made without reference to demand. Average cost of production depends on total cost and on units produced, whether or not they are ever demanded. To divide total cost by the number of units demanded (as is often done in highway discussions) does not yield the average cost of producing a unit of highway capacity.

\(^8\)Clearly the short run and very short run are the same for the marginal costs of highway capacity.

\(^9\)As for any product, the relationship between market demand and price is not instantaneous. The initial reaction to a price increase may be negligible. In due course, some people will move closer to their jobs, some businesses will move closer to their employees, some people will switch to public transport, night-time commercial traffic will probably increase, etc.
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quantity, the market demand curve (D) shows the benefit of a marginal unit, so it can also be called a marginal benefit curve (MB). The area under the curve shows the benefit generated by highways to highway users.10

Durable Goods with Indivisibilities

Analysis is greatly simplified if one starts with the assumptions that demand is uniform and non-stochastic. These assumptions are lifted later.

The efficient amount of capacity is that which maximizes net benefit, i.e., total benefit less total cost. A necessary condition for efficiency is the equality of LMC and MB. Because of indivisibilities, this will generally not be feasible, so the most efficient feasible capacity must be chosen from the feasible capacities just larger and just smaller than that denoted by the intersection of the LMC and MB curves. The larger capacity will be the more efficient if, in a comparison with the smaller capacity, the benefit difference exceeds the cost difference. The differences in benefit and cost are indicated by the areas under the MB and LMC curves; the difference in benefit less the difference in cost is indicated by the area A-B in Figure 2. The larger capacity is efficient when A > B, and conversely.11 (In Figure 2, LMC is the relevant portion of the LMC function of Figure 1. The efficient capacity is 3x.)

Efficient pricing equates the amounts of capacity supplied and demanded. It thereby avoids the inefficiency of excess capacity or of congestion. The efficient price is determined by the intersection of the demand and short-run marginal cost (MC) lines (P_e in Figure 2). Since P_e is generally unequal to LMC, and since LMC in turn is generally unequal to LAC, the revenues from efficient pricing will generally not equal total costs. The difference could be positive or negative, since P_e could be above or below LMC, and LMC can clearly be above or below LAC. The difference may be efficiently financed by non-distorting taxes or subsidies, or by non-distorting price discrimination. In practice, the difference is likely to be financed by inefficient methods, including distorting taxes, inefficient (e.g., average cost) prices, and flat fees on users.12 The inequality, in general, of efficient price revenues and total costs is partly the result of looking at only one part of the highway system at one point in time. On a system of efficient highways, revenue deficiencies on some highways would probably be offset by revenue excesses on others. Similarly, in an economy with growing demand, revenue deficiencies during some time periods would be offset by revenue excesses during subsequent periods.

Time-Peaked Demand

Maximization of net benefit requires comparison of marginal benefit and marginal cost during all the periods of a demand cycle. Clearly, capacity per period is the same

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10 In addition, there may be non-appropriable benefits and costs, such as annoyance and/or pleasure to nearby residents. Any net costs of this type should be added to appropriable costs. Although they might imply minor changes in efficient capacity and pricing, they would not change the essence of the following analysis. Their inclusion is left to the reader.

11 Since the demand curve could cut the step-function marginal cost curve in more than one place, this analysis yields local efficiency. Only a comparison of all points meeting the necessary conditions can determine global efficiency.

12 Flat fees discourage marginal users, just as inefficiently high prices discourage marginal use.
during all periods of the cycle. But the demand for (and benefit received from) this capacity varies from period to period.

**Efficient Amount.** During each period the benefit yielded is the area under the market demand (D₁) curve for that period. During the entire demand cycle, the benefit of a given capacity may be measured by the area under the vertical sum of the period demand curves. Similarly, during any one period, cost is measured by the area under the period LMC curve; during the entire cycle, the cost may be measured by the area under the vertical sum of the period LMC curves. Graphically, it is more convenient to take the vertical average of these vertically added curves...yielding an average demand curve (D̅AV) and the original period LMC curve,¹³ as in Figure 3. The efficient capacity is that capacity equal to or near the intersection of D̅AV and LMC. As argued above, the slightly larger capacity is efficient if A > B, and conversely.¹⁴

**Efficient Pricing.** Efficient prices equate capacity supplied and demanded during each period. (This avoids the inefficiencies of excess or deficit amounts of capacity. For each period, the efficient price is determined by the intersection of the period demand curve with the short-run marginal cost line at the efficient capacity).¹⁵ The point of intersection between the average demand curve and the MC line will be equal to (or greater than¹⁶) the average price. In general, the average efficient price is unequal to LAC. The problems and alternatives are as described above. Although efficient pricing will generally not yield revenues exactly equal to total costs, there is still a close relationship between the two.¹⁷ The literature has dis-

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¹³Vertically adding n period LMC curves, and then vertically dividing by n, yields the original curve.

¹⁴We have assumed that the highway plant produces the homogenous product “capacity”. Alternatively, the plant can be characterized as producing a set of joint products, but this interpretation does not change the efficient amounts of prices. For example, we could say that the highway plant produces the 24 products “highway capacity during the iᵗʰ hour of the day”, which are always produced in i : 11 ratios. The LMC of producing an additional set of joint products would be indicated by what we have called the vertical sum of the period LMC curves. (In the joint product context the LMC's of single products cease to be defined.) Similarly, the MB of an additional set of joint products would be indicated by what we have called the vertical sum of the period demand curves. The efficient number of sets of joint products is indicated by the intersection of SLMC and SD₁. Clearly this is the same as determining the capacity per period by (ΣLMC₁/n) and (ΣD₁/n).

¹⁵The minimum efficient price at any time is equal to the variable cost. For highways this is approximately zero. When demand is strong, a sufficiently high efficient price can keep the quantity demanded down to the available capacity. But when demand is weak, the zero-minimum price may leave the capacity demanded less than the capacity available.

Efficiency (maximization of net benefit) is achieved through the combination of both efficient capacity and efficient prices. If capacity is constrained to an inefficient amount, a different set of prices will be needed for constrained efficiency. Similarly, if pricing is constrained to the present inefficient type, a different capacity will be needed for constrained efficiency.

¹⁶The MC—D̅AV intersection is the average of the MC—D₁ intersections. But where a MC—D₁ intersection is negative the price will be zero. If the zero price constraint is binding during any periods, then some prices will be higher than the related MC—D₁ intersections. Thus the average price would be greater than the MC—D̅AV intersection.

¹⁷But we would disagree with Mohring’s assertion that “in the absence of scale economies...two simple operating rules would lead to...a long-run optimum network: (1) establish short-run marginal cost prices for the use of each link in the existing network; (2) alter the size of each link to the point where toll revenues equal the total costs.” [8, page 232; our italics.]
discussed the relationship between efficient prices and price discrimination at some length. The general conclusion is that efficient pricing is not discriminatory, since (i) only one price is charged at any one time; (ii) a competing supplier could not profitably undercut the efficient prices; (iii) users are free to switch demand from high priced to low priced periods; and (iv) Hirscheif [3, pages 456–59] interprets the efficient price as an opportunity cost price.¹⁹

The opportunity cost is the most valuable alternative foregone, which in this case is the failure to serve some other customer [at the same hour] willing to pay infinitesimally less than [the efficient price] for a unit of [capacity].

**Stochastic Demand**

The demand for highway capacity is clearly stochastic. This means that non-stochastic pricing cannot simultaneously eliminate excess capacity and congestion. Further, since amounts demanded generally adjust only slowly to price changes, it is unlikely that stochastic pricing would solve the problem.²⁰ Rather, the “given quality” must include a specification of the allowable likelihood (or probability distribution) of congestion.²¹ Efficient non-stochastic prices would keep the amounts demanded, during each period, within the distribution allowed by the quality specification.

### II. QUALITY

Alfred Marshall recognised the existence of quality differences but explicitly disregarded them, assuming “for the sake of simplicity, that all corn on the market is of the same quality”. Simplicity was well served by this assumption [2, page 164].

The results of section I were made easier by the assumption of a constant, given quality. But most public debate and most recent highway analysis by economists have dealt with quality. The most obvious aspect of quality – and generally that of most concern to the public and economists – is the travel time per mile.²² In general, one can expect this (and other quality aspects) to be of different value to different persons, according to their innate preferences and the size of their budgets. Under a system of consumer sovereignty, diverse preferences usually lead to diverse products. Mohning notes:

¹⁸Minasian [6] notes that the demand curves of the various periods are not independent for this reason.

¹⁹The public is likely to think of costs as the costs-per-unit-time of the highway plant, which are exactly the same at all hours. So viewed, peak prices would appear to exceed costs, and might be considered inequitable. Yet the public welcomes off-peak discounts on telephone service and airline travel. No doubt there are implications here for the political marketing of more efficient highways.

²⁰The efficient prices discussed above vary over the demand cycle in a non-stochastic fashion.

²¹The statistical analysis of highway congestion falls in the discipline of queueing theory. In spite of many attempts to analyze highway congestion, relatively little progress has been made. See the recent review article by Weiss [12].

²²Other aspects of quality include fuel consumption, mechanical wear, safety and aesthetics. In general, user costs per mile (including the cost of users’ time) can be used as an index of quality.
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"Individual tastes in various commodities . . . do differ . . . If a variety of choices was available . . . society as a whole would seem better off . . . The more alternatives available, the more likely is each consumer to find a combination of specifications that conforms closely to his tastes. So, too, with tastes in transportation routes; more importantly, the rates at which individuals would be willing to exchange dollars for time vary considerably. Thus ( . . . if no cost penalty is involved), the availability of routes possessing a wide variety of toll and time combinations would clearly give each traveller a better chance of finding a personally optimum travel mode than if no choice was available" [7, page 241].

Highway analysis by economists has often ignored the diversity of preferences for quality. The heroic assumption is often made that all highway users’ time has the same value. This expedient assumption has allowed some interesting analytic results in the fields of congestion-relieving pricing and of cost-benefit studies. And the somewhat more general quality analysis, in this section, would be impossible without the assumption. But the reader should always bear in mind the basic conflict between this assumption and consumer sovereignty, whenever the latter would call for diversity.

General Characteristics

As an index of highway quality, we will use average user costs AC(U). One way to incorporate quality as a variable is to shift the analysis from highway capacity to highway transport. This allows the inclusion of both plant costs and user costs. The plant costs (right-of-way, construction, etc.) are incurred by the highway supplier. The user costs (vehicle operation, accidents, travel time, etc.) are incurred by the vehicle suppliers. In the long run, an increase in plant costs will generally reduce user costs. Finding the efficient quality is the same as finding the efficient combination of plant and user costs. In the short run, the amount of transport which can be supplied is no longer a single number, since quality is a variable. Rather, the highway plant can be used more or less intensely, with a sloping short-run marginal cost curve. (Since plant costs are fixed in the short run, the marginal cost curve measures marginal user costs as the amount of transport is increased.)

To be comparable, demand curves must now measure the marginal benefit of additional units of transport. Clearly, demand must be a function of the total price paid by users: the cash price (if any) plus user costs. The suppliers and users of transport are not distinct entities, yet the supply (cost) and demand curves remain independent. Vehicle suppliers and highway suppliers jointly supply transport. The demand for highway transport is implemented by the vehicle suppliers. But supply (cost) curves indicate what it would cost to supply various amounts of transport, even if such amounts are not demanded. Similarly, demand curves indicate the

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23 Economists have used several indirect ways to estimate the money value of time — that is, what people are willing to pay, on the average, to save time. Mohring [7] bases his estimate on the rise in land values following a decrease in travel time to a suburb. Others use "the" wage rate, at least for business time saved. The American Association of State Highway Officials in its 1960 "Red Book" uses a value of $1.55 per hour [8, page 2433]. Prest and Turvey point out that calculations of the value of time "have not so far been very satisfactory" [10, page 712].
benefit which would be yielded by various amounts of transport, regardless of the present supply conditions.

With quality as a variable, the feasible amount of transport may vary widely. Given lanes may be used more or less intensely, and various sizes of lanes may be built. (In this sense, there is no indivisibility problem.) But the highway transport industry fits neither the one-plant decreasing costs case, nor the many-plant case. Average costs do not decrease over the entire relevant range, but the efficient number of plants will rarely be more than one or two. This will be reflected in a long-run average cost curve which falls and rises one or more times in the relevant range.

**Efficiency Analysis**

We start with the simpler case of *uniform* demand. If quality is measured by average user costs, the efficient quality may be defined as that which minimizes the sum of average plant and average user costs. In the long run, there is an efficient quality for each amount of transport. In Figure 4, average cost of transport AC* is plotted against average plant costs AC(P) for a given amount of transport. Minimum AC* denotes the average cost of transport, at the efficient quality for that amount. The positions of such points for all amounts of transport comprise the long-run average cost curve, LAC*, at efficient qualities. Since a single highway transport plant exhibits scale economies and then scale diseconomies, LAC* will fall and rise (and then fall again when a second plant is added, and so on), as in Figure 5. If there are very long-run constant returns to scale, the related LMC* curve will form a repeating pattern at the same cost levels. The efficient amount of transport, T_e, and efficient price, P_e, are determined by the intersection of LMC* and D*. The most efficient plant for the production of T_e transport will have a short-run marginal cost curve MC* which goes through the intersection of LMC* and D* (thereby indicating the same efficient amount and price).²⁴ In exceptional cases, D* may intersect LMC* at minimum LAC*. But in general, it will be efficient to operate at higher LAC*. Similarly, this means that it will generally be efficient to build a plant which will not be operated at its minimum AC*.²⁵ The efficient price will generally not equal long run average cost, so that efficient price revenues generally will not cover total costs. (As in Section I, efficient price revenues may equal total costs on an entire system of highways. If not, additional financing is necessary).

When demand is *peaked*, the problem is multidimensional. If there are n periods in the demand cycle, then there is an efficient quality for each n-tuple of amounts of highway transport. The minimum AC* points for each n-tuple form an n-dimensional LAC* surface. Any two-dimensional slice shows LAC* for different scales of highway transport, where the ratio of period amounts is the same at each scale. (That is, if T = (KT_1, KT_2, ..., KT_n), then a two-dimensional LAC* is a function of the scale factor K, for period amounts of transport having the same ratios T_1: T_2: ..., T_n at all scales.) Similarly, there is a total benefit for each n-tuple of amounts of highway transport. Related to this will be an n-dimensional MB* surface. Any

²⁴LAC* is the envelope of short-run average cost curves such as AC*. Since LAC* and AC* are tangent at T_e, they have the same slope, and hence the same marginal cost at that amount.

²⁵It is efficient to operate any plant where D* equals MC*. This will occur at minimum AC* only when LMC* equals D* at minimum LAC*.

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two-dimensional slice of MB* will show the marginal benefit to increases in scale, when the ratios of transport amounts in the various periods are held constant.

Analysis of efficiency involves two problems which must be simultaneously solved. If we know the ratios of transport amounts in the various periods, we can find the efficient plant. (As in Figure 5, we would plot LMC* and MB*, but as functions of scale K, and the efficient plant would have the scale indicated by the intersection of LMC* and MB*.) On the other hand, if we know the efficient plant, then we can find, for each period of the demand cycle, the efficient price and efficient amount and their ratios. In Figure 6, MC* is the marginal cost of transport for the efficient plant. (Since plant costs are fixed, MC* measures marginal user costs as the amount
of transport per period is increased). The intersection of MC* and a period demand curve D_{1\ast} determines the efficient price P_{1} and efficient amount of transport T_{1} for that period. The efficient cash price is the difference between P_{1} and the average user cost. Clearly, during peak periods, it is efficient to increase the amount of transport, even though this increases marginal and average user costs. Thus efficiency calls for simultaneously increasing prices and reducing quality during peak periods (and vice versa). The simultaneous determination of efficient quality, price and amount for each of the n periods cannot be done on two-dimensional graphs.

**Project Analysis**

Specific proposals for highway improvement often include changes in both the amount of transport and its quality. The cost-benefit analysis of a project aims at acceptance or rejection. Only two plants need be considered: the existing and the proposed. This greatly simplifies analysis, since the search for the most efficient plant (given demand and cost conditions) is eliminated. Most project analyses further eliminate the question of efficient pricing, by assuming that present pricing will be maintained. At present users pay both average user costs and a cash price. The latter is collected, even on “toll-free” roads, via fuel taxes. In the U.S., the fuel tax amounts to a cash price of about 0.6c. per mile for motorists.

It is plausible that the object of a cost benefit study should be to measure the increase in net benefits (that is, the increase in benefits less the increase in costs). We first explore the nature of net benefits when comparing two plants, with present pricing. Three cost-benefit studies are then cited, to show that other criteria than net benefit are often used.

Strictly speaking, gross benefits can increase only if the amount of transport increases. The D* demand curve for units of transport shows demand as a function of user costs plus cash price. The area under this demand curve (from zero to the amount demanded) is the total benefit of transport. This area increases only if the amount demanded increases. The amounts demanded under present pricing depend on a price line which is not the marginal cost curve. Rather, the relevant plant-parameter is its average user cost curve AC(U). The price line is equal to AC(U) plus the (constant) cash price. The intersection of the price line, P or P', and the demand curve determines amounts demanded. In Figure 7, the increase in benefit during the ith period is B_{i}, the area under ith period’s demand curve D_{I\ast} from the old to the new amounts of transport, T_{i} and T'_{i}.

A new highway plant will generally involve changes in user costs. Under present pricing, a highway improvement will always reduce user costs on the previous amount.

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27 This is partly because the short-run marginal cost curve is no longer vertical. When it is vertical, each period’s benefits and costs refer to the same amount, which allows vertical adding and averaging of cost and benefit curves.

28 A new highway plant may lower user costs, and thereby lower the total price paid by users. The increased amount of transport demanded reflects movement along the D* curve, not a change in the demand curve.
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of transport, but will also always involve new user costs on the increased amount of transport.\(^\text{29}\)

The increase in user costs is the area \( R \) (the user costs of the increased amount of transport) less the area \( S \) (the user costs saved by the previous traffic). Figure 8 shows average user costs on the old and new highway, at the amounts of transport \( T \) and \( T' \), calculated from Figure 7. A highway improvement also involves plant costs, and these can be expressed as plant costs per demand cycle, PC.

Summing over all demand periods in the demand cycle, the analyst must calculate the increased benefit, \( B \), increased user costs, \( R - S \), and increased plant costs, PC. Then the increased net benefit, \( NB \), is

\[
(2) \quad NB = B - (R - S) - PC
\]

Some project analyses are expressed in terms of consumers' and/or producers' surplus. It is straightforward to show that net benefit, \( NB \), is the sum of consumers' surplus, \( CS \), and producers' surplus, \( PS \). A highway improvement increases consumers' surplus to the extent that the increase in benefit exceeds the increase in user payments (user costs plus cash). Using \( \Delta T \) for the cash price and \( \Delta T \) for the increase in transport,

\[
(3) \quad CS = B - (R - S) - \Delta T \quad \text{(o.6)}
\]

The increase in producers' surplus is the increase in users' cash payments less the increase in plant costs:

\[
(4) \quad PS = \Delta T \quad \text{(o.6)} - PC
\]

From this the reader can easily verify that \( CS + PS = NB \).

Rather than measure net benefit, Mohring [8] looks only at the cost reduction to the existing amount of transport. (In effect, he assumes that \( B = R = O \).) In his analysis of freeway construction in the Minneapolis St. Paul area, he states that

No account is taken of the benefits and costs entailed in the additional trips that would almost certainly be generated as a result of a freeway-associated reduction in travel costs [page 263].

Mohring notes that, with freeways, each unit of transport between two points may involve more miles but lower user costs (primarily because of the reduction in travel time). Mohring's "benefits" (which might better be called user cost reductions) were measured by the difference between estimated total vehicle operating and time costs involved \( \Delta \) in current travel on the existing arterial street network and \( \Delta \) in the somewhat larger number of vehicle miles associated with the expanded network [page 263].

Thus, even though Mohring takes account of the added miles in producing the existing level of transport, he ignores costs and benefits of the additional transport which will be induced by this reduction in user costs.

Prest and Turvey [10] cite United Kingdom studies of the M1 highway. In addition to the measuring of the reduction in user costs to existing transport, \( S \), an approximate measure was used to estimate the net benefit to the additional transport. The exact measure is \( B - R \), which, if \( D \) is linear, is equal to the triangle with base

\(\text{29}\) Any highway improvement which lowers average user costs at the margin thereby lowers the price line, causing an increase in the amount demanded. Conversely, if a highway change did not lower user costs at the margin, there would be no change in either total benefits or total user costs; it would be hard to call it an improvement.
ΔT and height ΔAC(U), plus the rectangle with base ΔT and height F, the cash price collected via the fuel tax. The net benefit per unit of generated transport is therefore 1/2 ΔAC(U) + F, whereas the net benefit per unit of previous transport is ΔAC(U). The M1 studies simply assumed that the net benefit per unit of increased transport was half that of the net benefit to previous transport; this would be an underestimate if the demand for transport was linear:

In respect of generated traffic the argument is that the opening of the motorway would in effect reduce the “price” (in terms of congestion and inconvenience of motoring) and enable demand which had hitherto been frustrated to express itself in motorway usage. As it must be assumed that benefits per vehicle-mile to frustrated consumers are of less consequence than those to actual consumers (if not, they would not remain frustrated), they were rated as half as great as the latter in the M1 calculations [page 711].

Rather than measure net benefit, Kuhn [4] measured only producers’ surplus, ignoring consumers’ surplus. His numerical criterion is that producers’ surplus must be positive (see equation 4 above).

For purposes of project analysis, in accordance with contemporary United States and California highway policy, a user charge philosophy is assumed to prevail. . . . The question that will be asked is: How much does it cost the highway department to construct and operate the freeways, and will enough user revenue be forthcoming to cover these costs? [page 190].

Kuhn appears to have little regard for the consumers’ surplus segment of net benefit:

As for the unknown (and doubtful) consumers’ surplus items . . . (time savings . . . etc.) . . . and using the AASHO standard of about 2.5c. per minute per vehicle for the “value” of motorists’ time, a total “gain” of $165 million (undiscounted) results. . . . The temptation to justify the project through such arbitrary value adjustments can be great [page 196].

The assumption that all motorists’ time is of the same value is a poor one, as emphasized at the beginning of this section. But it would seem worse still to disregard the value of motorists’ time completely. After all, the cheapest transport system, disregarding the value of time, is one on which vehicles move at a very low speed.30

III. PRESENT FINANCING

In the financing of highway transport, users always pay user costs. The question is to what extent users pay the costs of the highway plant. We therefore return to the analysis of highway capacity and cash prices. The figures presented below suggest that there is a great amount of excess capacity on highways in the United States. The

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30Although Mohring underestimates net benefit, he still finds a high rate of return to freeway construction. Doubling the freeway system in the area analyzed would still leave a marginal rate of return of 60 per cent per annum, if time is valued at $3/hour; 35 per cent is valued at $1.55/hour, and 10 per cent if only vehicle-operating costs are considered [8, page 267]. On the basis of producers’ surplus alone, Kuhn found that the existing Embarcadero Freeway should not have been built; that the existing James Lick Freeway approximately breaks even; and that the proposed Western Freeway will not break even. (These freeways are in San Francisco).
total cost of capacity produced appears to exceed user fees, but user fees, in turn, appear to exceed the cost of capacity actually used. The figures are very rough, and are only meant to be suggestive. Two sets of figures imply that excess capacity is severe. And two sets of figures imply that the average cost of production of a unit of highway capacity is in the region of 0.1c. per mile for most U.S. highways.

**Excess Capacity**

Mohring analyzed an urban area for 1958 [8, pages 271-73]. He found that, during the peak period, the capacity demanded (and approximately supplied) in the peak direction was six times the daily average capacity demanded in that direction. This implies that the daily capacity supplied was about 1/6 demanded and 5/6 excess. Casual observation suggests that there is less excess capacity on urban roads than on rural.

The U.S. highway system is predominantly rural. A projection for 1975 [5, pages 66-67, Table 20] suggests that excess capacity may exceed nine-tenths of the capacity produced. The projection is that the capacity used in 1975 will be about 1 trillion (i.e., $10^{12}$) vehicle miles. The projection also gives the miles of each type of road which will be available in 1975. Even on the basis of low estimates of capacity produced, we nonetheless estimate a 1975 capacity produced of $18\frac{1}{4}$ trillion vehicle miles (see Table 1).

**Table 1**

*Forecast of U.S. Highway Capacity in 1975*

<table>
<thead>
<tr>
<th>Type of Road</th>
<th>Miles (1967)</th>
<th>Hourly Capacity</th>
<th>Annual Capacity Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstate</td>
<td>38,700</td>
<td>6,400</td>
<td>2 trillion</td>
</tr>
<tr>
<td>Other: Urban</td>
<td>413,000</td>
<td>640</td>
<td>2 trillion</td>
</tr>
<tr>
<td>Other: Rural</td>
<td>2,650,000</td>
<td>640</td>
<td>$14\frac{3}{4}$ trillion</td>
</tr>
</tbody>
</table>

**Average Costs**

The 1975 projection, referred to above, estimates that the "annual ownership [capital] and operating costs" (at 5 per cent interest) of the entire U.S. highway system will be $18\frac{1}{4}$ billion. Since the annual capacity produced will be at least $18\frac{1}{4}$ trillion vehicle miles, this suggests that the average cost of production, of a vehicle mile of highway capacity, is at most 0.1c.

In an impressive study Meyer, Kain and Wohl have developed cost equations for interstate highways [5]. They find that the average cost of production of a vehicle mile of highway capacity ranges from slightly more than 0.1c. in rural areas to nearly 0.8c. in the most densely populated urban areas. Considering the very small number of miles of urban interstate highways (5,000 compared with the highway

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31The capacity figure usually cited for interstate highways is 1,600 vehicles per lane per hour. Since many miles of interstate highways exceed 4 lanes, the capacity figure of 6,400 is an underestimate. Further, the estimate that non-interstate highways have only 10 per cent the capacity of interstate (i.e., 640) is obviously also an underestimate.
system's total of over 3,000,000), these estimates reinforce the impression that 0.1c.
is typical of the average cost of production. Table 2, based on the equations
developed by Meyer, Kain and Wohl,\textsuperscript{32} presents costs for four-lane highways, for the
addition of four lanes to an existing highway, and for eight-lane highways. A capacity
produced of 1,600 per lane per hour is assumed. The net residential densities of 100,
50, 10 and 0 correspond roughly to large, medium and small cities, and rural areas.\textsuperscript{33}

**Table 2**

*Average cost per vehicle mile capacity produced*

<table>
<thead>
<tr>
<th>Net residential density</th>
<th>Four lanes</th>
<th>Marginal 4 lanes</th>
<th>8 lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cents</td>
<td>cents</td>
<td>cents</td>
</tr>
<tr>
<td>0</td>
<td>0.14</td>
<td>0.10</td>
<td>0.12</td>
</tr>
<tr>
<td>10</td>
<td>0.23</td>
<td>0.11</td>
<td>0.17</td>
</tr>
<tr>
<td>50</td>
<td>0.69</td>
<td>0.11</td>
<td>0.40</td>
</tr>
<tr>
<td>100</td>
<td>*</td>
<td>*</td>
<td>0.78</td>
</tr>
</tbody>
</table>

*Omitted, as 4-lane highways are irrelevant in such densely populated areas.

**User Financing**

In the U.S. all automobiles pay approximately 0.6c. per mile by means of the
gasoline tax. (In addition, toll highways charge about 2c. per mile). Users also
pay flat fees (which are not prices for vehicle use, since they are not on a per-mile
basis). These fees include licences, excise taxes, etc., and average about 0.6c. per
mile.\textsuperscript{34} On the basis of the 1975 projection of 1 trillion vehicle miles, user price and
user fees will each yield about $6 billion dollars. But, since the projected annual cost
of the highway system is $184 billion, the difference will have to come from
general taxes (see Table 3). The total annual cost is, of course, the cost of capacity
produced, of which – as we have seen – only some 5 or 6 per cent is actually used.

\textsuperscript{32}The types of costs include right-of-way (R), construction (K) and maintenance (M) as related to
two variables: the number of lanes (L) and net residential density (D). (The last variable is used as
specifically defined by Hyman Joseph, "Construction Costs of Urban Expressways," CATS Research
News, vol. 4, no. 1, Dec. 19, 1960). The equations are:
(i) $R = 0.005 D K$
(ii) $K = 236 + 54 D + 65 L$
(iii) $M = 100L$
so that the total hourly cost (per mile) in cents (using a 6 per cent interest rate) is
(iv) $TC = (1 + 0.005 D) (236 + 54 D + 65 L) + 100L$

where equation (i) is based on page 210 (4); equation (ii) is based on page 204 (3) setting $W_{c} = 1$
for all cases, since its variation is only from 0.933 to 1.0; equation (iii) is based on estimate of $9,000 per
lane mile per year.

\textsuperscript{33}At $D = 0$, the total right of way plus construction costs for a four-lane highway would be $655,000
per mile, which is comparable to the interstate highway system average cost per rural mile of $625,000.

\textsuperscript{34}Meyer, Kain and Wohl estimate that the total fees on users are about 1.2c. per mile [5, p. 68].
THREE ASPECTS OF HIGHWAY EFFICIENCY

Kenneth D. Goldin

Table 3

Highway Finance

<table>
<thead>
<tr>
<th>Total Annual Cost</th>
<th>User Prices</th>
<th>User Fees</th>
<th>General Taxes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$18 billion</td>
<td>$6 billion</td>
<td>$6 billion</td>
<td>$6 billion</td>
</tr>
</tbody>
</table>

IV. POSTSCRIPT

Although highways have a number of tricky characteristics, they are hardly a unique product. The chief characteristics include demand which is peaked and stochastic, supply which is time-constant and durable goods which have sizable indivisibilities. Highways have much in common with other forms of transport, with public utilities, and with the entertainment and resort industries. The big difference is that only highways have a time-constant price and an almost complete lack of (simultaneous) quality/price choices. In comparison, airlines have lower midweek and off-peak-season fares, and they offer first-class, coach and economy travel at different prices. Ships also have peak and off-season fares, and various classes. Long-distance telephone calls have peak (before 6 p.m.), medium (6–8 p.m.) and off-peak (after 8 p.m.) rates, with different rates for "station" and "person" calls. Telegrams can receive fast service or night-letter service at different rates. Gas and electric services are often available (to industrial users) at lower rates during offpeak hours. Resorts increase their rates and eliminate "package plans" during peak seasons, and theatres have higher prices in the evening than in the afternoon.

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BIBLIOGRAPHY


35Of course, there are still some inefficiencies. The letter rate goes down at the peak period (Christmas cards get a special rate). Taxis have time-constant rates. Bus and train commuter rates effectively lower the peak-period rate, and there is rarely any quality/price choice in urban areas.

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