Induced Traffic and Induced Demand

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Although terms such as “induced demand” and “latent demand” have been used in transportation planning for several decades, the concept of induced demand has not been precisely defined nor has it been translated into an operational form suitable for modeling. This paper defines “induced” as referring to a movement along a travel demand curve, in which the price dimension includes travel time and other user costs. Selecting the relevant demand curve is then an analytic choice. For FHWA’s Highway Economic Requirements System (HERS) model, movement along the within-period, short-run demand curve is referred to as “induced traffic,” while movement along the between-period long-run demand curve constitutes a shift in the short-run demand curve and is referred to as induced demand. The model employs this definition to evaluate highway improvement projects using benefit-cost analysis, incorporating effects of short-run traffic volume on changes in the generalized price, as well as effects of long-run land use and other economic feedback. These features were used in the HERS model to prepare the 1997 “Conditions and Performance” report to Congress.

“Induced” is a term implying that a particular condition is indirectly caused by another condition. In the case of traffic volumes, the term arose from the phenomenon that improvements to a highway—especially capacity improvements—seemed to result in more traffic choosing to use the road than would be the case if the highway were not improved. To an economist, this is an example of demand elasticity. Simply recognizing that travel demand is elastic, however, is not sufficient to reconcile the conflicting views of engineers, planners, and environmentalists. On one side are those who argue that transportation facilities are provided to serve land uses and support economic activity; on the other are those who claim that whatever capacity is provided soon fills up to the same level of congestion, gaining nothing. The truth can be better understood by defining induced demand in a way that uses the concept of elasticity.

This paper describes the concepts guiding several modifications to the Highway Economic Requirements System (HERS) model for the 1997 “Conditions and Performance” report to Congress. With minor exceptions noted below, the model implements the concepts described here.

CONCEPTS OF INDUCED DEMAND

Frequent references are made in transportation planning to the concept of induced demand, but the term remains ambiguous. The intent here is to define the relevant concepts and to show how they can represent demand in a benefit-cost evaluation of capital improvement projects.

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Exogenous Demand Factors

Historically, demand forecasts in urban transportation planning have been based on exogenous variables such as land use, population, employment, and income. Once these variables are measured or estimated, the result is a “point” estimate for traffic volume at a future date. Demand, in this sense, is influenced neither by transportation infrastructure nor by money price, but is determined entirely by exogenous factors.

If demand is determined by forces beyond the control of the transportation planner, then failure amounts to not having adequate facilities to handle demand, and the planner is simply a messenger. Alternatively, if the facility creates its own demand, the planner is just furthering the careers of planners.

Demand Fills Capacity

A contrasting concept has emerged, claiming that additional capacity stimulates corresponding increases in demand. This concept embodies the “build it and they will come” idea—or a belief in the existence of “latent demand,” which suggests that there are willing buyers who will express their demand for travel once the service is offered (*1*,*2*). In growing urban areas, the evidence from recent decades seems to support the impression that any capacity provided would be used.

Although the idea has not been implemented as a formal forecasting method, the implication is that demand is entirely endogenous. If true, the policy choice is whether to permit travel to grow or to suppress it.

Elastic Demand

Perhaps the first recognition that demand responded to endogenous factors was the assertion that congestion was self-regulating, implying an automatic balancing of supply and demand. More recently, the economist’s concept of demand as a relationship between price and the quantity demanded has become accepted, if not necessarily applied in practice. From this perspective, all endogenous changes in volume are movements along the demand curve, whether they are called latent, induced, or something else. If price is generalized to include travel time, operating costs, and accidents, then changes in capacity and alignment alter the price, causing movements along the demand curve.

Overall, then, travel demand is the result of a combination of exogenous factors, which determine the location of the demand curve, and endogenous factors, which determine the price-volume point along the demand curve.

SHORT RUN VERSUS LONG RUN

The short run can be any period of time over which something remains fixed. What is fixed might be the capacity of a highway, fuel efficiency of the vehicle fleet, locations of employment, or anything else that changes slowly. The long run is enough time for these characteristics to change. In transportation planning, the short run typically is assumed to be about 1 year, but the dividing line depends on the practical context.

Short-Run Elasticity

Demand elasticity is the responsiveness of the quantity demanded to changes in price. Price is generalized for travel demand to include travel time, operating costs, and accidents, as well as user charges. The generalized price embodied in HERS includes time, operating costs, and accidents, but not user charges per se; the implications of this omission have been discussed in greater depth (*3*). Everything included in this generalized price is an endogenous factor with respect to induced traffic. An increase in capacity that lowers travel time, for example, results in additional travel if the elasticity is not zero.

Short-run demand elasticity tends to be lower (i.e., less elastic) than long-run elasticity, because more opportunities to increase or reduce consumption can be developed over the long run than in the short run, while short-run options do not diminish in the long run. If the price of fuel goes up, for example, highway travelers can reduce fuel consumption by taking fewer trips and chaining trips together, by carpooling to share expenses, by driving in ways that achieve better mileage, and by taking a larger share of trips on transit. In the long run, they also can switch to more fuel-efficient vehicles, and change their workplace and residence locations. If the price stays high, vehicle manufacturers will develop and produce more fuel-efficient vehicles, and better transit service may be offered.

Long-Run Elasticity

Though the distinction between short-run and long-run demand is really a continuum rather than two discrete states, the separation is useful both conceptually and for modeling purposes. In Figure 1, two short-run demand curves are shown in relation to their common long-run demand curve (indicated by a dashed line). Demand could be for a facility, a corridor, or even travel in a region. At a long-run price of p_1, the volume is v_1 and the short-run demand curve D_1 applies, so that in the short run, changes in the price cause changes in volume along this demand curve. If the price drops to p_2, for example, then volume will increase to a flow of $v_{1,s}$. If the price stays at that level for the long run, then the short-run demand curve will shift outward to D_2, resulting in the volume v_2 at that price. If the price were then to go back up to p_1, volume would only drop to $v_{2,s}$ in the short run, but eventually back to v_1 in the long run.

For example, secular declines in real fuel prices have led to increases in the size and weight of vehicles and concomitant declines in fuel economy; if the price of fuel were to increase, gasoline consumption would drop but the vehicle fleet would take time to evolve to a more fuel-efficient average. Changes are not necessarily completely reversible—knowledge gained from research leading to advances in technology for fuel efficiency, for example, is not lost when the need is lessened, but its application tends to diminish.

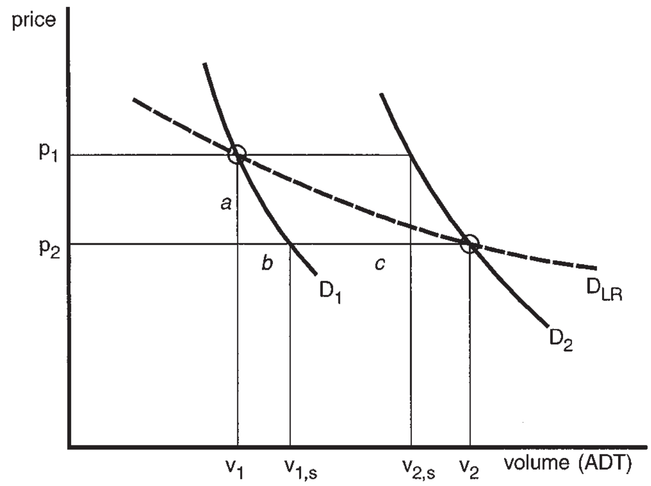

FIGURE 1 Long-run demand with short-run demand curves.

Induced Traffic Versus Induced Demand

A similar distinction can be made between induced traffic (or induced travel) and induced demand, by applying the short-run and long-run concepts. It is assumed that demand is fixed in the short run, so changes in volumes are the result of movements along the demand curve; but in the long run, the short-run demand curve can shift. In this way, these terms are defined so that induced traffic is a movement along the short-run demand curve, while induced demand is a movement along the long-run demand curve, or an endogenous shift in the short-run demand curve.

In Figure 1, no time direction is implied on the horizontal dimension; the shape of the long-run demand curve does not mean that price declines over time. Nor are the short-run demand curves necessarily ordered from one to two; demand could start at D_2 and then shift to D_1. The diagram shows only the relationship between price and volume under short-run and long-run conditions.

Disaggregation of Long-Run Elasticity

Long-run elasticity—as with any other demand elasticity—is a ratio of the percentage of change in quantity demanded to the percentage of change in the price of the good. Referring to Figure 1, the first circled point at (p_1,v_1) is taken to represent a point on both the short-run and long-run demand curves. The second circled point at (p_2,v_2) represents the long-run result of a price change, which lies on the previous long-run demand curve but also on a new short-run curve. The arc elasticity between the two points is

$$e_{\mathrm{LR}} = \frac{\%\Delta v}{\%\Delta p} = \frac{\Delta v}{\Delta p} \times \frac{p_1}{v_1} = \left(\frac{v_2 - v_1}{p_2 - p_1}\right) \times \frac{p_1}{v_1} \qquad (1)$$

where e_{LR} is the long-run elasticity of demand.

If the following simplifications are made for ease of presentation,

$$\begin{aligned} a &= p_2 - p_1 \\ b &= v_{1,s} - v_1 \\ c &= v_2 - v_{1,s} \end{aligned} \qquad (2)$$

as shown in Figure 1, then the long-run elasticity can be represented as

$$e_{\mathrm{LR}} = \frac{b+c}{a} \times \frac{p_1}{v_1} = \left(\frac{b}{a} \times \frac{p_1}{v_1}\right) + \left(\frac{c}{a} \times \frac{p_1}{v_1}\right) \qquad (3)$$

where the first term in parentheses is the short-run elasticity (e_{SR}) and the second term is the shift in the demand curve over the long run, represented as an elasticity.

Thus the long-run elasticity is the sum of the e_{SR} and a purely long-run component, which will be called the long-run share, e_{LRS}, defined as

$$e_{\mathrm{LRS}} = \left(\frac{c}{a} \times \frac{p_1}{v_1}\right) = \left(\frac{v_2 - v_{1,s}}{p_2 - p_1}\right) \times \frac{p_1}{v_1} \qquad (4)$$

so

$$e_{\mathrm{LR}} = e_{\mathrm{SR}} + e_{\mathrm{LRS}} \qquad (5)$$

The e_{LRS} component can be interpreted in the same way as a normal elasticity, and can be empirically measured as the difference between the short-run elasticity and the long-run elasticity, estimated for the appropriate time period (*4*).

Induced Traffic

As defined above, induced traffic is a movement along the short-run demand curve. Common usage of the term “induced” suggests additional traffic—that is, an increase in volume. Decreases might be called disinduced, deterred, or discouraged traffic. For present purposes, the term refers to any endogenous change, whether positive or negative. Increased congestion or higher tolls, other things being equal, will cause a reduction in volumes. If this occurs in the short run, this is negative induced traffic.

Some of the possible sources of induced traffic include the following:

- Diverted traffic that changes its route to the improved facility;
- Rescheduled traffic that previously used the facility at a different time, spreading or contracting the peak;
- Shifts from other modes, which might or might not have used the facility before, and which include changes in occupancy;
- Destination shifts, resulting from facility improvement; and
- Additional travel by persons already using, or in the market for, the facility.

Demand forecasts for a new or improved facility always include at least some of these sources, although such estimates seldom explicitly recognize a generalized price as the explanatory variable and do not produce a schedule of price-volume combinations.

Partial- and General-Equilibrium Demand Curves

All demand curves portrayed in this analysis are assumed to be general equilibrium demand curves, even those for the short run. They include traffic shifted to or from other modes or from alternative facilities. A partial-equilibrium demand curve, as represented in Figure 2, includes only the travel for those already in the market, whether they are currently taking trips or not (e.g., a person who did not travel at all in this corridor but who chose to do so after the price was reduced, and not by shifting a trip from another time or place). If the demand curve includes diverted travelers (from other modes, routes, times, or destinations), then it will be more elastic than the corresponding partial-demand curve because more options are offered. Thus some of the short-run induced travel comes from new

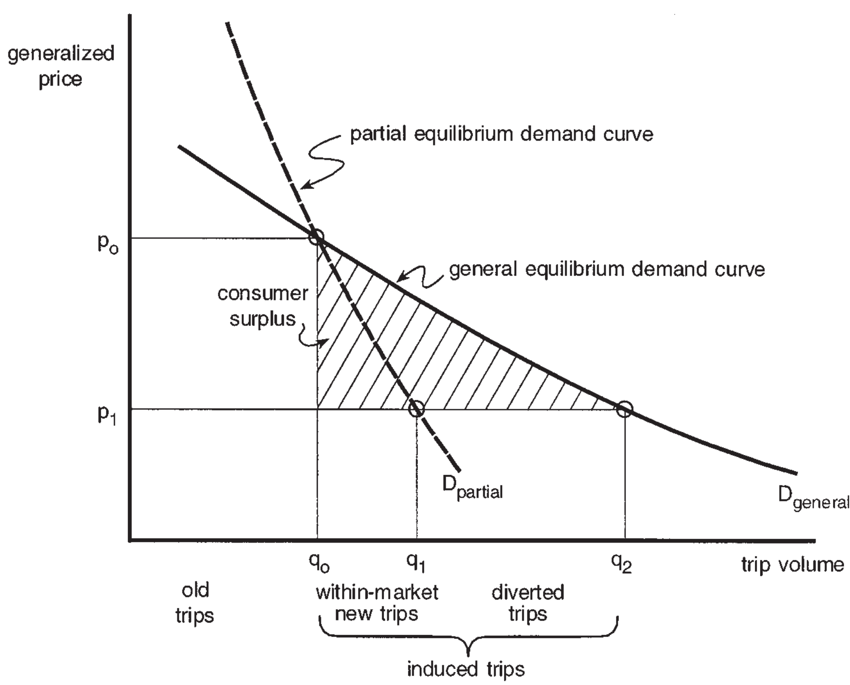

FIGURE 2 Partial- and general-equilibrium demand curves.

trips by persons already in the market, and some comes from trips diverted from other markets.

For every point on the general equilibrium demand curve there is a corresponding partial demand curve, representing the hypothetical demand if there were no substitution between markets. If the price were raised, for example, from a point on the general-equilibrium demand curve, a movement up the partial demand curve would imply that the travelers could not divert to another time or facility. Not surprisingly, such a demand curve cannot be observed in practice.

Because demand forecasts usually include diverted trips, practical demand forecasts are aimed implicitly at constructing (or locating points on) a general-equilibrium demand curve. If the demand is for a single facility, then induced traffic will appear large in relation to previous volumes, because most of the change will be from diverted trips. At the regional level, induced traffic—if it were actually estimated—would be a smaller share of total traffic growth, because only trips diverted from other regions, plus substitutions between transportation and other goods, make up the induced share. For a project evaluation, diverted travel and other components of induced demand, as measured in consumer surplus, represent the net valuation of systemwide impacts (*5–7*).

"Gross" Versus "Net" Induced Traffic

In Figure 2, all of the movement along the general-equilibrium demand curve stimulated by the reduction in price from p_0 to p_1 is labeled "induced trips." A portion of this induced traffic is labeled "diverted trips" (*8,9*). If the diverted trips are removed from the total "gross" induced traffic, the residual might be called "net" induced traffic. Some analysts prefer that the term "induced" be restricted to the net induced trips, and that the others be left as diverted trips (*10–13*).

For some purposes, this usage has an appeal, but the distinction is difficult to make. A trip between the same origin and destination but using a different route is clearly a diverted trip, but trips at other times, or to other destinations are less obvious. If the improved facility prompts a person to go to a movie instead of renting a video, and the video store is much closer, is this trip induced or diverted? Suppose the person would have walked to the video store. Or suppose the person would have had the video delivered, and the van would have used the same facility before it was improved. What can be observed directly is that more vehicles use the facility after it is improved, and that trips in the region do not go up by as large an amount as the volume on the improved facility. Labeling which travel is "new" and which is "diverted," however, is difficult and probably not necessary.

Schedule Delay and Peak Shifting

As noted earlier, changes in the generalized price can lead to changes in schedule. Peak congestion can be at least partially avoided by leaving earlier or later than preferred. A reduction in peak travel time will cause some travelers to join the peak because the cost to them of schedule delay (departing at a different time than preferred) is less then the new peak delay (*1*). Induced traffic, therefore, can be diverted from other times as well as other routes.

If the demand curve represents both peak and off-peak, then the elasticity will be lower than if peak is separated from off-peak. Because the two periods are so closely interrelated (off-peak demand depends on peak price, and vice versa), separating them for benefit-cost purposes can be tricky, but this is one way to include the benefits from reducing schedule delays.

INDUCED DEMAND

For evaluating costs and benefits, the overall analysis period for a project (generally the project's lifetime, e.g., 20 years) is broken into a series of discrete time periods, during each of which the demand curve is assumed to be fixed. A baseline long-range forecast is used to establish the short-run demand curve for each period.

Baseline Demand Forecast

A demand forecast is a functional relationship between time and traffic volume, assuming a set of conditions. Exogenous conditions include population growth, economic growth, land use patterns, and available transportation alternatives. Endogenous conditions include capacity, level of service (LOS), and user fees. For this analysis, all endogenous factors are represented in the generalized price. Both capacity and LOS, for example, would be subsumed under travel time cost and included in the generalized price.

The baseline long-run demand forecast assumes a generalized price, as well as whatever exogenous factors are thought to be relevant by the forecaster. Alternative forecasts might be constructed under different assumptions, as shown in Figure 3. One such forecast is selected for constructing the short-run demand curves.

Breaking the Forecast into Discrete Periods

The distinction between long-run induced demand and short-run induced travel is implemented by constructing a short-run demand curve for each of the shorter demand periods (e.g., 1–5 years), and allowing the initial curve to shift, depending on previous improvements. The forecast becomes a series of discrete points—shown circled in Figure 4—that provide the calibration points for the associated short-run demand curves The short-run demand curve can be a straight line calibrated with an elasticity, a constant-elasticity demand curve, or some other functional form that can be fitted to a single price-quantity combination. The elasticity chosen should be appropriate to the length of the demand period. (Currently, the demand or "funding" period in HERS is 5 years; the short-run elasticity should be selected to allow for adjustments that can be expected to take place within that span of time).

A single, fitted short-run demand curve is shown in Figure 5, along with other relevant prices and volumes. The price from the previous period $p_{\text{final},\,t-1}$ is adjusted to account for traffic growth, pavement wear, accident rates, and user-fee changes that have occurred since the previous period. The result is $p_{\text{no improvement}}$. Alternative improvements for the current period are evaluated, and if any are feasible, the best is implemented. This results in the p_{improved} price, which becomes the initial price for the next demand period. If no improvement is selected, the unimproved price carries into the next period.

Long-Run Shifts in the Demand Curve

Evolution of demand in the long run is built on what takes place in the short run. Operationally, induced demand is defined as the shift

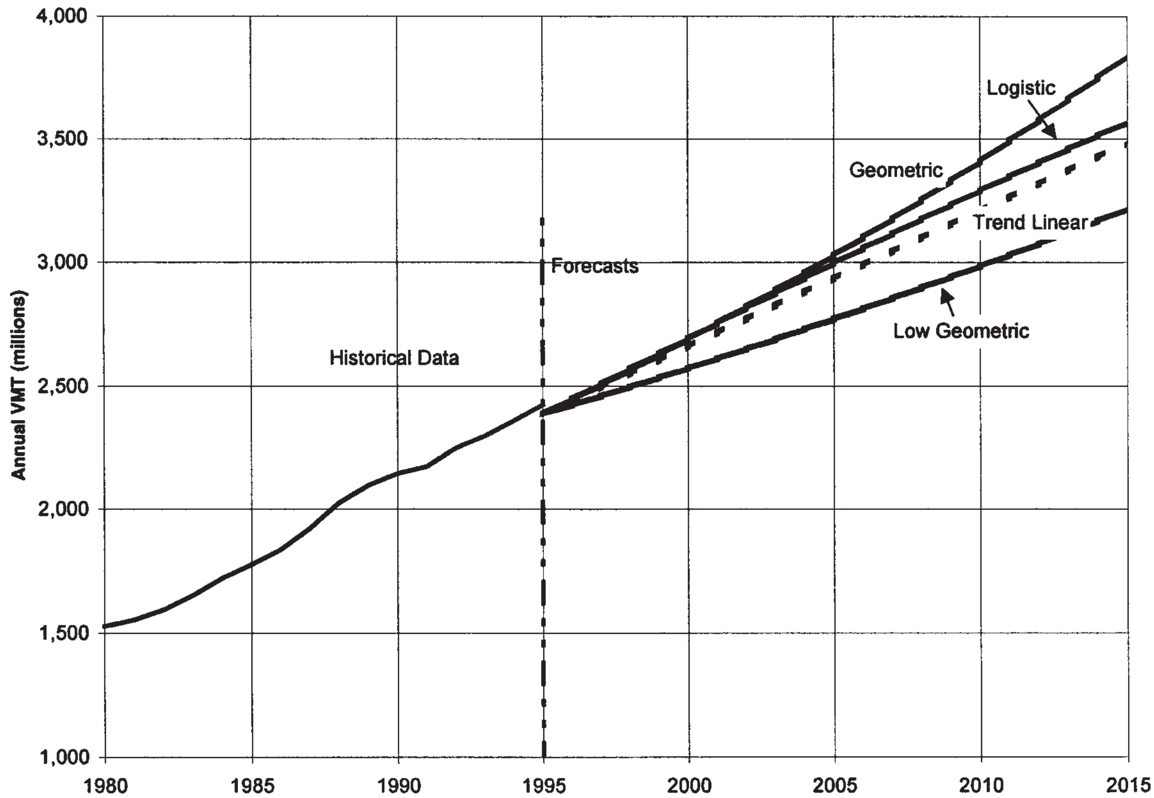

FIGURE 3 Alternative long-run travel forecasts.

in the short-run demand curve caused by the price in the previous period. If the price in all previous periods is the same as the baseline price, then the demand curve is fitted to the baseline forecast for that period. If an improvement is made in one period that reduces the price below the baseline price, this leads to a shifting of the demand curve outward, according to the percentage by which the price in the previous period is below the baseline price. If no improvement is made, the price increases relative to the baseline forecast price, and the demand curve shifts inward in the next period. These two possibilities are shown in Figure 6. For example, a price of $p_{\text{no improvement}}$ will shift the subsequent demand curve inward from q_{forecast} by a percentage equal to $(p_{\text{baseline}} - p_{\text{no improvement}}) \times e_{\text{LRS}}$.

The relationship between the difference in price of the final, improved—or not improved—price and the baseline price, for one period, and the horizontal shift in the demand curve in the next period, is governed by the long-run share e_{LRS}, as described earlier in the section on "Disaggregation of Long-Run Elasticity." There is no long-run demand curve as such, but the shift attributed to induced demand is a displacement of the short-run demand calibration point along the baseline price line.

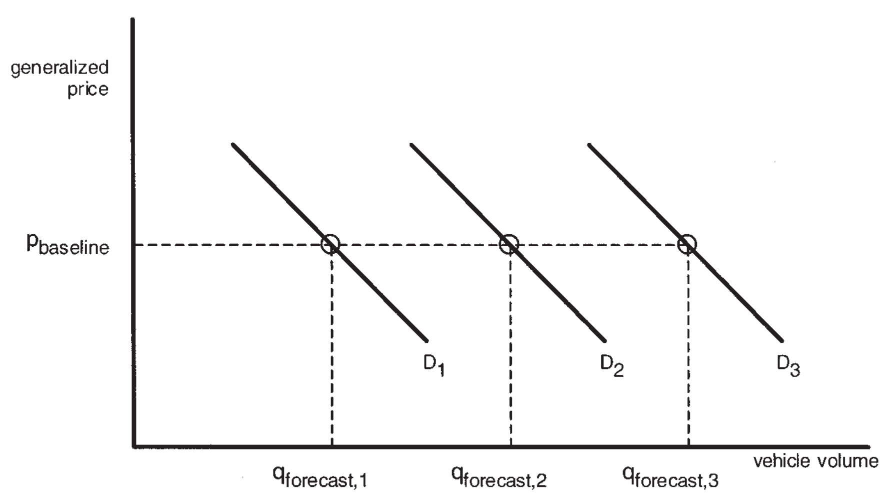

FIGURE 4 Baseline demand forecast for several periods.

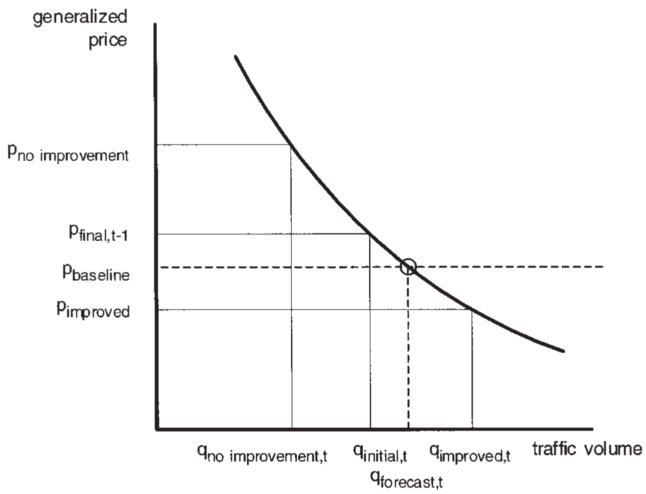

FIGURE 5 Short-run demand, showing prices with and without improvements.

Incorporating induced demand, then, allows each period's demand curve to be a function of the previous period's investment, since it affects price to the user. Investment that keeps the price in each period below the baseline price for the baseline forecast produces demand curves that shift farther and farther outward, compared with the baseline forecast. Similarly, if improvements are not made and price is allowed to rise in each period (e.g., due to congestion, pavement roughness, and accidents), the demand curve will be shifted continually inward in relation to the baseline.

The magnitude of this shift—the sensitivity of long-run demand to investment and pricing—is determined by the e_{LRS} parameter. The shorter the time period for the short run, the lower should be the long-run elasticity shift from period to period. If the long-run induced demand parameter is zero, the location of each short-run demand curve would be determined by the baseline forecast, without regard for which improvements—if any—were made in any demand period. Short-run movements along the demand curve still could occur, depending on the short-run price elasticity, but there would be no cumulative endogenous effects from one period to the next. Alternatively, with a high e_{LRS}, induced demand could alter the baseline forecast, even to the point of potentially offsetting the trend of the initial forecast, leading to growth in demand (due to keeping the price low) despite a declining forecast, or causing a decline in demand despite a growth forecast (traffic is deterred by congestion and bad pavement, a consequence of no improvements).

Getting to the Long Run

Empirical estimates of the two elasticities depend on the length of the short-run time period and the rate of adjustment to changes in price. The length of time between a change in conditions and a new equilibrium is somewhat arbitrary, because other conditions change before equilibrium is reached; however, the process is one of accelerating initial response followed by gradual refinement. In the context of highway volume adjustments in response to changes in the generalized price of travel, the short run is up to a year. The long run—allowing for changes in residence and workplace locations—begins within a year but may not run its course for 20 years or more. Such changes are not likely to be motivated solely by changes in transportation prices, but may take transportation user costs into account when the change is made for other reasons (e.g., new job, change in income, or change in family).

An approximate adjustment curve is shown in Figure 7. Although the curve is not fitted to specific data, it reflects the generally observed pattern that roughly half the adjustments take place within about a quarter of the time to long-run equilibrium. Some studies (*14–21*) focus on the time lag in response to highway capacity increases; others (*22*) investigate responses to reductions in capacity. If the full long-run adjustment period is 10 to 20 years, then half the long-run elasticity occurs within the first 2.5 to 5 years. There might be some accelerating adjustment in the first year, as shown, based on the idea that responses don't occur until consumers become sure the price change will stick, or until they begin feeling its effects.

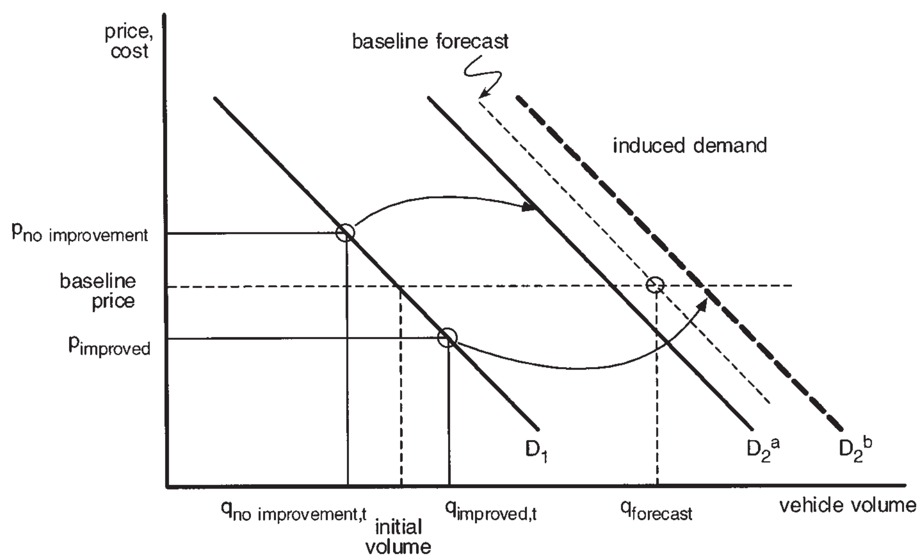

FIGURE 6 Long-run induced demand shift from one period to the next.

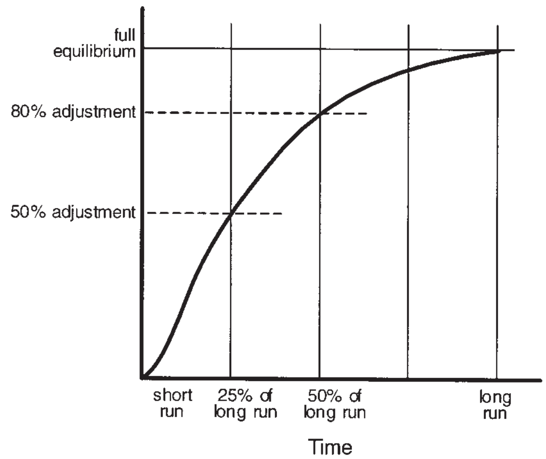

FIGURE 7 Path to long-run equilibrium.

Empirical Estimates of Short-and Long-Run Elasticities

Many studies have estimated travel-demand elasticities, but one of the difficulties in interpreting these results is the uncertainty of the time frame that is applicable to the data (*23–28*). Another confounding problem is the ambiguity of the base of the observed elasticity; because most of the empirical cases observe a change in a small component of the total price of travel, the base for computing the percentage change in price often is not obvious and might not be given explicit treatment. The potential differences are large (e.g., a factor of 3 or more); the empirical evidence and methods for estimating highway travel demand elasticities have been described (*3*).

The parameter sought is the elasticity of vehicle travel with respect to its own price, including user fees, operating costs, and travel time. Studies undertaken to date suggest that short-run elasticities tend to fall in a –0.5 to –1.0 range, and long-run elasticities from –1.0 to –2.0; a within-period, short-run elasticity for a 5-year period would be –0.6 to –1.0 and the between-period elasticity from –1.0 to –1.6, yielding an e_{LRS} of about –0.4 to –1.0.

Interpreting Demand Forecasts

Two aspects of the demand forecast are of particular interest. One is how to impute a presumed price to the baseline forecast. The second is whether long-run feedback of transportation investments on the demand curve has been incorporated into the forecast.

- Baseline price. Although the generalized price behind a demand forecast is seldom made explicit, such attributes as LOS, accident rates, and others can be guessed. Pavement quality is probably assumed to be good, and operating costs are typical for the conditions (terrain, vehicle type, congestion). The current LOS can be assumed as a default.
- Long-run demand feedback. Constructing or expanding a facility may stimulate or permit some additional travel in the long run, even if the price remains unchanged from the baseline in each period. Therefore, the baseline forecast should include growth in travel resulting from traffic-generating activities that locate to take advantage of the services provided by the facility at the baseline price. The long-run elasticity amplifies this effect up or down, but does not substitute for it.

If forecasts are based on historical patterns over a time horizon of half a dozen years or more, then the feedback effect implicitly is built in. Whether it needs to be made explicit or refined is an open question, but the impacts of errors in out-year forecasts are suppressed somewhat by discounting.

SUMMARY

Some of the ambiguity and confusion that surrounds the discussion of induced demand might be dispelled by applying the following definitions and principles:

1. The term *induced* means a movement along a travel demand curve as a result of changes in *endogenous* factors, which can be represented as components (time, running cost, money) of a generalized price.
2. The measurement of induced travel depends on the *market* for which the demand curve is defined; induced travel defined at the facility level will include traffic diverted from parallel routes, and induced travel at the regional level will include only trips that are new to the region.
3. A useful distinction can be made between *short-run* demand and *long-run* demand. Movement along the short-run demand curve amounts to *induced traffic.* However, movement along the long-run demand curve constitutes a *shift* in the short-run demand; this can be called *induced demand.*
4. Benefit-cost evaluation of projects requires that baseline demand forecasts be adjusted to take into account induced demand, both short and long run; simply stated, improvements that change user costs should be evaluated in light of whatever changes in volume actually occur. Such demand curves are referred to as general-equilibrium demand curves.
5. If the short-run elasticity is zero, then traffic volumes are unresponsive to changes in price within a single demand period, and the demand curve is vertical. If the elasticity of the long-run share (i.e., excluding short-run effects) is zero, then there are no long-run effects (e.g., no investment in highway-related facilities or land-use changes) stimulated by highway pricing and investment policies. Empirically, neither of these conditions seems to apply.

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