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Publication of this paper sponsored by Committee on Energy Conservation and Transportation Demand.

Evaluating the Costs and Benefits of Plans to Reduce Gasoline Queues

NANCY S. DORFMAN AND IAN E. HARRINGTON

The costs in terms of service station queuing of contingency plans designed to reduce gasoline demand during a shortfall in petroleum supply are analyzed. Queues are recognized as a response to market disequilibrium that will grow until the cost per gallon of queuing fills the gap between the equilibrium price and the price charged at the pump. The cost of queuing can thus be inferred from this price differential; the reduction in total queuing costs represents the benefits produced by the contingency plan. Benefits and costs of a contingency plan are measured relative to the alternative of rationing by queuing. The value of these benefits is measured for three such plans and compared with rough estimates of the costs of achieving them. Costs include the losses in consumer surplus caused by a plan and the expenses of implementing a plan. An economic model of the retail gasoline market is presented graphically to describe the theory that underlies the analysis. An important inference that can be drawn from the analysis is that, when more-efficient policies are precluded, restrictions on consumption may be designed that will yield benefits in excess of costs. The three plans analyzed in this paper are an employer-based plan to encourage more energy-efficient commuting travel, a sticker plan to require each household to give up use of all of its cars on a selected day of the week, and a ban on weekend use of off-road recreational vehicles, private boats, and aircraft. Estimates are based on data from secondary sources and a set of assumptions that include a 7 percent shortfall in the supply of gasoline in 1981. Benefits from all three plans are found to exceed their costs.

In the winter of 1973-1974 and again in the spring of 1979 the United States experienced shortages of gasoline. Not only did the supply of gasoline fall below consumers' demand, but also the price was not permitted to rise sufficiently to clear the market. The result was an excess of demand at the prices being charged at the pump. When prices fail to rise to the equilibrium level, some other mechanism perforce takes over to determine how limited supplies are allocated among competing users.

In the absence of any other type of rationing (for example, government-issued coupons), the tendency is for queues to form at gasoline stations. Under perfect market conditions (perfect information and absence of discrimination or product differentiation), queues will grow to be equal in length at all gasoline stations in a given market, and we would expect their length to be sufficient to cause the cost of queuing per gallon of gasoline to consumers to make up the difference between the dollar price at the pump and the price consumers would be willing to pay for the marginal gallons purchased. The cost of queuing will thus equilibrate the market when price is controlled. The queues' length will be determined by the excess of demand over supply.

Queuing is a real resource cost, in contrast to dollar payments, which represent transfers of purchasing power. They are what economists call a dead-weight burden. No one benefits from the use of resources employed in queuing nor can their cost be recovered through taxation. It is, therefore, a good idea to reduce or eliminate queues even at some cost to society at large. This paper concerns one method for doing so.

It is necessary at the outset to distinguish between queues that consumers join in order to stake a claim to a share of a product when there is not enough to go around at the current price and queues due to congestion caused by bottlenecks in distribution. The former phenomenon concerns us here. The latter can be eliminated by removing the bottlenecks (e.g., increasing the number of gasoline station pumps and attendants, having stations remain open longer, or instituting minimum purchase requirements); the former cannot. Speeding up the distribution system will merely cause the number of cars in line to grow to restore queuing time to its former level when queues serve as a price to bring demand and supply into equilibrium. It will also force stations to close sooner.

Barring an increase in the supply of gasoline, there are three ways to eliminate queues caused by a gasoline shortage:

1. Let the price rise to clear the market, via either market forces or a tax increase;
2. Substitute some other form of rationing that assures consumers a given amount of gasoline without queuing; and
3. Reduce demand for gasoline to the point where consumers are satisfied to purchase no more than the available supply at the price that is charged at the pump.

We report here on a study undertaken for the U.S. Department of Energy (DOE) to investigate measures to reduce demand. Under terms of the Energy Policy and Conservation Act of 1975, DOE was required to present to Congress standby plans for dealing with an emergency petroleum shortage. That act, as well as its successor, explicitly excluded the use of pricing and taxing measures by the federal government, and rationing is permitted only when the shortage is expected to reach 20 percent of normal. The Energy Emergency Conservation Act of 1979 calls for contingency plans to be imposed on a state-by-state basis only when states do not adequately implement their own plans in an emergency. Once again, taxing and pricing measures are not permitted to be imposed on states by the federal government. Thus, in spite of the fact that taxing, and possibly rationing, policies can be designed to eliminate queues at gasoline stations more efficiently (and therefore at a lower social cost) than can the alternatives, the focus of this paper is on contingency measures to reduce demand.

A major conclusion of the study is, however, that, although a reduction in demand is not the most-efficient or equitable means of eliminating queues and restoring an orderly market, in the event that other means are precluded, measures can be designed that will achieve total benefits in terms of reducing queues that exceed their costs to society.

ANALYSIS OF THE PROBLEM

Figure 1 illustrates the effect of a reduction in demand for gasoline on the total cost of queuing. Gallons of gasoline supplied per year are measured horizontally and price per gallon in terms of dollars or the dollar equivalent in queuing cost is measured vertically. The curve DD represents the normal demand for gasoline as a function of dollar price. The total supply of gasoline per year (q') will be completely inelastic above the dollar pump price. The equilibrium price is evidently at p'. If the pump price is controlled at p (below the equilibrium), queues will form to raise the total price, including the cost of queuing per gallon, to the average consumer, to the point where consumers are satisfied with purchases of q' gallons when the dollar price is controlled at p. The number of minutes of queuing time per gallon will depend on the demand for gasoline as a function of dollar price and on the marginal cost per minute of queuing to consumers. Since the latter will vary among consumers, the demand for gasoline as a function of its dollar price will not necessarily be identical with demand as a function of average queuing cost. It will, however, represent an adequate approximation. We assume in the analysis that follows, therefore, that demand can be measured interchangeably as a function of dollar price or of the dollar cost of queuing per gallon from the point of view of the average consumer.

The queuing cost would be exacted on all q' gallons of gasoline under perfect market conditions. Due to discrimination in favor of old customers or other market imperfections, however, some customers may obtain gasoline with little or no queuing. They will therefore consume more gasoline than they would at the higher price and less will be available for others. The result will be higher queuing costs for those who must queue. The cost of queuing averaged over all q' gallons of gasoline will be p' - p, which leads to a total queuing cost of q' (p' - p).

Approximately 1.7 billion gal of gasoline are currently sold at retail outlets each week. If the difference between the equilibrium price and the controlled price were $1.00, queuing would cost consumers in the neighborhood of $1.7 billion/week, or $90 billion/year. A $1.00 differential between the controlled price and the equilibrium price is not an outlandish possibility. By using a liberal estimate for demand elasticity of -0.15, a 10 percent reduction in supply starting from a $1.00/gal price in equilibrium before the shortfall would call for a $1.00 price increase in order to equilibrate the market if demand remained unchanged.

On the other hand, recent experience shows that a shortage may cause demand to shift. When prices or queues start to rise, fear that gasoline may be less available or higher priced in the future may shift the demand curve upward temporarily. Some consumers hoard gasoline against future contingencies. They increase the amount of gasoline stored in tanks by filling their tanks when they have less excess capacity than normal. Once the supply stabilizes, however, so that there is no reason to anticipate gasoline will be harder to find or more expensive in the future, tank storage returns to normal and demand is temporarily reduced below normal.

A more permanent downward shift in demand occurs, however, because gasoline stations voluntarily close on Sundays and often during other normal operating hours. There can be little question that the possibility of being unable to obtain supplies on out-of-town weekend trips significantly reduced demand during the summer of 1979. This, in turn, reduced queues so that the total cost of queuing was less than what it would have been had demand remained at its normal level.

We are concerned here with measures specifically designed to reduce demand. By a reduction in gasoline demand we mean a downward shift in the demand curve, which implies a reduction in the price that consumers are willing to pay for any total quantity. For any amount of gasoline, a reduction in demand will cause the price that will clear the market to be lower than before.

There is no costless way to reduce demand for gasoline. (This is not meant to imply that there is no costless way to reduce queues. Tax shifting can eliminate queues at no real cost to the economy as a whole.) Either alternatives to gasoline consumption must be made more attractive or gasoline consumption made less so. The first will generally impose a cost on the provider or promoter of substitutes in the form, for example, of increased subsidies to transit, paratransit, or ridesharing programs. The second will exact a loss in consumer or producer surplus from both individuals and businesses (the latter account for 16 percent of retail gasoline sales) by reducing the utility of some or all

Figure 1. Effect of demand reduction on total cost of queuing.

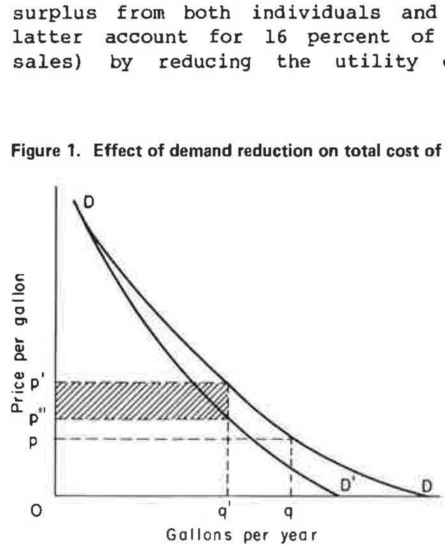
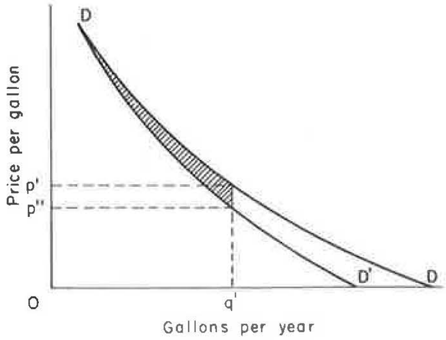


Figure 2. Effect of demand reduction on total gasoline consumption.



consumption and by causing consumers to substitute lower-valued uses for some that they are obliged to forgo. Total consumption will remain the same, given the inelastic supply. A measure, for example, that reduces the time, place, or manner in which consumers can obtain or use gasoline lowers the marginal utility of any given quantity of gasoline to consumers and, in turn, the price that they are willing to pay for it, whether in cash or in queuing.

If demand reduction is to be used as a means to reduce queuing costs, the minimum criterion for accepting a measure will have to be that the benefits (in the form of queuing costs saved) exceed the costs of reducing demand. This criterion is not, as it happens, difficult to meet. Figure 2 provides a clue as to why. DD' represents the new demand for gasoline after imposition of the contingency plan.

If the reduction in demand is achieved by restricting the use or sale of gasoline in such a way that people are willing to pay only a lesser price per gallon for any total quantity than before, consumers will suffer a loss in surplus on each gallon of consumption unless the price falls. If price remains at p', the loss in surplus on each incremental gallon will amount to the vertical difference between DD and DD' at the point on the graph that corresponds to that increment. For example, the loss in consumer surplus on the qth gallon would be equal to p' - p". The loss in surplus on all q' gallons together would amount to the shaded area in Figure 2.

If, on the other hand, the price paid falls by more than the reduction in demand for any gallon, there will be a net gain in consumer surplus on that gallon. In order to ensure that the cost per gallon of queuing falls by more than the reduction in demand on all q' units, all that is necessary is that demand be reduced in such a way that DD' is steeper, as well as lower, than DD. In that case, the fall in queuing cost on each gallon of q' (as illustrated by p' - p") will exceed the fall in value of consumption on that gallon for all units except the marginal one. The steeper DD' is in relation to DD, the lower will be the cost of reducing queues relative to the benefits. This steepening is achieved by designing the demand-restraint measure in such a way that it will eliminate uses of gasoline that consumers value least (i.e., the marginal uses) rather than those whose utility is relatively high to consumers.

There is no excuse, therefore, for designing measures to be any more onerous than is necessary to achieve a given reduction in demand at the margin. To deprive consumers of uses of gasoline that are especially valuable to them serves no purpose that cannot be achieved in a less-costly manner.

MEASURING IMPACTS

The main direct and intended benefits of a plan to restrict demand consist of the reduction in total queuing time it achieves. In order to assess these benefits it is necessary to have a good approximation of the demand for gasoline as a function of queuing cost and to be able to estimate the impact a given plan will have on that demand function. A subsequent section of this report describes the method used for approximating the impacts on queuing costs of three different contingency plans along with the results of analysis in each case. Although in interpreting the results allowance must be made for wide margins of error, the results represent, we feel, useful approximations.

The costs of a measure are likely to be more speculative. If the plan consists of reducing gasoline demand by making substitutes for gasoline consumption more attractive (e.g., improvement of transit or paratransit services), the costs will generally be susceptible to measurement according to straightforward accounting procedures. If, on the other hand, demand is reduced through restrictive measures, an estimate of the cost in terms of consumer surplus lost will necessarily demand a high degree of improvisation.

Three other considerations deserve attention when any measure is evaluated. Specifically, a measure may have more or less significant secondary impacts on specific industrial or geographical sectors. It may have some impact, favorable or otherwise, on aggregate variables such as gross national product, employment, and the price level. And, finally, whatever its overall benefit/cost ratio, the distribution of its costs and benefits among different income or other groups may be more or less acceptable.

METHOD FOR ESTIMATING EFFECTS OF PLAN ON QUEUING COST

As illustrated in Figure 2, we want to estimate for each of three contingency plans the amount by which the shift in demand from DD to DD' lowers the price from p' to p", with the quantity of gasoline stationary at q'. Briefly, the three plans include

1. An employer plan that requires that employers adopt measures to facilitate and promote energy-efficient work travel by their employees,
2. An automobile sticker plan that requires car owners to forgo use of their vehicles on a selected day of the week for the duration of the emergency, and
3. A ban on weekend use of off-road vehicles, private boats, and aircraft.

The Base Case

Since any such plan will be directed at some specific use of gasoline by category of traveler, day of week, purpose of trip, or type of vehicle, it is necessary, first, to project to the year in question the normal distribution of gasoline consumption according to the relevant travel categories and, second, the distribution after the shortage. We based our normal projections to 1981 on the McNutt and Dulla model of automobiles and light trucks (1), the growth rates indicated by 1974-1977 Highway Statistics data for heavy trucks and buses (2-5), and the personal travel characteristics indicating mode and purpose of trips on the 1970 Nationwide Personal Transportation Study (6).

In addition, we made the assumption that the 1981 price of gasoline, under normal conditions in 1977 dollars, would remain at about the 1978 level of $0.70/gal.

A fall in the supply of gasoline will cause its price to rise, either in dollars or in queuing costs, which will lead to a change in travel patterns. This effect must be estimated for the assumed level of shortfall before the net impact of the contingency plan can be assessed. Estimates of the price increase and the resulting distribution of consumption of gasoline by mode and trip purpose describe what we refer to as the base case, or the situation on which the contingency plan is assumed to be imposed.

For the analysis, we assumed that the total supply of gasoline available at retail outlets will fall 7 percent below the projected 1981 normal level and become completely inelastic beyond that level. The price increase caused by the shortage occurs, under our assumptions, in the form of gasoline station queues, rather than a dollar increase, which implies that the pump price is effectively controlled at the preshortfall level. Current gasoline price controls in the United States cannot actually prevent retail prices from rising because they permit increased import prices to be passed on to consumers. At best, they delay the impact on retail prices.

As noted earlier, we assume that the amount of time each consumer is willing to spend waiting in queues is equal to the price per gallon he or she would be willing to pay over and above the pump price for the marginal gallon. We also assume that the queues will lengthen until the queuing cost per gallon paid by the average customer is equal to p' - p. Thus

$$p + w = p' \quad (1)$$

where w is the cost of queuing per gallon of gasoline to the average customer.

To estimate p', we have assumed a total highway gasoline demand elasticity (e) with respect to either queuing or dollar price of -0.15. This is in line with a number of empirical estimates of price elasticities, although in the short run it may be, if anything, on the high side. The further assumption that elasticity is constant over the relevant range of prices is not as well substantiated.

By substituting the assumptions that e = -0.15, q'/q = 0.93, and p = $0.70 in Equation 2,

$$p' = [(q'/q)^{1/e}]p \quad (2)$$

we get p' = $1.14. This would imply a queuing cost per gallon of $1.14 - $0.70 = $0.44.

The assumption that the demand function used to estimate the price change remains unchanged in the face of the shortfall is tenuous, for reasons discussed previously. The assumption that dollar price would remain at the preshortfall level is also questionable on the basis of recent experience, but it does not seriously affect the analysis so long as the contingency plan does not reduce demand sufficiently that the equilibrium price falls below the pump price.

In order to estimate the redistribution of gasoline consumption among travel modes and trip purposes that results from the increase of queuing price, partial price elasticities of demand (e_{mi}) were estimated for combinations of mode m and purpose i. Price elasticities were estimated for fuel consumption by automobile, light truck, heavy truck, and bus from a review of available price elasticity literature. These elasticity estimates were then adjusted for different trip purposes based on the relative reduction in different trip frequencies during the 1973-1974 supply shortfall (7). The resulting distribution of gasoline consumption by mode and trip purpose was then estimated by using Equation 3, with p'/p = 1.57 and q_{mi} from the base case:

$$q'_{mi} = (p'/p)^{e_{mi}} q_{mi} \quad (3)$$

Effect of Contingency Plans on Queuing Price

From the base-case distribution of gasoline consumption by travel category, we estimated the likely reduction in gasoline consumption that the plan would cause in each category. These estimates were arrived at differently for each plan, depending on sources of data and the specific types of assumptions required. Considerable uncertainty necessarily surrounds them. Among other things, the degree of compliance with the law is hard to predict in each instance.

The total reduction in gasoline consumption targeted by a contingency plan is measured by the horizontal distance from C to B in Figure 3. Such plans do not reduce total consumption, which remains at q'; they merely reduce the price that consumers are willing to pay for q' gallons by forcing them to substitute uses that they would not have undertaken when the price was p' for some uses that were worth at least p' to them. This causes a shift to the left in the demand curve (DD).

Under some kinds of plans the new demand curve will be parallel to the old one below p', as illustrated by DD". The so-called employer plan, for example, would change the slope of the demand curve above p' but not below p', because it does not reduce the value of uses of gasoline that might replace those given up as the price falls. The effect of such a plan is to reduce queuing price by p' - p" in Figure 3.

If we call the distance from C to B (which is equal to the distance from G to H), Δq', the reduction in queuing price (Δp') can be estimated by making the appropriate substitutions in Equation 4:

$$\Delta p' = p' - p'' = p' - \left\{[(q' + \Delta q)/q']^{1/e}\right\}p' \quad (4)$$

This is equivalent to the effect of increasing the supply of gasoline by Δq'. The total reduction in queuing costs on all q' gallons of gasoline will be q' (Δp').

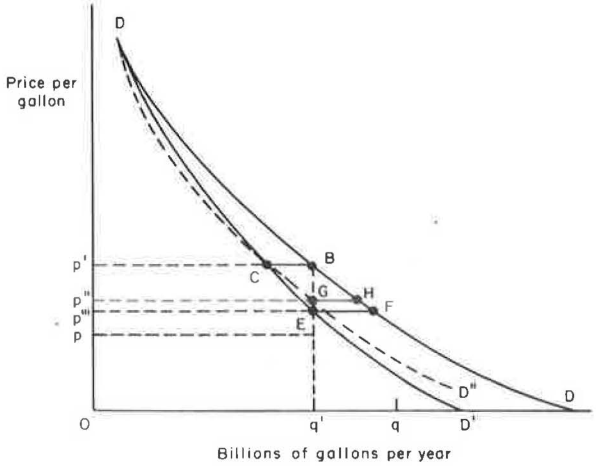
Other plans will not only shift the demand curve to the left but also lower e, which causes the new demand curve to be steeper than DD below p', as illustrated by DD' in all of the figures. This will occur when a plan not only causes consumers to forgo gasoline uses that they had undertaken at price p' but also restricts incremental uses that they would have undertaken when the price fell. The off-road plan and sticker plan have this effect on gasoline demand.

In order to estimate the new partial elasticity (e') for any category, we have assumed that increases in consumption in that category due to a price decrease are restricted in the same proportion as the reduction in consumption at price p'. The new total elasticity is thus derived from Equation 5:

$$e' = \sum_{mi}\sum e_{mi}(q'_{mi} - \Delta q'_{mi}) / \sum_{mi}\sum q'_{mi} \quad (5)$$

The effect of such a plan on the equilibrium price will exceed the effect of an increase in gasoline supply of Δq'. This follows from

Figure 3. Effect of demand reduction on changes in price with alternative elasticities.



substitution of e' for the larger e in Equation 4. The greater effect can also be seen from Figure 3, where the shift in demand from DD to DD' causes the equilibrium price to fall from p' to p'", below p". The fall in price is equivalent to the effect of an increase in gasoline supply that amounts to EF rather than GH. This quantity, which we refer to as Δq", can be estimated from Equation 6:

$$\Delta q'' = [(p'''/p')^{e'} - 1]\, q' \qquad (6)$$

The resulting fuel consumption for each travel category q''_{mi} is thus estimated as a function of the relative price change and previous consumption, as shown in Equation 7:

$$q''_{mi} = (p'''/p')^{e'_{mi}} (q'_{mi} + \Delta q'_{mi}) \qquad (7)$$

ESTIMATED IMPACTS OF THREE CONTINGENCY PLANS

Three possible contingency plans, an employer-based plan, a vehicle-use sticker plan, and an off-road travel-restriction plan, have been analyzed under the procedures described above. As of this writing, DOE has taken no position with respect to any of these plans.

To recapitulate the major assumptions that underlie the analysis:

1. Implementation is carried out in conjunction with a 7 percent shortfall from normal gasoline supplies in 1981 and supply becomes perfectly inelastic beyond that point;
2. Fuel allocations to retail service stations, airports, and marinas are reduced in proportion to the 7 percent shortfall;
3. Prices charged at the pump remain fixed at the assumed preshortfall level of $0.70/gal in 1977 dollars;
4. The price elasticity of demand for highway gasoline consumption is -0.15 and is constant over all quantities within the range considered;
5. The public is informed regarding the length of queues at different gasoline stations and responds in a rational manner;
6. Annual vehicle miles of travel and fuel efficiency for buses and heavy trucks will maintain the growth rates they exhibited in the 1974-1977 period;
7. Personal travel in preshortfall 1981 will have the proportional characteristics identified in 1972; and
8. Shortfall travel reductions for different purposes or modes will be proportional to those exhibited in the 1973-1974 supply shortfall.

Employer-Based Plan

This plan would require private-firm work sites of 100 or more employees and government work sites of 50 or more employees to implement at least a minimum number of measures to encourage shifts of mode for work travel from the single-occupant automobile to more energy-efficient modes. The measures may be selected by employers from a list that includes carpool matching programs, vanpools, transit subsidies, parking management strategies, transit prepaid-pass distribution, alternative work-hour programs, fleet-use restrictions, paratransit service programs, and a work-at-home plan.

The shortfall itself will, of course, induce an increase in carpooling. It may also make employees more responsive to employer efforts. On the other hand, employers will be more inclined to undertake such efforts in the event of a shortfall even without a plan; thus the effect of the plan will be minimized.

If the programs implemented under this plan achieve employer and employee responses similar to those of the more-successful employer experiments to date, we estimate that the demand for gasoline would be reduced by about 20 000 bbl/day (about 0.3 percent of retail sales at sevice stations). However, if employee responses actually improve enough to achieve a goal of 50 percent use of modes other than single-occupant automobile and the shortfall pressures produce greater employer response, the demand for gasoline may be reduced by about 50 000 bbl/day (about 0.8 percent of retail station sales). The latter case would lead to about a 6 percent reduction in the shortfall equilibrium price of gasoline.

The potential effect of the employer-based plan is rather limited, due in part to its limited scope, since it only affects the commuting trip and covers only work sites of sufficient size to implement effective programs. In addition, it does not place any restrictions on travel; it merely requires work sites to take steps to encourage voluntary modal shifts in commuter travel.

Sticker Plan

The vehicle sticker plan would require members of a household to display stickers on all of their automobiles to indicate a single day of the week on which none of them can be driven for the duration of the emergency. We assume that households in which all workers have access to work via modes other than single-occupant automobile during a shortfall would opt for a weekday sticker day. Also, since most trips other than work trips and recreational trips of two or more days are transferable to other days of the week, only a portion of the normal travel demand for any household's sticker day will be cut.

It was necessary to make plausible assumptions regarding levels of trip transferability, public compliance, and the granting of exceptions and exemptions. By using these assumptions, analysis indicates that the sticker plan would reduce the demand for gasoline by about 310 000 bbl/day (about 5 percent of retail gasoline sales) and lower the shortfall equilibrium price of gasoline by about 28 percent. This is the only one of the three plans that would have a significant impact. A side effect of the plan is to increase personal recreational and commercial travel and cause commuter automobile travel to fall below its expected shortfall level.

The plan would also overwhelm the capacity of many transit systems to carry passengers.

Although the potential effects of a vehicle-use sticker plan thus appear to be fairly large, it involves serious inequities. It would impose a severe burden on those households that do not have access to alternative work-trip modes but not force persons who customarily travel to work by other modes to make any sacrifices.

Off-Road Plan

The plan for emergency restrictions on boats, aircraft, and off-road vehicles would prohibit all personal, business, or executive flying of private planes, recreational powerboat trips, and off-road recreational travel on motorbikes, snowmobiles, four-wheel-drive vehicles, and dune buggies on weekends. Only portions of the off-road trips by these modes would be eliminated, since significant amounts of their use occurs on weekdays and some of their weekend use can be transferred to weekdays. Enforcement problems would be serious.

It was necessary to make plausible assumptions regarding the portion of use on weekdays, weekend-use transferability, and public compliance with the plan's restrictions for each type of off-road-vehicle use. We estimated that the plan would reduce the demand for gasoline by about 100 000 bbl/day (about 1.6 percent of retail gasoline sales) and lower the shortfall price of gasoline by about 11 percent. The plan would result in a net reduction in total recreational travel, although other forms of such travel would increase. Commuting and commercial travel would rise to compensate for the fall as the queuing price fell. The plan has serious distributional problems, impinging as it does chiefly on a small segment of the public. Industries that serve and supply recreational vehicle owners would also suffer serious losses. The inequity would be moderated if the plan were imposed in conjunction with the automobile sticker plan.

COSTS AND BENEFITS

The benefits of each of the three plans described above were measured in terms of the dollar value to all consumers combined of the reduction in queuing time that resulted. The percentage reductions in the queuing price that were estimated were converted to dollar reductions by multiplying by $1.14 (the equilibrium price after the shortfall). In the case of the employer plan, benefits would come to between $0.02 and $0.07/gal; for the sticker plan they would be in the neighborhood of $0.30/gal, and for the off-road plan between $0.10 and $0.15/gal.

The costs of reducing demand are of two sorts--implementation costs to government, employers, or other institutions responsible for financing measures and the loss in consumer (producer) surplus exacted from gasoline users.

In a program such as the employer-based plan described above, which depends on voluntary response by automobile users to an enhancement of the attractiveness of more energy-efficient modes, the cost will be borne entirely by those responsible for financing its implementation. The specific measure described here was estimated to cost employers about $0.5 billion if it were implemented for a full year. Under the assumptions described above, the reduction in queuing cost that would result was estimated to range from $0.02 to $0.07/gal. On the more than 90 billion gal sold at retail in a year, these savings would range from about $2 to $6 billion. If the estimates are anywhere near to being correct, the plan would be worthwhile on cost-benefit grounds in an emergency energy shortfall that was expected to last for several months. Note, however, that this plan would compensate for only a very small reduction in gasoline supply.

The other two plans take their toll mainly in the form of consumer surplus lost to gasoline users. This loss is the sum of the amounts over and above the price that consumers would be willing to pay, if necessary, for each of the q' gallons of gasoline purchased before the plan goes into effect. The loss is extremely difficult to estimate.

Based on the analysis, the loss is almost certain to be less than the benefits since neither plan will be likely to require most consumers to give up their more highly prized uses of gasoline. One way of thinking of the surplus from gasoline consumption that will be lost is the loss in value of fixed investment in vehicles due to their being unusable one or two days per week. We have developed some crude approximations to this value for each plan on the basis of estimates of the value of capital invested in vehicles or craft whose availability would have to be forgone in order to comply with the measures. These estimates fail to take account of the surplus that will be lost on these investments.

For the sticker plan we estimated that the average fixed cost of owning a car is about $1000/year in 1977 dollars. To give up one-seventh of its availability would mean a loss of $140/year if the value of the day's use given up every week (net of variable costs) were equal to the average cost per day of car ownership. This would come to less than $3/week. We can argue that, since a vehicle owner would give up the day of the week that is of least value to him, $140 would overstate the loss. But, on the other hand, it must be remembered that loss of a car on the least-valued day of the week will rarely mean giving up the least-valued one-seventh of its availability. Moreover, the $140 estimate does not allow for the consumer surplus on car ownership that will be lost but only for the cost of investment. Nevertheless, if $140/car is taken as the average cost of the sticker plan to owners, the total cost would come to about $14 billion if the plan were in effect for as long as a year. The sticker plan was estimated to reduce queuing costs by over $0.30/gal for a total of more than $28 billion in savings in the course of a year's gasoline purchases. Once again, on the basis of our approximations, the plan passes the cost/benefit test.

By use of a similar approach we estimated the cost to owners of off-road vehicles and craft that would result from the weekend ban on their use. This came to a total of about $2 billion at a minimum in lost use of investments. It compares with estimated savings in queuing costs as a result of the plan of about $11 billion in a year.

CONCLUSIONS

Although measures to reduce demand are neither the most efficient nor the most equitable way to reduce gasoline queues, they can serve a useful purpose when better alternatives are precluded for political or other reasons. By directing gasoline use restrictions at the uses of gasoline that are of only marginal value to consumers, the benefits in terms of reduced queuing costs can be made to exceed the costs of the plan, whether they take the form of losses in consumer surplus or implementation and administrative burdens. Crude estimates of the costs and benefits of such plans can be developed. In the case of three measures evaluated here, the estimated benefits would appear to exceed the cost.

ACKNOWLEDGMENT

The research reported in this paper was sponsored by the U.S. Department of Energy. The views expressed are our own.

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Publication of this paper sponsored by Committee on Energy Conservation and Transportation Demand.

Queuing and Search Delays Due to Gasoline Station Closings: Simple Equilibrium Framework

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This paper presents a simple framework for modeling the delays involved in searching for an open gasoline station and queuing at the station in urban areas. It includes an elastic response of the demand for gasoline and solves simultaneously for the number of users per unit of time and the search and queuing delays. The search-time model is based on simple geometric probability considerations, open gasoline stations are modeled as M/G/1 queues, and the demand curve is assumed to be a simple two-parameter curve. The model is concerned only with aggregate averages and not with detailed distribution of the delays. The solution is demonstrated, in a numerical example, as a function of the percentage of open gasoline stations and a demand sensitivity parameter. The example is focused on relative changes (in the output parameters) only, because the model is not calibrated to a particular urban area.

This paper describes a simple equilibrium framework for modeling the delays involved in searching for gasoline and queuing in gasoline stations, including an elastic response of the demand for gasoline. The analysis is macroscopic in scope and aggregate in nature. We deal with the aggregate number of users and average delay only, over a ubiquitous urban area characterized by a random distribution of gasoline stations and a random distribution of trip origins. Furthermore, we deal with relative delays only, since the model is not calibrated to a specific urban area.

The searching time and queuing delay involved in the process of obtaining gasoline can probably be found with a detailed network simulation. With the use of a disaggregate-choice model, the analyst can also determine the number of users in the system at equilibrium. Such methodology can provide microscopic analysis of a variety of policy options. However, it would involve a large data collection effort and a considerable computer budget.

The model presented in this paper is much simpler. Given the area size, the number of gasoline stations, and the percentage of stations that are open, it computes the average delay incurred by a motorist in finding an open station. Also, given the number of users per open station and the stations' average service rate, the model computes the average queuing delay. Lastly, given the search time and queuing delay, a simple demand curve is used to determine the number of users (customers) in the system. Naturally, the queuing delay grows as the number of users grows, and the number of users decreases as the queuing (and search time) grow. Thus, the queuing delay and the number of users in the system have to be solved for simultaneously, and their solution is referred to as the equilibrium queuing delay and the equilibrium number of users.

By use of this model one can investigate the effect of the percentage of open stations on the delays and number of users as well as the effect of other parameters, such as the service variability and the shape of the demand function for gasoline.

The strength of our approach lies in its simplicity. All the calculations can be performed with the aid of a programmable pocket calculator, and most of the major factors of the problem are included in the analysis.

THE TIME SPENT IN SEARCH

Consider an urban area of size A that has n_o gasoline stations located at random throughout the area. Assume that users (gasoline seekers) act independently of each other. Each user starts from a random point in the area and travels to the nearest gasoline station. If the station is closed, he or she keeps searching until the nearest open gasoline station is found. In this section we derive an expression for the mean time spent in the search (i.e., from the origin until an open station is found).

We start by developing an expression for the mean distance that a user has to travel in order to visit m stations, assuming an area of size A and a total number of stations n_o ($m < n_o$). From geometric probability considerations (1), the distance between a randomly selected point and the closest of a set of n_o points (D_{n_o}) is

$$D_{n_o} \cong \theta\sqrt{2\pi A/n_o} \quad (1)$$

where Θ is a network structure coefficient. For