Simple Analytical Model for Understanding Gasoline Station Lines

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Recent gasoline shortages have necessitated a better understanding of queues at gasoline stations and how to minimize their lengths. This paper is an attempt to model the gasoline-line phenomenon and to predict the effects of various policies on factors such as mean waiting time, quantity of gasoline purchased, hours that stations are open, and mean frequency of visits to stations. This is achieved through the use of a Cobb-Douglass demand equation and, simultaneously, an equation that represents "topping-off" behavior. No comprehensive data were available to estimate the model; therefore, the model was calibrated judgmentally. Policy tests should be seen in this light. Preliminary indications are that the use of odd-even gasoline rationing minimizes aggregate wait time as well as wait time per visit more than do minimum or maximum purchase plans. This paper represents more of a framework of analysis than econometrically acceptable results.

During June 1979, Americans again experienced the frustration of waiting in line to buy gasoline for their automobiles. Even the trend toward smaller, fuel-efficient automobiles (which was more accelerated by the first oil crisis) was not enough to prevent the occurrence of another gasoline crunch. Politicians were caught by surprise, and governments hastily developed policies to alleviate inconveniences suffered by their irate the citizens. Much to the relief of the governments, they found that whatever policy they adopted, it worked. Gasoline lines soon began to disappear as mysteriously as they had appeared.

Since accurate data on available supplies during that period are hard to find, it is difficult to determine whether gasoline lines disappeared due to government action or simply due to an improvement in supply. Since the problem may occur again, research efforts should be directed toward a better understanding of how and why gasoline lines form and toward developing models that could predict the effect of various policies on the gasoline-line situation should another (possibly more prolonged) supply shortage occur.

There is at least one serious obstacle to building a good model of the formation of gasoline lines--the lack of available data on which to calibrate a model. However, in real life, most decisions are based on the incomplete data on hand, and the situation is therefore not unique.

This paper is a modest attempt to use existing knowledge, of both a theoretical and a practical nature, to set up a model that would facilitate a better understanding of the complex phenomenon of gasoline lines. It is a beginning and not an end; however, there is some elegance in its simplicity.

The approach followed in this paper is to build what Manheim ($\underline{1}$) terms a "judgmentally estimated model". By combining microeconomic theory with professional judgment on the selection of important variables, much can be learned from the process as well as inferred from the results even without an available full data set.

The procedure followed in this paper was to formulate a simple set of equations that reflect gasoline purchase behavior and to judgmentally estimate the model. The estimation was done by first using parameters, such as estimated elasticities, that are available from prior studies. Next, the conditions that existed immediately after the worst of the crisis was over were used as a point for which the model had to be valid. From this, inferences could be drawn with regard to the relationships between parameters. An extensive sensitivity analysis was then done on both unknown and known parameters. The final selection of parameters was based on the model's ability to reproduce known conditions as well as the plausibility of its general behavior.

The paper is concluded with a discussion of the model results for various policies used during the previous energy shortage: (a) an odd-even plan, (b) a maximum purchase plan, and (c) a minimum purchase plan. A pricing policy is also treated.

BACKGROUND

Although generally transient in nature, severe queues for gasoline are perhaps the most publicly visible manifestation of what has been loosely termed the energy crisis. Given the dependence of the U.S. transportation system on the private automobile, gasoline shortages typically create enormous economic and social disruptions. At a minimum, these disruptions result in high economic costs (see paper by Dorfman and Harrington in this Record); at the worst, violent crimes are associated with gasoline lines.

In order to understand the formation of gasoline lines at the qualitative level, one must first recognize that the queues for gasoline serve a significant (albeit inefficient) function. In the recent shortages, the queues for gasoline have provided the basic short-run mechanism through which gasoline has been rationed.

In the short run, the supply of gasoline to service stations is, for practical purposes, fixed by federal allocation formulas and oil company Maximum pump prices are delivery schedules. regulated by using formulas that reflect estimated production and acquisition costs, not the demand for gasoline. If under these conditions the available supply of gasoline suddenly is curtailed to a level less than the equilibrium volume at the regulated price, some nonprice mechanism for clearing the market will operate. In the absence of any governmental action (e.g., relaxation of price regulation, restriction of operating hours, or rationing), the most typical mechanism is for queues to build up. Essentially, people pay more for gasoline through a time (rather than monetary) cost that is high enough to clear the aggregate, short-run market for gasoline.

Given this perspective, a number of questions are relevant to policy:

1. What is the social cost of allowing queues to serve as the basic market-clearing mechanism?

2. Are alternative mechanisms available for clearing the market that are more cost effective?

3. What is the effect of alternative mechanisms for clearing the market on various segments of the population?

Dorfman and Harrington estimated that the cost of using queues to clear the gasoline market in an urban area is significant. The obvious solution of

(2)

allowing prices to perform their usual marketclearing function has been widely rejected by the political process, particularly as a response to the very short-run shortage problems manifested in long gasoline lines.

Other strategies have been oriented toward reducing the number of visits to stations per liter of gasoline purchased. These plans all involve some form of minimum purchase or limited access to stations (e.g., odd-even plans). In an analysis of the effect of such strategies, one must explicitly recognize that lines can be reduced only by imposing some cost (monetary or other) that reduces the demand for gasoline to equal the current, fixed supply. Such costs can include reduced access to stations (the effect of odd-even plans).

The above discussion suggests that, in modeling the demand and market clearing of the gasoline market, one must incorporate measures of nonpecuniary cost into the demand function. Thus, the traditional notion of a demand function for gasoline must be extended to include wait time and availability. Nonpecuniary costs always influence demand, but in most typical situations they can be ignored since they are small and relatively uniform for the entire population. Only when gasoline queues are significant factors in clearing the market should these variables be explicitly modeled.

MODEL STRUCTURE

Before proceeding with a detailed description of the model, some assumptions of the analysis should be stated. First, market forces will be assumed to clear the market for gasoline. In the case where the dollar price of gasoline is artificially restricted to a price below the equilibrium market price, the consumer will have to pay the additional price in some other form, such as waiting time in line. Second, the model is aggregate in the sense that expected values of variables are used rather than disaggregate individual observations. This does not imply that all consumers are expected to have the same values for the different variables, since individual consumers might have values that vary around the expected values. Third, the model is applicable to an urban area in which gasoline stations are distributed proportionally to population. The actual size of the area under consideration is not important.

On the model's supply side, the allocation of gasoline to the area under consideration is assumed to be fixed--the amount is determined by forces outside the area, such as government allocation rules. This amount is then divided among the gasoline stations in the area. Because the supply of gasoline is limited, all gasoline will be consumed and each consumer (defined here as an automobile owner) is expected to obtain a fraction of the gasoline. Mathematically, this can be stated as follows:

$$Q = mq = Pu \tag{1}$$

where

- Q = allocation of gasoline per day to the area under consideration (L),
- P = automobile population in area,
- m = number of gasoline stations in area,
- u = use rate per vehicle per day (L), and
- q = average allocation per station in the area
 (L).

From Equation 1 follows

The above equation implicitly assumes that owners of gasoline stations ration their monthly supplies to a daily schedule.

The demand side is more complex and the following demand function is proposed:

$$u = \beta_0 \times C^{\beta} 1 \times \mu^{\beta} 2 \times n^{\beta} 3 \times t^{\beta} 4$$
(3)

where

 $u = (m/P) \times q$

- C = cost per liter of gasoline (\$),
- μ = mean waiting time in line per visit (min),
- n = expected number of visits to gasoline
- stations per day, and
- t = average number of hours per day that gasoline stations are open in the area.

 β_0 , β_1 , β_2 , β_3 , and β_4 are coefficients. Equation 3 assumes that various factors influence the demand for gasoline.

Cost of gasoline enters the demand function as expected. As price is increased, demand will decrease, and β_1 can therefore be expected to be less than zero.

It is postulated that waiting time in line to purchase gasoline will also influence the demand for the gasoline. An increase in waiting time can be expected to cause a decrease in demand if everything else is kept constant. It is further postulated that not only is waiting time important but also the number of times a consumer has to wait in line. Again, one would expect demand to drop with an increase in the number of trips, if everything else is kept constant. Therefore, β_2 and β_3 are expected to be less than zero.

The last variable used in the demand function is t, the number of hours per day that each gasoline station is open. This measure is an indication of schedule flexibility available to the consumer. If gasoline stations should open only on weekdays between 8:00 a.m. and 12:00 p.m., for example, this would severely limit the customer's flexibility in buying gasoline and, therefore, will also restrict his or her ability to make trips. The variable also serves to reflect risk aversion by drivers, so it can be expected that, as station hours become shorter, people will tend to conserve the fuel that they have due to the uncertainty of availability reflected in the short station hours. As station hours decrease, consumption will decrease (given that everything else stays constant), and β_4 can therefore be expected to be greater than zero.

In order to link the station hours to the shortage of gasoline, we postulated that stations only stay open every day until that day's allocation is sold. During that period, the service station is also constantly busy and people wait in line to be served. This means t is equal to the product of the vehicles that visit a station per day and the average service time per vehicle. Mathematically,

$$t = (P \times n/m) \times (1/\lambda)$$
(4)

where λ = service rate in vehicles per hour.

In the demand equation there is some interaction involved between the left-hand side (u) and the right-hand side that is not immediately apparent:

n = u/x

where x = number of liters of gasoline purchased per visit.

(5)

The measure \boldsymbol{x} is set by each consumer according to his or her taste and his or her perception of the

gasoline shortage. It is postulated that x is influenced by the total time spent waiting in line per time period and the hours that gasoline stations are open. Mathematically, this relationship is presented as follows:

$$\mathbf{x} = \alpha_0 + \alpha_1 \times \mathbf{t} + \alpha_2 \times (\mu \times \mathbf{n}) \tag{6}$$

where α_0 , α_1 , and α_2 are parameters.

The functional form of this equation was assumed, for simplicity, to be linear. Obviously, any other functional form might also be appropriate. The linear form, with positive parameters α_0 , α_1 , and α_2 implies a decrease in purchase size (x) with a decrease in station opening time and an increase in purchasing size with an increase in waiting time. This is in accordance with what is expected to happen in the real world. As gasoline supplies get more and more uncertain (t gets smaller), the motorist is expected to "top off" more regularly, hence the smaller x. However, for each visit the consumer makes to the gasoline station, there is a wait time. To minimize the wait time, the consumer can be expected to buy more gasoline per visit, hence an increase in x. There is also, therefore, a trade-off between these variables. This trade-off, as well as the fact that lines can be avoided altogether by not driving, is represented in the demand function. By solving the system of equations, the unknown variables t, x, n, and μ can be solved for as functions of q, P, m, λ , and the parameters.

MODEL ESTIMATION, BEHAVIOR, AND SENSITIVITY ANALYSIS

Since no data were available to econometrically estimate the α 's and β 's, the model parameters could not be estimated by conventional techniques, and a method of judgmental estimation was adopted. In such situations, a combination of previously reported conclusions, a priori expectations, and intuition are combined. This procedure, although far from ideal, can provide useful insights into the process under study. It should be further noted that frequently data are not available when real-world policy decisions need to be made and, by using judgment to estimate a model, some structure may be imposed on an otherwise unstructured decision-making process.

Returning to Equation 3, one is able to treat the coefficients β_1 through β_4 as elasticities of consumption with respect to their respective variables. Initially, signs and expected ranges can be assumed for their values as follows.

1. There is a considerable literature that attempts to estimate the elasticity of gasoline consumption with respect to price. Available estimates range from 0 to -0.9 with the figure of -0.15 most often cited in the literature [Charles River Associates (2)].

2. As stated earlier, β_2 and β_3 are expected to be negative, and it is now further assumed that they are set such that the elasticity with respect to mean waiting time and with respect to number of trips made are greater in absolute value than the elasticity with respect to price. This assumption is based largely on inferences from various mode-choice studies [e.g., Lisco, Lave, and McGillivray (3-5)].

3. It was also felt that consumers are more sensitive to mean waiting time than to number of trips. Hence the β_2 and β_3 coefficients were assumed to be in the range of -0.15 to -0.20, with β_3 closer to the more negative extreme of the range than β_2 .

4. Finally, the elasticity of consumption with respect to hours that a station is opened was assumed to be relatively low and would be in the area of +0.10.

In order to set β_0 , a point on the demand curve was selected that was assumed to simulate the non-gasoline-crisis situation. This value is denoted by an asterisk. Hence mean waiting time (μ *) was set to 6 min, x* to 30 L/visit, u* to 7.5 L/vehicle per day, (P/m)* to 1000 vehicles/station, C* to \$0.26/L, and λ to 20 vehicles/h. This leads to a value for t* of 12.5 h/day and a β_0 of 3.19.

Similarly, in Equation 6 one can interpret α_0 as approximately the average amount of gasoline a consumer would typically purchase if there were no crisis, and this could range from 19 to 38 L/visit. The remaining coefficients, α_1 and α_2 , can both be expected to be positive. Remember that for the base-case (existing) conditions the number of hours the station is open (t*) is large and the expected waiting time in line (μ^*) is small. A decrease in station hours would therefore be expected to lead to a decrease in refill level (x), mostly due to the uncertainty and schedule inflexibility that accompany reduced station hours. This requires a positive α_1 .

However, as station hours decrease, waiting time increases and one would expect the amount purchased to increase, since the consumer would rather make fewer visits to the gasoline station to prevent waiting. This requires a positive α_2 .

It is difficult to predict exactly what the values of α_1 and α_2 should be and, as a starting point, values were obtained subjectively. This was done by (a) constructing typical cases for the independent variables, (b) hypothesizing the likely response in x, and (c) fitting α_1 and α_2 to those hypothesized responses. Note that subsequent sensitivity analysis on the values of the α 's indicated the model to be very insensitive to the chosen values.

In order to arrive at final values for exogenous variables and the coefficients, each coefficient was varied iteratively, and the effects on the model were observed. Coefficients were selected such that a priori decisions regarding model behavior were not violated. (Given the exploratory nature of this model, the actual predicted values are not as important as the qualitative behavior of the model as a whole.) The final selection of coefficient values is shown in the list below.

 $\begin{array}{l} \beta_0 = 3.19, \\ \beta_1 = -0.15, \\ \beta_2 = -0.18, \\ \beta_3 = -0.20, \\ \beta_4 = +0.07, \\ \alpha_0 = 19.00, \\ \alpha_1 = 0.95, \text{ and} \\ \alpha_2 = 22.80. \end{array}$

When they are set as in this list, the model behaves as follows: As allocations per station (q) decrease from the base-case values of 7600 L/day,

1. The amount of gasoline purchased (x) initially drops, as the number of hours that stations are opened decreases; when supply (q) is low, there is some topping off and consequently x will be small but, as q becomes even smaller, people will want to buy more per visit in order to minimize the number of visits in all as the waiting time for each visit becomes excessive;

2. The hours that stations are open (t) also decreases;

Figure 1. Wait time and purchase size as allocation varies for the do-nothing scenario.



Figure 2. Purchase size, station hours, and visits per week as allocation varies for the do-nothing scenario.



- 3. Mean waiting time (μ) increases; and
- 4. The number of visits (n) decreases.

Also, as cost increases,

- 1. u and x decrease and
- 2. t increases slightly.

POLICY ANALYSIS

The model was designed so that it could be used to test the relative effects of various gasoline-supply policies, some of which were in effect during the gasoline crisis of spring 1979. Specifically, the tests include

- 1. The raising of the price of gasoline,
- 2. Minimum and maximum purchase plans, and
- 3. Odd-even rationing.

Other types of rationing (for example, coupon rationing) could not be tested due to their complexity.

First, it is necessary to analyze what happens as the allocation per station (q) varies, particularly when no policy is in effect. Essentially, this is what happened during the recent crisis, before government intervention and, therefore, this can be



Figure 3. Wait time per visit and purchase size as a function of station

termed the do-nothing scenario.

Figures 1 and 2 depict what occurs as q decreases. As stated earlier, allocations of about 7600 L/station per day are assumed to be the base-case or noncrisis situation.

In Figure 1, as q decreases, mean waiting time per visit and total waiting time both begin to rise. At the same time, the amount of gasoline purchased drops, and in Figure 2 the number of visits and hours that a station is open both fall. Here, less gasoline is being purchased, less is being used, and waiting time increases. This seems to indicate that the topping-off phenomenon is simulated in this model.

As supplies of gasoline become much lower, waiting time begins to increase drastically; hence, for every visit, consumers will want to buy as much gasoline as they can. Because less gasoline is being sold, the hours that a station is open continue to be less than in the base case. Conversely, as allocations per station increase over the base case, mean waiting time falls, more gasoline is used, and more is purchased per visit.

Increasing Price of Gasoline

One would expect that, as the price of gasoline increases, waiting time (μ) and the amount of gasoline purchased per visit (x) would decrease. This is indeed the case, as shown in Figure 3. If one examines the base-case situation where 7600 L are allocated per station, μ drops quickly as price increases. Gasoline purchases per visit do fall but not dramatically. Not shown in Figure 3 for this example is that the number of visits per week and hours that stations are open both increase but not enough to have a significant impact on the results.

Also shown in Figure 3 is the impact of both changing price and allocation per station. As allocations decrease, the differences between the variables at different prices appear to diverge. In Figure 4. Wait time per visit and purchase size as a function of allocation and maximum and minimum purchase policies.



Figure 5. Wait time per week as allocation varies for maximum and minimum purchase policies.



other words, as price increases and allocations decrease, μ and x become increasingly small. This is not entirely intuitively obvious, but, as allocations fall, less gasoline is used, so this

Figure 6. Visits per week as allocation varies for maximum and minimum purchase policies.



Figure 7. Time stations are open as q varies for maximum and minimum purchase policies.



fact combined with smaller purchases per visit and increasing price cause μ to fall more than it would otherwise.

Minimum and Maximum Purchase Policies

During the recent gasoline crisis, numerous retailers and several governments instituted one form or another of maximum or minimum purchase plans in hopes that gasoline lines would become shorter. Such policies can be simulated by this model and compared with the do-nothing policy results. Figures 4-7 describe various aspects of this simulation for a maximum purchase plan of 19 L and minimum purchase plans of 30 and 38 L.

Figure 4, which graphs the effects of this policy, is presented for later comparison with similar graphs for other policies. It shows that, at a given q, the least waiting time per visit is when a maximum plan of 19 L is in effect. This is

Figure 8. Wait time per week and purchase as allocation varies for the odd-even plan.



immediately counterintuitive, because one would expect that lines would be long because consumers would return frequently for more gasoline. On the contrary, one would expect the minimum purchase plan of 38 L to be the best.

By comparing total waiting time and number of visits per week (Figures 5 and 6), the issue becomes more clear. Although there is little difference in the total waiting times for a given q, the maximum plan is worse than the minimum plans or the do-nothing approach. Although not graphed, this observation is more pronounced at extremely low allocations of gasoline.

The final piece of evidence that places this issue in perspective is the hours per day that stations are open (Figure 7). It seems that waiting time per visit can be so low for the maximum purchase plan because drivers must make more visits per period than for other options.

Of the three policies presented, the minimum purchase plan of 38 L seems to be most appropriate because it limits total waiting time and the hours stations must be open to a reasonable level under all allocation levels.

Odd-Even Rationing

Odd-even rationing is a method by which consumers may be barred from purchasing gasoline on a given day depending on a digit of their vehicle's license plate. Essentially, this means that, for any given consumer, stations are perceived to be open only half the total hours per day. This decrease in t (as perceived by each individual) induces smaller purchases per individual but also reduces queues at the station needed to reduce demand to the available supply. Given the parameters chosen for the model, the net effect is a reduction of total wait time per week.

The results of the model for different allocation levels are presented in Figure 8.

Comparison of Policies

Even though this model was estimated judgmentally, some guarded statements can be made with regard to the relative merits of the various policies tested.

It is clear that the higher the price of gasoline, the shorter gasoline lines will be, but there is evidence from European experiences and from activity during the American gasoline crises that indicate that, in the short run, higher gasoline prices may not curtail consumption as much as was previously believed. In other words, the population does not necessarily have a constant elasticity of consumption with respect to price, as is assumed by this model. Therefore, the results of the price simulations must be examined with this thought in mind.

If a policymaker were forced to choose among maximum or minimum purchase plans or odd-even rationing, the results of these simulations imply that odd-even rationing yields lower total waiting time. Given the political infeasibility of enormous short-run price changes and all else considered, the odd-even plan seems to be relatively better than the others tested with this model.

FUTURE DIRECTIONS

The model developed in this paper is a first attempt to represent the formation of gasoline lines as a result of the supply-demand interaction. Given the paucity of existing data, the first priority in improving the model is the collection of information on traveler behavior both before and during serious, short-run gasoline shortages. Such data, in the form of vehicle logs or traveler diaries, have been collected in the past under normal circumstances. Other information, such as measurements of q in the model, is easily collected. The key to obtaining such data during periods of shortage is to prepare for the data collection in anticipation of a future shortage and to implement the plan immediately on occurrence of a shortage. Such data would provide the basis for rigorous estimation of the demand function and the equation for x and would provide some greater assurance regarding the appropriateness of the chosen functional forms.

A second area for potential extension of the model is disaggregation of the population. will be affected Different socioeconomic groups quite differently by various policies. The current model provides no insight into the incidence of the impacts. By either estimating different demand functions for different socioeconomic groups or incorporating socioeconomic variables (particularly income) into the demand equations, the relevant impacts could easily be forecast for different segments of the population.

A third potential area for further work is the incorporation of dynamic effects into the model. In a situation that occurs as quickly as the formation of a gasoline line, people adjust dynamically to a rapidly changing environment. It is quite possible that some of the lines are the result of drivers' increasing the amount of gasoline they carry in their tanks to levels greater than normal, thereby, in the short run, reducing dealers' inventories. Such effects would obviously be transitory, since each individual's shortage capacity is limited. It would be useful to be able to predict such responses over time and to better understand how they influence the length of queues.

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Review of Analytical Models of Gasoline Demand During an Energy Emergency

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This paper provides a framework for evaluating various proposals for reducing the costs of queueing for gasoline during energy shortages. Two types of proposals have been offered to address the problem: queue-management techniques, such as minimum or maximum purchase requirements, and demand-managment techniques, such as improved transit service or bans on weekend sales of gasoline. The paper starts with the presumption that three bodies of literature are relevant to the problem: (a) literature on wartime hoarding and speculative demand, (b) literature on congestion pricing, and (c) literature on inventory managment and transport cost trade-offs. Which of these bodies of literature is the dominant determinant of public behavior during gasoline shortages to a large degree determines the success of any proposed policy recommendation. For example, if the congestion cost imposed by waiting in line is necessary to equilibrate the total supply and demand for gasoline, queue-management techniques will be self-defeating, because reduced congestion costs only encourage more demand and reestablishment of the equilibrium. If speculative demand is a large factor in explaining shortages, controls on purchase size could reduce total demand, free up inventories in tanks for consumption, and reduce the length of queues. If the inventory cost-transport cost model prevails, lengthy queues will discourage speculative demand and lead to recommendations for demand management such as carpooling incentives and improved transit service. Without an adequate time-series data base to monitor the public's behavior during a crisis, a definitive policy recommendation is not possible and the debate will not be resolved. Based on the present state of knowledge, a combination of minimum purchase requirement and demand suppression (especially of the "carrot" variety through improved transit service and carpooling) is recommended. Even-odd plans do not have a sufficiently plausible conceptual rationale to make it likely that they will improve queueing costs materially.

The paper first identifies behavioral principles that are relevant to the issue. It concludes with suggestions for future research.

BEHAVIORAL PRINCIPLES RELEVANT TO EXPLAINING CONSUMER BEHAVIOR DURING AN ENERGY EMERGENCY

Literature on the economics of demand provides three precedents for understanding how automobile drivers will respond to gasoline shortages. Before this literature is reviewed, however, note that the gasoline queueing that we are examining is a relatively temporary phenomenon. Lines result from the domestic price controls that prevent suppliers from taking advantage of the shortage to raise prices. However, the price at the pump is a weighted average price from various suppliers, designed to spread the effects of price controls evenly over suppliers and consumers. However, the consequence is that gasoline lines are a signal to the Organization of Petroleum Exporting Countries (OPEC) that prices are too low. Experience has shown that world oil prices and domestic pump prices rise after a relatively short lag, and eventually prices are raised to eliminate the queues. Any proposals to eliminate queues must recognize, therefore, that the cost will be large but temporary under current regulatory mechanisms.

The first body of literature relevant to the issue is that on wartime hoarding and speculation. Keynes identified speculative demand as a major element of instability in a market economy $(\underline{1})$. The current price of a commodity and the history of price changes create destabilizing expectations of further price changes. Where there is great uncertainty regarding the future terms on which a commodity is available, this speculative demand leads to boom and bust cycles.

However, in the case of gasoline demand, there is a limit to the magnitude of speculative demand caused by the size of a gasoline tank. Speculative demand can be affected by "topping off," but a limit is imposed by the size of the tank and the increase in waiting time per gallon caused by more frequent fill-ups. Once such demand is satisfied, there may be a tendency for lines and expectations to stabilize, which will lead to tank inventory reductions and actual decreases in lines. Any theory of demand must, therefore, distinguish between gasoline demand for consumption and demand for hoarding and between purchase decisions and consumption decisions.

The second body of relevant literature is that on congestion pricing $(\underline{2},\underline{3})$. An external economy is imposed by congestion, which arises from the fact that each individual who joins a queue does not take into account the fact that service for that individual imposes costs on other users. Depending on the circumstances, an extra individual who joins a congested facility may impose additional waiting time on other users that is many times more than his or her own waiting time. This additional waiting time is a social cost, or deadweight loss, not offset by benefits to any users. Therefore, any proposals to discourage use of congested facilities must account for the benefits of reduced congestion on other