

# Modeling Locations and Pricing Decisions in the Gasoline Market: A Structural Approach

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## Abstract

We propose a structural econometric model of both the geographic locations of gasoline retailers in Singapore, as well as price competition between these retailers conditional on their geographic locations. Using empirical data on geographic locations and gasoline prices collected from the entire set of 226 gasoline stations in Singapore, and local market-level demographic data, we estimate the parameters of the proposed structural model. Although market demand for gasoline are not observed, we are able to infer the effects of such demand on stations' location and pricing decisions using available data on local market-level demographics and assumptions about price competition. Using the proposed location model, that is based on the assumption of social welfare maximization by a policy planner, we find that local potential gasoline demand depends positively on the following local demographic characteristics of the neighborhood: population, median income, number of cars, proximity to airport, downtown and highways. Using the proposed pricing model, that is based on the assumption of Bertrand competition between retail chains, we find retail margins for gasoline to be about 25%. We also find that consumers are willing to travel up to a mile for a price saving of 3 cents per liter. Using the estimates of our structural model, we answer counterfactual questions pertaining to a recent merger between two firms in the industry. Answering these questions has important policy implications for both gasoline firms and policy makers in Singapore.

*Keywords:* Location Modeling, Networks, Discrete Locations, Price Competition, Gasoline Markets, P-Median Problems, Empirical Industrial Organization, Structural Econometric Models.

# 1 Introduction

Location is repeatedly stressed in the business press as one, if not the only, requirement for success in retailing. It is also recognized in the academic literature as being an important determinant of retail competition and performance. In fact, some of the earliest work on retail competition (e.g., Hotelling 1929, D'Aspremont, Gabszewicz and Thisse 1979) were based on models of spatial heterogeneity given the location decisions of retail firms. This paper attempts to understand the phenomenon of retail performance by developing a structural model of retail location and retail price decisions. The simultaneous consideration of both location and marketing-mix interactions allows us to address a broader set of questions related to public policy as well as to provide a more comprehensive answer to questions of firm conduct and market performance. For example, we can now address questions such as

- What are the important factors contributing to the potential demand at a location?
- How important is a retailer's geographic location when consumers choose among alternative retailers? What are the trade-offs involved for a retailer between facing large potential demand at a location versus also being in close proximity to competitors at the location?
- What will be the impact of a merger between two retail chains on prices and profits in the retail industry?

The context for this paper is the gasoline market in Singapore. Using a primary dataset - representing a census of all gasoline stations in Singapore -that tracks geographic locations, gasoline prices and various station characteristics across 226 gasoline stations, as well as the demographic characteristics of the stations' local neighborhoods, we undertake the estimation of a structural model of location and pricing decisions of gasoline stations.

The location model is built on the premise (which is consistent with institutional realities in Singapore, as discussed in section 4) that the Singapore government determines where to locate gasoline stations in the city. The government, being a social welfare planner, is assumed to minimize aggregate travel costs incurred by consumers in their efforts to buy gasoline in Singapore. This leads to a decision model that is called a *P-Median* problem. We use a minimum-distance method to estimate such a location model, that enables us to infer the geographic

distribution of potential gasoline demand across local markets in Singapore, and the dependence of such demand on local demographic characteristics.

We then propose a pricing model for gasoline stations, conditional on their locations, based on the premise of Bertrand competition between retail chains.<sup>1</sup> The pricing model requires local firm-level demand - which is a function of the potential demand for gasoline at various locations, prices and gasoline characteristics - as inputs. Since gasoline demand is unobserved in the data, we use equilibrium conditions of demand and supply to obtain an estimable model of pricing. Estimating the pricing model allows us to infer both the cost and demand functions. Using the estimates of the parameters of the location model and pricing model, we answer counterfactual questions pertaining to the relative profitability of various retail chains, as well as the consequences of a merger between two retail chains on prices and profits of firms in the industry.

From estimating our proposed location model, we find that local potential gasoline demand depends positively on the following local demographic characteristics of the neighborhood: population, median income, number of cars, proximity to airport, downtown and highways. Using the estimated potential gasoline demand at each local neighborhood in Singapore as an input, we then estimate our proposed pricing model using empirical data on actual prices of gasoline at various stations. We find retail margins for gasoline to be about 25%, and that market share for a gasoline station is negatively influenced by the price of gasoline and travel cost. We find that consumers are willing to travel up to a mile for a price saving of 3 cents per liter (which translates to a saving of \$1.1 on a 40-liter tank of gasoline).

## 2 Relationship to the Literature

The primary contribution of this paper is in developing a structural model of location and pricing decisions in the gasoline market. We position it in the context of previous research on gasoline markets, as well as previous research on retail competition models.

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<sup>1</sup>We run reduced-form pricing regressions, based on which we make this assumption about the nature of competition between firms.

## 2.1 Gasoline Markets

Shepard (1991) and Iyer and Seetharaman (2003) estimate pricing models for gasoline stations that have local monopoly power. Their models are not applicable for competitive markets, as in this paper. Slade (1992) estimates a competitive pricing model using time-series data on demand and prices at 13 gasoline stations in the Greater Vancouver area. In focusing only on a limited number of firms in the same geographic neighborhood, the model ignores the role of location on competition. Png and Reitman (1994) and Iyer and Seetharaman (2005) address the puzzle of why retailers in the same geographic space adopt very similar strategies in certain instances and very different strategies in other cases assuming retail location decisions as exogenous. Pinkse, Slade and Brett (2002) estimate a competitive pricing model that accommodates the effects of spatial locations of firms. However, all of these studies take a *reduced-form* approach to modeling the effects of location on price competition between firms. In contrast, we estimate a *structural* model of pricing behavior in this study, as in Manuszak (1999). Further, none of the above studies attempts to explain location decisions of firms. We believe that our paper is the first effort at modeling location decisions in gasoline markets. The institutional reality that the Singapore government serves as a social planner in determining locations of gasoline stations makes our location model both realistic and mathematically tractable.

## 2.2 Retail Competition Models

An alternative model of locational choices of firms, based on free entry of firms (as opposed to a social planner determining the optimal locations), has been recently proposed by Seim (2002), who models geographic locations of video retailers. A rich literature exists in marketing that casts firms and consumers on a common perceptual map in order to analyze optimal marketing decisions of firms (Hauser and Shugan 1983, Hauser 1988, Moorthy 1988, Choi, Desarbo and Harker 1990 etc.). Marketing models of this type recognize that brands occupy different positions - in terms of not only their objective attributes, but also consumers' subjective evaluations of these attributes - in the perceptual map, while consumers have different ideal points (i.e., most preferred combinations of attributes) on the same perceptual map. Our location model can be viewed in light of this literature as one where consumers' ideal points correspond to their place of residence or work, while brand positions correspond to the geographic locations of stores.

Consumers' ideal points are inferred as a function of geographic characteristics in our case, unlike in the perceptual map literature where subjectively perceived brand positions, as well as consumers' ideal points for attributes, are measured using marketing research techniques. It is useful to note that location is a *horizontal* attribute (i.e., different consumers would disagree on what is the best location for a firm, based on where their ideal points reside), as opposed to attributes such as price and quality that are *vertical* attributes (i.e., all consumers would agree that lower price is preferable to higher price, higher quality is preferable to lower quality etc.).

Recently, Thomadsen (2003) has developed a retail price competition model based on the assumption of Bertrand price competition between fast-food retail chains. This model uses a multinomial logit model of demand as an input to the pricing equations. Demand for retailers are parameterized as a function of observed geographic characteristics, prices and travel distances of consumers to stores. Both demand- and supply-side parameters are inferred solely from observed prices, since demand for various retailers are not observed in the data. Since we also do not observed demand for gasoline retailers in our data, we adopt the Thomadsen (2003) approach to model price competition between retailers. However, unlike Thomadsen (2003), who relies on the pricing model only, we use a location model that exploits the observed geographic distribution of gasoline stations across local markets to infer the potential gasoline demand at each local market.

The remainder of the paper is organized as follows. In section 3 we develop empirical models to estimate location and pricing decisions of gasoline stations in Singapore, along with estimation techniques to estimate model parameters. In section 4 we describe our data. Section 5 presents the empirical results of our analyses. In Section 6, we discuss the policy implications of our results. Concluding remarks are made in Section 7.

### **3 Model of Location and Pricing Decisions of Gasoline Stations in Singapore**

We present this section in two parts. First, we develop a model of gasoline stations' locational choices by the government, making explicit the parametric specification of the location model, and discussing estimation details. Second, we develop a model of gasoline pricing decisions conditional on the observed locational choices, presenting a specific parameterization of the

pricing model, and setting up the estimation procedure.

### 3.1 Location Model

It is useful to note the following two features of the gasoline market in Singapore (that make it different from the gasoline market in the US):

1. Gasoline stations can only be built on specified plots determined by the government. Land is offered on a public tender in an open-bid system, and any company can bid.<sup>2</sup>
2. Price competition among gasoline stations in Singapore is a relatively recent phenomenon. Prior to this, gasoline prices were determined on the basis of a multi-lateral agreement between the Singapore government and gasoline retailers. Therefore, prices were assumed to be equal by the Singapore government while determining optimal locations for gasoline stations.

On account of the above two features of the Singapore gasoline market, we make the following assumptions for our location model.

1. In empirically explaining observed locations of gasoline stations in Singapore, we assume that the Singapore government is the decision-maker.
2. Since gasoline prices are constant across gasoline stations, they do not play a role in the location model.
3. The government picks geographic locations for the  $P$  gasoline stations so as to minimize the total expected travelling costs of all consumers in Singapore who constitute the total potential demand for gasoline.
4. The supply capacity of each gasoline station exceeds its potential demand, i.e., an under-capacity problem does not exist.

We acknowledge that station characteristics (such as convenience store, car wash etc.) would also affect consumers' choices among stations, and therefore consumers' welfare functions. However, the Singapore government cannot know, *a priori*, which retail chain would successfully

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<sup>2</sup>Bidding decisions of oil companies only determine *who* owns each location, and not *where* the locations themselves ought to be.

bid for a specific location, and the station characteristics that the chain would then choose for that location. Therefore, it is impossible for the government to determine locations by taking into account station characteristics at various possible locations. This underlies assumption 3.<sup>3</sup> Assumption 4 was confirmed by managers at Exxon-Mobil, Shell and Caltex, the three major oil companies in Singapore.

By discretizing the two-dimensional map of Singapore into  $N$  equally spaced grid points, we define the Singapore government's problem as one of choosing  $P$  grid points, among the full set of  $N$  available grid points, to locate gasoline stations, in order to minimize the sum of travelling distances across all consumers who constitute potential gasoline demand. Let  $Y_{ij}$  denote a binary outcome that takes the value 1 if consumers within grid point  $i$  choose the gasoline station in grid point  $j$  and 0 otherwise. Based on the above discussion, the Singapore government's objective function can then be written down as follows<sup>4</sup>:

$$\min_X \sum_{i=1}^N \sum_{j=1}^N q(Z_i; \alpha) d_{ij} Y_{ij} \quad (1)$$

such that

$$\sum_{j=1}^N Y_{ij} = 1 \quad (2)$$

$$\sum_{j=1}^N X_j = P \quad (3)$$

$$Y_{ij} - X_j \leq 0, \forall i, j \quad (4)$$

$$Y_{ij} = 0 \text{ or } 1 \quad (5)$$

$$X_j = 0 \text{ or } 1 \quad (6)$$

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<sup>3</sup>Consistent with this assumption, our estimation results from the pricing model show that station characteristics are not as important as price or travel cost in influencing consumer demand for gasoline stations.

<sup>4</sup>Our conversations with government planners indicate that models of this kind are routinely used in urban development.

where  $q(Z_i; \alpha)$  is the potential demand for gasoline at grid point  $i$ ,  $Z_i$  is a vector of all relevant factors that explain potential gasoline demand at grid point  $i$ ,  $\alpha$  is the corresponding vector of unknown parameters,  $d_{ij}$  is the geographic distance between grid points  $i$  and  $j$ ,  $X_j$  is an indicator variable that takes the value 1 if a gasoline station resides in grid point  $j$  and 0 otherwise, and  $Y_{ij}$  as a binary outcome that takes the value 1 if consumers within grid point  $i$  choose the gasoline station in grid point  $j$  and 0 otherwise. Equation (1) is the objective function of the Singapore government. Equation (2) embodies the constraint that consumers within a grid point  $i$  can choose one and only one gasoline station. Equation (3) embodies the constraint that the government is working with  $P$  stations in its locational planning decision. Equation (4) captures the logical condition that consumers cannot choose to go to grid point  $j$  for their gasoline purchase if no gasoline station is located at  $j$ . Equation (5) implies that consumers at grid point  $i$  will choose either to travel to grid point  $j$  ( $Y_{ij} = 1$ ) or not ( $Y_{ij} = 0$ ). Finally, equation (6) implies that a gasoline station is either set up at grid point  $j$  ( $X_j = 1$ ) or not ( $X_j = 0$ ).

We specify potential gasoline demand at a grid point  $q_i = q(Z_i; \alpha)$  in a log-linear manner using the following multiplicative model.<sup>5</sup>

$$\ln(q_i) = \alpha_1 \ln\left(\frac{POP_i}{POP_0}\right) + \alpha_2 \ln\left(\frac{INC_i}{INC_0}\right) + \alpha_3 \ln\left(\frac{CAR_i}{CAR_0}\right) + \alpha_4 I_i^{AIR} + \alpha_5 I_i^{DT} + \alpha_6 I_i^{HWY} \quad (7)$$

where  $POP_i$  is the residential population of grid point  $i$ ,  $INC_i$  the median income of grid point  $i$ ,  $CAR_i$  the total number of owned cars in grid point  $i$ ,  $I_i^{AIR}$  is an indicator variable that takes the value 1 if grid point  $i$  is near the airport and 0 otherwise,  $I_i^{DT}$  is an indicator variable that takes the value 1 if grid point  $i$  is in the downtown area and 0 otherwise, and  $I_i^{HWY}$  is an indicator variable that takes the value 1 if grid point  $i$  is close to a highway and 0 otherwise.  $POP_0$ ,  $INC_0$ , and  $CAR_0$  are explanatory variables for a reference grid point, whose potential demand level  $q_0$  is fixed at 1 (for identification purposes). Therefore, the explanatory variables for all other grid points are operationalized relative to the corresponding variables of this reference grid point. It is useful to note that the parameters  $\alpha_1, \alpha_2, \alpha_3$  of the multiplicative model can directly be interpreted as the elasticities of potential gasoline demand to changes in

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<sup>5</sup>This demand model has been extensively used to estimate the effects of marketing mix variables on brand sales (see, for example, Van Heerde, Leeflang and Wittink 2000).

the relative values of the explanatory variables with respect to the reference grid point. It is also useful to reiterate here that while potential gasoline demand at a grid point is a function of local demographic variables, it depends on neither the prices and station characteristics of stations that may choose to locate themselves at or near the grid point, nor on travel distances of consumers within the grid point. This is consistent with the definition of potential market size in the existing literature on choice models.

The geographic distance between grid points  $i$  and  $j$ , denoted by  $d_{ij}$ , is operationalized using the *Euclidean distance* measure<sup>6</sup>. In other words, suppose  $(x_i, y_i)$  and  $(x_j, y_j)$  are the Euclidean coordinates of  $i$  and  $j$ , then  $d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$

We assume that the consumer's decision rule for choosing a gasoline station, as perceived by the government, is the following: Given all grid points  $k$  such that  $X_k = 1$ ,

$$Y_{ij} = 1 \text{ iff } d_{ij} = \min d_{ik} \quad (8)$$

In other words, consumers within a given grid point are assumed to choose the locationally closest gasoline station for their gasoline purchases. This stems from our assumption that the government assumes prices to be constant across all gasoline stations in Singapore while making its location decisions.<sup>7</sup>

To estimate model parameters, we cast the location model in estimable econometric form as shown below.

$$X_j = \hat{X}_j(Z, P; \alpha^0) + e_j \quad (9)$$

where  $X_j$  is the *observed* location of station  $j$ ,  $\hat{X}_j(Z, P; \alpha^0)$  is the *predicted* (based on solving the objective of the Singapore government, as given in equation 1) location of station  $j$ ,  $\alpha^0$  is the true value of the unknown parameter vector  $\alpha$  (that is known to the Singapore government but unknown to the econometrician),  $e_j$  stands for measurement error (with mean zero). Minimizing this measurement error in some manner, using an appropriate loss function, will serve as the

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<sup>6</sup>Using data from the New York State Department of Transportation, Phibbs and Luft (1995) find a correlation of 0.987 between straight-line distances and travel times. Other studies that use Euclidean distances as proxies for travel times include Manuszak (1999), Thomadsen (2003), Davis (2001), McManus (2003).

<sup>7</sup>It is possible to use a probabilistic choice function, such as the multinomial logit, instead of the binary indicator function, for  $Y_{ij}$ . However, this renders the government's decision problem non-linear and computationally difficult to solve.

estimation technique to recover estimates of  $\alpha$ . It is useful to recognize here that  $X_j$  and  $\hat{X}_j(Z, P; \alpha)$  are both two-dimensional variables since they represent station locations in two-dimensional Euclidean space.

The Singapore government's location problem, represented by equations 1-6 and called the *P-Median Problem*, can be solved using the *Lagrangian algorithm* (see Daskin 1995 for details)<sup>8</sup>. For a given  $\alpha$ , therefore, one can compute the predicted locations  $\hat{X}_j(Z, P; \alpha)$  using this algorithm. The estimation objective is to pick the value of  $\alpha$  that minimizes the following *quasi* mean-squared error (QMSE).

$$QMSE(X, Z, P; \alpha) = \min_{\alpha} \frac{1}{P} \sum_{j=1}^P \sum_{k=1}^P \sqrt{[X_j^{(x)} - \hat{X}_k^{(x)}(Z, P; \alpha)]^2 + [X_j^{(y)} - \hat{X}_k^{(y)}(Z, P; \alpha)]^2} \cdot \chi_{jk} \quad (10)$$

$$\sum_{j=1}^P \chi_{jk} = 1 \quad (11)$$

$$\sum_{k=1}^P \chi_{jk} = 1 \quad (12)$$

$$\chi_{jk} = 1 \text{ or } 0 \forall j, k \quad (13)$$

where  $X^{(x)}$  and  $X^{(y)}$  denote the  $x$ - and  $y$ -coordinates of  $X$  respectively. The rationale of using  $\chi_{jk}$  in the QMSE is as follows: After obtaining  $\hat{X}$  by solving the P-median problem, one must pair up each of the  $P$  predicted locations with one of the  $P$  observed locations in the data before computing a mean-squared error. However, there are numerous ways of undertaking this pairing-up task. We pick the one that minimizes the mean-squared error. That is, among all possible pairings of locations in  $\hat{X}$  and  $X$ , we pick the one that has minimum mean squared error. This is computationally achieved using the *Exchange* algorithm (see Daskin 1995 for details)<sup>9</sup>.

The estimator for  $\hat{\alpha}$  that we propose is that value that minimizes the QMSE. In other words,

$$\hat{\alpha} = \arg \min QMSE(X, Z, P; \alpha) \quad (14)$$

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<sup>8</sup>The starting values are picked using the *Exchange algorithm*.

<sup>9</sup>The starting values are picked using the *Myopic algorithm*.

The rationale for this estimation algorithm is to employ an estimator that matches the observed and predicted station locations as closely as possible. In this sense, our proposed estimator is a *minimum distance* estimator, just like the *least squares* estimator. We use the Nelder-Mead (1965) non-derivative simplex method to search for  $\hat{\alpha}$ .

It is important to note that our location model specifies the potential gasoline demand at a grid point using all relevant demographic variables, such as local residential population, number of cars owned, median income etc. Previously proposed location models have used only local population to characterize potential local demand for a product (see, for example, Seim 2000). Our location model is unique in that it captures the objectives of a social welfare maximizer, specifically the government, in determining retail locations. It can be generalized to other decision contexts pertaining to retail location where the government or a central city planner is the decision-maker whose objective is to increase social welfare by reducing travelling inconvenience of consumers. It can also be generalized to contexts that involve greater discretion on the part of firms deciding where to locate themselves, such as supermarket location decisions in the US. The objective of the P-Median problem would then involve the maximization of some firm-specific measure of interest, such as profit or market share, across all chosen locations for stores belonging to that chain, conditional on chosen locations of competing stores. Our model could be extended to a context where pricing and service decisions of firms are also allowed to influence their locational choices. Such a model would entail the specification and estimation of a simultaneous system of equations governing location, price and service choices of firms.<sup>10</sup>

### 3.2 Pricing Model

Given relative locations of  $P$  gasoline stations, as determined by the Singapore government and represented using the location model discussed earlier, we next model gasoline prices at the  $P$  gasoline stations. There are six gasoline retail chains in Singapore: Shell, Caltex, Esso, Mobil, BP (British Petroleum) and SPC (Singapore Petroleum Company).<sup>11</sup>

In order to gain an understanding about the nature of price competition among stations in

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<sup>10</sup>This is an important and challenging extension of our model for future research.

<sup>11</sup>The merger of Exxon, called Esso in Singapore, with Mobil obviously reduces the number of independent chains in Singapore. However, at the time of data collection these stations retained their original identity. We retain this structure since it helps us illuminate better the brand specific effects on retail competition as also eases the exposition. In fact, more recently, BP and SPC have also merged. We address the effects of this merger in the policy implications section.

the gasoline market, we run reduced-form pricing regressions.<sup>12</sup> The results of these regression analyses lead us to assume that observed prices at  $P$  gasoline stations emerge from Bertrand competition between the six gasoline retail chains, where each chain manager sets the price at each station belonging to his/her chain.<sup>13</sup> Under this model, a gasoline retail chain's problem is one of choosing (possibly different) gasoline prices from all its stations in order to maximize the total variable profits from selling gasoline at all its stations. Retail chain  $m$ 's objective function (at time  $t$ ) can then be written down as follows:

$$\max_{p_{jt} \forall j \in m} \sum [(0.55p_{jt} - C_{jt})Q_{jt}] \quad (15)$$

where  $C_j$  refers to the marginal cost of selling gasoline at station  $j$ ,  $Q_{jt}$  refers to the demand for gasoline at station  $j$  during time  $t$ , and  $0.55p_{jt}$  represents revenues (after taxes) that accrue to the retailer from charging a price  $p_{jt}$ .<sup>14</sup>

$$0.55Q_{jt} + \sum_{l \in m} [(0.55p_{lt} - C_{lt}) \frac{dQ_{lt}}{dp_{jt}}] = 0 \quad (16)$$

We specify demand for gasoline at station  $j$  during time  $t$ , i.e.,  $Q_{jt}$ , as follows.

$$Q_{jt} = \sum_{i=1}^N Q_{ijt} + \nu_{jt} \quad (17)$$

where  $Q_{ijt}$  is the demand in grid point  $i$  for gasoline at station  $j$  during time  $t$ , and  $\nu_{jt}$  is a random shock denoting unobserved (by the econometrician) influences on demand for gasoline at station  $j$  during time  $t$ . For simplicity, we assume that  $\frac{\partial \nu_{jt}}{\partial p_{kt}} = 0 \forall k$ . Further,  $Q_{ijt}$  is specified as follows.

$$Q_{ijt} = S_{ijt}q_i \quad (18)$$

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<sup>12</sup>The results of these reduced-form regressions are available from the authors.

<sup>13</sup>An alternative assumption would be that each station manager maximizes some weighted combination of the profits at his/her station and the profits of other stations belonging to the same chain. Such a model would allow for station-level, as opposed to chain-level, price competition (when the estimated weight for other stations belonging to the same chain is zero). We estimated such a model, and it reduced to the special case of chain-level profit maximization discussed here.

<sup>14</sup>In Singapore, the excise tax rate charged for gasoline is 35%. There is an additional corporate income tax rate of 15%. This results in  $\$1 - 0.35*\$1 - 0.15*(0.35*\$1) = \$0.55$  of every \$ of pre-tax revenues accruing to the retailer.

where  $S_{ijt}$  denotes the market share in grid point  $i$  for gasoline at station  $j$  during time  $t$ , and  $q_i$  denotes the potential demand for gasoline at grid point  $i$  (as discussed under the location model). Further,  $S_{ijt}$ , is specified as follows.

$$S_{ijt} = \frac{e^{W_j\beta + d_{ij}\delta + p_{jt}\gamma}}{\sum_{k=1}^P e^{W_k\beta + d_{ik}\delta + p_{kt}\gamma}} \quad (19)$$

where  $W_j$  stands for a vector of station characteristics (number of pumping bays, pay-at-pump facility, presence of convenience store, specialty deli, service station, and car-wash) that are relevant in terms of influencing market share for gasoline at a station,  $\beta$  is the corresponding vector of parameters,  $d_{ij}$  is the geographic distance between grid points  $i$  and  $j$ ,  $p_{jt}$  refers to the price of gasoline at station  $j$  during time  $t$ ,  $\delta$  and  $\gamma$  stand for the travel cost and price sensitivity parameters of consumers respectively. This market-share model, also called the multinomial logit model, is consistent with random utility maximization on the part of individual consumers (McFadden 1974).<sup>15</sup> The probabilistic choice rule that underlies the multinomial logit model is on account of other (i.e., unobserved by the econometrician) variables that are believed to influence consumers' utilities for stations. This is not necessarily inconsistent with the fixed choice rule determining  $Y_{ij}$  in the location model discussed earlier. This is because the government assumes that price and all other relevant station characteristics - observed or unobserved - are identical across stations when making location decisions. In such a case, the random utility model will reduce to a deterministic utility model (that sets the randomness in the consumer's utility function to zero) based on travel costs only.

Under the conditions of the above market share model, consumers within a given grid point are assumed to allocate themselves between gasoline stations, taking two types of station characteristics into account (Iyer and Seetharaman 2003, 2005): 1. horizontal characteristics (i.e., geographic locations, that determine  $d_{ij}$ ), and 2. vertical characteristics (i.e.,  $W_j$  and  $p_{jt}$ ).

The marginal cost of firm  $j$  at time  $t$  is specified as follows.

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<sup>15</sup>This market-share specification ignores the effect of the outside good (i.e., consumers' option of not purchasing gasoline at any of the available gasoline stations, and choosing to travel by bus or taxi instead). This assumption is reasonable given that pricing fluctuations are not large in our data, varying from a lowest of \$1.057 to a highest of \$1.234, which implies that consumers may not give up driving for other alternatives such as public transportation. Consistent with this intuition, estimation results obtained using a model that allows for the outside good are very similar to those reported in this paper. However, the standard errors of some estimates become unreasonably large. We do not have an explanation for this.

$$C_{jt} = C_t + \epsilon_{jt} \quad (20)$$

where  $C_t$  refers to the time-varying marginal cost of gasoline that is assumed to be the same across stations, and  $\epsilon_{jt}$  is a random shock that represents the effects of unobserved (by the econometrician) variables on the marginal cost of gasoline at a station.

Plugging in equations (17)- (20) within equation (16) yields the following first-order conditions, represented in matrix form, for gasoline station  $j$  that belongs to chain  $m$ .

$$0.55p_t - C_t i_P + 0.55\Omega(p_t, \Theta)^{-1}Q_t = \xi_t \quad (21)$$

where  $p_t$  is a  $P \times 1$  vector of retail prices at the  $P$  stations,  $i_P$  is a  $P \times 1$  vector of ones, and  $\Omega(p_t, \Theta)$  is a  $P \times P$  matrix whose  $j$ th diagonal element is given by  $\gamma \sum_{i=1}^N S_{ijt}(1 - S_{ijt})q_i$ , and whose off-diagonal element (j,k) is equal to  $-\gamma \sum_{i=1}^N S_{ikt}S_{ijt}q_i$  if stations  $j$  and  $k$  belong to the same chain, and equal to 0 otherwise.  $\Theta = (\beta \ \delta \ \gamma)'$  is the vector of parameters in the market share model,  $Q_t$  is a  $P \times 1$  vector whose  $j$ th element is given by  $\sum_{i=1}^N S_{ijt}q_i$ , and  $\xi_t = (\xi_{1t}, \dots, \xi_{Pt})'$  is a  $P \times 1$  vector of random shocks that can be represented as follows.

$$\xi_t = \epsilon_t - 0.55\Omega(p_t, \Theta)^{-1}\nu_t \quad (22)$$

where  $\epsilon_t = (\epsilon_{1t}, \dots, \epsilon_{Pt})'$  and  $\nu_t = (\nu_{1t}, \dots, \nu_{Pt})'$ .

From equation (22), it is clear that the econometric error,  $\xi_t$ , is a composite of demand shocks,  $\epsilon_t$ , and cost shocks,  $\nu_t$ .<sup>16</sup> While this error captures the effects of unobserved variables from the econometrician's standpoint, they may include variables that are observed by the retail chain managers, and therefore incorporated by them while making their pricing decisions. This introduces an endogeneity problem in the estimation on account of possible correlation between  $p_t$  and  $\xi_t$  in equation (21). Further, to the extent that  $\nu_t$  also incorporates demand shocks, it may also be correlated with station characteristics that are embodied in  $\Omega(p_t, \Theta)$  and  $Q_t$ , thus leading to an additional source of possible endogeneity bias in equation (21). For example, some unobserved locational advantage of a station (that is time-invariant) may simultaneously increase

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<sup>16</sup>Our pricing model, and the associated estimation procedure, is in the spirit of Thomadsen (2003). However, while Thomadsen (2003) allows only for cost shocks in his econometric error, we have a more general specification of the error.

demand for the station and also encourage the chain manager to install additional pumps at the station. We will refer to the two possible sources of endogeneity as PRICE ENDOGENEITY and CHARACTERISTICS ENDOGENEITY respectively.

We use Generalized Method of Moments (GMM) to estimate equation (21). In order to correct for PRICE ENDOGENEITY, we choose four instrumental variables for  $p_{jt}$ : (1) an indicator variable that takes the value 1 if other stations belonging to the same retail chain as station  $j$  exist within a one-mile radius of station  $j$ , and the value 0 otherwise, (2) log of the number of stations belonging to retail chains different from that of station  $j$  that exist within a one-mile radius of station  $j$ , (3) average estimated potential gasoline demand (from our location model) per station within a one-mile radius of station  $j$ , and (4) potential demand at each grid point on the Singapore map, divided by its distance to station  $j$ , summed over all grid points. The validity of the first three instruments relies on an assumption that the time-invariant demand shocks are localized and do not spill over to other nearby stations (within the one-mile radius). For example, suppose station  $j$ 's locational advantage arises from the fact that it is at the junction of two streets. In that case, neither the number of nearby stations belonging to the same chain, nor the number of nearby stations belonging to competing chains, is likely to be a function of such a locational advantage of station  $j$ . In other words, instruments 1 and 2 will be uncorrelated with the unobserved demand shock. However, these instruments will be highly correlated with the price at station  $j$  to the extent that station  $j$  will be less aggressive while setting price in the presence of other stations belonging to the same chain (to avoid cannibalizing sales of the same chain's stores), and more aggressive while setting price in the presence of competitors.<sup>17</sup> Similarly, since the average estimated potential gasoline demand at nearby stations (i.e., instrument 3) depends only on observed demographic characteristics of the neighborhood (as specified under the location model), instrument 3 will also be uncorrelated with the unobserved demand shock. Finally, the rationale for the fourth instrumental variable is that it is a more *global* measure of competitive effects compared to the first three instrumental variables that capture *local* effects of competition. Further, it takes into account both how far away a competing station is as well as the intensity of gasoline demand in that station's neighborhood. Suppose  $U_t$  denotes a  $P \times 18$  matrix, where each row represents a different sta-

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<sup>17</sup>Our reduced-form price regressions show that instruments 1, 2 and 3 are indeed highly correlated with the observed prices.

tion, and the 18 columns represent 1 intercept, 2 indicator variables for time  $t$  (representing 3 waves of data collection), 5 indicator variables for chain (representing the 6 chains), 6 variables representing station characteristics (as will be explained later), and 4 instrumental variables (as discussed above), the following moment condition then underlies the GMM estimation (ignoring CHARACTERISTICS ENDOGENEITY).

$$E(\xi_t|U_t) = 0 \tag{23}$$

When the station characteristics correlate either with demand or cost shocks, the moment condition in equation (23) is invalid. We are unable to find appropriate additional instruments in order to correct for CHARACTERISTICS ENDOGENEITY. Therefore, we re-estimate our proposed model by excluding the station characteristics as explanatory variables within  $W_j$ , and as instruments within  $U_t$ , thereby precluding concerns about possible endogeneity of such variables in the estimation. We compare the estimates of the travel cost ( $\delta$ ) and price sensitivity ( $\gamma$ ) parameters obtained using this modified specification to those obtained using our original specification. This allows us to understand the robustness of these two parameter estimates, i.e., their sensitivity (or lack thereof) to the inclusion of possibly endogenous station characteristics in the estimation.<sup>18</sup>

Under this specification of the pricing model, observed price variations in the data arise on account of differences in demand characteristics across stations, time-varying cost changes (that are equal across stations), as well as demand and cost shocks – time-varying or time-invariant – at the station-level. Last, but not the least, potential gasoline demand at a grid point, i.e.,  $q_i$ , is not observed in the data. We use the *estimated* potential gasoline demand in grid point  $i$ , obtained using the estimates of the location model, as a proxy for  $q_i$ . This allows the potential gasoline demand to be not only simultaneously determined by local population, median income, number of cars owned, presence of highway and downtown, but also lets the weights associated with these factors be endogenously estimated from the observed distribution of gasoline stations. This also relieves us from the burden of having to estimate potential gasoline demand (in addition to the parameters of the pricing model) from the price data.

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<sup>18</sup>Further, our primary interest is in understanding the price elasticity of the Singapore gasoline market as well as the importance of travel cost in influencing consumers' choices among gasoline stations.

It is useful to discuss some identification issues. We identify marginal costs from the average price across all stations, and the changes in this average price across time periods (i.e., waves). Although station-level demand is not observed in the data, we are able to identify the same by invoking the equilibrium conditions of demand and supply. What identifies the demand function is sufficient systematic variation in prices in the data across stations that reside in neighborhoods with different levels of local potential gasoline demand and different levels of local competitive intensity.<sup>19</sup> For example, suppose a station that faces little local competition (i.e., few nearby stations) prices higher than another station that faces higher local competition (i.e., many nearby stations), for the same level of local potential gasoline demand, this would serve as the source of identification for the travel cost and price sensitivity parameters in the demand function. Suppose two stations belonging to different chains price differently within the same local market, this would serve as the source of identification of the brand intercepts in the demand function. Two caveats are in order, however. First, since we rely on price data to infer both cost-side as well as demand-side parameters, our estimates of demand are likely to be less efficient compared to estimates obtained using demand data. Second, since we rely on specific assumptions such as Bertrand price competition between retail chains, and Multinomial Logit demand for gasoline stations, in order to achieve this identification, it is possible that our estimates are subject to mis-specification bias. However, our reduced-form pricing regressions suggest that our assumption about Bertrand price competition is quite reasonable.

## 4 Description of Data

Our data pertains to the gasoline market in Singapore. This market is a good geography for examining firm conduct for a variety of institutional considerations. First, it is a self-contained market of substantial size. For instance, 2002 petrol<sup>20</sup> sales alone were in excess of a billion liters and, more infamously, Singapore ranks second (next to the U.S.) in global carbon dioxide emission per unit of GDP (Economist, May 9, 2003). Second, all the demand is supplied by local refiners and there is no possibility of supply-side leakage. Motorists crossing the borders into Malaysia (the only possible road transit) are required by law to have their

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<sup>19</sup>Proof of sufficient variation in prices is easily observed in the results of our reduced-form pricing regressions, where we find the effects of all the competitive environment factors to be significant.

<sup>20</sup>We use the terms *gasoline* and *petrol* interchangeably in this paper.

gas-tanks filled to at least three-quarters prior to crossing the border. Hence, supply-demand leakages due to the price differences between the two markets do not hold.<sup>21</sup> Third, the market is increasingly viewed as being a mature and competitive market. Gasoline demand is stable and expected to grow slowly due to the controlled increase in automobile ownership. Traditionally, retail competition was conducted through non-price instruments (sweepstakes, freebies, loyalty programs). Price promotions are a recent addition (past three to five years) to this mix and are becoming increasingly common and distributed across the entire island. Currently, upwards of 25% of gasoline stations are running promotions ranging in depth from 5% to 15% on petrol and/or diesel. Fourth, the oil majors control all elements of their channel from production to distribution to retailing. However, the location decisions for retail outlets are decided by the URA (Singapore's Urban Redevelopment Authority).

We employ survey data, representing a cross-section of 226 gasoline stations in Singapore during late 2001 and early 2002. We include all gasoline stations in mainland Singapore in our empirical analyses, ignoring gasoline stations that are located in islands off the Singapore coast<sup>22</sup>. Among the 226 stations in mainland Singapore, 75 stations are owned by Shell, 43 by Mobil, 39 by Esso, 32 by Caltex, 29 by BP, and 8 by SPC. The survey data include, for each gasoline station, the prices of four grades - Premium, 98UL, 95UL and 92UL - of petrol, the price of diesel, as well as a large number of station-specific characteristics, e.g. number of pumping bays, presence of convenience store, pay-at-pump facility, car wash, service station, ATM, store hours, prices of goods at convenience store etc. Our dataset also contains demographic information - population, home ownership, age, employment status, mode of transportation, income etc. - pertaining to each gasoline station's market. Three waves of data collection - all of which used the same survey instrument - were undertaken at the same set of 226 gasoline stations during the months of November 2001, December 2001 and January 2002. This yielded some time-series variation in gasoline prices. Since 98UL is the most popular grade of gasoline in Singapore, we report the estimation results for our pricing model based on this grade of gasoline<sup>23</sup>.

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<sup>21</sup>The price differential between the two countries is substantial. The price of a liter of 98-octane petrol in May 2002 was 1.244 S\$ in Singapore and 0.630 S\$ in Malaysia (prices are in Singaporean dollars). The substantial gasoline tax revenues was suggested to the authors as one of reasons for the Singaporean ordinance.

<sup>22</sup>There are a total of 229 gasoline stations in mainland Singapore. We had to exclude three stations - two belonging to Mobil and one to BP - whose geographic locations were missing in the survey data.

<sup>23</sup>Estimation results for the other grades are consistent with those obtained for the 98UL grade, and are available from the authors.

For the location model, we divide mainland Singapore into a rectangular grid of 1550 grid points that are equally spaced both in the horizontal and vertical dimensions. Picking 1550 as opposed to a smaller number of grid points ensures that each grid point has no more than one gasoline station, which is required to be consistent with our location model (see equations 1-6). Estimating the location model enables us to endogenously characterize potential gasoline demand at each grid point in Singapore. We allow the following demographic characteristics to influence local potential gasoline demand at each grid point (i.e.,  $q_i$ ). (1)  $POP_i$ , the local population represented within grid point  $i$ , computed as the total population of the census tract to which the grid point belongs divided by the total number of grid points within that census tract; (2)  $INC_i$ , the median income of the census tract to which grid point  $i$  belongs; (3)  $CAR_i$ , the total number of cars represented within grid point  $i$ , computed as the total number of cars within the census tract to which the grid point belongs divided by the total number of grid points within that census tract; (4)  $AIR_i$ , an indicator variable that takes the value 1 if grid point  $i$  is located adjacent to the airport, and 0 otherwise; (5)  $DT_i$ , an indicator variable that takes the value 1 if grid point  $i$  is located within the downtown area, and 0 otherwise; (6)  $HWY_i$ , an indicator variable that takes the value 1 if grid point  $i$  is located adjacent to a major highway, and 0 otherwise.

For the pricing model, we use the same set of 1550 grid points as in the location model in order to compute aggregate demand for each gasoline station (see equation 17). We also plug the estimated values of  $q_i$  from the location model directly into equation (18) while estimating the pricing model. We allow the following station characteristics ( $W_j$ ) to influence market shares for gasoline stations (i.e.,  $S_{ij}$ ) in equation 19: (1)  $CHAIN_j$ , a five-dimensional vector of indicator variables representing which of six different retail chains station  $j$  belongs to; (2)  $PUMPS_j$ , the total number of gasoline pumping bays available in station  $j$ ; (3)  $PAY_j$ , an indicator variable that takes the value 1 if STATION  $j$  has pay-at-pump facility, and 0 otherwise; (4)  $HOURS_j$ , an indicator variable that takes the value 1 if station  $j$  is open 24 hours a day, and 0 otherwise; (5)  $WASH_j$ , an indicator variable that takes the value 1 if station  $j$  has a car wash facility, and 0 otherwise; (6)  $SERV_j$ , an indicator variable that takes the value 1 if station  $j$  has a service station, and 0 otherwise; (7)  $DELI_j$ , an indicator variable that takes the value 1 if station  $j$  has a specialty deli, and 0 otherwise.

The variable  $PUMPS_j$  is observed to vary from 4 to 20 across stations in our dataset. The remaining indicator variables -  $PAY_j$ ,  $HOURS_j$ ,  $WASH_j$ ,  $SERV_j$  and  $DELI_j$  - are observed to take the value 1 for 69, 88, 50, 52 and 22 percent of the stations in our dataset respectively. In addition to the above station characteristics, the market share model also includes the price of gasoline at station  $j$ ,  $PRICE_j$ , as well as travel distance,  $d_{ij}$ , as explanatory variables (see equation 19).

Given in Table 1 are the means and standard deviations of prices of 98UL gasoline, the most popular grade of gasoline in Singapore, at various retail chains in Singapore. The average price of 98UL gasoline is about 5 cents lower at SPC compared to the other retail chains. The standard deviation of price of gasoline is about 0.03 cents (for most grades and retain chains), which is much smaller than the standard deviation of price observed in US markets (see, for example, Shepard 1991, Iyer and Seetharaman 2003a etc.). This price variation includes variation across stations within a chain, as well as across time.

<i>Chain</i>	<i>Mean</i>	<i>Std.Dev.</i>
<i>Shell</i>	1.19	0.03
<i>Caltex</i>	1.18	0.04
<i>Esso</i>	1.19	0.03
<i>Exxon – Mobil</i>	1.19	0.03
<i>BP</i>	1.19	0.03
<i>SPC</i>	1.14	0.03

Table 1: *Chain-Specific Means and Standard Deviations of 98UL Gasoline.*

## 5 Empirical Results

We report the estimates of our proposed location model (called PROPOS) in column 2 of Table 2 (the sampling intervals associated with these estimates, obtained using bootstrapping<sup>24</sup> are reported in columns 3 and 4). The results show that, as expected, potential gasoline demand at a grid point is a positive function of the population, median income and number of cars owned

<sup>24</sup>The bootstrapping procedure is as follows: Based on the estimate  $\hat{\alpha}$ , we generate the empirical distribution of  $e_j$ , using equation (9), as the difference between the observed and predicted locations. Using this empirical distribution of errors, as well as the estimate  $\hat{\alpha}$ , we simulate locations for the gasoline stations. Taking these simulated locations as actual locations, we re-estimate the proposed location model. We then cycle through the same procedure again. We do this until we have 50 sets of  $\hat{\alpha}$ , based on which we compute the 90 percent confidence interval.

in the local neighborhood. This validates our earlier contention that population is only one among several demographic variables that influence local demand for gasoline. We also find, as expected, that proximity to the airport, downtown and highways increase local potential gasoline demand, with proximity to highways accounting for the largest increase. All of these results are intuitively sensible and give excellent face validity to our proposed location model. We also estimate a benchmark model (called BENCH) that restricts potential gasoline demand to be equal to the local population (as in, say, Seim 2002). In order to understand how well we are able to predict observed gasoline station locations using our chosen set of six demographic variables, we compare the predictive ability of PROPOS to that of BENCH. The quasi mean-squared error based on PROPOS is 7210, while that based on BENCH is 15199, thus indicating more than 50% predictive gains from using demographic variables to predict local potential gasoline demand as in our proposed location model.

<i>Parameter</i>	<i>Estimate</i>	<i>10thPercentile</i>	<i>90thPercentile</i>
<i>POP<sub>i</sub></i>	2.3425	2.2442	2.3732
<i>INC<sub>i</sub></i>	2.5327	2.4368	2.6293
<i>CAR<sub>i</sub></i>	0.9462	0.9243	0.9860
<i>AIR<sub>i</sub></i>	1.8075	1.5610	1.8925
<i>DT<sub>i</sub></i>	1.8394	1.6186	1.8394
<i>HWY<sub>i</sub></i>	2.9434	2.8345	3.0021

Table 2: *Estimated Parameters of the Location Model.*

Figure 1 visually represents the estimated local potential gasoline demand across grid points on the Singapore map. Overlaying the distribution of estimated potential gasoline demand across grid points on top of the observed distribution of gasoline stations across the same set of grid points enables us to visually convey the government’s basis for placing large number of gasoline station locations at some geographic neighborhoods and not at others. In order to facilitate interpretation, we color-code Figure 1 into four (equal-sized) colored regions – low demand (green), middle demand I (light blue), middle demand II (orange), high demand (dark blue) – using the quartiles of the estimated distribution of potential gasoline demand. The dense cluster of observed gasoline stations in the north-east portion of Figure 1, along with the estimated high degree of potential gasoline demand in this part of the map, is a consequence of three effects: the presence of downtown in the horizontal line spanning (380,380) to (620,380),

the presence of the airport close to (700,350), and the presence of a major highway spanning the region (700,420) to (800,400). Overall there appears to be a good degree of agreement between the estimated locations and the actual locations of the 226 stations. For example, our estimated locations are also highly concentrated in the north-east portion of Figure 1.

In Table 3 we present the results of the pricing model for 98UL gasoline. In this table, the second column excludes station characteristics as explanatory variables within  $W_j$ , while the third column includes such variables. Understandably, the minimized criterion function value is lower under column 3 (since it includes additional explanatory variables) than under column 2, but the estimates of common parameters are similar to each other. The estimated price-cost margins from columns 2 and 3 are 25.2% and 25.1% respectively. These are higher than estimated margins in the North American gasoline market<sup>25</sup>, perhaps reflecting lower intensity of price competition in the Singapore market.<sup>26</sup> In terms of intrinsic brand preferences of consumers (reflected in the estimated brand intercepts in the demand model), BP and Esso appear to be the strongest brands in the market place.<sup>27</sup> The coefficients associated with both price and travel distance are negative and significant (-4.8358 and -0.1474 under column 2, and -4.6804 and -0.1476 under column 3). This implies that both price and travel distance are important considerations for consumers when they choose between gasoline stations, which is intuitively pleasing since this underscores the importance of locations in firms' pricing decisions. The price sensitivity and travel cost estimates translate into the following substantive interpretation: Consumers will be willing to travel an extra mile to save about 3 cents per liter of gasoline. Assuming an average purchase of gasoline in Singapore to involve 40 liters of gasoline, this implies that consumers would save about \$1.1 by traveling that extra mile. Under the same assumption, the highest estimated brand intercept for BP translates to the following substantive interpretation: Compared to SPC, BP would be able to command a price premium of 10 cents per liter while still keeping the consumer indifferent between the two brands. We find that including station characteristics, as in column 3, does not substantively change any of the estimates reported in column 2. However, on account of our inability to explicitly address potential endogeneity

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<sup>25</sup>For example, Manuszak (1999) estimates retail price-cost margins in Hawaiian gasoline stations to be about 10%.

<sup>26</sup>In fact, price promotions were long absent in the Singapore market, and became a prevalent retail activity only recently, as discussed in the Euromonitor report for 2004.

<sup>27</sup>The brand intercept for SPC is normalized to zero.

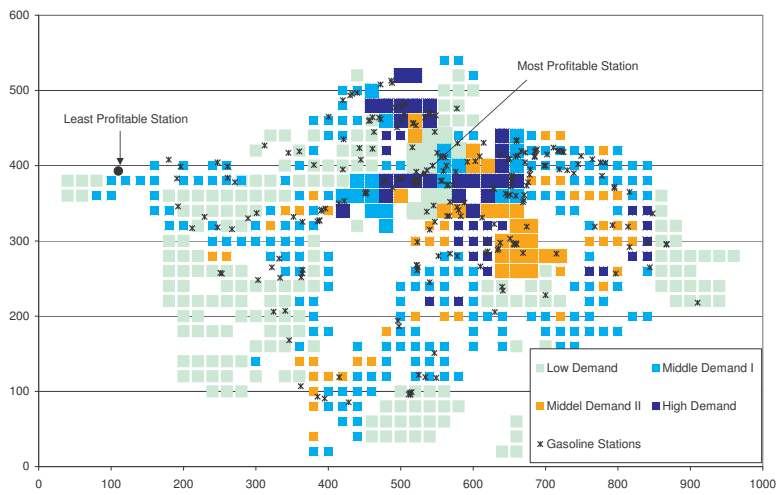


Figure 1: Estimated Potential Gasoline Demand

issues pertaining to station characteristics in the pricing model (as discussed earlier), we do not attempt to directly interpret the estimated parameters associated with such characteristics.

<i>Parameter</i>	<i>PricingModel1</i>	<i>PricingModel2</i>
<b>COST</b>		
<i>Constant</i>	0.3671 (0.0094)	0.3684 (0.0125)
<i>Wave2</i>	-0.0089 (0.0006)	-0.0102 (0.0006)
<i>Wave3</i>	0.0278 (0.0010)	0.0253 (0.0011)
<b>DEMAND</b>		
<i>Shell</i>	-0.0049 (0.0101)	-0.0005 (0.0133)
<i>Caltex</i>	0.0967 (0.0083)	0.1026 (0.0112)
<i>Esso</i>	0.1265 (0.0114)	0.1322 (0.0150)
<i>Mobil</i>	0.0974 (0.0104)	0.1101 (0.0142)
<i>BP</i>	0.1887 (0.0128)	0.2002 (0.0171)
<i>PUMPS<sub>j</sub></i>	na	0.0034 (0.0002)
<i>PAY<sub>j</sub></i>	na	0.0019 (0.0006)
<i>HOURS<sub>j</sub></i>	na	-0.0445 (0.0030)
<i>WASH<sub>j</sub></i>	na	0.0066 (0.0006)
<i>SERV<sub>j</sub></i>	na	-0.0128 (0.0009)
<i>DELI<sub>j</sub></i>	na	-0.0166 (0.0013)
<i>PRICE<sub>j</sub></i>	-4.8358 (0.2296)	-4.6804 (0.2816)
<i>DIST<sub>ij</sub></i>	-0.1474 (0.0088)	-0.1476 (0.0108)
<i>CriterionFn.Value</i>	0.0073	0.0053

Table 3: *Estimated Parameters of Pricing Model (standard errors within parentheses).*

## 6 Policy Implications

### 6.1 Estimated Market Shares and Profits

Based on the estimated parameters, we compute the weekly market shares, and therefore profits (computed at observed prices), of the six retail chains in our dataset<sup>28</sup>. The results are reported in Table 4. The estimated market shares agree remarkably well with corresponding reported market shares of 33.0% (Shell), 14.2% (Caltex), 35.2% (Exxon-Mobil), 13.7% (BP) and 3.9% (SPC) for 2002. This lends excellent face validity to our parameter estimates. Among the six retail chains, the most profitable chain is estimated to be Shell with an estimated profit of \$7.11 mil. per week, while the least profitable is SPC with an estimated profit of \$0.96 mil.

<i>Chain</i>	<i>Share</i>	<i>Profit</i>
Shell	32.61%	\$7.11 mil.
Caltex	14.81%	\$3.23 mil.
Esso	16.92%	\$3.69 mil.
Mobil	18.97%	\$4.13 mil.
BP	12.30%	\$2.68 mil.
SPC	4.39%	\$0.96 mil.

Table 4: *Estimated Market Shares and Profits of the Six Retail Chains.*

In Figure 1, we also identify the most and least profitable stations in Singapore (based on the estimated parameters). The most profitable station is run by Shell (with estimated weekly profits of S\$30,000) and is located in the densest neighborhood in Singapore in terms of potential gasoline demand, which suggests that competitive pressures do not dissipate the profitability of “prime real estate”.<sup>29</sup> The least profitable station is run by SPC (with estimated weekly profits of S\$23,000) and is located in a remote neighborhood in Singapore that is estimated to have low potential gasoline demand. The estimated weekly sales for the most and least profitable stations are S\$138,000 and S\$92,000 respectively. These numbers are very much in the vicinity of publicly available weekly average sales figures (reported by Euromonitor) of S\$114,000 and S\$85,500 for large and small petrol stations in Singapore.<sup>30</sup> One reason for why our estimated

<sup>28</sup>For the market share computation, we use the price data collected from the first wave. For the profit computation, we assume the total weekly demand for petrol to be 18 million liters. This is arrived at as follows: The reported annual retail sales of petrol in Singapore for 2001 was S\$1.149 bil., which is equivalent to S\$22 mil. a week. Assuming an average retail price of S\$1.234 per liter, this translates to 18 mil. liters.

<sup>29</sup>This lends further evidence to the popular emphasis in retailing of “location, location, location!”.

<sup>30</sup>According to the Euromonitor report, average weekly retail sales of large and small stations for 2002 were

numbers are higher may be that we have used a premium (i.e., higher priced) grade of gasoline (98UL) in our computations.

## 6.2 Merger Simulation

In July 2004, SPC announced that it would acquire all petrol stations from BP, after the latter had decided to exit from the petrol retail market in Singapore. In September 2004, SPC announced that the acquisition was complete. SPC also announced that it will continue to retain the BP brand name for the BP stations, gradually changing the names of these stations to SPC in a phased manner over time. We consider the effects of this merger scenario by running an appropriate simulation using our estimated parameters. Specifically, we simulate the equilibrium market shares, and therefore, equilibrium prices, of the 226 stations after assuming that the 8 stations owned by SPC merge with the 29 stations owned by BP, thus belonging to a single chain that maximizes the sum of profits across 37 stations. Since our estimation results show that BP is the most preferred brand, while SPC is one of the least preferred brands, in the Singapore petrol market (as evidenced by the estimated brand intercepts in Table 4), and to be consistent with the “post-merger” scenario described above, we make two alternative assumptions: 1. Each station retains its previously held brand name (i.e., SPC or BP), or 2. All BP stations are renamed with the SPC brand name. We will refer to these two assumptions as SCENARIO 1 and SCENARIO 2 respectively.

We face a technical issue in conducting this policy experiment. We have to calculate equilibrium prices of 226 firms following the merger. This involves a “fixed point” computation that is based on the following equilibrium condition.

$$0.55\hat{p}_t - \hat{C}_t i_P + 0.55\Omega(\hat{p}_t, \hat{\Theta})^{-1}\hat{Q}_t = 0 \quad (24)$$

The dimensionality of the fixed points is too large to be computed using conventional “hill-climbing” derivative methods or the simplex method. To solve the problem, we employ the following contraction mapping algorithm.

$$p^{\hat{n}+1} = \hat{p}^{\hat{n}} + \Delta[0.55\hat{p}_t - \hat{C}_t i_P + 0.55\Omega(\hat{p}_t, \hat{\Theta})^{-1}\hat{Q}_t] \quad (25)$$

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S\$140,000 and S\$105,000 respectively, with petrol accounting for 81.5% of retail sales. This yields weekly average petrol sales of S\$114,000 and S\$85,500 respectively.

where  $n = 0, 1, \dots$  is the iteration number,  $\Delta \in [0, 1]$  is a contraction factor. The iterative algorithm converges when  $d^n < \varepsilon$ , where  $d^n = \text{Max}|p^{n+1} - p^n|$ , and  $\varepsilon$  is a pre-determined tolerance level. The algorithm converges very quickly to within the tolerance level, as long as  $\Delta < 1$ .<sup>31</sup>

Table 5 presents the equilibrium prices, market shares and profits under the pre-merger scenario, as well as under the two post-merger scenarios (i.e., SCENARIO 1 and SCENARIO 2). Average prices at all chains are found to increase from 2 to 7 cents under the merger (under both post-merger scenarios), which suggests that the merger will reduce the intensity of price competition in the Singapore market. The price increase under both post-merger scenarios are roughly the same for all chains except for BP, for which the price increase under SCENARIO 2 is only a third (i.e., 2 cents, or 1.25%) compared to that under SCENARIO 1 (i.e., 6 cents, or 4.93%). The reason for this is that since the estimated brand preference for BP is higher than that of SPC, BP stations stand to lose some pricing power by forfeiting the stronger brand name after the merger and adopting the weaker name instead.<sup>32</sup> Since BP stations price lower under SCENARIO 2 than under SCENARIO 1, the other chains also price somewhat less than they would under SCENARIO 1, on account of competitive pressures. Specifically, the increase in equilibrium prices for Shell, Caltex, Esso and Mobil are 4.61%, 4.41%, 4.48% and 4.49% respectively under SCENARIO 1, and 4.07%, 3.88%, 3.94% and 3.95% respectively under SCENARIO 2. Profits are found to increase for all chains<sup>33</sup> under SCENARIO 1, while they increase for all chains except BP under SCENARIO 2.<sup>34</sup> Overall, these results suggest that the merger will lead to increased profits, and decreased price competition among all the firms in the petrol industry. Given our findings under SCENARIO 2 about profits decreasing for BP stations, it is indeed wise that SPC is not changing the name of existing BP stations to SPC immediately after the merger. Our policy experiment assumes the cost structure of the

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<sup>31</sup>We experimented with several values of  $\Delta$  in the  $[0, 1]$  range, and initial values  $p^0$ , in order to ensure that the computed fixed points were unique and insensitive to our choice of  $\Delta$  and initial values. The algorithm always converged to a unique fixed point as long as  $\Delta < 1$ . When  $\Delta = 1$ , we experienced convergence problems. Investigating why is beyond the scope of this paper.

<sup>32</sup>In fact, this also leads to decreased profits for BP under SCENARIO 2.

<sup>33</sup>Market shares for BP and SPC are found to decrease after the merger. However, the increase in their prices more than offsets this effect from a profit standpoint.

<sup>34</sup>The profit decrease for BP under SCENARIO 2 is on account of BP stations disadopting their (strong) brand name and adopting the relatively weak brand name of SPC instead. In fact, this decrease profit is strong enough to decrease the combined profit of SPC and BP compared to its pre-merger counterpart.

industry, as well as consumers' brand preferences, to remain unchanged after the merger. It is quite possible that these parameters may change in the long run after the merger. For example, consumers' preference for the SPC brand name may strengthen gradually as it gains a larger presence in the Singapore gasoline market.

<i>Measure</i>	<i>PRE – MERGER</i>	<i>SCENARIO1</i>	<i>SCENARIO2</i>
<i>Shell</i>			
Price (\$)	1.23	1.28	1.28
Market Share (%)	30.45	30.49	30.72
Profit (\$000)	1307.95	1463.03	1455.72
<i>Caltex</i>			
Price (\$)	1.21	1.26	1.26
Market Share (%)	14.77	14.92	15.02
Profit (\$000)	624.21	702.00	698.24
<i>Esso</i>			
Price (\$)	1.23	1.28	1.28
Market Share (%)	17.82	17.95	18.08
Profit (\$000)	770.34	863.96	859.54
<i>Mobil</i>			
Price (\$)	1.22	1.28	1.27
Market Share (%)	19.28	19.42	19.56
Profit (\$000)	828.64	929.41	924.63
<i>BP</i>			
Price (\$)	1.23	1.29	1.25
Market Share (%)	13.85	13.68	13.01
Profit (\$000)	603.41	669.58	584.54
<i>SPC</i>			
Price (\$)	1.16	1.23	1.22
Market Share (%)	3.83	3.54	3.61
Profit (\$000)	150.25	162.75	162.74

Table 5: *Merger Simulation Results.*

## 7 Conclusions

In this paper, we propose and estimate a structural model of location and pricing decisions of gasoline stations in the Singapore market. Our location model, the first of its kind and the first to be estimated for gasoline markets, is built on the premise that the Singapore government determines optimal retail locations for gasoline stations on the basis of maximizing social welfare of Singapore residents by minimizing their travel costs. Our conditional pricing model is built on the premise of Bertrand competition between gasoline retail chains.

By estimating our proposed location model using empirical data on actual geographic locations of gasoline stations, we are able to quantify the explicit dependence of local potential gasoline demand on the following local demographic characteristics of the neighborhood: population, median income, number of cars, proximity to airport, downtown and highways. Using the estimated category-level demand at each local neighborhood in Singapore as an input, we then estimate our proposed pricing model using empirical data on actual prices of gasoline at various stations. We find retail margins for gasoline to be about 25%, and that market share for a gasoline station is negatively influenced by the price of gasoline as well as travel cost. We find that consumers are willing to travel up to a mile for a price saving of 3 cents per liter (which translates to a saving of \$1.1 on a 40-liter tank of gasoline).

We use our estimates to calculate the relative profitability of various retail chains, identify the most and least profitable gasoline stations in Singapore, as well as perform a policy experiment relating to the merger of SPC and BP during the latter part of 2004. We find that prices and profits of all firms in the Singapore petrol industry will increase in response to this merger.

At this point, some caveats are in order.<sup>35</sup> First, we use the current census data, and the demographic information there-in, to understand the demographic drivers of the Singapore government's decisions pertaining to gasoline stations' locations that were made over a long period of time. Locating and employing the census data from several periods would be useful to check the robustness of our estimation results. Second, our location model is built on the assumption that the Singapore government decides the locations and assumes prices to be equal across gasoline stations. While this does seem reasonable in our case (based on our conversations with public policy planners with Singapore), it would be of research interest to investigate the consequences

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<sup>35</sup>We thank the Editor and two anonymous reviewers for alerting us to these issues.

of relaxing these assumptions. For example, in some cases (such as supermarket retailing in the US), retail chains may choose locations for their stores with the objective of maximizing total profits across all their stores. This may involve the consideration of the strategic impact of the firm's location decisions on competing chains' location decisions. Handling such an extension of our model, while it poses a computationally non-trivial challenge, is an important avenue for future research since it would usefully apply to many business problems. Third, our pricing model assumes immediate adjustment of retail prices to cost changes, although empirical findings suggest that gasoline prices respond slowly to cost changes (Borenstein, Cameron and Gilbert 1997, Borenstein and Shepard 2002). We are unable to address this issue because of the limited time series (i.e., three waves) of prices that is represented in our dataset. It is difficult to accommodate the lagged effects of cost changes using just three temporal observations at the station-level. We believe that our effort at estimating cost and demand parameters from price data, using a structural model of pricing, is valuable from the standpoint of obtaining a preliminary understanding of the Singapore gasoline market. Taken together with our location model, our estimation methodology and results can be used to answer counterfactual questions of interest to both firms and policy-makers. For example, our results highlight the importance of factors such as proximity to highway, airport and downtown in terms of influencing potential gasoline demand. Furthermore, our methodology can be used to throw light on how gasoline prices at various stations would change in response to mergers and acquisitions. We hope that our work spurs future research on gasoline markets.

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