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Bertrand competition with capacity constraints: mergers among parking lots

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Abstract

To analyze the effects of mergers among firms facing capacity constraints, we develop a numerical model of price-setting behavior among multi-product firms differentiated by location and capacity. We perform a number of computational experiments designed to inform merger policy, with specific reference to the Central Parking–Allright merger of 1999. The experiments show that capacity constraints on merging firms attenuate merger effects by much more than capacity constraints on non-merging firms amplify them. The experiments also highlight the dependence of merger welfare effects on parking demand. In preparation for further industry consolidation, we propose estimators of parking demand to more precisely estimate the costs and benefits of future mergers.

JEL classification: L41; C63; C35

Keywords: Capacity constraints; Parking; Merger; Demand estimation

1. Introduction

Interest in the demand for parking has been driven by the public policy interest in reducing traffic congestion. A number of empirical studies, appearing in economics, transportation, and urban studies journals, have found that the availability, convenience, and price of parking are major determinants of the decision to drive to work and where to park (see Feeney (1989) and Young et al. (1991) for surveys).

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Interest in the supply side of the parking industry is more recent, motivated by a merger between the two largest parking companies in the United States. In March 1999, the Antitrust Division of the U.S. Department of Justice approved Central Parking's $585 million acquisition of Allright after the companies agreed to divest 74 off-street parking facilities in 18 cities (United States vs. Central Parking Corp., 99-0652, D.D.C. filed March 23, 1999). From the Division's press release, "Without these divestitures, Central would have been given a dominant market share of off-street parking facilities in certain areas of each of the cities, and would have had the ability to control the prices and the type of services offered to motorists" (U.S. Department of Justice, 1999).

In similar cases (Werden, 2000), the Justice Department has begun using numerical models of Bertrand competition, calibrated to observable industry characteristics, to assess the welfare effects of mergers. A numerical approach to economic modeling in general (Judd, 1998) and to merger policy in particular (Werden and Froeb, 1996) has several advantages. First, it allows greater realism than is afforded by an analytic approach. Second, it permits inference not only about the signs, but also about the magnitudes of welfare effects, which is crucial for designing policy. Most importantly, a numerical approach permits the enforcement agencies to replace simple market share heuristics with formal benefit–cost analysis.

While some characteristics of the parking industry, like product differentiation and price-setting behavior, are captured by existing numerical models of competition, capacity constraints are not. When one product is capacity-constrained, it drops out of consumers choice set, and this shifts demand to the remaining unconstrained products. To account for the effects of capacity constraints, we develop an algorithm to compute Nash equilibrium and apply the methodology to the parking industry. Following the empirical literature, consumers choose to park at the lot with the lowest total cost (price plus walking cost). The demand for any individual lot is an integral over all possible driver destinations, which yields a functional form for the potential demand similar to the mixed logit models of Berry et al. (1995) and Brownstone and Train (1999). It differs from these models in that observed quantity is the minimum of potential demand and lot capacity.

To inform antitrust policy in this area, we perform a number of computational experiments in which merger effects are computed as the difference between pre- and post-merger Nash equilibrium. The most striking result from the experiments is that capacity constraints on merging firms attenuate merger price effects by much more than capacity constraints on non-merging firms amplify them. This result suggests criticism of the parking merger divestitures and of the Horizontal Merger Guidelines (U.S. Department of Justice and Federal Trade Commission, 1992) which recognize the latter effect, but not the former.

In any given case, the welfare effects depend on the cost of walking, variation in the random component of demand, locations and capacities of the merging lots, locations and capacities of the non-merging lots, locations of desired destinations, and unobserved lot quality. The estimators of Berry (1994) and Berry et al. (1995) can be used to recover model parameters despite the confounding effects of capacity constraints because, for capacity-constrained lots, price is set where expected demand equals capacity. Thus, in equilibrium, observed demand is equal to potential demand. In other

words, the effects of capacity constraints can be safely ignored for estimation purposes. Capacity does play a role in constructing instruments for endogenous prices.

In what follows, we present a model of Bertrand competition between multi-product firms facing capacity constraints and an algorithm for computing equilibrium that "smoothes" the kink in the first-order conditions caused by capacity constraints. We review the issues raised by the Central Parking–Allright merger, and use the model to critique the Justice Department's divestiture as a remedy for the parking lot merger. In preparation for future industry consolidation, we propose estimation strategies to recover the parameters that would permit formal benefit–cost analysis of mergers.

2. Bertrand competition with capacity constraints

In this section, we characterize Bertrand equilibrium behavior in differentiated products industry subject to capacity constraints. The bulk of the literature in this area has been theoretical (for an exception see Bresnahan and Suslow, 1989) and focused on homogenous goods industries (Edgeworth, 1897). In modern applications, capacity constraints have been used to address the question of whether above-cost pricing is pro- or counter-cyclical (e.g., Staiger and Wolak, 1992), and to investigate long-run equilibrium in two-stage games where firms first invest in capacity, then compete in either price or quantity (e.g., Kreps and Scheinkmam, 1983).

In this paper, we focus on the short-run where industry structure, i.e., product characteristics and capacity, are fixed for two reasons. First, it is the context of merger enforcement as practiced by the enforcement agencies and articulated by the Merger Guidelines (U.S. Department of Justice and FTC, 1992). In the long run, without barriers to entry, product re-positioning and entry into the industry are presumed to mitigate merger effects (e.g., Werden and Froeb, 1998), so the policy concern is about the short run. Second, equilibrium models of competition where firms choose both structure and price are not well developed (see Crawford and Shum, 2001 on the intractability of the simpler monopoly problem).

In equilibrium, we assume all consumers receive their first choices according to a qualitative-choice demand model. Specifically, if one product was priced so that potential demand exceeded capacity, then its price would rise until excess demand disappears. Actual demand will differ slightly from this specification in that a constrained product with excess demand means that some consumers move to their second choices. This shifts demand to the remaining products and puts a kink in the profit function of the unconstrained products. The result is that a pure strategy equilibrium need not exist. The numerical importance of this effect is small if demand is sufficiently smooth and may disappear altogether if products near capacity become less desirable due to search costs, for example, when searching for a parking space in a nearly full lot.

In a multi-product setting, let I index the set of products, and suppose $I_1, I_2, I_3, \ldots, I_M$ partitions the set I into disjoint subsets according to ownership, i.e., take I_n to be the subset of products controlled by the nth supplier. Take p_i to be the price of the ith good, that price being set by supplier n if i is in I_n, and let $\bar{p}$ denote the vector of all

prices. Take the quantity demanded of the ith good to be

$$q_i = q_i(\bar{p}) = \min(q_i^*(\bar{p}), k_i),$$

where q_i^* is the potential demand for the good, and k_i is the capacity.

We assume q_i^* is a decreasing function of p_i and an increasing function of p_j for $j \neq i$. Let $c_i(q_i)$ be the cost of producing q_i units of the ith good, a non-decreasing function of q_i (but for simplicity independent of the other q_j even for i and j in the same I_n). The derivative of the cost function is denoted $c_i'(q_i) = mc_i(q_i)$, the marginal cost. The profit of the nth supplier is then given by

$$\Pi_n = \sum_{i \in I_n} (p_i q_i - c_i(q_i(\bar{p}))).$$

Each supplier n sets prices p_i for $i \in I_n$ so as to maximize his own profit subject to the capacity constraint. For now, we assume that the demand and cost functions are such that the profit functions are convex and consistent with the existence of (usually a unique) Nash equilibrium. When the model is used empirically, existence and uniqueness of pure strategy equilibrium cannot be assumed. For example, as one good becomes capacity-constrained, it drops out of consumers' choice set, and shifts demand to the remaining lots. This shift in demand introduces a kink into the first-order conditions of the unconstrained products. If there are a number of consumers on the "border" between two products, prices tend to bounce between two levels. If two lots are located near a large building, one lot would reduce price to "capture" demand at the building. This would induce the second lot to "concede" demand in the building by raising its price. But once the second lot raised price, the first lot would find room to raise price as well. And once the first lot raised price, the second lot would try to capture demand, and the cycle would repeat.

Because there is no point in leaving any constrained lot with excess demand, the equilibrium conditions are analogous to the familiar Kuhn–Tucker first-order conditions, where the "slack" variable is the potential demand minus capacity, $q_i^*(\bar{p}) - k_i$.

If the product is not constrained, i.e., $q_i^*(\bar{p}) < k_i$, the profit of the nth supplier is maximized with respect to the setting of the price p_i, $i \in I_n$ when

$$\frac{\partial \Pi_n}{\partial p_i} = q_i(\bar{p}) + \sum_{j \in I_n} (p_j - mc_j(q_j(\bar{p}))) \frac{\partial q_j(\bar{p})}{\partial p_i} = 0 \tag{2.1}$$

which is the usual first-order condition for a multi-product profit-maximizing firm. Note that when product j is capacity-constrained, its derivative with respect to price is zero. In other words, all the terms that correspond to capacity-constrained products drop out of Eq. (2.1). In the case of a single-product firm, this reduces to the familiar mark-up equation

$$\frac{p_i - mc_i}{p_i} = \frac{1}{|e_{ii}|}$$

where e_{ii} is the own-price elasticity of demand for product i.

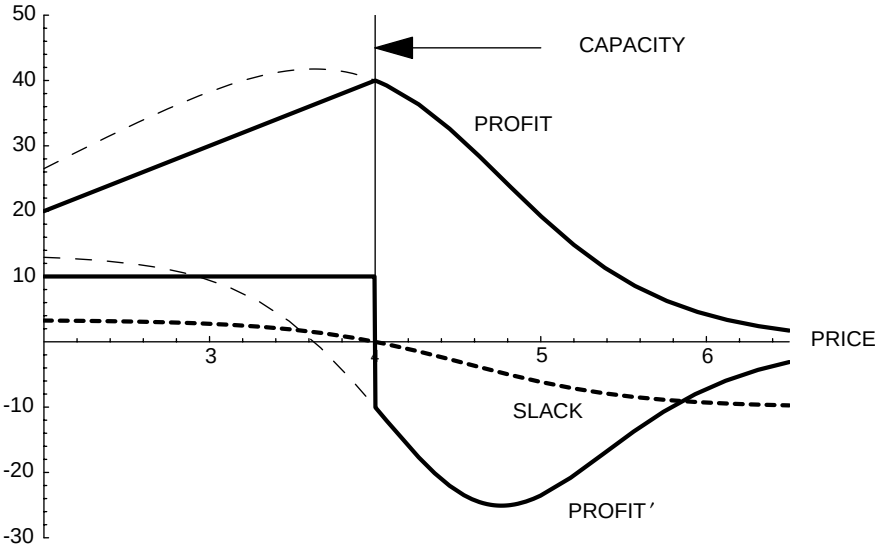

Fig. 1. Profit, its derivative, and slack.

If the product constraint is binding, then the slack variable is zero, and the firm prices where the derivative of the (unconstrained) profit function is less than zero:

$$\frac{\partial \Pi_n}{\partial p_i} \leqslant 0. \tag{2.2}$$

The complementarity of the slack variable and the profit derivative (if one is zero, then other is negative, and vice versa) will form the basis of our algorithm for computing equilibrium.

2.1. Algorithm for computing equilibrium

Since the first-order conditions of a monopolist are analogous to those of a single-product firm in a Bertrand equilibrium, we use the monopoly case to illustrate the computational algorithm.

In Fig. 1, we plot a short-run profit function based on a logit demand curve, a zero marginal cost, and a capacity constraint of 10. The unconstrained profit function (dashed) has its maximum at a price of \$3.6, where the derivative of the unconstrained profit function crosses the x-axis (solid). At this price, potential demand is greater than capacity, so the actual profits (solid) lie below the unconstrained profits (dashed). Note that at a price of \$3.6, the slack variable (dotted) is positive, illustrating the complementarity of the slack variable and the profit derivative.

The price of \$3.6 is not an equilibrium because the firm has room to raise price without reducing quantity. Equilibrium occurs at the point where demand just equals capacity, at a price of \$4 in Fig. 1. At this price the slack variable is equal to zero. If

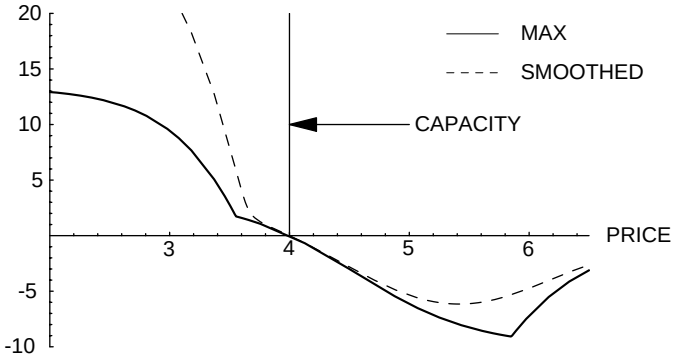

Fig. 2. Maximum and Fischer's smoothing function.

the firm sets a price below \$4, it foregoes profit on every unit it sells; and if it sets a price above \$4, it foregoes profits on the unused capacity.

It is interesting to note the difference in the "peaks" of the unconstrained profit function (dashed) and the observed profit function (solid) in Fig. 1. The profit consequences of a mistaken pricing decision are relatively small for an unconstrained firm because the unconstrained profit function is relatively flat near the optimum. A mistaken price has a much bigger opportunity cost for a capacity-constrained firm. Consequently, managers of capacity-constrained firms have relatively large incentives to collect information that would help them make better pricing decisions. This will be important for estimation because it implies that managers probably have better information about demand than econometricians, which induces a correlation between price and unobserved demand components.

To find equilibrium, we exploit the complementarity of the slack variable and the derivative of the profit function. As seen in Fig. 1, either the product is capacity-constrained (the slack variable is zero), or the firm is not capacity-constrained, and the derivative of the profit function is zero. The complementarity suggests using the maximum of the two to compute Nash equilibrium

$$\max\left(\frac{\partial \Pi_n}{\partial p_i}, q_i^* - k_i\right) = 0, \quad i = 1, 2, \ldots, N, \tag{2.3}$$

where we take n, the index of ownership, to be a function of i that returns the firm that owns product i, and sets the price for it.

Steepest-decent root-finding algorithms will sometimes fail to find the equilibrium price due to the kinks in the first-order conditions, as can be seen in Fig. 2. One way to deal with the kinks is to replace the maximum function with a function that has the same roots, but is smoother and therefore less prone to numerical difficulties. One function that has proven very effective for solving this type of problem in practical applications is Fischer's smoothing function $f(u,v)=u+v+\sqrt{u^2+v^2}$ where $u=\partial \Pi_n/\partial p_i$ and $v = q_i^* - k_i$ (Miranda and Fackler, 2001).

The maximum function and Fischer's smoothing function are both plotted in Fig. 2. The built-in root-finding command in *Mathematica* is able to find a pure-strategy equilibrium (when it exists) with a few exceptions. Sometimes, for large starting values, the algorithm shoots off towards an infinite price. And sometimes, differences in scale between the profit derivative and the slack variable leads to convergence problems. Choosing different starting values, or re-scaling the expressions, by multiplying by a positive constant, solves these problems.

3. Competition between parking lots

In this section we present a model of competition between parking lots differentiated by location and capacity. We imagine a rectangular downtown city area, as in Fig. 3, and assign x and y coordinates to each point in the rectangle. The distance from a point (x_1, y_1) to a point (x_2, y_2) is given by the taxi-cab metric as

$$d((x_1, y_1), (x_2, y_2)) = |x_1 - x_2| + |y_1 - y_2|,$$

that is the distance following horizontal and vertical routes only. We take the goods indexed from 1 to N, with each lot associated with a specific location (x_i, y_i) in the city grid, with price p_i and capacity k_i. An outside alternative good will be indexed by 0 but have no specific location and fixed price p_0. The outside good includes a no-purchase option and other location-independent options, like public transportation.

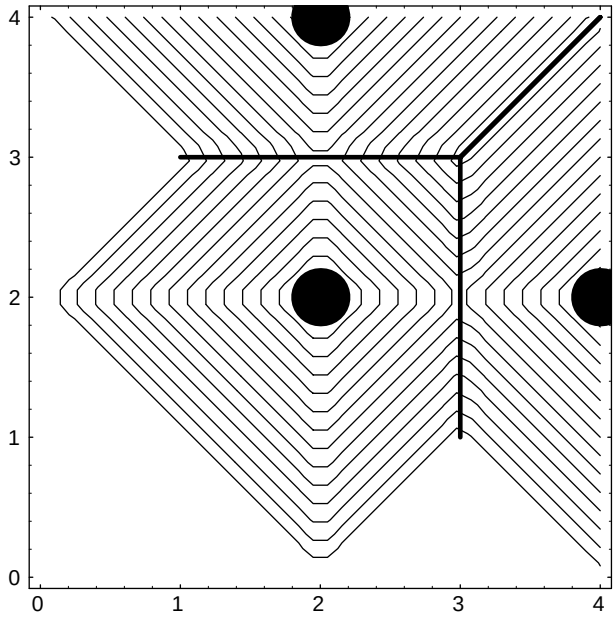

Fig. 3. Isodistance lines around three parking lots.

The taxi-cab distance metric yields isodistance "diamonds" instead of circles derived from Euclidean distance. In Fig. 3, we plot isodistance lines around three lots, located at points (2,2), (2,4), (4,2). In this plot, the left and bottom areas are blank because customers who have to walk more than two blocks prefer the "no-purchase" option, e.g., public transportation. The isodistance contours are drawn around the nearest lot, so it is possible to visualize the areas served by each lot. Boldface lines are drawn on the "boundary" between the areas in which consumers always choose the closest lot. Below, we show how these areas can be used to construct instruments for endogenous prices.

There are two reasons why consumers would not always make the minimum distance choice. First, closer lots may charge higher prices, and second, choices are somewhat "noisy". If a consumer at location (x_i, y_i) chooses to park at lot j then she receives indirect utility:

$$V_{ij} = \eta_j - \rho d((x_i, y_i), (x_j, y_j)) - p_j + \upsilon_{ij},$$

where ρ is the opportunity cost of travel from the customer's location to the lot and p_j is the price charged by lot j. The η_j parameter captures consumer's preferences among the alternatives due to factors other than the distance from his location. Without loss of generality, we set $\eta_0 = 0$ and $p_0 = 0$.

The random component of indirect utility, υ_{ij}, is distributed according to an independent extreme-value distribution (Gumbel) with a common spread parameter μ. The Gumbel has the cumulative distribution function

$$F(t) = \mathrm{e}^{-\mathrm{e}^{-\mu(t-\eta)}}. \tag{3.1}$$

The distribution is characterized by a location and spread parameter (η, μ), which are related to its first two moments as follows:

$$E(X) = \eta + \frac{\gamma}{\mu}, \tag{3.2}$$

$$\mathrm{Var}(X) = \frac{\pi^2}{6\mu^2}. \tag{3.3}$$

A small μ means that choice is relatively noisy, or that competition is relatively global, i.e., for a given price vector, consumers travel farther, and market shares are closer to $1/n$, (e.g., Brannman and Froeb, 2000). A large μ corresponds to a small variance, and more localized competition, similar to the deterministic model of Braid (1999) where consumers always make the minimum-distance choice. This discussion highlights the confounding effects of μ and ρ. Localized competition could be due to either the high cost of walking or the low variance of the random component of utility.

We are assuming that income effects are negligible and that consumers are similar except for their desired destinations, i. We say that consumers are "located" at their desired destinations i, which are chosen independent of the travel cost. For example, this implies that if the price of parking increases, commuters will not take a job in a

different location. Depending on the available data, it might be beneficial to generalize the model by allowing for random coefficients, for example, consumers who differ in their taste for walking. At this point, we find it convenient to re-parameterize the indirect utility. For a consumer i choosing lot j,

$$\begin{aligned}\tilde{V}_{ij} &= \mu V_{ij} = (\alpha_j + \beta p_j + \gamma c_{ij}) + \varepsilon_{ij} \\ &= \delta_{ij} + \varepsilon_{ij},\end{aligned} \tag{3.4}$$

where $\alpha_j = \mu\eta_j$, $\beta = \mu$, $\gamma = \mu\rho$, $c_{ij} = d((x_i, y_i), (x_j, y_j))$, $\varepsilon_{ij} = \mu\upsilon_{ij}$ and $\delta_{ij} = \alpha_j + \beta p_j + \gamma c_{ij}$. The coefficients β and γ determine the (negative) contribution to utility of the price of parking and walking, respectively, and α_j reflects the lot-specific quality contribution to utility.

The random component of utility is now a standardized Gumbel variate which implies that the probability that consumer located at i would choose lot j has the logistic form

$$q_{ij} = \frac{(\exp\delta_{ij})}{\sum_{k=1}^{N} \exp \delta_{ik}}. \tag{3.5}$$

The demand for parking at lot j is a sum over all possible consumer locations i is

$$q_j = \sum_i n_i q_{ij} = \sum_i \frac{n_i (\exp \delta_{ij})}{\sum_{k=1}^{N} \exp \delta_{ik}}, \tag{3.6}$$

where n_i is the number of consumers at location i.

When a particular lot is filled to capacity, the remaining consumers choose from among the remaining unconstrained alternatives. By the IIA Property for the logit demand, the consumers at a particular location shift from the unavailable option to the remaining available options in proportion to the original choice probabilities. However, integrating over the distribution of consumer destinations, this property will not hold. That is, the IIA property does not apply to the average of IIA choice functions (e.g., Davis, 1999). Geographically close lots will of course be better substitutes than widely separated ones.

Nash equilibrium is computed using the algorithm of Section 2.1 and is illustrated in Fig. 4 for a 16-square-block downtown area. Three parking lots, labelled A, B, and C, are located at points (2,2), (2,4), and (4,2) with capacities 2500, 3000, and 1200 represented by the areas of the circles. There are 16 consumer destinations represented by buildings where the height of each building is proportional to the number of consumers at each location, which varies from 100 to 800. The buildings are subdivided by shades of gray according to the number of consumers in the building who park in the corresponding lot. The no-purchase or outside option is denoted by the color white. We assume that marginal costs are zero. The Nash equilibrium price vector for the three lots is ($1.27, $1.19, $1.39) and the equilibrium quantity vector is (2058, 1562, 1200). For each lot, realized demand relative to capacity is represented by the shaded areas of

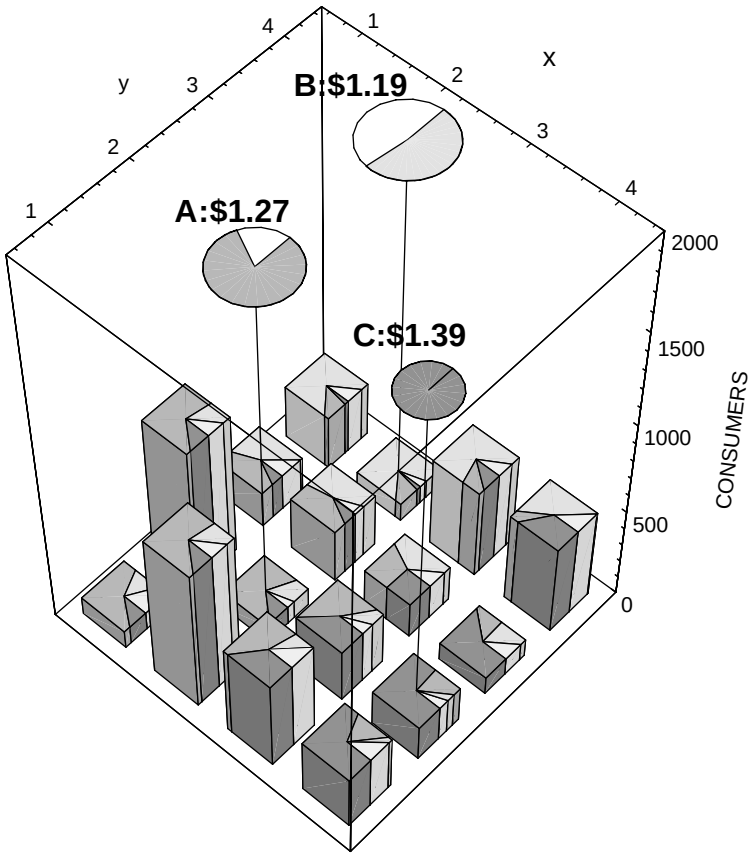

Fig. 4. Three parking lots in Nash equilibrium.

the circles at the top of the figure. Only lot C, located at $(4,2)$, is capacity constrained. As one would expect, it also has a higher price.

3.1. Modeling mergers

A merger is modeled as a change in the ownership partition. Suppose firms number 1 and 2 merge. Before the merger, products are partitioned as $I_1, I_2, I_3, \ldots, I_M$ and after the merger they are partitioned as $I_0, I_3, \ldots, I_M$ with $I_0 = I_1 \cup I_2$. In general, the changed profit calculus changes the price. Let $\bar{p}^0$ denote the before-merger equilibrium price vector and $\bar{p}^1$ the after-merger equilibrium price vector. The effect of the merger is to move the industry from $\bar{p}^0$ to $\bar{p}^1$.

The consumer welfare effect of a change in prices from $\bar{p}^0$ to $\bar{p}^1$ is computed as the change in expected maximum utility for consumer i:

$$\Delta CS_i(\bar{p}^0, \bar{p}^1) = V_{\max i}(\bar{p}^1) - V_{\max i}(\bar{p}^0), \tag{3.7}$$

where

$$V_{\max i}(\bar{p}) = \log\left(\sum_{j=0}^{N} \exp(\alpha_j + \beta p_j + \gamma c_{ij})\right). \tag{3.8}$$

The aggregate change in consumer surplus is computed as the sum over all consumers

$$\Delta CS(\bar{p}^0, \bar{p}^1) = \sum_{i=1} n_i \Delta CS_i(\bar{p}^0, \bar{p}^1). \tag{3.9}$$

4. Analyzing merger effects

4.1. Policy motivation

As a condition for not challenging the Central Parking–Allright merger, the U.S. Department of Justice asked for divestitures in five-square-block areas where the sum of the shares of the merging firms exceeded 35 percent. In essence, the Department was using shares in a five-square-block area as a proxy for the loss of localized competition between the merging firms.

Criticisms of merger policy based on market shares in differentiated products industries are well known. There are two basic problems: market boundaries represent bright lines where there are only shades of gray; and shares within a market may be poor proxies for the loss in competition following a merger (Werden and Froeb, 1996). In the parking application, these two problems are easy to illustrate. For example, if walking costs are low, distant lots outside a five-block square may compete with merging lots, and if walking costs are high, competition may be more localized than in a five-block square. Certainly, the diamond-shaped isodistance contours of Fig. 3 suggest that diamonds have more economic justification than squares. The second problem is that an analysis based on shares ignores the location of products within a delineated market. In particular, non-merging lots in between the merging lots attenuate the price effects of mergers.

What we want to focus on in this paper is the particular issues raised by capacity constraints. It has long been understood that capacity constraints on the non-merging firms prevent share-stealing quantity responses, and thus lead to larger merger price effects. The policy approach embodied in the Horizontal Merger Guidelines (U.S. Department of Justice and FTC, 1992) explicitly recognizes the diminished ability of capacity-constrained firms to discipline merger price effects.

What has been less appreciated is the effect of capacity constraints on the profit calculus of merging firms. If firms are capacity-constrained, they are pricing where potential demand equals capacity. This pricing calculus is less likely to be changed by merger. In the case where the merged firm is capacity-constrained, there is no merger price effect. The intuition behind this result is the same as that behind a trick question that has appeared on numerous microeconomics exams: “For a vertical supply curve, what is the difference between monopoly and competition?” If the capacity constraint

Table 1
Computational experiments

Abbreviation	Experiment
Base case	None of the firms are capacity-constrained
One M	One merging firm is capacity-constrained
Both M	Both merging firms are capacity-constrained
One NM	One non-merging firm is capacity-constrained
Both NM	Both non-merging firms are capacity-constrained
Duopoly	Both non-merging firms are capacity-constrained at zero

binds on the monopolist, the answer is "none". The movement from competition to monopoly is analogous to the effect of a merger.

4.2. Computational experiments

It is clear how capacity constraints matter, but to inform policy, we need to know by how much. Although the effects depend on the particulars of a given case, the following computational experiments are designed to shed light on the relative magnitudes of the effects of capacity constraints on mergers. In this section, we present the results of computational experiments designed to isolate the effects of capacity constraints on mergers. To do this, we posit an industry of four one-lot firms on a 10-square-block grid, located at points (3,3), (7,7), (6,4) and (2,8) and consider a merger of the first two firms. We chose this particular array of firms for its ability to illustrate the effects of capacity constraints on the magnitude of merger effects. In particular, we place the two non-merging lots in between the merging lots. This makes it more likely that they will be able to constrain the post-merger price rise.

We specify a uniform distribution of 4000 consumers over the grid for several reasons. First, the uniform distribution means that demand is not "lumpy", so profit functions are smooth and a pure-strategy equilibrium can be easily computed. Second, the uniform distribution means that we can easily illustrate merger effects in two dimensions with contour plots. The welfare effects of the merger are computed as the expected loss in consumer surplus, as in Eq. (3.7).

We set the price coefficient $\beta = 1$, the attractiveness parameter of the outside, or no-purchase alternative, $\alpha_0 = -2$, and the attractiveness of the four other choices $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0$. We compare a walking cost γ of 0.6/block to a walking cost of 0.3/block. A higher walking cost gives each firm greater local market power and leads to higher prices. For example, with walking cost of $\gamma = 0.6$/block, on average, a consumer would be willing to walk $\alpha_0/\gamma = 3.33$ blocks before the attractiveness of the average no-purchase alternative exceeded the attractiveness of purchasing from one of the lots.

To isolate the effects of constraints, we compute six different equilibria which are described in Table 1. Our base case, where none of the lots are capacity-constrained, is reported in column 2 of Table 2 (high travel cost) and Table 3 (low travel cost). We compare the base case to equilibria where one or more of the lots are capacity-constrained, in columns 3–7 of Tables 2 and 3.

Table 2
Effects of capacity constraints on mergers: high travel cost

Variable	Base case (%)	One M (%)	Both M (%)	One NM (%)	Both NM (%)	Duopoly (%)
Δ Industry price	1.40	0.72	0.00	1.55	1.66	3.99
Δ Industry quantity	−1.09	−0.57	0.00	−1.29	−1.21	−3.76
Δ Consumer surplus	−1.30	−0.68	0.00	−1.54	−1.45	−3.57
Δ Total welfare	−0.98	−0.51	0.00	−1.16	−1.08	−3.47

Table 3
Effects of capacity constraints on mergers: low travel cost

Variable	Base case (%)	One M (%)	Both M (%)	One NM (%)	Both NM (%)	Duopoly (%)
Δ Industry price	5.88	3.24	0.00	6.97	8.29	16.2
Δ Industry quantity	−2.76	−1.59	0.00	−3.36	−3.94	−12.5
Δ Consumer surplus	−5.51	−3.08	0.00	−6.64	−7.82	−14.3
Δ Total welfare	−2.77	−1.56	0.00	−3.27	−3.83	−12.6

In Table 3, the travel cost is half of what it is in Table 2 which puts the two merging firms in closer competition with one another. When this competition is lost via merger, the merger effects increase by a factor of three over the base case merger in Table 2.

Summary performance statistics for each experiment are presented in the rows of Tables 2 and 3. The price effect is computed as the change in a Laspeyres price index. The change in consumer surplus is the change in expected maximum utility defined by Eq. (3.7). The change in total welfare is computed by adding the change in profits to the change in consumer welfare. Both of the welfare measures are expressed as a percentage of pre-merger revenue.

In both tables, we see similar quantitative effects of the constraints. Putting capacity constraints on one merging firm ("One M") cuts the merger effects in half; constraints on both merging firms ("Both M") cut the effects to zero.

It is interesting to look at the last two columns of Table 3. The effect of a merger facing two constrained non-merging firms ("Both NM") is about half of what it is when facing no competition ("Duopoly"). In the former case, the existence of non-merging firms, albeit constrained at the pre-merger quantities, forces the merged firm to attract customers from greater distances. These customers have more elastic demands because the no-purchase alternative is a closer substitute and this reduces the post-merger price rise. From a policy perspective, this means that the existence of constrained non-merging lots, even though they have no ability to expand output, can attenuate merger effects.

4.3. *Contour plots of experiments*

In this section, we illustrate the merger experiments with contour plots showing the reduction in consumer surplus from pre- to post-merger measured as a percentage

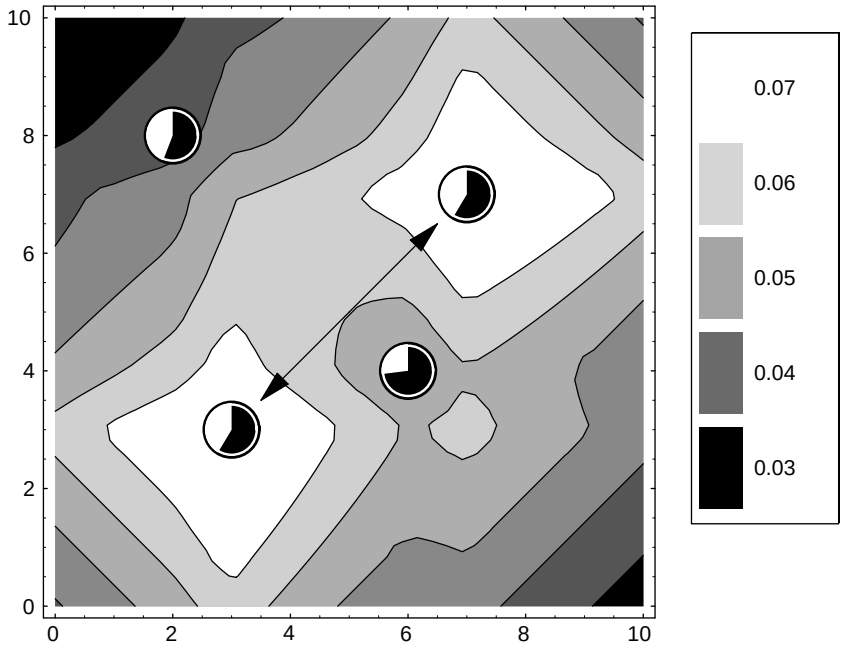

Fig. 5. Consumer surplus loss.

of pre-merger revenue. The key on the right-hand side of the graph shows the consumer welfare loss. Parking lots are represented as circles, the size of which represents the capacity. The shaded area of the circle represents demand for the lot. A capacity-constrained lot is entirely shaded. An arrow is draw between the two merging lots.

In Fig. 5, we plot the base case in Table 3 ($\gamma = 0.3/block$). We see that consumer surplus losses are concentrated around the merging firms because the merged lots raise price by more than the non-merging lots, and because customers located near the lots are likely to choose one of the merging lots. The lack of good substitutes for these consumers means that they lose more from the merger than do consumers located farther away.

In Fig. 6, we illustrate merger effects in the case where one capacity constraint binds post-merger. Following the merger, the unconstrained merged lot raises price substantially, while the constrained lot raises price by a smaller amount. Consumer surplus losses are concentrated around the unconstrained product.

In Figs. 7 and 8, we plot the welfare losses for mergers with constraints on one and both non-merging firms, respectively. In Fig. 7, welfare losses are small around the lot in the northeast corner because the probability of choosing one of the merging lots is small, and price does not change very much on the non-merging lots. The intricate pattern of welfare losses in the Southeast corner of Fig. 8 is more complex. Welfare losses are small around the non-merging lots, and small where the probability

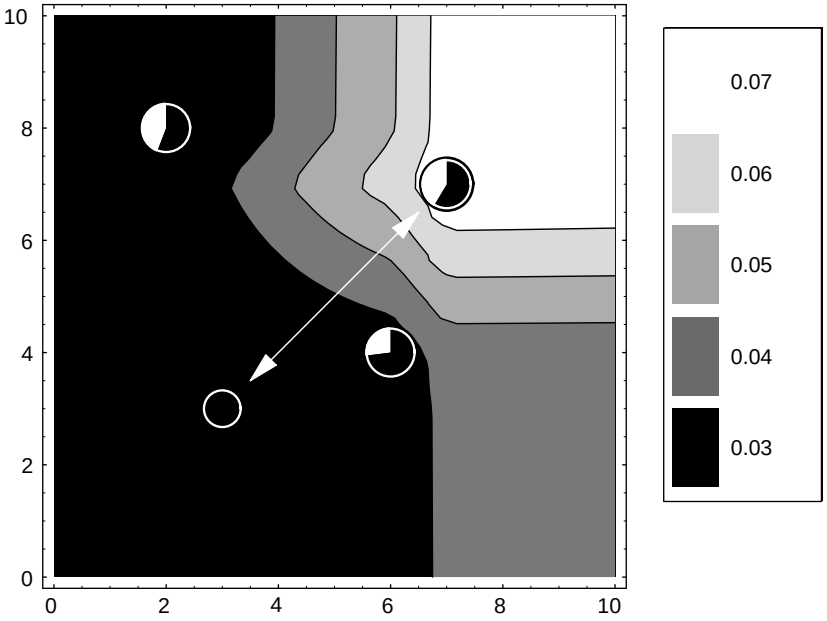

Fig. 6. Consumer surplus loss: one merging firm constrained.

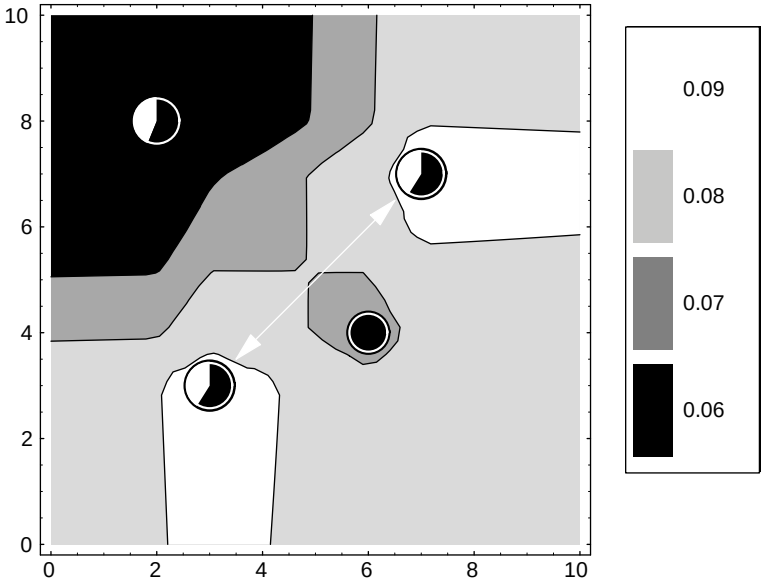

Fig. 7. Consumer surplus loss: one non-merging firm constrained.

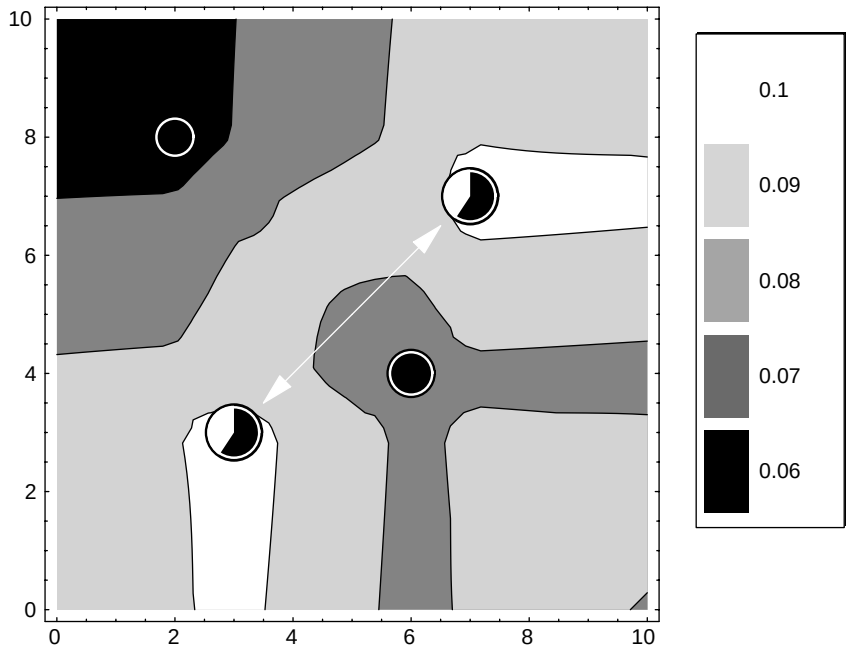

Fig. 8. Consumer surplus loss: both non-merging firms constrained.

of choosing a merging lot is low. But near the corner, welfare losses rise as the probability of choosing one of the merging lots rises.

5. Estimation strategies

The experiments above show that the size and pattern of merger effects are quite complex and depend on the particulars of each case. For example, in our experiments, a low travel cost puts the merging lots into closer competition with one another, which raises the merger-induced welfare loss. To answer the policy question whether the merger synergies outweigh the welfare loss requires a demand estimator.

The time constraints of the merger statutes (Section 7A Clayton Act, 15 U.S.C. Section 18a.) would make it difficult to conduct estimation in the context of an actual case. If the agencies expect future consolidation, an alternative is to estimate the relevant parameters ahead of time, and then apply them to the specific facts of a case. In this section, we show how to recover the demand parameters from observed data.

The insight that allows us to recover demand from observed data comes from the characterization of equilibrium in Section 2.1. Recall that optimization implies that either the lot is unconstrained, or that the constraint binds and price is set at the point where $q_i^*(p) = k_i$. In either case, potential demand is equal to observed quantity at

every lot, i.e., $q_i^*(\bar{p}) = q_i(\bar{p})$. Potential demand has the familiar mixed logit format, so the estimators described in Nevo (2000) can be applied to this industry. Various kinds of data are illustrated in Fig. 4. Aggregate data would correspond to data observed at each lot (price and quantity), while individual data would correspond to information available from each building (who parks where).

The only difficulty comes in finding instruments for endogenous prices. From the discussion in Section 2.1 we know that opportunity cost of suboptimal pricing is relatively large, and it is likely that lot owners or managers have private information about unobserved lot characteristics that affects price. Econometrically, this means that price will be correlated with unobserved lot characteristics, e.g., $\mathrm{Cov}(p_j, \alpha_j) > 0$ so that an instrumental variables estimator is required. Following Berry (1994) and Berry et al. (1995), we use our competitive model to identify instruments.

Gaynor and Vogt (1999) face a similar problem in estimating hospital demand. They construct instruments from the number of rival hospitals within a 5-mile radius of a given hospital. The more the local competition is, the more the elastic demand becomes and the lower the price will be. In our application, competition is on a much finer scale, so we propose different instruments. Going back to Fig. 3, first construct market "areas" using the isodistance contours. The bold-faced lines in the figure represent the boundaries of the three areas. A firm with many nearby rivals will have a smaller market area. An important part of the construction is to guess the attractiveness of the no-purchase option. This will determine how far consumers will walk before they prefer to take public transportation. For example, the blank area south and west of the parking lot located at (2,2) is more than two blocks away from the nearest lot. One instrument can be constructed as the number of consumers in the area relative to lot capacity. Large net demand will be positively correlated with price.

Another instrument is the average distance to the desired destinations within each area. Consumers who must walk farther have more elastic demands because the outside alternative is a closer substitute than for those who do not have to walk so far. For example, the lot located at (2,2) in Fig. 3 has a much lower price than the other two because it is far away from any large buildings. It must attract consumers from farther away, and these consumers have more elastic demands. Consequently, the lot maximizes profits with a relatively low price.

If panel data are available, and changes in demand or supply induce equilibrium changes in price and quantity, e.g., office buildings or lots being constructed or torn down, we could use a fixed effects estimator instead (see Nevo (2000) for estimation details).

6. Discussion

Structural oligopoly models can be used to answer the counterfactual policy question "are the benefits of this merger larger than its costs?" A model must be specified, estimated, and then used to compute the effects of mergers. Practically, this approach shifts the focus of merger investigations away from tangential issues like market delineation, and towards factors that determine merger effects. This kind of analysis gives

enforcement agencies a methodology for weighing merger synergies against the loss in competition.

In the parking application, this kind of analysis highlights the important role played by capacity constraints. The computational experiments suggest that constraints on merging lots are likely to be more important than constraints on non-merging lots in determining the merger effects. In addition, captive non-merging capacity can attenuate merger effects by making demand for the merging lots more elastic. The magnitude of merger effects depends on the specifics of demand and supply, and we propose a demand estimator to recover model parameters from available data.

Further research in this area is suggested by the non-existence of pure strategy equilibrium for lumpy demand. If we do not observe lots using mixed strategy pricing, which would be implied by a mixed strategy equilibrium, the model is missing some important feature of demand or competition.

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