

# MERGERS INCREASE OUTPUT WHEN FIRMS COMPETE BY MANAGING REVENUE

ABSTRACT. We find that hotel mergers increase occupancy. In some specifications, price also rises. Because these effects occur only in markets with high capacity utilization and high uncertainty, we reject simple models of price or quantity competition in favor of models of “revenue management,” where firms price to fill available capacity in the face of uncertain demand.

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## 1. INTRODUCTION

For mergers, the predictions of theory—anticompetitive mergers increase price and decrease output, while pro-competitive mergers do the opposite—are so well accepted that they are enshrined in both law and policy.<sup>1</sup> However, there are particular circumstances where the standard predictions do not apply (e.g., Froeb et al., 2003) and evidence on mergers remains thin. This has led to calls for more and better empirical work, especially from those who work at the enforcement agencies, e.g., Bailey (2010), Froeb et al. (2005), Carlton (2007), and Farrell et al. (2009). These policy makers want enough data on mergers, and enough variation across observed merger effects to determine which theoretical models should be used to evaluate the competitive effects of a particular merger in a particular industry (FTC, 2005, p.174).

There is a debate about whether structural models or “natural experiments” are better suited to answer these questions (Whinston and Nevo, 2010). Angrist and Pischke (2010) argue that natural experiments provide the shortest route from data to findings which enhances credibility. However, interpreting the results of natural experiments requires theory, which can re-impose much of the theoretical structure that the estimation was designed to avoid (Keane, 2010). In this paper, we use a differences-in-differences estimator, designed to isolate the competitive effects of mergers, and use the results to distinguish between different classes of oligopoly models.

We focus on mergers in the U.S. lodging industry, where firms practice “revenue management.” In addition to lodging, revenue management industries include not only the standard examples of airlines and casino tables, but also restaurants, golf courses, spas, ski resorts, self-storage sites and even palapas (Anderson and Xie, 2010, Talluri and Van Ryzin, 2004 provide many examples). The peculiar features of this industry—marginal costs are small relative to fixed or sunk costs, and price must be set before demand is realized—imply that firms maximize profit by maximizing revenue, i.e., by pricing to match *expected* demand to capacity. Under these

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<sup>1</sup>See, for example, the US Dept. of Justice and Federal Trade Commission, Horizontal Merger Guidelines.

conditions, the standard merger predictions of increased price and decreased output need not apply. Indeed, in the empirical work that follows, we test these predictions and reject them.

In general, estimating the competitive effects of mergers presents two problems. The first is censoring. Most big mergers must obtain regulatory clearance from competition agencies. This means that we observe only mergers that were thought not to be anticompetitive,<sup>2</sup> or those which were allowed to proceed after court or regulatory challenges failed.<sup>3</sup> The second problem is that mergers may have a variety of effects, many of them unrelated to their effect on competition. For example, an acquisition may induce higher levels of effort among employees at the acquired firm as they try to impress new management. This could lead to an observed merger effect that has nothing to do with competition.

To address these two difficulties, we examine a large sample of U.S. lodging mergers in many different local markets. Our sample of mergers is the largest that we are aware of.<sup>4</sup> Almost all of the 898 lodging mergers are too small to raise anticompetitive concerns (the exceptions are two hotel-casino mergers), so data censoring, and its attendant bias, are expected to be small.

The relatively small size of the merging firms means that we do not expect to see big anticompetitive effects in the data. However, due to our large sample size, we expect to have enough statistical power to estimate small merger effects, if they exist. To isolate the competitive effects of merger, we measure the effects of within-market mergers (in the same geographical tract) relative to out-of-market mergers. If there are merger effects unrelated to competition, this difference-in-difference estimator (pre- vs. post-merger and within- vs. out-of-market) should remove them.

The large size of the sample allows us to estimate merger effects across two dimensions that are potentially important determinants of merger effects in industries where firms manage revenue: (1) the level of uncertainty about future demand and (2) the level of capacity utilization.

Our main empirical finding is that hotel mergers raise occupancy, without reducing capacity. In some regressions, price also appears to increase. These effects are small, but statistically and economically significant. Because the effects occur only in markets with high capacity utilization and high uncertainty we reject simple models of price or quantity competition in favor of models of “revenue management,” where firms price to fill available capacity in the face of uncertain demand.

We identify two theoretical mechanisms that could explain the empirical results. The first is that mergers reduce uncertainty about demand, which would reduce forecast errors. Better forecasts mean fewer pricing errors—and higher occupancy—as the hotels are better able to match *realized* demand to available capacity.

A second mechanism—that the merged hotels are better able to compete for group and convention business—could also account for price and/or quantity increases. If the merged hotels are large enough to host groups, but the pre-merger hotels are not, then the merger could increase convention demand for the merged

<sup>2</sup>See Pautler (2003) and Danzon et al. (2007) for summaries of empirical work in the banking, and pharmaceutical and biotech industries.

<sup>3</sup>Werden et al. (1991) estimate the effects of the Northwest/Republic airline merger; and Farrell et al. (2009) report on hospital mergers.

<sup>4</sup>The largest published study is that by Dranove and Lindrooth (2003) who study the cost effects of 122 hospital mergers.

hotels. However, our finding that occupancy increases only in markets with high levels of capacity utilization leads us to prefer the former explanation, although we cannot rule out the possibility that increases in group demand, particularly during low-demand periods, could also account for the results.

In what follows, we motivate the topic by reviewing three antitrust investigations of firms in industries that manage revenue. We then characterize mergers using several models of oligopoly revenue management to develop testable hypotheses. We present the data, estimation, and interpretation of the results. We conclude by discussing the implications of our empirical results for oligopoly modeling and antitrust policy.

## 2. MOTIVATION: ANTITRUST ENFORCEMENT IN INDUSTRIES WHERE FIRMS MANAGE REVENUE

In two of three antitrust decisions, it appears that enforcement decisions were guided by intuition gleaned from standard models of price or quantity competition, i.e., in only one of the cases does it appear that the antitrust agencies took account of the peculiar industry features that led the firms to practice revenue management.

First, 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 seventy-four off-street parking facilities in eighteen cities (*United States v. Central Parking Corp.*, 99-0652, D.D.C. filed Mar. 23, 1999). The Division's press release stated "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."

Froeb et al. (2003) criticize the Justice Department's enforcement action by arguing that the merger would not have raised price because there is very little uncertainty about parking demand. Each day, each parking facility gets to "see" a realization of demand, so individual lots can price to fill capacity with very little error. A simple algorithm achieves this result: if the lot is full before 9:00 am, the parking lot increases price; otherwise, it reduces price. An optimal price is one that just fills the lot at 9:00 am. If the merging lots are still capacity constrained after the merger, then the post-merger price is equal to the pre-merger price, and there is no merger effect.

This is an old result (Dowell, 1984; Froeb et al., 2003), and the intuition behind it is the same as that behind a standard microeconomics exam question, "what is the difference between monopoly and competition for a vertical supply curve?" The answer is "none" if the monopolist is capacity constrained. Similarly, if the merged firm is capacity constrained, then the pre-merger firms will be capacity constrained, and the prices that match demand to capacity, both pre- and post-merger, are the same.

Second, in February 2003, Carnival, the cruise industry's largest firm, paid \$5.5 billion to acquire P&O Princess, the third-largest firm. The U.K. Competition Commission, the European Commission, and the U.S. Federal Trade Commission all investigated, but eventually cleared, the merger. In the published decisions there were lengthy discussions of the "revenue management" problem—that prices for cruises had to be set long before demand for the cruise was realized, and the investigations appeared to be focused on whether and how the merged firm could

exercise market power in this setting. Coleman et al. (2003) summarized the empirical findings that presumably caused the U.S. agency to close its investigation: (i) no correlation between pre-merger prices and concentration; (ii) no correlation between changes in capacity and changes in price; and (iii) behavior appeared inconsistent with collusion as all firms were adding capacity, increasing amenities, and competing on price.

Third, in November, 2005, six luxury hotels in Paris, all ranked by the Michelin travel guides at the highest level of luxury (five red stars), were fined for running an illegal cartel. An Associated Press story reported the specific charge of France’s Conseil de la Concurrence: “Although the six hotels did not explicitly fix prices, . . ., they operated as a cartel that exchanged confidential information which had the result of keeping prices artificially high” (Gecker, 2005). According to a report by the Conseil, the hotels shared many features: “a prestigious site in the center of Paris; a high proportion of suites, some of which are exceptional; a gastronomic restaurant; exceptional amenities such as swimming pools or gyms; and a large number of personnel at the disposal of guests.” The six hotels exchanged information about past and projected occupancies, average room prices, and revenue (Conseil de la Concurrence, 2005: paras. 51-54; also summarized by Crampton, 2005).

However, only the occupancy data could be considered “confidential”; indeed, hotels often collect pricing information by having their employees pose as potential customers of competing hotels, by perusing competitors’ internet sites and by perusing third-party GDS (Global Distribution System) sites such as Travelclick.<sup>5</sup> The latter means of obtaining price information were noted by the Conseil’s report (paragraph 259). Once occupancies and prices are known, revenues can easily be calculated.

An obvious pro-competitive justification for the information sharing is that the hotels can better forecast demand. Better forecasts mean fewer pricing errors—and higher expected occupancy. Indeed, in response to the charges, industry executives insisted that their information sharing was to “to bring more people to the area and to maximize hotel utilization” (Hotels Magazine, 2006). However, the Conseil, as well as an appeals court, were apparently unmoved by this rationale for the information sharing.

### 3. MERGER MODELS AND TESTABLE HYPOTHESES

There are a number of pricing strategies available to firms for addressing uncertainty about demand (e.g., Stole, 2007; Anderson and Xie, 2010). Firms might adjust prices dynamically according to realized demand, increasing prices if they are selling at a pace that would exhaust their inventory of a perishable good, or decreasing prices if they are selling at a slow pace that would result in an unsold quantity of that good, e.g., McAfee and te Velde (2008). Alternatively, they might use a strategy of reserving fractions of the inventory for sale at higher prices that serve to automatically implement price increases when demand is high, but at the

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<sup>5</sup>Even occupancies of competitors can be estimated without cooperation. A general manager related an anecdote to the authors of this paper that his hotel sent an employee out every night to count (1) the number of cars in competitors’ parking lots, and (2) the number of rooms with lights on. Another manager provided an anecdote that independent companies exist in his urban market that provide “competitive intelligence” services such as these for a fee.

cost of unsold capacity when demand is lower (Dana, 1999). Firms may also engage in various strategies designed to discriminate between customer types based on arrival times, preferences for regular rooms or luxury suites, and block reservations for conventions. While these pricing strategies add realism and can increase the range of parameter values for which pure strategy equilibria exist (Martinez-de-Albeniz and Talluri, 2011), they come at some modeling cost. Even ignoring the problem of how such strategies would affect consumers' expectations, the Nash equilibria for such a set of prices would be difficult to compute, and it is not clear that the added complexity would add much in the way of insight given the data that we have.

Instead, we characterize merger effects with a static model in which hotels set a single, unchanging price before demand is realized. While this is a simplification of the way that hotels actually price, it captures an essential tradeoff: a price too high means unused capacity, and a price too low means that the hotel could have priced higher, without sacrificing occupancy. To maximize *expected* profit, each hotel chooses a price that balances the *expected* costs of over- and under-pricing.

**3.1. Benchmark model: unconstrained.** Suppose that demand for product  $i$  is given by a random variable  $q_i(\mathbf{p})$  depending on the vector of prices of all firms  $\mathbf{p}$ . We assume that demand curves slope downward  $\partial q_i/\partial p_i < 0$ , that the products are substitutes  $\partial q_i/\partial p_j > 0$ , and that own-price effects are bigger than cross-price effects, or that  $(\partial q_1/\partial p_1)(\partial q_2/\partial p_2) - (\partial q_1/\partial p_2)(\partial q_2/\partial p_1) > 0$ .

Suppose also that firms all have the same information about uncertain demand. While we relax this assumption in section 3.3 below, for now it allows to isolate the effects of eliminating competition among the two merging firms. Assuming a constant marginal cost  $mc_i$ , and that demand has no chance of exceeding capacity, then expected profit is linear in the uncertain demand, i.e.,  $\pi_i = E[\Pi_i] = (p_i - mc_i)E[q_i(\mathbf{p})]$ . In other words, optimal prices are the same as the case with a deterministic demand  $\bar{q}_i(\mathbf{p}) = E[q_i(\mathbf{p})]$ .

Formally, an acquisition or “merger,” in this case between two single-product firms, is a change from a pre-merger Nash equilibrium defined by a set of first-order conditions:

$$(1) \quad \frac{\partial \pi_1}{\partial p_1} = 0, \quad \frac{\partial \pi_i}{\partial p_2} = 0, \quad \frac{\partial \pi_i}{\partial p_i} = 0, \quad i = 3, 4, \dots, n$$

to a post-merger Nash equilibrium in which the merged firm internalizes the effects of price on its commonly owned products,

$$(2) \quad \frac{\partial \pi_1}{\partial p_1} + \frac{\partial \pi_2}{\partial p_1} = 0, \quad \frac{\partial \pi_1}{\partial p_2} + \frac{\partial \pi_2}{\partial p_2} = 0, \quad \frac{\partial \pi_i}{\partial p_i} = 0, \quad i = 3, 4, \dots, n$$

Post-merger prices are higher, and quantity lower, for the merged firms, e.g., Werden and Froeb (1994).

In this case, merger effects can be easily understood by how they change marginal revenue. After the acquisition, an increase in sales on one product will “steal” some sales from the other, reducing the post-merger marginal revenue of each. The size of the reduction is determined by how “close” the two products are. If the acquisition does not also reduce marginal cost, post-merger marginal revenue falls below marginal cost, and the merger will cause price to increase and quantity to decrease on both products. This is the “unilateral” anti-competitive merger effect, so named because the merged firm does not need the cooperation of non-merging firms in order to raise price (e.g., Werden and Froeb, 2007). Unilateral

effects arise when firms compete by setting price or quantity, by bidding, or by bargaining (Werden and Froeb, 2008).

If, however, merger synergies push marginal cost below post-merger marginal revenue, the merged firm decreases price and increases output (Werden, 1996; Froeb and Werden, 1998; and Goppelsroeder et al., 2006). In this case, price decreases and quantity increases, and we say the merger is “pro-competitive.” These predictions are summarized in the first row of Table 1. Furthermore, these predictions do not depend on certainty, and we denote this independence in the first row of Table 1 by leaving the entry under “Demand Uncertainty” column blank.

Merger Theory	Demand Uncertainty	Capacity Constraint	Prediction for occupancy	Prediction for price	Comment
<b>Unilateral effects:</b> price or quantity competition		Not binding	Down, unless outweighed by efficiencies	Up, unless outweighed by efficiencies	P and Q move in opposite directions
<b>Pricing to fill capacity:</b> when demand is known	Low	Binding	No effect	No effect	Price to fill capacity, both pre- and post-merger
<b>Merger reduces uncertainty:</b> pricing to fill capacity when demand is uncertain	High	Binding	Up	No prediction	Fewer over-pricing errors leads to higher expected occupancy
<b>Demand externalities:</b> merged firm is able to bid for group business			No effect if capacity constrained; Up if not.	Up, if capacity constrained; no prediction if not.	Demand increase for merged hotel.

TABLE 1. Hypotheses about Mergers

**3.2. No uncertainty, constrained: pricing to fill capacity.** If hotel demand is as predictable as parking demand and the merged hotel is capacity constrained, then we would expect no price or quantity changes following hotel mergers. Hotels price to fill available capacity,

$$q_i(p_i, p_{\sim i}) = \kappa_i, \quad i = 1, 2, \dots, n$$

where  $p_{\sim i}$  is the vector of rival prices, and this profit calculus is the same, pre- and post-merger (Froeb et al., 2000). Here we are careful to limit our conclusion to the short run, the period of time during which the structure (capacity) of the industry is fixed. The following theorem, extends this result to the case where one hotel is constrained, but the other is not.

**Proposition 1.** *In the deterministic case, if the post merger Nash equilibrium prices make demand equal to capacity for the products of the merging firms, then the pre-merger Nash equilibrium prices of those firms will also match demand to capacity; the pre- and post merger Nash equilibria are at same prices and there is no merger effect.*

*Proof.* Fix other prices, and consider the profit function of the merged firm

$$(3) \quad \Pi_{12}(p_1, p_2) = (p_1 - mc_1) \min(\kappa_1, q_1(p_1, p_2)) + (p_2 - mc_2) \min(\kappa_2, q_2(p_1, p_2))$$

Assuming the merged firm can price so low that demands exceed its capacities for its products, the  $(p_1, p_2)$  plane is divided into 4 regions by the level curves for the two products defined by  $q_1(p_1, p_2) = \kappa_1$  and  $q_2(p_1, p_2) = \kappa_2$ . These are each of positive slope, if the products are substitutes, with tangent vectors in the directions of  $v_1 = (\partial q_1 / \partial p_2, -\partial q_1 / \partial p_1)$  and  $v_2 = (-\partial q_2 / \partial p_2, \partial q_2 / \partial p_1)$  respectively. These will intersect at some point  $(p_1^{**}, p_2^{**})$  where both demands match capacity.

In the region where  $q_1(p_1, p_2) > \kappa_1$  and  $q_2(p_1, p_2) > \kappa_2$ , the profit increases linearly with both  $p_1$  and  $p_2$ . Where  $q_1(p_1, p_2) > \kappa_1$  but  $q_2(p_1, p_2) < \kappa_2$ ,

$$\frac{\partial \Pi_{12}}{\partial p_1} = \kappa_1 + (p_2 - mc_2) \frac{\partial q_2}{\partial p_1} > 0$$

since the products are substitutes, and the profit is increasing in  $p_1$ . Similarly, where  $q_1(p_1, p_2) < \kappa_1$  and  $q_2(p_1, p_2) > \kappa_2$ , the profit is increasing in  $p_2$ . In short, the merged firm will price its products so demands are at most the corresponding capacity constraints.

The first order condition for the corner  $(p_1^{**}, p_2^{**})$  of the remaining region being a maximum is that the derivatives of  $\Pi_{12}$  in the directions of  $v_1$  and  $v_2$  are both negative, i.e.,

$$(4) \quad \left( q_1 + (p_2 - mc_2) \frac{\partial q_2}{\partial p_1} \right) \frac{\partial q_1}{\partial p_2} - \left( q_2 + (p_2 - mc_2) \frac{\partial q_2}{\partial p_2} \right) \frac{\partial q_1}{\partial p_1} < 0$$

and

$$(5) \quad - \left( q_1 + (p_1 - mc_1) \frac{\partial q_1}{\partial p_1} \right) \frac{\partial q_2}{\partial p_2} + \left( q_2 + (p_1 - mc_1) \frac{\partial q_1}{\partial p_2} \right) \frac{\partial q_2}{\partial p_1} < 0$$

respectively, when  $p_1 = p_1^{**}$  and  $p_2 = p_2^{**}$ . But then with the expected signs for partial derivatives for substitute products, also

$$(6) \quad q_2 + (p_2 - mc_2) \frac{\partial q_2}{\partial p_2} < 0$$

and

$$(7) \quad q_1 + (p_1 - mc_1) \frac{\partial q_1}{\partial p_1} < 0$$

that is, the separate profit functions  $\Pi_2$  and  $\Pi_1$  for the pre-merger firms are decreasing at  $(p_1^{**}, p_2^{**})$ . If these prices are profit maximizing for the post merger firm given the other prices, then the pre-merger firms would independently choose these same prices as their pre-merger prices given the other prices. But if the other firms are choosing individually profit maximizing prices, given these prices for products 1 and 2 in the post merger case, the same prices are profit maximizing for these firms in the pre-merger case given these prices for products 1 and 2, i.e., the pre-merger Nash equilibrium prices are the same as the post merger Nash equilibrium prices when the merged firm prices to match demand and capacity.  $\square$

It is important to note that pre-merger pricing at capacity does not necessarily imply post merger pricing at capacity. If the inequalities 6 or 7 are barely satisfied, so a pre-merger firm is nearly indifferent to pricing to capacity or just below capacity, the merged firm would raise price. However, it seems unlikely that the extra terms in 4 or 5 would result in a reversed inequality.

This “pricing to fill capacity” characterization of mergers has the feature that in markets without uncertainty about demand, and where firms are capacity constrained, we would expect no merger effects. This prediction is denoted in the second row of Table 1 labeled “pricing to fill capacity.”

**3.3. Uncertainty, constrained: merger reduces uncertainty.** When firm demand can potentially exceed capacity, two complications arise. First, we have to specify what happens to consumers who are turned away from a capacity constrained firm. One alternative is to allow consumers denied their first choice to make a second choice among the remaining alternatives. Another is that the merging firms might preferentially refer their overflow customers to their merging partner. Though both of these strategies can be numerically simulated, it makes a theoretical analysis essentially intractable.<sup>6</sup> Instead, we assume simply that consumers denied a first choice are lost, e.g., Carlton (1978), so the sales for product  $i$  are  $\min(\kappa_i, q_i(\mathbf{p}))$  where now  $q_i$  is a random variable.

Second, the nonlinearity of the *minimum* function,  $s_i = \min(\kappa_i, q_i(p_i, p_{\sim i}))$ , imparts an asymmetry to the costs of over- and under-pricing. We show that as uncertainty shrinks, optimal price changes in predictable ways. It follows that mergers which allow the merged firm to share information can change price and quantity, even without the internalization of competition described section 3.1.

What is critical for interpreting our empirical results is that (i) within-market demand has a common, unknown component that affects both merged firms and (ii) out-of-market demand does not share this component. This is analogous to the way that Mares and Shor (2008) model mergers in common-value auctions, i.e., as a coarser partition of the information about an unknown, but common value. This characterization of information sharing can also be thought of as a model of the pro-competitive justification for exchanging information offered by the Paris hotels to the Conseil de la Concurrence.

We isolate the effects of information sharing by decomposing the effects of mergers into two steps: first, firms share information; and second, they internalize price competition. At each step, we imagine one firm adjusts price assuming other prices are fixed and then each other firm adjusts in response, to which the first firm responds in a convergent cycle of diminishing steps, but the direction and most of the magnitude of the resulting price changes will be indicated by the initial adjustment.

In the proposition and example that follow, we show that in the initial adjustment, uncertainty causes each firm to “shade” price away from a “target” price where expected demand equals capacity and that this shading increases with uncertainty. It follows that reducing uncertainty would move price back towards the target price. Price can increase or decrease, but quantity increases because there are fewer pricing errors. We recognize, of course, the possibility that the effects of information sharing identified in the first step could be masked by the usual anti-competitive merger effects that occur in the second.

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<sup>6</sup>See the Appendix for a characterization of how mergers change equilibrium in this more general case.



**Proposition 2.** *Assume a single firm faces uncertain demand of a fixed form  $q(p) = \sigma Z + \mu(p)$  where  $Z$  is a zero mean, unit standard deviation, symmetric distribution. Let  $\mu(p)$  be the expected demand as a function of  $p$ , where the standard deviation of demand is given by  $\sigma$ , independent of  $p$  and sufficiently small in comparison to capacity  $\kappa$ . Take  $p_*$  with  $\mu(p_*) = \kappa$  and let  $\lambda = \mu(p_*) + (p_* - mc)\mu'(p_*)$ . Let  $p_{\text{opt}}$  be the expected profit maximizing price for the firm. If  $\lambda < 0$ , then the optimal price will have a linear approximation valid for small  $\sigma$  of  $p_{\text{opt}} = p_* + \gamma\sigma$  with  $\gamma > 0$  if  $\kappa > -\lambda$ , and  $\gamma < 0$  if  $\kappa < -\lambda$ . The expected sales will fall short of capacity by an amount in proportion to  $\sigma$  for small  $\sigma$ .*

*Proof.* Given  $\sigma$ , take sales  $S = S(p) = \min(\kappa, q(p))$ . Then the expected profit is given by  $E[\Pi] = (p - mc)E[S(p)]$ . The optimal price is determined by the first order condition

$$(8) \quad 0 = \frac{\partial E[\Pi]}{\partial p} = E[S(p)] + (p - mc)\frac{\partial E[S(p)]}{\partial p}$$

This equation defines  $p_{\text{opt}} = p_{\text{opt}}(\sigma)$  implicitly as a function of  $\sigma$ . The task is to determine how  $p_{\text{opt}}$  varies with  $\sigma$ . We take  $\sigma$  sufficiently small that the implicit function can be approximated by a first order expansion.

As  $\sigma$  goes to zero, demand approaches a deterministic demand  $q(p) = \mu(p)$ . By the previous analysis of the deterministic case, the capacity constraint is binding and the optimal price is the corner price  $p_*$  making  $q(p_*) = \kappa$  when

$$(9) \quad 0 > \frac{\partial}{\partial p} ((p - mc)q(p)) \Big|_{p=p_*} = \mu(p_*) + (p_* - mc)\mu'(p_*) = \lambda$$

Suppose then  $\lambda < 0$ . If  $p < p_*$ ,  $\partial E[\Pi]/\partial p$  approaches  $\kappa > 0$  as  $\sigma \rightarrow 0$ , while if  $p > p_*$ ,  $\partial E[\Pi]/\partial p$  approaches  $\mu(p) + (p - mc)\mu'(p)$  as  $\sigma \rightarrow 0$ , which is negative assuming a unique maximum of  $(p - mc)\mu(p)$  as already  $\mu(p_*) + (p_* - mc)\mu'(p_*) < 0$ . Thus  $p_{\text{opt}}(\sigma)$  will be bigger than a given  $p < p_*$  when  $\sigma$  is sufficiently small and  $p_{\text{opt}}(\sigma)$  will be smaller than a given  $p > p_*$  when  $\sigma$  is sufficiently small. That is, the deterministic optimal price  $p_*$  is in fact the limit of  $p_{\text{opt}}(\sigma)$  as  $\sigma \rightarrow 0$ . So for  $\lambda < 0$  the constant term in the expansion of  $p_{\text{opt}}$  in  $\sigma$  is simply  $p_*$ .

It remains to show that  $(p_{\text{opt}}(\sigma) - p_*)/\sigma$  approaches a limit  $\gamma$  as  $\sigma$  goes to 0, so the price shading from  $p_*$  is approximately linear in  $\sigma$  for small  $\sigma$ , determining in the process the sign of the coefficient  $\gamma$ .

Let  $F(z)$  be the cumulative distribution function for  $Z$  and  $f(z) = F'(z)$  be its probability density function (and think for example,  $Z$  a standard normal distribution). Assuming  $Z$  is symmetric about 0,  $F(0) = 1/2$ ,  $F(z) < 1/2$  for  $z < 0$ , and  $F(z) > 1/2$  for  $z > 0$ . Take  $z_\kappa = z_\kappa(p, \sigma) = (\kappa - \mu(p))/\sigma$ , the  $z$  value corresponding to the random demand matching capacity, depending on the demand distribution determined by  $p$  and  $\sigma$ . Taking an approximation  $\mu(p) = \mu(p_*) + (p - p_*)\mu'(p_*) + O((p - p_*)^2)$  for  $p$  near  $p_*$ ,

$$(10) \quad \begin{aligned} z_\kappa(p, \sigma) &= \frac{1}{\sigma} (\mu(p_*) - \mu(p_{\text{opt}}(\sigma))) \\ &= \frac{1}{\sigma} (\mu(p_*) - (\mu(p_*) + (p - p_*)\mu'(p_*) + O((p - p_*)^2))) \\ &= \frac{p - p_*}{\sigma} (-\mu'(p_*) - O((p - p_*))) \end{aligned}$$

As  $\mu'(p_*) < 0$ , for sufficiently small  $\sigma$ ,  $z_\kappa(p_{\text{opt}}(\sigma), \sigma)$  is a positive multiple of  $(p_{\text{opt}}(\sigma) - p_*)/\sigma$  and so it suffices to evaluate

$$(11) \quad \gamma = \lim_{\sigma \rightarrow 0} \frac{p_{\text{opt}}(\sigma)}{\sigma} = \frac{1}{-\mu'(p_*)} \lim_{\sigma \rightarrow 0} z_\kappa(p_{\text{opt}}(\sigma), \sigma)$$

that is, to measure the deviation of optimal price from  $p^*$  it suffices to determine how far out in the resulting demand distribution it is that demand reaches capacity. To determine the limit and sign of  $z_\kappa(p_{\text{opt}}(\sigma), \sigma)$  it suffices to determine a limit for  $F(z_\kappa)$  and determine whether this limit is more or less than  $1/2$ .

With a change of variable for  $q(p) = \sigma z + \mu(p)$ ,

$$(12) \quad \begin{aligned} E[S(p)] &= \int_{z \leq z_\kappa} (\sigma z + \mu(p)) f(z) dz + \int_{z > z_\kappa} \kappa f(z) dz \\ &= \left( \int_{z \leq z_\kappa} z f(z) dz + \int_{z > z_\kappa} z_\kappa f(z) dz \right) \sigma + \mu(p) \\ &= \left( \int_{z \leq z_\kappa} z f(z) dz \right) \sigma + \kappa(1 - F(z_\kappa)) + \mu(p)F(z_\kappa) \\ &= -\sigma g(z_\kappa) + \kappa(1 - F(z_\kappa)) + \mu(p)F(z_\kappa) \\ &= \kappa - \sigma(g(z_\kappa) + z_\kappa F(z_\kappa)) \end{aligned}$$

where  $g(x) = \int_{z \leq x} -z f(z) dz$ . (Interestingly,  $g(x)$  is also a density function for a distribution, a standard normal distribution if  $Z$  is the standard normal distribution.) Then

$$(13) \quad \begin{aligned} \frac{\partial E[S(p)]}{\partial p} &= (\sigma z_\kappa f(z_\kappa) - \kappa f(z_\kappa) + \mu(p) f(z_\kappa)) \frac{\partial z_\kappa}{\partial p} + \mu'(p) F(z_\kappa) \\ &= \mu'(p) F(z_\kappa) \end{aligned}$$

since the terms in parentheses cancel. Setting  $p = p_{\text{opt}}(\sigma)$  and substituting into equation (8)

$$(14) \quad 0 = -\sigma g(z_\kappa) + \kappa(1 - F(z_\kappa)) + (\mu(p_{\text{opt}}(\sigma)) + (p_{\text{opt}}(\sigma) - mc)\mu'(p_{\text{opt}}(\sigma))) F(z_\kappa)$$

and so

$$(15) \quad F(z_\kappa(p_{\text{opt}}(\sigma), \sigma)) = \frac{-\sigma g(z_\kappa(p_{\text{opt}}(\sigma), \sigma)) + \kappa}{\kappa - (\mu(p_{\text{opt}}(\sigma)) + (p_{\text{opt}}(\sigma) - mc)\mu'(p_{\text{opt}}(\sigma)))}$$

As the quantity in parentheses in the denominator approaches  $\lambda$  as  $\sigma \rightarrow 0$ , and  $g(z_\kappa)$  in the numerator is bounded,

$$(16) \quad \lim_{\sigma \rightarrow 0} F(z_\kappa(p_{\text{opt}}(\sigma), \sigma)) = \frac{\kappa}{\kappa - \lambda}$$

Now if  $\kappa > -\lambda$ , then the limiting value for  $F(z_\kappa)$  is  $\kappa/(\kappa - \lambda) < 1/2$ ,  $z_\kappa$  approaches a negative value and so  $\gamma < 0$ . If  $\kappa < -\lambda$ , then the limiting value for  $F(z_\kappa)$  is  $\kappa/(\kappa - \lambda) > 1/2$ ,  $z_\kappa$  approaches a positive value and so  $\gamma > 0$ . In either case, the last line of equation (12) shows that the expected sales falls short of capacity in proportion to  $\sigma$  for small  $\sigma$ .  $\square$

A similar analysis can be performed for the case where  $\lambda > 0$  and the capacity constraint is not binding in the limit as  $\sigma \rightarrow 0$ . This is illustrated in Figure 2 below. As above, the difference between the optimum price and the target price will go to zero as  $\sigma \rightarrow 0$ .

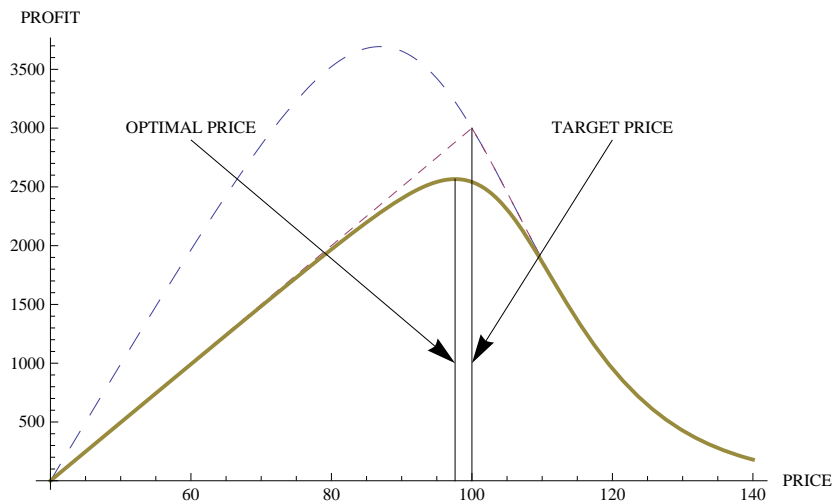


FIGURE 1. Information Sharing Increases Price: Expected (solid line) and deterministic (dashed line) profit functions, exaggerated variance

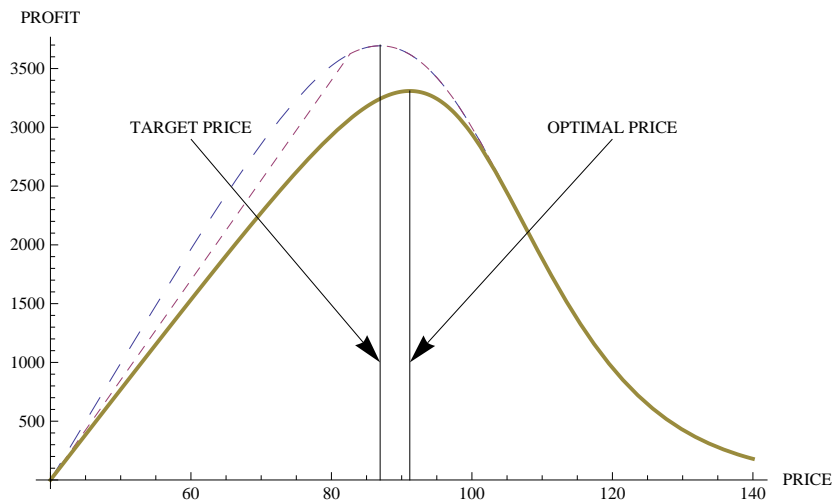


FIGURE 2. Information Sharing Decreases Price: Expected (solid line) and deterministic (dashed line) profit functions, exaggerated variance

3.3.1. *Illustration of optimal “shading” away from the target price.* To illustrate the shading of Proposition 2, imagine that market demand for reservations is governed by a Poisson arrival process on top of an  $(n + 1)$ -choice logit random utility model (including an outside option). The arrival process determines market demand, and then conditional on arrival, each consumer chooses among the  $(n + 1)$  alternatives. This configuration results in  $n$ -independent Poisson processes at each of the  $n$  hotels,

with an arrival rate equal to the market arrival rate times the logit probability that a given hotel is chosen.

The two examples below assume a Poisson arrival process with a rate of  $\theta = 100$  per period, and a two-choice logit demand  $s = \exp(\alpha - \beta p)/(1 + \exp(\alpha - \beta p))$  with  $\alpha = 10$  and  $\beta = 0.1$ . This would result in the single firm seeing a demand which is Poisson distributed with expected value  $s\theta$ . However, the resulting price shading would be only  $1 - 2\%$ . For clarity's sake, we exaggerate the shading by assuming that consumers arrive and purchase in blocks of size 10 so market demand is ten times the Poisson. We divide the random arrival process by ten, which has the effect of increasing the standard deviation of demand by a factor of  $\sqrt{10}$ , while keeping the mean arrival rate constant at 100. We assume a marginal cost of  $mc = 40$ , and plot expected profit vs. price for two different capacity constraints:  $\kappa = 50$  ("binding" in Figure 1; and  $\kappa = 85$  ("non-binding") in Figure 2.

The terms binding and non-binding tell us whether the hotel would be capacity constrained at the optimal target price (denoted by a vertical line) at the maximum of the deterministic profit function, *i.e.*, if there were no uncertainty. This deterministic profit function is plotted with a dashed line. The expected profit function in the two figures is plotted with a solid line, and the optimal price is denoted by a vertical line at the maximum of the expected profit function. The difference between the two vertical lines is the shading of Proposition 2.

For the binding capacity constraint, plotted in Figure 1, we see that the steep fall off in the target profit function to the right implies that the expected profit reaches a maximum at a price below the target price. Intuitively, the hotel prices below the target price to avoid the high cost of over-pricing errors.

For the non-binding constraint, plotted in Figure 2, we see that the steep fall off in the target profit function to the left implies that the expected profit reaches a maximum at a price above the target price. Intuitively, the hotel prices above the target price to avoid the high cost of under-pricing errors.

The figures show that as we move from an uncertain to a certain world (a proxy for the effects of sharing information), price can go up or down, depending on the shape of the profit function. Expected occupancy increases due to fewer pricing errors.

We summarize these predictions in the third row of Table 1, labeled "Mergers reduce uncertainty," *i.e.*, Quantity goes up, but price can increase or decrease. We shade the two cells in the table because they correspond to our empirical findings, below.

**3.4. Demand externalities among the merging firms.** Approximately 50% of U.S. hotel business is group business. Conventions are often booked years in advance. To be able to compete for this demand, a hotel must have both meeting space, and enough capacity to handle the size of the group or convention. If the merged hotels are large enough to host groups, but the pre-merger hotels individually are not, then the merger could increase demand. Of course, it is possible that two hotels located near each other could "share" a group booking, or coordinate to host a convention, but this kind of joint effort is often subject to incentive conflicts.<sup>7</sup> If merger allows the hotels to better manage this incentive conflict, and to bid for previously unattainable business, then the merger could increase demand.

<sup>7</sup>In particular hotel managers have told us that the primary problem is amicably allocating the shares of a group's rooms to each hotel.

An increase in group demand could be modeled in a couple of different ways. If it simply increases the arrival rate without changing the choice model, and hotels are near capacity, it would have two effects. First it would increase the target price at which expected demand equals capacity. Second, it would change the shading away from the target price by making the target price bind more tightly, as in Proposition 2, and illustrated in Figure 2. We expect that the former effect is much bigger than the latter, so price would increase. Since the hotel is near capacity, we would expect occupancy to change by a smaller amount.

Convention demand could also be modeled by assuming that it comes during off-peak periods. In this case, we would expect average occupancy to increase. If the merged hotel is able to price discriminate, i.e., set an individualized price to the convention business then price could go up or down. If group demand is more elastic than non-group demand, e.g., due to the greater bargaining power of groups (Kalnins, 2006), then price would go down.

The prediction of this “demand externalities” characterization of mergers is summarized in row four of Table 1, labeled “Demand externalities.” If the hotel is capacity constrained, then price will increase; otherwise, we would expect occupancy to increase.

#### 4. DATA AND ESTIMATION

**4.1. Data.** The price and occupancy data was provided by Smith Travel Research (STR). Between 2001 and 2009, 32,314 U.S. hotels reported to STR the average room-night price actually received each day, as well as the total number of rooms available and the number of rooms sold<sup>8</sup>. Hotels that provide data receive aggregated data from competing hotels in their vicinity. We have up to 97 monthly observations of occupancy and price from December 2001–December 2009 for each hotel. These 32,314 hotels represent about 95% of chain-affiliated properties in the United States and about 20% of independent hotels.

Smith Travel Research has split the United States into 618 “tracts.” Large cities are typically split into five tracts or more. Atlanta is split into the maximum of twelve tracts; Houston, Washington, Chicago and Los Angeles are split into nine, Dallas into eight, Orlando into seven, Philadelphia and several other cities into six, and Detroit and Manhattan and many others into five. We define a “market” as a tract, and postulate that competitive and informational effects occur within a tract, an assumption that is supported by the tightly circumscribed nature of the tracts. We note that each state has between one and three broad rural tracts within which hotels may in fact not be substitutes, nor benefit from the same demand information. Ninety mergers take place within such tracts. Robustness tests that exclude these tracts and their hotels yield results virtually identical to those presented below.

We have obtained from STR the management company/franchisee identity for 9,503 out of these 32,314 U.S. hotels from January 2004 through October 2009. The management companies/franchisees are the entities that analyze demand conditions and set prices, and are thus the relevant entities for the study of merger. For simplicity’s sake, we refer to franchisees as well as management companies as a “management company”.

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<sup>8</sup>Because we observe only the average price, we cannot detect the presence of mixed-strategy equilibria.

Within chain-affiliated properties, there are two possible relationships. The most basic relationship is between the brand owner (the franchisor) and a hands-on franchisee (who often both owns and operates his/her properties). In this simple case, the relevant issue is joint management of multiple properties by the same franchisee, because the franchisee sets prices. Often in the case of upscale hotels, however, the “franchisee” becomes an owner who does not engage in daily management activities such as demand assessment or price setting. This “franchisee” hires a professional management company, which becomes the entity that assesses demand and sets price (Eyster, 1977; de Roos, 2010). In this case it is the joint management of multiple hotels by the same management company that matters. Management companies typically receive a share of profits in exchange for their services. Thus the management companies have an incentive to maximize profits and to use market power if possible, a point explicitly made in de Roos (2010).

We have complete “portfolio” information for 752 management companies that operate and maintain these 9,503 properties. We refer to these as “management company ID hotels”. In July 2009, the largest of these management companies operated 298 properties, and the next largest two operated 96 and 80 properties. The median number of properties managed by these companies is 5, while the 75th percentile is 10. The largest three management companies operated properties of 16, 5, and 11 brands respectively. The median management company operated hotels affiliated with 3 brands. The largest management companies operate in many tracts. The three largest management companies, mentioned above, operate in 152, 82, and 71 tracts, respectively. None of these three manage more than five properties in any one tract. Conversely, smaller management companies tend to concentrate in one or a few tracts. Of the three management companies that operate the most properties within a single tract (16, 14 and 11 properties) two operate no hotels anywhere else and the third operates only one property in a different tract.

We define a local, or within-tract, merger as the case where a management company that has been operating one or more hotels in a tract takes over operations at an additional property in that same tract, which was previously operated by someone else. This definition yields 898 within-tract mergers involving 2,628 hotels that took place between January 2004 and October 2009 among the 9,503 management company ID hotels. At least one within-tract merger took place within 398 of the 618 market tracts.

Among the 1,079 hotels who switched management company as a result of a merger, 199 were management company ID hotels before the merger. For the remaining 880, we know only that a change in management company took place on a certain date, and that the new management company previously had at least one other hotel in the same tract—hence a “local merger”. Comparing holdings within the same geographical tract as the merger, 142 of the 199 management company ID hotels were previously managed by a company with no other hotels in the same tract. In contrast, only 105 of the acquiring management companies had only one hotel within the tract before the merger, and the remainder had more than one. In only 5 of the 199 cases was the post-merger management company smaller than the pre-merger company in terms of total hotels within the same tract. Thus, a vast majority of our mergers should improve the quality of the information available to the hotels.

Because we have information only about mergers from January 2004 through October 2009, all our analyses below use panels that begin in December 2003, one month before our management company information begins, and that end in November 2009, one month after the management company information ends.

**4.2. Estimation and Variable definition.** As we mention above, we defined a local, or within-tract, merger as the case where a management company that has been operating one or more hotels in a tract takes over operations at an additional property in the same tract, which was previously operated by someone else. This definition yields 898 within-tract mergers involving 2,628 hotels. The binary “within-tract merger” is set to zero for all properties for the earliest observations from December 2003. The value of one is added to this variable for any hotel involved in a merger, for all its monthly observations from the date of the merger onwards. In a few cases the merger is undone, at which point the value of one is subtracted for all subsequent monthly observations for the involved hotels. A total of 331 hotels are involved in more than one merger so the “within-tract merger” variable can take on values greater than one. Five hotels are involved in nine mergers, the maximum. We note that our results are robust to the case where we only count the very first merger in which a hotel is involved.

When creating this variable, we do not distinguish between the hotels that change management companies due to the merger (the targets) and those that keep the same management company (the acquirers). Regressions that assign separate variables to these two groups find very similar results, in terms of economic magnitude. These are discussed in the robustness tests section.

We created a variable for non-local mergers. The variable “Out-of-tract merger” is included to distinguish effects of within-market mergers from out-of-market mergers.

We create two sets of fixed effects. First, create a fixed effect for each of 11,462 hotel\*brand combinations of our 9,503 hotels in the Merger ID data set, or for 45,585 combinations when we analyze all data-reporting hotels. Thus, almost all our analyses are “within-brand-at-hotel” in nature. That is, we are comparing pre- and post-merger occupancies and prices while holding the location and brand constant. Hotels may change brand names as they get older and revenues may vary substantially as a result of these brand changes. Occasionally the management company changes when the brand changes so we do not want to confound effects from these two issues. We note that all our results remain similar when we use 9,503 management company ID hotel fixed effects or 32,314 data-reporting hotel fixed effects and ignore brand changes.

Second, we wish to include a precise set of fixed effects that isolates temporal effects by market. Thus we create fixed effects, one for each of the 72 months in the panel for each of the 618 tracts in the data, as long as there are at least two hotels operating in that tract in that month. These are included because *local* macroeconomic conditions may substantially influence price and occupancy at hotels throughout each period. Including these fixed effects allows us to distinguish merger effects from macroeconomic effects that apply to all hotels in a given tract in a given month.

Estimating large data sets with two large dimensions of fixed effects can present challenges due to memory and computer processing limitations. We cannot simply add over ten thousand fixed effects as dummy variables to our half million monthly

observations after already incorporating the hotel\*brand fixed effects using the standard mean-based approach. Therefore, we have used the memory-saving algorithm provided by Abowd, Creecy, and Kramarz (2002), as implemented by Cornelissen (2008), to estimate all our regressions.

Further, using a panel data structure very similar to ours (many panels with a long time series, before and after a policy change) Bertrand et al. (2004) found that standard errors for DID estimators were biased downward, i.e., they rejected the null hypothesis of no effect too frequently. Because our estimation strategy depends on us being able to precisely estimate small merger effects, we also employ a heteroskedasticity-consistent covariance estimator (White, 1980), clustering on each panel (hotel\*brand combination), which allows for a flexible pattern of within-tract correlation. When the number of panels is large as is the case here, Bertrand et al. (2006) find that this estimator performs well.

**4.3. Measuring capacity constraints and uncertainty.** The theories that we want to test make distinctions between markets where capacity constraints are likely to be binding and those where they are not, and between markets where uncertainty about future demand is high and those where it is low. To create these categories, we used the price and occupancy data from the period from December 2001 through November 2003. These data are not included in our main analyses because we do not have management company information from this time period. To estimate the likelihood that capacity constraints are binding we calculate total occupancy at the level of the tract, i.e., we divide total room-nights occupied for all hotels in the tract by total room-nights available for all hotels in the tract, for the year 2002. We then split tracts into upper and lower halves based on the 2002 occupancies. Capacity constraints are more likely to bind in urban areas and at airport locations than in rural locations or small towns. For example, 20.34% of hotels designated as within an “urban area” by STR fall in the lowest quartile of capacity utilization, while 35.63% of urban hotels are in the highest quartile of utilization.

While even the upper half of 2002 occupancy has a median (50th percentile) occupancy of 0.68, seemingly far from binding capacity constraints, hotels often begin to consider themselves constrained at occupancies of 75% or 80%. While hotels still have empty rooms at 80% they often do not have the workforce in place to service these rooms, although we recognize the workforce capacity is more easily changed than room capacity.

To measure the level of uncertainty in a lodging market we use the correlation between daily occupancies from December 2001 through November 2002 with those exactly 364 days later, (not 365, so that the day of the week remains the same). A high correlation indicates that hotels can predict occupancy based on the previous years occupancy. Hotel managers have confirmed to us that the previous years occupancy is an important baseline that they use to predict occupancies for a given day, such as the “first Monday in June,” for example<sup>9</sup>. Demand uncertainty is typically greater in urban areas and at airport locations than in rural locations or small towns.

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<sup>9</sup>General Managers of four-star hotels in Orlando, San Francisco and Chicago all independently emphasized this metric in conversations with us.



**4.4. Appropriate Comparison Groups.** An important question in any longitudinal analysis of merger effects is the group of non-merging hotels to be included as a control group in the analysis (see, e.g., Dafny, 2009, for a discussion of various possibilities). We have three obvious possibilities. First, given that the 898 mergers take place at different times, we can plausibly identify merger effects by including only the panels of the 2,628 hotels that have been involved in mergers. This approach eliminates the concern that merged hotels are different than non-merging properties, and that this unobservable difference, not the actual merger, is driving what appears to be a merger effect. The disadvantage is that the 160 market tracts with only one merger must be eliminated because there will be no variation in the “within-tract merger” variable for all tract\*months. This leaves us with 238 tracts with 738 mergers. Second, at the other extreme, we could include all 32,314 hotels for which price and occupancy data exist, even though we have no information about any merger activity from the 22,811 non-ID hotels. The advantage to this approach is that the tract\*month effects can be better estimated, i.e., without discarding information. A middle ground would be to include only those 9,503 hotels that are managed by management companies for which we have merger information.

We calculated some descriptive statistics to help us make the decision. In particular, the average number of rooms offered per night in December 2003, before any of these mergers took place, was 135 for the merging hotels and 134 for the non-merging hotels for which we do have management company ID. But the non-ID hotels were far smaller, offering only 87 rooms per night in December 2003. Similarly, prices and occupancies were \$75.89 and 0.488, respectively, for the management company ID properties but only \$63.87 and 0.454 for the non-ID data-reporting properties.

In our most general analysis, we compute results for all three comparison groups. For our more fine-grained analyses that separate market tracts by likelihood of capacity constraints and level of uncertainty, we restrict our analysis to the case where the management company ID properties are the comparison group. In fact, in the Robustness Tests section we show that including only merged hotels or including all properties in these analyses in place of the management company ID properties largely leads to the same conclusions regarding occupancies as those shown below. Conclusions about the price effects of mergers, however, do seem to be sensitive to the choice of control group.

## 5. RESULTS

**5.1. Effects on price and occupancy.** In Table 2, we analyze the effects of merger throughout our entire sample, regardless of level of uncertainty or the likelihood of binding capacity constraints, using the three possible comparison groups discussed above: (1) all management company ID properties, (2) merged properties only, and (3) all data-reporting properties. When we analyze occupancy, we see quite similar results across all three comparison groups: mergers raise occupancy. This result is most significant, statistically and in magnitude, when the comparison group is the set of merged hotels only (in column 4). The statistically significant coefficient of the within-tract merger variable in the third column of 0.008 suggests that hotels gain just over four-fifths of a percentage point of occupancy when they share a common management company. For a hotel with 100 rooms this represents

about 24 room-nights per month. We conclude that the increases in occupancy are not simply an effect of economic conditions in the tracts where mergers took place because the tract\*month fixed effects are included. Significant average daily rate (price) effects appear only when all 32,314 data-reporting hotels are included in the analysis. We cannot rule out the hypothesis that an unobservable difference between the management company ID hotels and the non-ID hotels is the source for the observed price effect. The economic significance is best captured by the effect on a hotel's total revenues per month. Depending on the comparison group, the merging hotels enjoy statistically significant gains of between \$10,600 (column 9) and \$16,000 (column 6) per month. Further, our "Differences in Differences" F-test shows that the effects of within-tract mergers are often statistically significantly greater than the effects of out-of-tract mergers. This is true for all three comparison groups for the dependent variable of revenues/month and for the latter two comparison groups for occupancy.

Comparison Groups →	9,305 management company ID hotels			2,628 hotels involved in mergers			32,314 data-reporting hotels		
	Occ.	ADR	Rev/ Month	Occ.	ADR	Rev/ Month	Occ.	ADR	Rev/ Month
	\$ \$000			\$ \$000			\$ \$000		
1. Within-tract merger	.0041+ (.0023)	0.53 (.34)	14.7** (5.08)	.0083* (.0033)	.55 (.50)	16.0+ (8.30)	.004** (.0017)	1.51** (.23)	10.6** (3.7)
2. Out-of-tract merger	.0010 (.0010)	.07 (.05)	1.23* (.383)	.0023* (.0011)	.07 (.12)	1.57 (2.07)	.0005 (.0003)	.48** (.04)	1.1* (.47)
DiD: (1)-(2) = 0	1.93	2.11	7.47**	3.80+	1.15	2.92+	5.6*	20.8**	6.88**
Observations	369,627			93,368			1,826,487		
FX: Hotel*brand	9,607			2,285			36,139		
FX: Tract*month	8,975			1,868			42,579		

Huber-White standard errors in parentheses, clustered by hotel\*brand combination.

\*\* p < 0.01; \* p < 0.05; + p < 0.10 as per two-tailed tests

TABLE 2. Occupancy and ADR (Price) Regressions for All Hotels with Different Comparison Groups

**5.2. Effects in presence of uncertainty and capacity constraints.** The finding that occupancy goes up post-merger appears to reject the first two merger theories in Table 1, and is consistent with the latter two theories, mergers reduce uncertainty and demand externalities. To more precisely determine the role that capacity and uncertainty play in the estimation, we split the sample based on the 2002 occupancy levels and on the 2003-2003 same-day correlations, as described above. For all regressions below we use only the management company ID hotels, those that merge and those that do not, as the comparison group. In the robustness tests section, we summarize results when using the other two comparison groups. All findings are consistent with those presented below.

We split our full sample of hotels into two halves based on the 2002 tract-level occupancies. Separate results from the upper and lower half are included in the first six columns of Table 3. Here we see that occupancy increases statistically significantly – by seven-tenths of a percentage point – only for within-tract mergers in the capacity-constrained tracts. The average daily rate (price), on the other hand, does not appear to increase regardless of the level of capacity constraints. Finally, monthly revenues appear to increase for both groups, but the increase is far larger for the upper half.

<b>Table 3: Occupancy, ADR (Price), and Revenue regressions split by capacity constraints and uncertainty, using hotel*brand fixed effects and tract*month fixed effects. Comparison group is the set of 9,305 management company ID hotels</b>												
	Likelihood of Capacity Constraints						Level of Uncertainty					
	Lower Half			Upper Half			Lower Half			Upper Half		
	Occ.	ADR	Rev/ Mon.	Occ.	ADR	Rev/ Mon.	Occ.	ADR	Rev/ Mon.	Occ.	ADR	Rev/ Mon.
	\$ \$000		\$ \$000		\$ \$000		\$ \$000		\$ \$000		\$ \$000	
1. Within-tract merger	-.001 (.01)	.81 (.53)	4.6+ (2.59)	.007* (.003)	0.34 (.43)	20.9* (8.69)	-.001 (.003)	-.27 (.36)	1.96 (2.89)	.007* (.003)	1.1* (.51)	24.3** (8.50)
2. Out-of-tract merger	.001 (.01)	.15* (.06)	1.5** (.411)	.001+ (.001)	-.001 (.07)	.862 (.616)	.001 (.001)	-.02 (.06)	1.1** (.422)	.002* (.001)	.14* (.07)	1.22* (.611)
DiD: (1)-(2)=0	0.15	1.65	1.45	3.87*	0.69	6.72**	.07	.55	0.10	3.57+	4.1*	7.77*
Obs.	184,296			185,331			181,569			188,058		
FX: Htl*brd	4,912			4,695			4,701			4,906		
FX: Tr*mon.	4,583			4,394			4,390			4,587		
Mergers	400			498			415			483		
Merging Htls	1,123			1,505			1,217			1,411		
Avg. of DV	0.60	\$93	\$240K	0.66	\$102	\$335K	0.62	\$94	\$238K	0.64	\$101	\$336K

Huber-White standard errors in parentheses, clustered by hotel\*brand combination.  
 \*\* p < 0.01; \* p < 0.05; + p < 0.10 as per two-tailed tests

TABLE 3. Occupancy and ADR (Price) regressions split by capacity constraints and uncertainty. Comparison group is the set of 9,305 management company ID hotels

The last six columns of Table 3 split the population into a lower half and upper half of market-level uncertainty. Occupancy, price, and monthly revenue increase significantly due to within-tract merger only in the high uncertainty tracts. The “Differences in Differences” F-test shows that the effects of within-tract mergers are statistically significantly greater than the effects of out-of-tract mergers for the upper halves of both dimensions for the dependent variables of revenues/month and occupancy.

To most precisely test the applicability of the theories summarized in Table 1, we split market tracts into quadrants based on the likelihood of binding capacity constraints and level of uncertainty. These results are shown in Table 4.

Table 4 splits all market tracts by both the likelihood of capacity constraints and by market-level uncertainty. Each hotel only appears in one quadrant. In Q1, the

Table 4: Occupancy, ADR (Price) and Revenue regression results for four quadrants using hotel*brand fixed effects and tract*month fixed effects Comparison group is the set of 9,305 management company ID hotels							
		Low Uncertainty Markets (2002-2003 Correlations > 0.583)			High Uncertainty Markets (2002-2003 Correlations < 0.583)		
		Quadrant 4 (Q4)			Quadrant 1 (Q1)		
		Occ.	ADR	Rev/Month	Occ.	ADR	Rev/Month
		(in \$)		(in \$000)	(in \$)		(in \$000)
Market tracts where capacity constraints are likely to bind	1. Within-tract merger	.00018 (.0004)	-0.65 (.53)	-3.74 (5.04)	.0114** (.004)	0.98+ (.60)	32.8* (14.9)
	2. Out-of-tract merger	-.00001 (.0008)	-0.10 (.08)	-0.35 (.726)	.0018* (.0008)	0.07 (.09)	0.81 (1.18)
	DiD: (1)-(2) = 0	0.001	1.23	0.51	5.20*	2.45	4.70*
(2002 Occ. > 0.625)	Observations	84,906			100,425		
	FX: Hotels*Brd	2,120			2,575		
	FX: Tract*Mon.	1,986			2,410		
	Within-tract mgr	212			286		
	Merging Hotels	684			871		
	Average of DV	0.65	\$98.91	\$189.6K	0.67	106.30	\$394.1K
		Quadrant 3 (Q3)			Quadrant 2 (Q2)		
		Occ.	ADR	Rev/Month	Occ.	ADR	Rev/Month
		(in \$)		(in \$000)	(in \$)		(in \$000)
Market tracts where capacity constraints are unlikely to bind	1. Within-tract merger	-.0013 (.0045)	0.17 (.46)	3.56 (5.25)	.0006 (.0046)	1.40 (.94)	4.30 (4.85)
	2. Out-of-tract merger	-.0008 (.0008)	.06 (.08)	2.27** (.678)	.0010 (.0008)	.24 (.09)	1.40* (.66)
	DiD: (1)-(2) = 0	.24	1.31	0.06	.01	1.70	1.50
(2002 Occ. < 0.625)	Observations	96,663			87,633		
	FX: Hotels*Brd	2,581			2,331		
	FX: Tract*Mon.	2,406			2,179		
	Within-tract mgr	203			197		
	Merging Hotels	583			540		
	Average of DV	0.595	\$89.79	\$216.7K	0.615	\$95.95	\$192.7K

Huber-White standard errors in parentheses, clustered by hotel\*brand combination.

\*\* p < 0.01; \* p < 0.05; + p < 0.10 as per two-tailed tests

TABLE 4. Occupancy and ADR (Price) regression results for four quadrants using tract\*month fixed effects. Comparison group is the set of 9,305 management company ID hotels

upper right quadrant, which includes hotels in tracts that have high uncertainty on average as well as a high likelihood of being capacity constrained, we observe a strong positive effect of within-tract merger on hotel occupancy, raising the occupancy more than one full percentage point. And we observe an estimate of a room-night price increase due to within-tract merger of \$0.98, which is marginally significant relative to zero. Further, the increase in monthly revenues is striking. The average hotel here, with monthly revenues of \$394K can expect an increase

of \$32K in revenues as a result of a within-tract merger. Finally, the “Differences in Differences” F-test shows that the effects of within-tract mergers are statistically significantly greater than the effects of out-of-tract mergers for the dependent variables of revenues/month and occupancy. The increase in occupancy, price, and monthly revenues due to a merger is consistent with the “mergers reduce uncertainty” theory for the case of capacity constrained firms with uncertain demand.

In Q4, the upper left quadrant, which includes hotels in tracts that have the lowest uncertainty on average but are in tracts with the highest occupancies, we observe no statistically significant effects of occupancy, price, or monthly revenue. This lack of any significant effect due to a merger is consistent with “pricing to fill capacity” for the case of capacity constrained firms with fairly certain demand.

The lower half of the table displays results from hotels from tracts with a low likelihood of capacity constraints that are also in the lower half of tract-level uncertainty (Q3) and in the upper half in terms of uncertainty (Q2). In neither group do we observe any statistically significant occupancy, price or revenue effects, nor is there any significance of the “Differences in Differences” F-test. These results are not fully consistent with those predicted by the theory described above. The “mergers reduce uncertainty” model suggests that *occupancies* should increase in the tracts with high uncertainty and where capacity constraints do not likely bind for example. Yet we see no hint of that. For those tracts where occupancies are typically low and where there is little uncertainty, the theory does not make any clear predictions save the possibility of the basic pro- or anti-competitive models of merger. Perhaps the hotels merging in these “unconstrained but certain” tracts are simply too small to exert any market power post-merger. Alternatively the pro- and anti-competitive effects of merger may be cancelling each other out.

To assess robustness we re-estimated all regressions of Table 4 using a fixed effect for every tract\*month\*quality scale combination instead of just tract\*months. These results are presented in Table 5. STR splits the data into six scale levels, five for chain properties and a single category for independents. The five chain quality scale levels are luxury, upper upscale, upscale, mid-scale, and economy. It is plausible that these quality scale levels will react differently to temporal shocks even if the properties are collocated. For example, upper upscale properties in an area may lose market share in a market downturn to the midscale and economy properties. The specification presented below eliminates any possibility of such effects from being confounded with merger effects. We observe that the occupancy results remain very similar to those of Table 4: occupancy only increases for the Q1 hotels. Relative to other properties in the same tract, same quality scale, merging allows a property to gain almost 1.5 percentage points of occupancy. The price effects however are insignificant for Q1. Thus, it appears that the price increase in Table 4, Q1, only held relative to other hotels of different quality scale levels in the same market tract, but once these are swept out by a fixed effect then there remains no statistically significant price effect.

**5.3. Additional Robustness Tests (alternative fixed effects).** We have presented evidence that mergers in highly uncertain and capacity constrained markets, that is, in Q1, the upper right-hand quadrant of Tables 4 and 5, result in increases in occupancy, monthly revenues, and sometimes price (Table 4 only) using as a comparison group all management company ID properties that were not involved

<b>Table 5: Occupancy, ADR (Price), and Revenue regression results for four quadrants using hotel*brand fixed effects and tract*month*quality scale fixed effects</b> Comparison group is the set of 9,305 management company ID hotels							
		Low Uncertainty Markets (2002-03 Correlations > 0.583)			High Uncertainty Markets (2002-03 Correlations < 0.583)		
		Quadrant 4 (Q4)			Quadrant 1 (Q1)		
		Occ.	ADR	Rev/Month	Occ.	ADR	Rev/Month
		(in \$) (in \$000)			(in \$) (in \$000)		
Market tracts where capacity constraints are likely to bind (2002 Occ. > 0.625)	1. Within-tract merger	.0037 (.0053)	-.73 (.71)	10.28 (9.85)	.0143* (.0065)	.68 (.88)	42.3* (20.8)
	2. Out-of-tract merger	-.0004 (.0010)	-.11 (.13)	.345 (1.17)	.0010 (.0010)	-.01 (.15)	1.38 (2.49)
DiD: (1) – (2) = 0		.62	.85	1.16	4.53*	.69	3.93*
Observations		101245			110819		
FX: Hotel*Brand		2599			2888		
FX: Tr*mo*scale		1765			1919		
Within-tract mgrs		212			286		
Merging Hotels		684			871		
Average of DV		0.65	\$98.91	189.6	0.67	106.30	394.1
		Low Uncertainty Markets			High Uncertainty Markets		
		Quadrant 3 (Q3)			Quadrant 2 (Q2)		
		Occ.	ADR	Rev/Month	Occ.	ADR	Rev/Month
		(in \$) (in \$000)			(in \$) (in \$000)		
Market tracts where capacity constraints are unlikely to bind (2002 Occ. < 0.625)	1. Within-tract merger	-.0079 (.0071)	.78 (.65)	1.90 (3.56)	-.0063 (.0071)	1.66 ( 2.32)	-9.26 (7.86)
	2. Out-of-tract merger	.0000 (.0013)	.07 (.10)	.511 (.690)	.0006 (.0012)	.16 (.14)	.210 (.780)
DiD: (1) – (2) = 0		1.33	1.34	.22	1.00	.46	1.53
Observations		85930			71633		
FX: Hotel*Brand		2247			1873		
FX: Tr*mo*scale		1451			1186		
Within-tract mgrs		203			197		
Merging Hotels		583			540		
Average of DV		0.595	89.79	216.68	0.615	\$95.95	192.7

Huber-White standard errors in parentheses, clustered by hotel\*brand combination.

\*\* p < 0.01; \* p < 0.05; + p < 0.10 as per two-tailed tests

TABLE 5. Occupancy and ADR (Price) regression results for four quadrants using tract\*month\*quality scale fixed effects Comparison group is the set of 9,305 management company ID hotels

in mergers. Importantly, there is no statistically significant increase in either occupancy or price in any of the other three quadrants of Tables 4 and 5. However, in Table 2 we presented overall results not just with the non-merging management company ID hotels as the comparison group, but also with a smaller comparison group of 2,628 merging properties, and with the much larger comparison group of all 32,314 data-reporting properties. As we noted above, comparing only merging

properties has the virtue of avoiding unobservable differences between merging and non-merging properties, but also has the downside of discarding information from the 160 tracts with only one merger. Using this comparison group but keeping all else identical as in Tables 4 and 5 we find that here, too, mergers have a positive and significant effect on occupancies for hotels in Q1, that is, tracts with high demand uncertainty and high capacity constraints. And, here the price effect is positive and significant for Q1 hotels in the equivalents of both Table 4 and 5, consistent with Table 4 but not Table 5.

Using the much larger set of all 32,314 data-reporting properties better identifies fixed effects if the population is homogeneous but we noted above that (1) we have no merger information about the non-ID hotels, and (2) management company ID vs. non-ID hotels differ in terms of average size (134 vs. 87 rooms) and price (\$75.89 vs. \$63.87). Using this comparison group but keeping all else identical as in Tables 4 and 5 we again find that mergers have a positive and significant effect on occupancies, prices, and monthly revenues for Q1 hotels. However, we note that price effects exist not only in Q1 in the equivalent of Table 4, but for the three other quadrants as well. Only in the equivalent of Table 5 where the fixed effects distinguish among the quality scales does only Q1 get a positive price effect. We conclude that the price effects for the other quadrants are the result of heterogeneity between management company ID and non-ID hotels.

We also consider two alternative sets of fixed effects to use in place of the tract\*month and tract\*scale\*month effects of Tables 4 and 5, respectively. We re-estimated the regressions of Tables 4 and 5 with (1) only 72 monthly fixed effects constrained to be identical across all tracts and quality scales, and (2) only 504 month\*quality scale effects, again with no distinction by tract. These specifications would be appropriate if we assume that temporal shocks are mostly national in nature. Of course, substantial tract-level heterogeneity might be confounded with our merger effects in this case.

Using the set of management company ID hotels as the comparison set of hotels, as we do in Tables 4 and 5, mergers continue to have a positive effect on quantities for hotels in tracts with high demand uncertainty and high capacity constraints regardless of the set of temporal fixed effects chosen. Whether we use only the 72 fixed effects that only capture temporal effects, or the 504 fixed effects that capture separately temporal effects for each quality tier, the occupancy result is very similar to those shown in Tables 4 and 5 in terms of magnitude and statistical significance. The results regarding price are not so robust. Only when we include separate temporal fixed effects for every tract as we do in Tables 4 and 5 is the price effect significant.

In sum, the statistically significant positive occupancy effect for Q1 held for every specification that we estimated. The positive price effect for Q1 held for approximately half the specifications that we estimated, implying a lack of robustness for this latter effect.

**5.4. Additional Robustness Tests (Targets vs. Acquirors).** We estimated additional regressions where we split the within-tract merger variable into two groups: the hotels that switched management company due to the merger (the targets), and the ones that were previously managed by the same company (the acquirors). The occupancy effects are almost identical for both groups in the high

uncertainty/high capacity utilization quadrant. Both groups enjoy a 1 percentage point increase in occupancy post-merger. However, the standard error for the targets is larger, so the 1 point increase in occupancy is not statistically significant, while it is highly significant for the “previously managed” group. Similarly, the monthly revenues increase substantially for both groups in the high uncertainty/high capacity utilization quadrant, but the increase is only statistically significant for the “previously managed” group (it is very close to significant for the targets, at  $p = 0.12$  with a two-tailed test). The larger standard error for the target group makes sense because switching management companies often causes some temporary havoc on a hotel’s performance.

No other quadrants show positive effects for either the targets or acquirors. Given the similar results, we believe it is appropriate that the results in the main body of the paper do not distinguish between target and acquiror.

## 6. CONCLUSION

In this paper, we have shown that mergers in “revenue management industries,” that is, industries with fixed capacities, perishable goods, and uncertain demand, may have quite different economic effects than the higher prices and reduced welfare traditionally associated with anticompetitive mergers. Simple models of revenue management predict mergers can result in higher capacity utilization because the merged firm faces less uncertainty, which allows it to better match *expected* demand to capacity. To empirically test this theory, we analyzed a panel data set of U.S. hotels that included 898 mergers, and found that mergers in the lodging industry are associated with increased occupancies at the merged properties.

That this improvement in occupancy occurs only in capacity constrained and uncertain markets leads us to conclude that the merged multi-hotel management companies have better information about future demand. However, we cannot rule out the possibility that the increased ability of these firms to attract group business may explain a part of this improvement in occupancy, as long as these typically capacity constrained markets face periods of lower demand when the capacity constraints do not bind. Our empirical finding is robust across several specifications and comparison groups.

Importantly, we found little evidence that mergers decrease occupancy or raise price. It is informative to contrast this industry with the rental car industry where there is evidence of unilateral merger effects (Doane et al., 2013), and where the FTC recently challenged the Hertz acquisition of Dollar-Thrifty. Rental cars differ from lodging in that capacity can be relatively easily adjusted, which puts rental cars into our “unconstrained” category where theory suggests unilateral merger effects are more likely.

We conclude that mergers in revenue-management industries should not be analyzed using models of competition that ignore the significant industry features that cause firms to practice revenue management (e.g., Werden et al., 2004). The same warning applies to the scrutiny of information sharing by proximate hotels—if outright merger does not appear to have anticompetitive effects then neither should the type of information sharing that was condemned by the Conseil de la Concurrence. Lest we be hoist on our own petard, we are careful to note that this conclusion would depend on careful analysis of the particulars of the case. It appears that the



Grand Dame hotels of Paris would fall into the capacity constrained category—the Conseil de la Concurrence’s Report (2005) notes in several places their high occupancies—and possibly the high uncertainty category as well, suggesting that their information sharing might well have increased occupancy.

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## 7. APPENDIX: NASH EQUILIBRIUM

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**7.1. Modeling considerations.** Understanding merger effects requires a model of pricing decisions that predicts how a merged firm will price in comparison with the separate, pre-merger firms. Typically, it is sufficient to assume firms face a known demand function of prices. Though analytic solutions are rarely available, so general theoretical conclusions are rather weak, numerical solutions for Nash equilibrium profit maximizing prices can often be found. In this context, two additional considerations, random demand and capacity constraints on individual hotels, where sales are given by the minimum of demand and capacity,  $s_1 = \min(q_1, \kappa_1)$ , further complicate the picture.

In a single-product monopoly setting, which characterizes much of the research in this area, consumers who are turned away from a capacity constrained product simply disappear from the model, e.g., Carlton (1978). But for our application—mergers—consumers who are turned away from one hotel might end up in a commonly owned or “sister” hotel. Keeping track of this “diverted” demand requires that we keep track of second choices.

For example, we could specify a “second-choice model” where  $q_{ij}$  is the quantity demanded of product  $i$  as first choice which would go to  $j$  as the second choice, if  $i$  is unavailable. If  $q_1 > \kappa_1$ , but  $q_2 < \kappa_2$ , then a fraction  $q_{12}/q_1$  of the  $q_1 - \kappa_1$  consumers turned away from firm 1 will go to their second choice, firm 2, and similarly if firm 2 reaches capacity and firm 1 can supply some of the diverted demand. In the second-choice model, sales are given by

$$(17) \quad \begin{aligned} s_1 &= \min\left(q_1 + \frac{q_{21}}{q_2} \max(q_2 - \kappa_2, 0), \kappa_1\right) \\ s_2 &= \min\left(q_2 + \frac{q_{12}}{q_1} \max(q_1 - \kappa_1, 0), \kappa_2\right) \end{aligned}$$

Alternatively, we could assume that firms can refer customers, and the customers accept referrals at some rate  $r$ ,  $0 \leq r \leq 1$ , in which case the sales of each product will be given instead by

$$(18) \quad \begin{aligned} s_1 &= \min(q_1 + r \max(q_2 - \kappa_2, 0), \kappa_1) \\ s_2 &= \min(q_2 + r \max(q_1 - \kappa_1, 0), \kappa_2) \end{aligned}$$

However, with the referrals or with second-choice demand, firms could choose to pursue “bait and switch” strategies, where one hotel deliberately prices low to attract demand in excess of its capacity,  $q_1 > \kappa_1$ , and then refers the excess demand to an unconstrained but higher-priced sister hotel,  $q_2 + r(q_1 - \kappa_1) < \kappa_2$ . This is profitable if the loss in profit on sales  $s_1 = \kappa_1$  of product 1 is offset by greater profit  $(p_2 - mc_2)r(q_1 - \kappa_1)$  on product 2. Specifically, if

$$(19) \quad \kappa_1 < -(p_2 - mc_2)r \frac{\partial q_1}{\partial p_1}$$

then  $\partial \Pi_1 / \partial p_1 = \kappa_1$  and

$$(20) \quad \frac{\partial \Pi_2}{\partial p_1} = (p_2 - mc_2) \left( \frac{\partial q_2}{\partial p_1} + r \frac{\partial q_1}{\partial p_1} \right) < (p_2 - mc_2)r \frac{\partial q_1}{\partial p_1}$$

so that  $\partial(\Pi_1 + \Pi_2) / \partial p_1 < 0$ . In other words, increasing price  $p_1$  to bring  $q_1$  back toward capacity  $\kappa_1$  would not be profitable. In fact, this leads to increasing total profit at a low  $p_1$ , making  $q_1$  as large as  $\kappa_1 + \kappa_2$ , while increasing  $p_2$  without bound. But such a degenerate case violates the spirit of the assumption behind successful referrals; and consumers would likely balk at being sucked in by a loss leader and then being pushed off on an high-price substitute that they would not have otherwise chosen. Instead, we consider the possible effects of referrals, but only at reasonable price differentials. We rule out the degenerate cases by assuming that the referrals occur only when there is a local maximum of total profit  $\Pi_1 + \Pi_2$  near the prices where the separate firms were maximizing individual profits.

**7.2. Nash Equilibrium.** We assume that demand for each product has a random component, and imagine that firms have limited information about the distribution of demand. In making pricing decisions firms maximize expected profit, conditional on the information they have. Each firm may have different information about demand, and the Nash equilibrium pricing strategies account for this uncertainty as well as uncertainty about information possessed by rival firms.

Suppose that, as functions of prices  $p_1$  and  $p_2$ , individual demands are given by random variables  $Q_1$  and  $Q_2$  (and more generally also second-choice demands by  $Q_{12}$  and  $Q_{21}$ ) having joint probability density function  $f(q_1, q_2; p_1, p_2, \theta)$  of a known form parameterized by prices and  $\theta$ . As a function of parameters then, let

$$\Pi_i(p_1, p_2, \theta) = E[(p_i - mc_i)s_i] = \int \int_{q_1, q_2} (p_i - mc_i)s_i f(q_1, q_2; p_1, p_2, \theta) dq_2 dq_1$$

where  $s_i$  are the sales of product  $i$  determined by demands, capacities, and second choice or referrals, if any.

Suppose that a fixed common prior distribution,  $g(\theta)$ , is known to both firms, and that each collect additional information,  $I_1$  and  $I_2$ , for example, by sampling a known number of times. Let  $I_{12} = I_1 \cup I_2$  represent the information that merging firms would have if they share. Suppose firms update the prior distribution of  $\theta$

to firm-specific posterior distributions  $g_1$  and  $g_2$ , or with sharing, to a common posterior distribution  $g_{12}$ , in each case defined by

$$g_i(\theta) = g(\theta|I_i) = \frac{\Pr(I_i|\theta)g(\theta)}{\int_{\theta} \Pr(I_i|\theta)g(\theta) d\theta}$$

where  $\Pr(I_i|\theta)$  is the probability density of observing  $I_i$  given a particular  $\theta$ . The different information sets of the firms gives each a different belief  $g(\theta|I_i)$  which each uses to compute expected profit.

In deciding on an optimal price, each firm must forecast what price their competitor will set, which depends on the information the competitor has, but which is unknown to rivals. For example, suppose that firm 1 knows the sample size available to firm 2 but not the observations of firm 2, so firm 1 can determine the probability of any particular possible information realization  $I_2$  firm 2 might have  $\Pr(I_2|\theta)$ , and similarly for firm 2 imagining what firm 1 knows. Suppose also, for simplicity,  $I_1$  and  $I_2$  are independent. Then, as a function of the information  $I_1$  firm 1 collects, firm 1 sets its price  $p_1$  so as to maximize its expected profit, over the posterior distribution it has for  $\theta$  and the distribution of information  $I_2$  that firm 2 is likely to see, assuming how firm 2 will set its price as a function of information  $I_2$ . And firm 2 acts similarly, determining price  $p_2$  as a function of  $I_2$ . A Nash equilibrium is thus a pair of functions  $p_1(I_1)$  and  $p_2(I_2)$  such that, for all  $I_1$ ,

$$\begin{aligned} p_1(I_1) &= \arg \max_{p_1} \mathbb{E}[\Pi_1(p_1, p_2(I_2), \theta)|I_1] \\ &= \arg \max_{p_1} \int_{\theta} \int_{I_2} \Pi_1(p_1, p_2(I_2), \theta) \Pr(I_2|\theta) dI_2 g_1(\theta) d\theta \end{aligned}$$

while at the same time, for all  $I_2$ ,

$$\begin{aligned} p_2(I_2) &= \arg \max_{p_2} \mathbb{E}[\Pi_2(p_1(I_1), p_2, \theta)|I_2] \\ &= \arg \max_{p_2} \int_{\theta} \int_{I_1} \Pi_2(p_1(I_1), p_2, \theta) \Pr(I_1|\theta) dI_1 g_2(\theta) d\theta \end{aligned}$$

For any particular value of  $\theta$ , we can compute the pre-merger equilibrium prices,

$$(21) \quad \mathbb{E}[p_i|\theta] = \int_{I_i} p_i(I_i) \Pr(I_i|\theta) dI_i$$

After a merger, prices are determined, as functions of  $I_{12}$ , so as to maximize total profit,

$$\begin{aligned} (p_1(I_{12}), p_2(I_{12})) &= \arg \max_{(p_1, p_2)} \mathbb{E}[\Pi_1(p_1, p_2, \theta) + \Pi_2(p_1, p_2, \theta)] \\ &= \arg \max_{(p_1, p_2)} \int_{\theta} (\Pi_1(p_1, p_2, \theta) + \Pi_2(p_1, p_2, \theta)) g_{12}(\theta) d\theta \end{aligned}$$

and similarly for expected post-merger prices

$$(22) \quad \mathbb{E}[p_i|\theta] = \int_{I_{12}} p_i(I_{12}) \Pr(I_{12}|\theta) dI_{12}$$

At this level of generality it is difficult to say much about the effect of a merger, measured as the difference between equations 21 and 22. However, as mentioned in the body of the paper, we can isolate the effects of information sharing by imagining that mergers occur in two separate steps: first, firms share information; and then, they price jointly. Decomposing merger effects in this way allows us to derive

analytic results rather than trying to demonstrate the properties of equilibrium using specific functional forms and numerical experiments.