

# POSTED PRICING AS A PLUS FACTOR

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## ABSTRACT

This paper identifies conditions under which an industry-wide practice of posted (or list) pricing is a plus factor sufficient to conclude that firms established an agreement to coordinate their prices. For certain classes of markets, it is shown that, under competition, all firms setting a list price with a policy of no discounting is contrary to competition. Thus, if all firms choose posted pricing, it is to facilitate collusion by making it easier for them to coordinate their prices. It is then argued that the adoption of posted pricing communicates the necessary intent and reliance to conclude concerted action.

*JEL: K21, L13, L41*

## I. INTRODUCTION

To discuss collusion from both an economics and legal perspective, it is best to begin by defining what is meant by "collusion" because economists and lawyers speak of it differently. With regards to market conduct, economists have two categories of behavior: competition and collusion. Competitive behavior is consistent with an equilibrium for a static oligopoly game. That is, a firm's price (or quantity) maximizes current profit given the correctly anticipated prices (or quantities) of its rivals. Collusive (or coordinated) behavior is an equilibrium for a repeated oligopoly game that produces prices in excess of those associated with a static equilibrium (that is, prices are supracompetitive). Though a firm prices in excess of (or produces short of) that which maximizes current profit, it is in the firm's self-interest to do so because of the anticipated reaction by other firms in the future if it was to price lower (or produce more). It is then a feature of collusion that a firm's behavior hinges on what firms have done in the past.<sup>1</sup>

For firms to be at an equilibrium - whether it involves competitive or collusive prices - they must have achieved mutual understanding regarding the strategies that they are pursuing. Collusion is distinguished according to how this mutual understanding is achieved. With explicit collusion, mutual understanding arises through express communication among firms. Generally, this takes the form of verbal communication in which firms reach an agreement as to the strategies they will deploy. Tacit collusion is when mutual understanding occurs without express communication. It is worth noting that while economic theory can describe when collusion is feasible (that is, supracompetitive prices can be sustained as an equilibrium), it has little to say about the likelihood of collusion (since whenever there is an equilibrium with collusion, there is also an equilibrium with competition) nor about the

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<sup>1</sup> For non-technical treatments of how economists think of collusion and how it relates to the law, see Jonathan B. Baker, *Two Sherman Act Section 1 Dilemmas: Parallel Pricing, the Oligopoly Problem, and Contemporary Economic Theory*, 38 ANTITRUST BULLETIN 143 (1993); Dennis A. Yao and Susan S. DeSanti, *Game Theory and the Legal Analysis of Tacit Collusion*, 38 ANTITRUST BULLETIN 113 (1993); Gregory J. Werden, *Economic Evidence on the Existence of Collusion: Reconciling Antitrust Law with Oligopoly Theory*, 3 ANTITRUST L.J. 719 (2004).

relative ease of tacit and explicit collusion because the current paradigm presumes an equilibrium and therefore cannot address whether collusion is achieved through explicit or tacit means.

In defining collusion from the economics perspective, the focus is on the outcome - are prices supracompetitive or not? - and the mechanism used to sustain that outcome. In contrast, collusion as defined by the law rests on whether firms have reached an agreement.

By operationalizing the idea of an agreement, antitrust law clarified that the idea of an agreement describes a process that firms engage in, not merely the outcome that they reach. Not every parallel pricing outcome constitutes an agreement because not every such outcome was reached through the process to which the law objects: a negotiation that concludes when the firms convey mutual assurances that the understanding they reached will be carried out.<sup>2</sup>

When it comes to the law, there are three types of collusion, not all of which violate Section 1 of the Sherman Act. *Conscious parallelism* is when supracompetitive prices are achieved without an agreement. An example often associated with adjacent gasoline or petrol stations is one station raising its price to a supracompetitive level and the other station matching the price hike. While there may be mutual understanding regarding the underlying mechanism that stabilizes those supracompetitive prices (for example, any price undercutting results in a return to competitive prices), this understanding was not reached through any form of direct communication. *Express collusion* is when supracompetitive prices are achieved via express communication about an agreement; there has been a direct exchange of assurances regarding the coordination of their conduct. Conscious parallelism is legal because there is not thought to be an agreement, while express collusion is illegal.

Residing between these two extremes is concerted action. *Concerted action* is when supracompetitive prices are achieved with communication - such as about intentions - but firms do not expressly propose and reach an agreement.

The parties ... engage in a concerted practice by communicating and then act consistently with the communications. While American courts typically use "concerted action" interchangeably with "agreement," Interstate Circuit appears to recognize concerted action as a species of agreement that requires the concurrence of both a plan and an action in accordance with the plan.<sup>3</sup>

In *Interstate Circuit, Inc. v. United States*, 306 US 208 (1939), the Court stated:

It was enough that, knowing that concerted action was contemplated or invited, the distributors gave their adherence to the scheme and participated in it. ... [A]cceptance by competitors, without previous agreement, of an invitation to participate in a plan, the necessary consequence of which, if carried out, is restraint of interstate commerce, is sufficient to establish an unlawful conspiracy under the Sherman Act.<sup>4</sup>

In their attempt to avoid prosecution under the Sherman Act, steel manufacturers assiduously avoided talk of any agreement about prices during their regular meetings.<sup>5</sup> Instead, they made statements as to whether prices

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<sup>2</sup> Baker, *supra* note 1, at 179.

<sup>3</sup> William H. Page, *Communication and Concerted Action*, 38 LOY. U. CHI. L.J. 439 (2007).

<sup>4</sup> *Interstate Circuit, Inc. v. United States*, 306 U.S. 208, 226 (1939).

<sup>5</sup> William H. Page, *The Gary Dinners and the Meaning of Concerted Action*, 62 SMU L. REV. 597 (2009).

were "fair and reasonable" and suggesting prices to be charged. In spite of the lack of express communication as to an agreement, participants admitted to achieving mutual understanding and they were convicted.

In comparing the economic and legal definitions, conscious parallelism and concerted action are types of tacit collusion (as defined by economists) which differ in how mutual understanding is reached. In this paper, the concern is with determining when we can conclude tacit collusion was achieved through concerted action, rather than conscious parallelism, and thus is prosecutable under the Sherman Act.

Given the legal standard, the challenge faced in prosecuting tacit collusion is providing "direct or circumstantial evidence that reasonably tends to prove that [the parties] had a conscious commitment to a common scheme designed to achieve an unlawful objective."<sup>6</sup> What has to be established is that firms have a "unity of purpose or a common design and understanding, or a meeting of minds."<sup>7</sup> The problem is then "how far may we move away from direct, detailed, and reciprocal exchanges of assurances on a common course of action and yet remain within the statutory and conceptual boundaries of an agreement."<sup>8</sup>

This task has proven to be difficult though not entirely insurmountable. One line of attack is to forego trying to establish that there was a "meeting of the minds" through tacit means, and focusing instead on those practices which are suspected of facilitating mutual understanding with regards to coordinated pricing.

I am convinced that the difference between unlawful "tacit collusion" and lawful oligopolistic interdependence is not to be found in any phrase that describes the state of mind of the industry participants. Once we are outside the boundary of a formal agreement, whatever degree of "assurance", "meeting of the minds", "conscious commitment to a common scheme", etc., that exists in a situation of tacit collusion can exist to the same extent in a situation of (lawful) classic oligopoly. Rather, if there is to be a category of unlawful tacit collusion which is to be distinguished from classic oligopoly, the difference must lie, not in the state of mind of the competitors, but on the specific elements of behavior that brought about that state of mind.<sup>9</sup>

Pursuant to this approach, a practice that has arisen in several cases is the public announcement by firms of a policy to set a list price with no discounting off of that list price, or what is referred to as *posted pricing*. This practice was a central feature in a case brought against General Electric and Westinghouse in the market for turbine generators, which are high expenditure custom-ordered equipment commonly purchased by power generating companies.

In May 1963 ... General Electric announced a new pricing policy for turbine generators. One facet of the policy was the publication of a new and more simplified pricing book that permitted rival Westinghouse rather easily to compute the "book" price of any generator on which the two firms might be asked to bid. GE also announced a standard multiplier it would apply to the book price on each bid, and it communicated its intent not to deviate from the standard "book price times

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<sup>6</sup> Monsanto Co. v. Spray-Rite Serv. Corp., 465 U.S. 752, 753 (1984).

<sup>7</sup> American Tobacco Co. v. United States, 328 U.S. 781, 810 (1946).

<sup>8</sup> Phillip E. Areeda, cited in William E. Kovacic, *The Identification and Proof of Horizontal Agreements Under the Antitrust Laws*, 38 ANTITRUST BULLETIN 5, 18-19 (1993).

<sup>9</sup> George A. Hay, *The Meaning of 'Agreement' under the Sherman Act: Thoughts from the 'Facilitating Practices' Experience*, 16 REV. INDUS. ORG. 113, 127-128 (2000).

announced multiplier" procedure in bidding. The multiplier itself varied over time, but changes were publicly announced by General Electric. Consequently, what might otherwise have been a very complex coordination problem was reduced to a matter of Westinghouse's knowing how to calculate the so-called book price and following GE's price leadership with respect to the multiplier. ... [T]he two companies are said to have applied identical multipliers to identical book prices on their turbogenerator bids for the next 12 years - until the practices were challenged by federal antitrust authorities. In sharp contrast to the history of the 1950s and early 1960s [when they explicitly colluded], GE and Westinghouse effected no generator price decreases during this period. General Electric led a number of price increases, with Westinghouse typically following by announcing an identical multiplier increase within four days (although on one occasion the lag was three months). Thus, by linking price leadership to a simplification of the methods for computing bid prices, General Electric successfully avoided the pricing coordination breakdown that had materialized even with outright collusion in earlier periods.<sup>10</sup>

In response to this and other practices, the U.S. Department of Justice planned to file a civil antitrust suit but then the parties settled with a modification of the 1962 consent decree from the previous Section 1 case against these firms. The DOJ's view was:

[Though] there was no evidence of any formal communication or agreement between GE and Westinghouse, ... the independent yet parallel adoption of the new policy by GE and Westinghouse had brought about a meeting of the minds and *facilitated* the elimination of price competition.<sup>11</sup>

Another case in which this practice arose was the private suit *Wall Products Co. v. National Gypsum Co.*, 326 F. Supp. 295 (1971). The major producers of gypsum wallboard had a policy of not offering discounts off of their list price, though with some exceptions. Due to declining demand and excess industry capacity, this policy unraveled in 1964-65 with ever-increasing discounts and a drastic decline in profits. In response, United States Gypsum Company (USG) mailed the following announcement to its customers:

Any discounts of gypsum board and/or plaster products previously extended to meet competition will be withdrawn as of December 15, 1965. As a constructive move, we have decided to sell our gypsum products solely on the basis of our published prices.<sup>12</sup>

In its decision, the U.S. District Court stated:

The USG witnesses unanimously testified that the success of the new pricing policy was dependent on the other major competitors following suit. As Mr. Watt [Vice-President of Marketing at USG] said, the great danger of this announcement was "the possibility that the other producers would go right on making or meeting lower prices."<sup>13</sup>

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<sup>10</sup> F. M. SCHERER, *INDUSTRIAL MARKET STRUCTURE AND ECONOMIC PERFORMANCE* 182 (2d Ed. 1980).

<sup>11</sup> Hay, *supra* note 9, at 115.

<sup>12</sup> *Wall Products Co. v. National Gypsum Co.*, 326 F. Supp. 295, 319 (1971).

<sup>13</sup> *Id.* at 319.

Shortly after this announcement, all major suppliers followed USG's lead by adopting the same no-discounting policy with the same effective date. Georgia-Pacific and National made their announcement one week later, with five other suppliers following suit within two weeks. The U.S. District Court concluded:

That during the period from December 15, 1965 until January 1, 1968, USG, National and Kaiser combined and conspired among themselves and with others, to stabilize and maintain the price level of gypsum wallboard through a course of interdependent conscious parallel action pursuant to a tacit understanding by acquiescence coupled with assistance whereby they mutually agreed to, and did in fact, effective December 15, 1965, withdraw all deviations from list or published prices of gypsum wallboard ...<sup>14</sup>

In both the turbine generator and gypsum wallboard cases, the practice of direct concern was the contemporaneous public adoption of a policy to set list prices and not offer discounts. There was no evidence of an express agreement to adopt this new pricing policy, nor regarding the list prices to be set. The open question I seek to address here is whether circumstances can be identified under which the parallel adoption of posted pricing is sufficient to establish an agreement to restrain trade. A critical step in doing so will be to rule out reasons for adopting posted pricing unrelated to collusion, for if there is a legitimate rationale for posted pricing then it will be difficult to "exclude the possibility of independent action"<sup>15</sup> and avoid a summary judgement in favor of the defendants. Towards that end, the various effects of posted pricing are described in Section 2, which are: i) reducing consumers' search costs; ii) reducing firms' selling costs; iii) reducing the responsiveness of price to cost and demand conditions; and iv) affecting the manner in which firms compete. As (i) and (ii) provide legitimate rationales for the adoption of posted pricing, market situations are identified for which these effects are minimal. To explore (iii) and (iv), economic analysis is conducted to determine when competitive firms will adopt posted pricing. A non-technical summary of that analysis is provided in Section 3, while the technical analysis is provided in Appendix A. Using that economic analysis, Section 4 builds on some recent legal arguments by William Page to make the case for concerted action when there is parallel adoption of posted pricing.<sup>16</sup>

## II. CATALOG OF EFFECTS OF POSTED PRICING

Posted pricing has a long history. Quakers were an early proponent on the grounds that customers should be charged a "fair price" and if what is fair does not vary with the customer then all customers should receive the same price.<sup>17</sup> With the advent of department stores and sales being conducted by paid employees (compare this to the owner-run general store), it became desirable to centralize pricing authority. By the mid-19<sup>th</sup> century, Bon Marche in Paris<sup>18</sup> and Macy's in New York<sup>19</sup> were charging a fixed price for goods. Clearly, posted pricing has a history quite

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<sup>14</sup> *Id.* at 328.

<sup>15</sup> *Monsanto*, 465 U.S. at 768.

<sup>16</sup> Page, *supra* note 3; William H. Page, *Facilitating Practices Under Section 1 of the Sherman Act*, in ANTITRUST LAW AND ECONOMICS 23 (Keith Hylton, ed., 2010).

<sup>17</sup> Stephen A. Kent, *The Quaker Ethic and the Fixed Price Policy: Max Weber and Beyond*, 53 SOC. INQUIRY 16 (1983).

<sup>18</sup> MICHAEL B. MILLER, *THE BON MARCHE: BOURGEOIS CULTURE AND THE DEPARTMENT STORE, 1869-1920* (1993).

<sup>19</sup> RALPH M. HOWER, *HISTORY OF MACY'S OF NEW YORK, 1858-1919* (1943).

independent of any role it might play in facilitating collusion. It is then critical to distinguish the many instances in which posted pricing is legitimate from when it is not.

In considering the various effects of posted pricing, the alternative is to have, to some degree, transaction-specific pricing, whereby price may vary with customer traits, the particulars of the product demanded, and the time at which the customer requests a price quote.<sup>20</sup> Transaction-specific pricing can involve a range of institutions ranging from the seller making a take-it-or-leave-it offer to the buyer (as they do with posted pricing but where now the price is tailored to the transaction) to back-and-forth negotiation between the buyer and seller. In our economic analysis, the former is assumed and there will be some discussion of the robustness of results to the latter. The general discussion in this section applies quite broadly to transaction-specific pricing.

There are four possible effects of moving from transaction-specific pricing to posted pricing: i) reducing consumers' search costs; ii) reducing firms' selling costs; iii) reducing the responsiveness of price to cost and demand conditions; and iv) affecting the manner in which firms compete. The first two effects relate to buyers and sellers incurring lower costs to transact.

By having a set price, it is potentially easier for a consumer to collect price information compared to some other institutions such as bargaining. These lower search costs from posted pricing can benefit consumers in three ways. First, even if the prices charged are the same and a consumer considers the same set of sellers (that is, conduct the same set of searches), lower search costs mean a consumer has engaged in less time and effort in collecting this information, and thereby benefits. Consider, for example, the retail automobile market where buyers and sellers negotiate over price. A buyer engages in a time-consuming and, depending on the person, mentally-draining negotiation in order to learn a car's price. An auto retailer posting a non-negotiable price avoids those consumer costs.<sup>21</sup> There is then a pro-competitive benefit from posting prices in that it reduces these search costs. Second, a reduction in search costs will generally mean it is optimal for consumers to engage in more search. Thus, even if each firm's price is unchanged with posted pricing (compared to the preceding pricing institution), conducting more search means a consumer will find a better deal because the minimum observed price will be lower, on average. Third, competing firms may be inclined to price lower in response to the anticipation that consumers will search more, in which case consumers again benefit.<sup>22</sup>

If firms are not colluding, they too can benefit from the reduction in consumers' search costs brought about by posted pricing. By making it easier for consumers to search, more consumers are attracted to the market because they anticipate finding a better deal. Firms can then benefit from larger demand. This effect potentially provides a

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<sup>20</sup> To some degree, these features can be built into a posted pricing scheme by specifying a formula mapping product features into price or having seasonal pricing. But even if this is done, price will be less sensitive to these factors under posted pricing.

<sup>21</sup> It has been argued that firms may offer a mixture of formats - some posting price, some negotiating over price - because of buyer heterogeneity in the skill or cost of bargaining among buyers. Unskilled bargainers will buy from posted price firms - at relatively high prices - and skilled bargainers will buy from those which negotiate. See, e.g., Michael A. Arnold and Steven A. Lippman, *Posted Prices versus Bargaining in Markets with Asymmetric Information*, 36 *ECON. INQUIRY* 450 (1998); Preyas S. Desai and Devarat Purohit, 'Let Me Talk to My Manager': *Haggling in a Competitive Environment*, 23 *MARKETING SCI.* 219 (2004).

<sup>22</sup> See, e.g., Anderson, Simon and Regis Renault, *Pricing, Product Diversity, and Search Costs: A Bertrand-Chamberlain-Diamond Model*, 30 *RAND J. ECON.* 719 (1999). They find that prices fall when search costs are lower. In that paper - and related ones which endogenize price in a market with search costs - the pricing institution is kept fixed (which happens to be posted pricing) and an exogenous cost to search is changed.

rationale for firms to adopt posted pricing which is predicated on reducing market frictions, rather than facilitating collusion.

Posted pricing can also act to reduce firms' selling costs. Consider again the case of auto retailing. If price is to be determined through buyer-seller bargaining then a sales representative needs to be skilled in the art of negotiation. But when there is posted pricing - as occurs through the use of such web sites as Autobytel.com - an auto dealer's sales representative does not negotiate price, though must still sell the merits of the car and the dealership. For the firm, posted pricing reduces training expenditure, lowers the wages they have to pay to attract skilled sales representatives, and results in more transactions per employee as each transaction takes less time since there is no negotiation over price. Firms directly benefit from these lower selling costs. Consumers may also benefit if these lower selling costs translate into lower prices. As with lower consumer search costs, lower selling costs provide a pro-competitive benefit and a rationale for firms to adopt posted pricing apart from aiding collusion.

As the preceding discussion suggests, there are clearly some markets - perhaps most markets - for which the savings in consumers' search and firms' selling costs from posting prices are likely to be significant, and thereby provide a legitimate basis for this practice. Most retail markets in developed countries have naturally evolved to having posted pricing, presumably for these reasons. The point seems obvious and not worth belaboring.

What I want to claim is that there are also markets for which the reduction in consumers' search and firms' selling costs from posted pricing - as opposed to transaction-specific pricing - are likely to be trivial, and thus do not provide a pro-competitive benefit nor a competitive rationale for firms setting list prices with a no discounting policy. One such example is the market for turbine generators, which was previously discussed. It is reasonable to presume that a purchasing agent for an electric power company would receive a price quote from both GE and Westinghouse, whether those suppliers post prices or a purchasing agent must go through a series of price negotiations with employees of GE and Westinghouse. The expenditure associated with the product is sufficiently large to warrant investing the time to get a price quote. In that case, consumers will have the same information irrespective of the pricing format used by sellers. Furthermore, any savings in search costs are small relative to the expenditure involved and thus are very unlikely to affect any welfare calculation. From the suppliers' perspective, there is still a need for a well-trained sales force even with posted pricing. Though there is no price negotiation, there are many non-price traits to inform a customer on, including product features, quality, warranty, delivery and installation, and after-sales support. Again, the savings in time and training from posting prices are likely to be minimal. It would then seem that this market is one for which posted pricing would generate little in terms of cost savings to consumers and firms.

Moving beyond examples, it is useful to identify those factors which determine the extent of savings in consumers' search and firms' selling costs from the adoption of posted pricing. First, the fewer suppliers there are, the more likely that a consumer will learn all suppliers' prices whether or not firms engage in posted pricing, in which case pro-competitive benefits from posted pricing are less. Second, the larger expenditure associated with the product (whether due to a high price per unit or high volume), the more attractive is it to engage in intense search regardless of the firms' pricing format in that the expected benefit from a lower price is likely to be large relative to the search costs. Third, the more differentiated and less-standardized the product, the more valuable it is for firms to

have a well-trained skilled sales force, even if they post prices. In sum, savings in consumers' search and firms' selling costs are likely to be lowest when consumers are industrial buyers making large purchases of a non-standardized product from a limited set of suppliers. In contrast, markets involving standardized low expenditure products with many suppliers are likely to have significant pro-competitive benefits from posted pricing. While the cost savings from posting price are then apt to be quite ubiquitous in retail markets, they may be of much less relevance when customers are industrial buyers.

Let us hereon consider markets for which the savings in consumers' search and firms' selling costs are minimal, which leaves two effects to be evaluated. First, posted pricing reduces the responsiveness of price to cost and demand conditions. By setting a list price for some period of time and not offering discounts, price is less sensitive to changes in input prices, customer characteristics, capacity constraints, and the like. Second, posted pricing affects the manner in which firms compete. A firm is likely to end up charging a different price if its rivals are posting price compared to when they are setting transaction-specific prices. The direction of that effect is not obvious and is examined in the next section.

### III. ECONOMIC ANALYSIS

This section provides a non-technical summary of the formal economic analysis, which is in Appendix A. Results are first described for a simple setting with firms offering identical products, and then followed with a discussion of how the main finding is robust to various modifications including firms having differentiated products.

Consider a market with two firms, each with a single product. A firm's marginal cost varies over time because of changes in, for example, input prices, productivity of plant and equipment, and customer preferences (that is, the cost of supplying the current customer may depend on that customer's traits). On average, firms have the same cost but, in any given period, these costs may differ because of the aforementioned cost shocks. Firms decide whether to have a list price without discounting (referred to as the posted price format) or to have customer-specific discounts (quoted price format). As with GE's price book, the idea of a posted price is that it is fixed over some extended length of time. In the context of our model, this means that price is chosen prior to learning the current period's cost. For example, the price book or multiplier may be adjusted annually, while there is a customer arriving each week. In contrast, a quoted price format means that price is set for each customer, and thus is set after a firm learns its cost for supplying the current period's customers. What is critical is that a firm's price under the quoted price format is more sensitive to the cost of serving a particular customer at a particular point in time than the posted price format.

The sequence of decisions is as follows:

- Price Format Stage: Firms simultaneously choose between the posted price and quoted price formats.
- Price Stage
  - If a firm chose the posted price format then it chooses its price prior to learning its cost. (It price is then based on its expected marginal cost.)



- If a firm chose the quoted price format then it chooses its price knowing its current cost and, if the other firm chose the posted price format, the other firm's (posted) price as well. If both firms chose the quoted price format then they simultaneously choose price, each knowing its own cost but not the other firm's price.

Assume that any savings in consumers' search and firms' selling costs from the posted price format are minimal. A firm's decision concerning its price format is then driven by its effect on the intensity of competition and the responsiveness of price to cost conditions.

When both firms choose the same format - whether posted or quoted price - price competition is as it is usually modelled in that firms set prices and a consumer chooses between the two firms' products given those prices. The difference is that when both firms have the quoted price format, their prices are able to respond to the most recent cost information, which is not the case when they both have the posted price format. If firms have different price formats then the posted price firm is effectively a first-mover because the quoted price firm knows its rival's posted price when it selects the price for the current customer. Consistent with the assumption of low consumer search costs, consumers costlessly observe both firms' prices, regardless of the price format.

Let us consider the incentives of firm 1 with regards to its price format, when firm 2 has the posted price format. If firm 1 chooses the posted price format as well then firms will simultaneously choose prices based on their expected cost. As is usual with Bertrand price competition, prices are set at a firm's (expected) unit cost.<sup>23</sup> Thus, if both firms have the posted price format then, with identical products, firms price at cost and earn zero profit (that is, a competitive rate of return). Now consider firm 1 instead choosing the quoted price format, while continuing to suppose that firm 2 posts price. Firm 1 then chooses its price after learning its cost and the posted price of firm 2. Now, firm 1 can earn positive expected profit. If firm 1's cost proves to be below the posted price of firm 2, firm 1 undercuts firm 2's price and sells at a positive profit margin. If instead firm 1's cost exceeds the posted price of firm 2 then it prices at cost and makes no sales. Thus, in expectation, firm 1 earns positive profit from quoting price, which exceeds the zero profit from posting price. Intuitively, a firm gains a tremendous advantage with the quoted price format when its rival posts price as it can simply undercut the posted price by a small amount and capture the whole market at a positive margin, while if it also chooses the posted price format then intense price competition ensues with price equal to expected marginal cost.

Now suppose firm 2 chose the quoted price format. The analysis is more subtle but, again, firm 1 earns higher profit with the quoted price format. If firm 1 chooses the posted price format then, by the argument above, firm 2 (which now has the quoted price format) will undercut firm 1's posted price as long as it exceeds firm 2's cost. Thus, if firm 1 posts price and firm 2 quotes price, firm 1 will end up selling if and only if its price is less than firm 2's current cost. From firm 1's perspective, it is "as if" firm 2 is pricing at its cost because firm 1 has the lower price only when its posted price is less than firm 2's cost. Now suppose firm 1 instead also chooses the quoted price format. Both firms are then learning their current cost and choosing price. In that setting, it'll be optimal for firms to price above cost. If both firms instead priced at cost, each would earn zero profit; by instead pricing a little bit above its cost, a firm will still make a sale with positive probability (specifically, when its rival's cost - and price - exceeds

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<sup>23</sup> It is not stable for both firms to set a common price above cost and share the market because each firm would have an incentive to undercut its rival's price and capture all of demand. Only when firms price at cost is there no incentive to undercut.

this firm's price) and thus earn positive expected profit. Hence, when both firms quote prices and thereby have their prices responsive to current cost, each will price above its current cost. Summarizing, given firm 2 chooses the quoted price format, if firm 1 chooses the posted price format then firm 1 only makes a sale when firm 2's cost exceeds firm 1's price, while if firm 1 has the quoted price format then it makes a sales when firm 2's price (which exceeds its cost) exceeds firm 1's price. The latter environment involves less aggressive pricing by firm 2 and thus firm 1 has higher expected profit from the quoted price format. In concluding, when a firm's rival uses the quoted price format, the rival prices less aggressively when a firm also uses the quoted price format than when it uses posted price format. In addition, with the quoted price format, a firm is able to adjust its price to its cost, in which case expected profit is even higher.

We have then argued that, regardless of the price format chosen by the rival firm, a firm's profit is higher from the quoted price format than from the posted price format. When firms' products are identical, adoption of the posted price format is then inconsistent with competitive firms acting in their best interests. This leads to the following conclusion.

**Remark 1:** If firms' products are identical then, under competition, both firms choose the quoted price format.

In the remainder of this section, I want to argue the robustness of the general conclusion that the mutual adoption of posted pricing is inconsistent with competition when savings in consumers' search and firms' selling costs are minimal. While the preceding analysis was done when firms choose their price formats simultaneously, results extend to when formats are chosen sequentially, which is more consistent with the turbine generator market as GE announced a posted price format and then Westinghouse reciprocated. If GE was to chooses its format first then, regardless of which format it chose, Westinghouse will find it more profitable to respond with the quoted price format (under the assumption that firms are competing). Anticipating that response, it is optimal for GE to choose the quoted price format as well. Thus, whether formats are chosen simultaneously or sequentially, firms will choose the quoted price format.

Thus far it has been assumed that the alternative to posting price is making a customer-specific fixed price offer. A different alternative is for the seller and buyer to negotiate. This raises the question of whether posted pricing is inconsistent with competition if firms had to choose between negotiation and the posted price format; in fact, it is. If both firms have the posted price format then competition will drive price down to expected cost so that each firm earns zero expected profit. Now suppose a seller negotiated with buyers. As long as negotiation does not always give all of the surplus to the buyer - for example, the firm with the lower cost in the current period is bargained down to a price below the higher cost firm but not all the way down to its own cost - then expected profit is positive to a firm who chooses a negotiation format, regardless of the pricing format chose by its rival. Thus, it is inconsistent with competition for both firms to choose the posted price format even when the alternative is negotiating with buyers.<sup>24</sup>

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<sup>24</sup> It is less clear that this robustness to having the negotiation format extends to the case of differentiated products. The issue is left to future research.

Finally, let us consider when firms' products are differentiated, so a consumer would be willing to pay a higher price for its more preferred product. A firm's expected demand is generally positive - even if its price exceeds the price of its rival - and is higher when its price is lower and the rival's price is higher. Suppose firm 2 has the posted price format. It can be shown that, under competition, firm 2's posted price is higher when firm 1 has the quoted price format than when firm 1 has the posted price format; the reason is as follows. When firm 2 posts price and firm 1 quotes price, firm 2 acts like a price leader, and firm 2 knows that firm 1 will have a tendency to undercut firm 1's price in order to raise its market share.<sup>25</sup> Recognizing this undercutting tendency, firm 2 will price higher in order to induce firm 1 to price higher since firm 2's expected demand and profit are increasing in its rival's price. In contrast, when firm 1 also posts price then firm 2 does not have the position as a price leader and thus the aforementioned incentive of firm 2 to price higher is absent. Given that firm 2 prices higher when firm 1 quotes price than when it posts price, firm 1 will earn higher profit by quoting price since its profit is increasing in firm 2's price. The implication is that if one firm selects the posted price format then the other firm will surely select the quoted price format; therefore, under competition, both firms will not post price.<sup>26</sup>

**Remark 2:** If firms' products are differentiated then, under competition, both firms do not choose the posted price format.

To summarize the results of this section, when firms have homogeneous products, it is strictly more profitable for a firm to use the quoted price format than the posted price format, regardless of its rival's format. When firms have differentiated products, the industry-wide adoption of posted pricing is inconsistent with competition. The parallel adoption of posted pricing is then not in a firm's best interests when firms are competing and any savings in consumers' search and firms' selling costs from the posted price format are minimal. Since the posted price format is known to facilitate collusion, it follows that the mutual adoption of posted pricing is in firms' best interests only if they anticipate coordinating their prices.

#### IV. LEGAL ANALYSIS

There are three steps to the analysis in this section. First, I review the legal argument that an agreement can be inferred without express communication if it can be shown that firms communicate their intent to coordinate pricing and their reliance on each other to do the same. This communication is a plus factor that establishes concerted action. Second, it is argued that such communication of intent and reliance is achieved when each firm takes an action that is only in its best interests if it would subsequently lead to coordinated pricing. Third, using the economic analysis of Section 3, this legal argument is used to conclude that, under certain circumstances, the parallel adoption

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<sup>25</sup> With differentiated products, this undercutting will not be as stark as with homogeneous goods (in which case firm 2's price is just below firm 1's price) but it is present nevertheless.

<sup>26</sup> The possibility that one firm posts price and the other quotes price has not been ruled out. Further analysis is required to determine whether that can or cannot occur under competition.

of posted pricing meets the standard laid out in the second step and thereby demonstrates the existence of an agreement.

The starting point to our analysis is the lack of evidence that firms have engaged in express communication regarding an agreement. As is now well-established, plus factors must be identified from which it can be inferred there was an agreement. Useful for identifying such plus factors is considering what is sufficient to conclude that firms have engaged in concerted action. Under the principle of concerted action, firms, while not expressly engaging in an agreement, do, in some manner, communicate a plan and then follow through with it. Applying the work of Black<sup>27</sup>, William Page argues:

[F]irms' actions become concerted when the firms have achieved the conditions of conscious parallelism by communication of their intent to raise prices and their reliance on one another to do the same. Crucially, the rivals need not have exchanged promises of assurances of their actions; it is enough that they have communicated their intent to act and their reliance on others to do so. ... Communication of intent and reliance is a tangible, culpable action that differs from the actions of firms in an ordinary competition or in a simple conscious parallelism. The character of the communications and their proximity to parallel action in conformity with the communications distinguish them from other, benign exchanges.<sup>28</sup>

A plus factor can then be a practice that communicates the intent and reliance among firms to coordinate pricing. Towards identifying such plus factors, let us review how express communication achieves intent and reliance. Suppose a firm is aware of how supracompetitive pricing results from conscious parallelism, as is described in any industrial organization textbook. If a firm proposes to its rival that they price in the described manner of conscious parallelism and the rival accepts this invitation then, in fact, they are not engaging in conscious parallelism for there is an agreement. The literal interpretation of their expressions leads to the mutual understanding that we think of as an agreement because a firm finds it in its best interests to do as it has expressed as long as it is believed by the other firm. In other words, this communication produces an agreement because the words have meaning as to what firms intend to do. A firm proposes to coordinate pricing because it believes that if the other firm accepts this proposal then said coordinated pricing will ensue. Similarly, the other firm accepts this proposal because it believes that, by doing so, coordinated pricing will ensue.

Now suppose there is an action that would be in a firm's best interests to take only if it believed it would subsequently lead to coordinated pricing. Furthermore, it is in the best interests of a rival firm to respond by taking the same action only if it believed it would result in coordinated pricing. Just as the verbal invitation to coordinate prices is made because its acceptance is expected to result in coordinated pricing, a firm takes this action because the other firm's similar response is expected to result in coordinated pricing. Whether it is the spoken word or the implemented action, each is made with the anticipation that firms will coordinate their prices. Of course, whether they succeed or not is a distinct matter. What is essential is that firms anticipate coordinated pricing when making a verbal proposal to do so or taking an action that is in a firm's best interests only if it resulted in coordinated pricing.

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<sup>27</sup> OLIVER BLACK, CONCEPTUAL FOUNDATIONS OF ANTITRUST (2005).

<sup>28</sup> William H. Page. *Twombly and Communication: The Emerging Definition of Concerted Action under the New Pleading Standards*, 5 J. COMPETITION L. & ECON. 439, 451-452 (2009).

In a related manner, Richard Posner has proposed that conscious parallelism can, in some instances, be thought as a contractual arrangement and thus warrant prosecution (though he also recognizes that this approach is not consistent with current judicial practice).

[O]ne seller communicates his "offer" by restricting output, and the offer is "accepted" by the actions of this rivals in restricting their outputs as well. It may therefore be appropriate in some cases to instruct a jury to find an agreement to fix prices if it is satisfied that there was a tacit meeting of the minds of the defendants on maintaining a noncompetitive pricing policy. ... What is being proposed is less the alteration of the substantive contours of the law than a change in evidentiary requirements to permit illegal price fixing to be found in circumstances in which an actual meeting of the minds on a noncompetitive price can be inferred even though explicit collusion cannot be proved.<sup>29</sup>

As a member of the Seventh Circuit Court, Judge Posner also articulated this view *In re High Fructose Corn Syrup Antitrust Litigation*, 295 F.3d. 651, 652 (7th Cir. 2002).

Section 1 of the Sherman Act forbids contracts, combinations, or conspiracies in restraint of trade. This statutory language is broad enough, as we noted in *JTC Petroleum Co. v. Piasa Motor Fuels, Inc.*, 190 F.3d 775, 780 (7th Cir. 1999), to encompass a purely tacit agreement to fix prices, that is, an agreement made without any actual communication among the parties to the agreement. If a firm raises price in the expectation that its competitors will do likewise, and they do, the firm's behavior can be conceptualized as the offer of a unilateral contract that the offerees accept by raising their prices.<sup>30</sup>

At least as described, Posner's example is problematic because the inference of an agreement to coordinate pricing is just one of several that can be drawn. A firm raising its price and the other firm responding in kind could just as well reflect competitive pricing in response to a rise in cost or demand. Either of those factors would induce the first firm to raise price, while a competitive response by its rival would be to also raise price. As is recognized, Posner's argument would not survive summary judgment for it does not "exclude the possibility of independent action," nor would it survive the pleading stage because

when allegations of parallel conduct are set out in order to make a §1 claim, they must be placed in a context that raises a suggestion of a preceding agreement, not merely parallel conduct that could just as well be independent action.<sup>31</sup>

By comparison, the approach I am deploying is more stringent in that it requires that the *only* reasonable inference from firms' behavior is that they plan to coordinate pricing because their actions are consistent with their best interests *only if* coordinated pricing ensues.

I now turn to applying this approach to when posted pricing is the practice in question.

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<sup>29</sup> RICHARD POSNER, *ANTITRUST LAW* 94-95, 98 (2d Ed. 2001).

<sup>30</sup> *In re High Fructose Corn Syrup Antitrust Litigation*, 295 F.3d. 651, 652 (7th Cir. 2002).

<sup>31</sup> *Bell Atlantic Corp. v. Twombly*, 550 U.S. 544, 559 (2007).

**Recommendation:** An agreement is inferred when:

1. Prior to the adoption of posted pricing, firms routinely sold at prices below any publicly announced list price, or did not have a publicly announced list price.
2. The adoption of posted prices is consistent with a firm's best interests only if it anticipates that firms will subsequently coordinate their pricing.
3. Following the adoption of posted prices, prices are higher and more uniform across firms.
4. The market is characterized by conditions (number of firms, entry barriers, etc.) that make collusion (as defined by economists) feasible.

(2) provides communication of intent and reliance for the purpose of establishing an agreement, as has been argued. By the analysis in Section 3, we know that (2) is not vacuous for, when the savings in consumers' search and firms' selling costs from posting price are minimal, it is not profitable for firms to post prices if they anticipate pricing competitively; only if posted pricing can assist in coordinated pricing is such behavior optimal.

(1) provides context to enhance the clarity of the communication in (2), the relevance of which was noted in *Esco Corp. v. United States*, 340 F.2d 1000 (9th Cir. 1965).

[I]t remains a question for the trier of fact to consider and determine what inference appeals to it (the jury) as most logical and persuasive, after it has heard all the evidence as to what these competitors had done before such meeting, and what actions they took thereafter, or what actions they did not take.<sup>32</sup>

When its rivals are expected to engage in discounting, it is clearly against a firm's interests to fix its price at some publicly announced level, as doing so makes it exceedingly easy for rivals to undercut the firm's price and capture sales. Thus, if it has been common practice to offer discounts off of a list price, the adoption of a fixed publicly announced price can only be in a firm's best interests if it anticipates rivals discontinuing the activity of discounting.

If posted pricing successfully facilitated collusion then corroborative evidence is that firms' prices are higher and more uniform (as, for example, was found in the turbine generator market). Thus, (3) provides evidence that the adoption of posted pricing had the effect of allowing firms to coordinate their prices, and serves to support the theoretical argument that it could only have been done for that purpose.

In the absence of an admission [by the defendants that they agreed to fix their prices], the plaintiff must present evidence from which the existence of such an agreement can be inferred. The evidence upon which a plaintiff will rely will usually be and in this case is of two types – economic evidence suggesting that the defendants were not in fact competing, and noneconomic evidence suggesting that they were not competing because they had agreed not to compete.<sup>33</sup>

As has been argued, (2) is evidence that firms agreed not to compete, while (3) is evidence that they did not compete.<sup>34</sup>

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<sup>32</sup> *Esco Corp. v. United States*, 340 F.2d 1000 (9th Cir. 1965)

<sup>33</sup> *In re High Fructose Corn Syrup*, 295 F.3d. at 653.

<sup>34</sup> For other types of evidence of collusive behavior, see Joseph E. Harrington, Jr., *Detecting Cartels*, in *HANDBOOK OF ANTITRUST ECONOMICS* 213 (Paolo Buccirossi, ed., 2008).

Finally, as specified in (4), it is important to establish that market conditions are consistent with collusion being stable, according to economic theory and empirical evidence.<sup>35</sup> These have been referred to as "background plus factors":

With *Monsanto* in mind, it is useful to distinguish between "plus factors" that establish a background making conspiracy likely and "plus factors" that tend to exclude the possibility that the defendants acted without agreement. ... Background facts showing a situation conducive to collusion do not tend to exclude the possibility of independent action ... but they nevertheless form an essential foundation for a circumstantial case. In *Matsushita Electric Industrial Co. v. Zenith Radio Corp.*, 475 U.S. 574, 593-598 (1986), the Supreme Court held that a conspiracy case based on circumstantial evidence must be economically plausible. The background "plus factors" of market structure, motivation and opportunity play an important role in establishing such plausibility.<sup>36</sup>

If, in fact, (4) was not satisfied then we would be left with a contradiction. By (2) and (3), economic theory and evidence would have established that firms have effectively colluded, while failure to satisfy (4) would have shown that effective collusion is highly unlikely.

The analysis has focused on identifying circumstances under which the adoption of posted pricing is the basis for inferring that firms have entered into an agreement to coordinate their prices and thereby restrain trade. As posted pricing is not (and should not be) a *per se* offense, proving a violation of Section 1 of the Sherman Act requires showing it is an *unreasonable* restraint of trade under the rule of reason. There must be evidence that there was an effect on price - specifically, prices are higher than they would have been but for the agreement - and sufficiently offsetting pro-competitive benefits are lacking. As the presence and size of pro-competitive benefits from posted pricing will vary from case to case, a universal statement regarding whether the adoption of posted pricing will satisfy the rule of reason is not possible. However, if the criteria laid out above are satisfied, it is, in fact, likely that the rule of reason will be satisfied. (3) requires that there is an anti-competitive effect in the form of higher prices. (2) requires that there is no rationale for firms to adopt posted pricing other than for the purposes of coordinating their prices, which serves to rule out the most common sources of pro-competitive benefits from posted pricing. Indeed, the set of circumstances under which posted pricing provides pro-competitive benefits but the source of those benefits do not provide an independent rationale for firms to adopt posted pricing is surely to be small if not non-existent. In sum, satisfaction of the criteria for concluding that the adoption of posted pricing is evidence of an agreement will go a long way to proving that the agreement has unreasonably restrained trade and thus violated Section 1 of the Sherman Act.

I have argued that, under certain conditions, the adoption of posted pricing can provide the requisite communication of intent and reliance to conclude concerted action among firms. One critique is that the communication is not private among firms, and public messages are too ambiguous to provide what is necessary to lead to mutual understanding among firms.

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<sup>35</sup> For a summary of some these conditions, see MASSIMO MOTTA, *COMPETITION POLICY: THEORY AND PRACTICE* (2004).

<sup>36</sup> *Blomkest Fertilizer, Inc. v. Potash. Corp. of Saskatchewan, Inc.*, 203 F. 3d 1028, 1065 (8th Cir. 2000).

[C]oncerted action under Section 1 of the Sherman Act requires, beyond evidence of parallel conduct, evidence that rivals have communicated their intentions to act in a certain way and their reliance on each other to follow suit. To convey the requisite information, the communication must ordinarily be private and repeated, and must relate to present or future prices. These considerations apply in the case of facilitating practices as well. In the rural gas station hypothetical, for example, coordination of prices would be more difficult if the stations did not post their prices on signs as well as at the pump. Thus, public price posting is literally a facilitating practice that involves price communication. But courts would certainly not find that posting prices on signs amounted to a plus factor, because it also has the legitimate purpose of informing consumers of rivals' prices. Public "signaling" and "monitoring" of prices are too ambiguous in their effects to amount to plus factors, because they cannot convey the necessary intent and reliance.<sup>37</sup>

While these are valid points regarding the *potential* ambiguity of public signals, the heart of the matter is not whether signals are public or private but rather whether the signal's content is clear. When a signal is meaningful to different agents for different reasons, there can be ambiguity as to a firm's intent in sending it, but not all public signals suffer from such a lack of clarity. That publicly announced prices could lead to an inference of conspiracy was recognized as a possibility *In re Coordinated Pretrial Proceedings in Petroleum Prods. Antitrust Litigation*, 906 F.2d 432 (9th Cir. 1990).

[T]he tankwagon prices or dealer discounts are not of immediate significance to anyone other than the oil companies and their franchised dealers. ... [T]he dealers were individually notified concerning any changes in the tankwagon prices or in the level of dealer discount. In light of this fact, it appears that the public dissemination of such information served little purpose other than to facilitate interdependent or collusive price coordination. ... [W]e believe that the evidence concerning the purpose and effect of price announcements, when considered together with the evidence concerning the parallel pattern of price restorations, is sufficient to support a reasonable and permissible inference of an agreement, whether express or tacit, to raise or stabilize prices.<sup>38</sup>

The Ninth Circuit Court was making the point that, because the public announcement of prices was of value only to sellers, it was not to be treated differently from a private announcement among sellers. This is quite analogous to the preceding argument made with respect to posted pricing. While a policy of publicly announcing fixed prices *could* be of value to buyers, in some instances it is not (specifically, where consumers' search costs are low) and, in those cases, a firm's public announcement of list prices (with a policy of no discounting) is information that is useful only to its rivals.

Finally, it may prove instructive to draw a contrast with the theory being argued here and the arguments made in connection with *United States v. Container Corp. of America*, 393 US 333(1969). In that case, ... all that was present was a request by each defendant of its competitor for information as to the most recent price charged or quoted, whenever it needed such information and whenever it was

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<sup>37</sup> Page, *supra* note 10, at 25-26.

<sup>38</sup> *In re Coordinated Pretrial Proceedings in Petroleum Prods. Antitrust Litigation*, 906 F.2d 432, 445, 448-449 (9th Cir. 1990).



not available from another source. Each defendant on receiving that request usually furnished the data with the expectation that it would be furnished reciprocal information when it wanted it.<sup>39</sup>

The Court concluded there was an agreement among sellers to exchange price information but there was no agreement over prices. The rule of reason was then used to reverse the lower court's dismissal of the case by appealing to evidence that this agreement influenced firm behavior. The Court's argument was then two-fold: i) there was an agreement to exchange price information; and ii) this agreement had unlawful effects.

The *Container* case and the theory articulated here both revolve around facilitating practices: the reciprocal exchange of price information and posted pricing, respectively. However, the role they play in the legal strategy is quite different. In *Container*, it was argued there was an agreement among firms to exchange price information. The legal strategy used here is not based on showing there was an agreement to post prices but rather that the mutual adoption of posted pricing is evidence of an agreement to coordinate prices. While this would require further economic analysis to substantiate, this legal strategy could well have been applicable to the *Container* case. That is, I conjecture that the private exchange of price information is consistent with a firm's best interests only if it anticipates that firms will subsequently coordinate their pricing. Just as much as, under competition, a firm would not want to post price because it would give its rival an opportunity to undercut it, it would seem that a firm would not want to inform a rival of its price. Whether that casual intuition is correct requires a more systematic analysis into the incentives to exchange price information.

## V. CONCLUDING REMARKS

Posted pricing is a common feature of many markets, and may be used to make consumer search easier and the cost of selling less burdensome. While there are then legitimate reasons for firms to stick to selling at list price, there are also cases - such as the markets for turbine generators and gypsum wallboard - for which posted pricing was implemented for the purpose of coordinating firms' prices. One objective of this paper was to identify market conditions under which the use of posted pricing is inconsistent with competition. When the adoption of posted pricing has little effect on consumers' search and firms' selling costs, it was shown that the industry-wide adoption of setting a list price with no discounting is contrary to firms' interests when they compete. Therefore, the adoption of posted pricing is optimal for firms only if it results in coordinated pricing. While this finding may be sufficient to convince economists that the adoption of posted pricing is evidence of collusion, it does not, by itself, establish that firms have an agreement to restrain trade. It was then argued that the adoption of posted pricing communicates the necessary intent and reliance to coordinate prices which is required to infer concerted action.

Critical to drawing this inference is the argument that if some practice is only in a firm's best interests when it anticipates coordinated pricing then the adoption of that practice is an invitation to coordinate pricing, and the subsequent adoption of that same practice by a rival firm signals its acceptance of that invitation. From this interpretation, an agreement is inferred. The courts have long recognized that there can be an agreement without express communication but there remains the matter of drawing the line between communication that conveys an

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<sup>39</sup> United States v. Container Corporation of America, 393 US 333, 335 (1969).

agreement and communication for which any such conveyance is ambiguous. On the "too ambiguous" side of the spectrum is the scenario posed by Posner<sup>40</sup>, whereby a firm raises its price (as an invitation to set supracompetitive prices) and its rival responds in kind (as an acceptance of that invitation). Getting closer to the legal-illegal divide is the public exchange of price intentions which the U.S. Department of Justice claimed to be a device to coordinate prices in the Airline Tariff Publishing Company (ATPCO) case.<sup>41</sup> Note that announcing future prices sheds some of the ambiguity of the Posnerian signalling scenario because consumers cannot transact at these prices; they are purely intentions about future prices. As the ATPCO case was resolved with a consent decree, there was no judicial ruling as to whether announcing future price changes can be construed as communicating an agreement. Where the parallel adoption of posted pricing falls with respect to the legal-illegal divide is similarly still to be determined.

## VI. APPENDIX A: ECONOMIC ANALYSIS (TECHNICAL)

### A. Model

Consider a duopoly setting in which, in each period, there is one unit of demand. Firm  $i$ 's cost to supplying this unit - denoted  $c_i$  - is drawn from  $[\underline{c}, \bar{c}]$  according to cdf  $F$ .  $F$  is twice continuously differentiable with positive density on  $(\underline{c}, \bar{c})$  and mean  $\mu$ . Assume firms' costs are independent across firms and time. The extensive form is as follows:

**Price Format Subgame:** Firms simultaneously choose between the posted price and quoted price formats.

**Price Subgame:**

**Stage 1:** If a firm chose the posted price format then it chooses its price.

**Stage 2:** Firms realize their costs. Costs are private information.

**Stage 3:** If a firm chose the quoted price format then it chooses its price knowing its cost and, when the other firm chose the posted price format, the other firm's price as well. If both firms chose the quoted price format then they simultaneously choose price, each knowing only its own cost.

If both firms chose the posted price format then they make simultaneous price decisions based on their prior beliefs on costs. If they both chose the quoted price format then they make simultaneous price decisions given each firm knows only its own cost, which is exactly the informational setting in Spulber.<sup>42</sup> Finally, if, say, firm 1 posts price and firm 2 quotes price then firm 1 chooses price as a first-mover (given its prior beliefs on firms' costs) and firm 2 chooses its price after learning its cost and firm 1's price.

The solution concept is perfect Bayes-Nash equilibrium. A Bayes-Nash equilibrium is solved for each of the four price subgames: both have the posted price format, both have the quoted price format, and they have mixed formats. Price formats are then chosen in this simple  $2 \times 2$  game:

<sup>40</sup> *In re High Fructose Corn Syrup Antitrust Litigation*, 295 F.3d. 651 (7th Cir. 2002).

<sup>41</sup> For details, see Severin Borenstein, *Rapid Price Communication and Coordination: The Airline Tariff Publishing Case (1994)*, in *THE ANTITRUST REVOLUTION* 233 (John E. Kwoka, Jr. and Lawrence J. White, eds., 4th ed. 2004)

<sup>42</sup> Daniel F. Spulber, *Bertrand Competition when Rivals' Costs are Unknown*, 43 J. INDUS. ECON. 1 (1995).

Price Format Subgame

Firm 2

		Posted Price	Quoted Price
Firm 1	Posted Price	$\pi^{PP}, \pi^{PP}$	$\pi^{PQ}, \pi^{QP}$
	Quoted Price	$\pi^{QP}, \pi^{PQ}$	$\pi^{QQ}, \pi^{QQ}$

where  $\pi^{RS}$  is the equilibrium expected profit earned by a firm that chose format  $R \in \{P, Q\}$  and its rival chose format  $S \in \{P, Q\}$ , where  $P$  denotes posted price and  $Q$  denotes quoted price. Let  $p^{RS}$  be the associated equilibrium price. If there is an equilibrium for each of the price subgames - so that the payoffs in the Price Format Subgame are defined - then there will be a perfect Bayes-Nash equilibrium as follows:

- If  $\pi^{PP} \geq \pi^{QP}$  then both having posted prices is an equilibrium outcome.
- If  $\pi^{QQ} \geq \pi^{PQ}$  then both having quoted prices is an equilibrium outcome.
- If  $\pi^{PP} \leq \pi^{QP}$  and  $\pi^{QQ} \leq \pi^{PQ}$  then one firm having posted prices and the other firm having quoted prices is an equilibrium outcome.

The one remaining element to model is the determination of which firm ends up selling to the current period's customer. I first consider when firms' products are identical - in which case the firm with the lower price sells with probability one - and then allow for differentiated products by assuming the probability of selling depends continuously on the price difference and is decreasing in the amount by which a firm's price exceeds its rival's price.

Before moving on to the results, it is worth discussing this set-up when firms' costs are deterministic and common knowledge. Under that assumption, the game is the standard two-period endogenous move game which has been analyzed many times before.<sup>43</sup> Each firm decides whether to set its price in period 1 (corresponding to posting price in our model) - in which case it is a price leader if the other firm chose to price in period 2 - or in period 2 (corresponding to quoting price in our model) - in which case it is a price follower if the other firm chose to price in period 1. If both firms chose to price in the same period then it is a simultaneous-move price game. With firms choosing prices, their decision variables are strategic complements and thus there is an advantage to being a second mover. Equilibrium is characterized by one firm pricing in period 1 and the other firm pricing in period 2. Intuitively, the first-mover prices above the Nash equilibrium price for the simultaneous-move game so as to induce the second-mover to price higher, given that the latter's best reply function is increasing in its rival's price. This benefits both firms relative to when there is no price leader.

Thus, without cost variability, it is not an equilibrium for firms to set prices simultaneously and thus not an equilibrium for both to post prices. With cost variability - as is presence in our model - there is an additional benefit to quoting price (that is, moving second) in that a firm's price can be responsive to its cost. This certainly suggests that we should not find it to be an equilibrium for both firms to post prices and that it may even be the case that

<sup>43</sup> See, e.g., Rabah Amir and Anna Stepanova, *Second-mover Advantage and Price Leadership in Bertrand Duopoly*, 55 GAMES & ECON. BEHAV. 1 (2006) and the sources cited there.

equilibrium involves both firms quoting price, with no firm taking the role of price leader. Why this result is not immediate - and, in fact, it'll take some structure to deliver it - is that, from the perspective of a posted price firm, its rival's price is now stochastic (being driven by its stochastic cost) when its rival moves second by quoting price. This significantly complicates the analysis in comparing pricing incentives when posting and quoting price, given the other firm quotes price. However, by putting plausible structure on demand, we can show that this complication does not disturb the pricing incentives in the deterministic cost case and thus it will be inconsistent with equilibrium for both firms to post prices.

## B. Equilibrium Formats: Homogeneous Products

The existence and characterization of perfect Bayes-Nash equilibria for when products are homogeneous can easily be shown by pulling together existing results in the literature. Specifically, I draw heavily upon Spulber<sup>44</sup> and Arozamena and Weinschelbaum,<sup>45</sup> both of whom draw upon Maskin and Riley<sup>46</sup> for existence of equilibrium when both firms have the quoted price format. I initially solve for equilibrium in prices for each of the three possible price format subgames: both firms post price, both firms quote prices, and firms have different formats. With those equilibrium payoffs, the price format subgame is then solved.

### 1. Price Subgames

- Both firms have the posted price format

As there is no private information - each firm chooses its price prior to learning its cost - this is the classical Bertrand price game except that expected cost,  $\mu$ , replaces deterministic cost. Thus, firm 1's expected profit is:

$$\pi^{PP}(p_1, p_2) = \begin{cases} p_1 - \mu & \text{if } p_1 < p_2 \\ \frac{1}{2}(p_1 - \mu) & \text{if } p_1 = p_2 \\ 0 & \text{if } p_1 > p_2 \end{cases}$$

The unique Nash equilibrium has each set price equal to expected cost,  $p^{PP} = \mu$ , and earn zero expected profit.

- Both firms have the quoted price format

The price subgame is exactly as analyzed in Spulber<sup>47</sup> except that unit demand is assumed here rather than having market demand be strictly decreasing in price. In Proposition 2, Spulber establishes the existence of a unique

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<sup>44</sup> Spulber, *supra* note 42.

<sup>45</sup> Leandro Arozamena and Federico Weinschelbaum, *Simultaneous vs. Sequential Price Competition with Incomplete Information*, 104 ECON. LETTERS 23 (2009).

<sup>46</sup> Eric Maskin and John Riley, *Optimal Auctions with Risk Averse Buyers* 52 ECONOMETRICA 1473 (1984).

<sup>47</sup> Spulber, *supra* note 44.

symmetric Bayes-Nash equilibrium, and that a firm's equilibrium price is strictly increasing in its cost.<sup>48</sup>

Straightforward inspection reveals that the proof of Proposition 2 also works with unit demand.

Letting  $\phi: [\underline{c}, \bar{c}] \rightarrow \mathfrak{R}_+$  denote the symmetric equilibrium price function, it is defined by

$$\phi(c) = \operatorname{argmax}(p - c)[1 - F(\phi^{-1}(p))], \quad \forall c \in [\underline{c}, \bar{c}]. \quad (1)$$

Given, say, firm 2 uses  $\phi$ , if firm 1 charges a price of  $p_1$ , it has the lowest price - and sells to the customer - if and only if  $\phi(c_2) > p_1$ . Since  $\phi$  is strictly increasing, this condition is equivalent to  $c_2 > \phi^{-1}(p_1)$  and, therefore, the probability that firm 1 sells is  $1 - F(\phi^{-1}(p_1))$ , as stated in (1). From the first-order condition (FOC),

$$1 - F(\phi^{-1}(p)) - (p - c)F'(\phi^{-1}(p)) \left( \frac{\partial \phi^{-1}(p)}{\partial p} \right) = 0,$$

one can derive that  $\phi$  is the unique solution to the differential equation,

$$\phi(c) - c = \phi'(c) \left( \frac{1 - F(c)}{F'(c)} \right) \quad (2)$$

with boundary condition  $\phi(\bar{c}) = \bar{c}$ . Since  $\phi'(c) > 0$  then (2) implies  $\phi(c) > c \quad \forall c < \bar{c}$ . Firms then have positive expected profit when they have the quoted price format:

$$\int [\phi(c) - c][1 - F(c)]F'(c)dc > 0.$$

- Mix of posted price and quote price formats

Suppose firm 1 chose the posted price format and firm 2 chose the quoted price format. Firm 1's strategy is then simply a price - as it chooses its price before learning its cost - while firm 2's strategy maps the space of cost levels for firm 2 and price levels for firm 1 into its own price space. Let's start with solving for firm 2's equilibrium strategy. If  $p_1 > c_2$  then firm 2 sets a price just below  $p_1$  and sells with probability one. If we assume that ties go to the firm with the quoted price format then firm 2's equilibrium price is  $p_1$  when  $p_1 > c_2$ . If  $p_1 \leq c_2$ , then firm 2 prices at or above its cost and firm 1 sells with probability one. Thus, firm 2's equilibrium strategy can be stated as:

$$\phi_2^{PQ}(p_1, c_2) = \begin{cases} p_1 & \text{if } p_1 > c_2 \\ c_2 & \text{if } p_1 \leq c_2 \end{cases}$$

As firm 1 sells if and only if its price is less than firm 2's cost, its optimization problem is

$$\max_{p_1} \int (p_1 - c_1)[1 - F(p_1)]F'(c_1)dc_1 = \max_{p_1} (p_1 - \mu)[1 - F(p_1)],$$

which has a unique solution if  $F'' \geq 0$  or  $F''$  is not too negative.

## 2. Price Format Subgame

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<sup>48</sup> *Id.* at 5.

In characterizing what happens when firms are choosing a price format, let us begin by comparing a firm's profit between the two price formats, given its rival chooses the quoted price format. The ensuing analysis uses results from Arozamena and Weinschelbaum<sup>49</sup>.

For when firm 1 posts price, it was shown above that firm 1 sells if and only if its price is less than firm 2's cost; in other words, it is "as if" firm 2 is pricing at its cost. Firm 1's expected profit is then

$$(p_1 - \mu)[1 - F(p_1)]. \quad (3)$$

For the same price for firm 1, now consider expected profit if it quotes price (once again assuming firm 2 quotes price):

$$\int (p_1 - c_1)[1 - F(\phi^{-1}(p_1))]F'(c)dc_1 = (p_1 - \mu)[1 - F(\phi^{-1}(p_1))]. \quad (4)$$

Since  $\phi^{-1}(p) < p$  - that is, the cost for which firm 2 prices at  $p$  (with the quoted price format) is less than  $p$  - then

$$1 - F(\phi^{-1}(p_1)) > 1 - F(p_1).$$

Hence, for any  $p_1$ , (4) exceeds (3) and therefore, expected profit is higher when firm 1 chooses the quoted price format, given firm 2 chose the quoted price format. This result comes from firm 2 pricing less aggressively when firm 1 also quotes price compared to when it posts price. Thus, if firm 1 were to choose the same price under the quoted price format as it would have chosen under the posted price format, its expected profit will be higher because firm 2 doesn't price as low. In addition, with the quoted price format, firm 1 is able to adjust its price to its cost, in which case expected profit is then even higher. In sum,  $\pi^{QQ} > \pi^{PQ}$ .

When products are homogeneous, the price format subgame is then:

		Price Format Subgame	
		Firm 2	
Firm 1		Posted Price	Quoted Price
		Posted Price	0, 0
Quoted Price	$\pi^{QP}, \pi^{PQ}$	$\pi^{QQ}, \pi^{QQ}$	

where  $\pi^{QQ} > \pi^{PQ}$  and  $\pi^{QP} > 0$ . Thus, quoting price strictly dominates posting price and, therefore, perfect Bayes-Nash equilibrium implies that both firms have the quoted price format. Intuitively, a firm gains a tremendous advantage by quoting price when its rival posts price as it can simply undercut the posted price and make a sale for sure. Thus, a firm surely want to quotes price when its rival posts price. It also means that if the other firm quotes price, a firm is at a great disadvantage if it posts price.

**Theorem 1** *If products are homogeneous then both firms choose the quoted price format at a perfect Bayes-Nash equilibrium.*

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<sup>49</sup> Arozamena, *supra* note 47.

### C. Equilibrium Formats: Differentiated Products

In this section, I consider when firms' products are differentiated so that a firm has a positive probability of making a sale even when its price is higher than its rival. Let us continue to assume there is one customer per period who buys from either firm 1 or firm 2. The stochastic process describing the consumer's purchase decision is assumed to depend only on the price difference. Let  $\beta(\Delta): \mathfrak{R} \rightarrow [0,1]$  denote the probability that a firm sells when the difference between its rival's price and its own price is  $\Delta$ . For example, suppose the quality differential between firm 2 and firm 1 is the random variable  $v$  with cdf  $H$ , and a consumer buys from firm 1 iff  $v < p_2 - p_1$ ; then  $\beta(\Delta) = H(\Delta)$ . The following assumptions are made.

**A1**  $\beta(\Delta) + \beta(-\Delta) = 1, \forall \Delta \in \mathfrak{R}$ .

**A2**  $\beta(\cdot)$  is twice continuously differentiable.

**A3**  $\beta'(\Delta) > 0, \forall \Delta \in \mathfrak{R}$ .

**A4**  $\beta''(\Delta) \geq 0$  if  $\Delta \leq 0$ ,  $\beta''(0) = 0$ , and  $\beta''(\Delta) \leq 0$  if  $\Delta \geq 0$ .

A1 states that a consumer buys from either firm 1 or firm 2, and implies  $\beta(0) = 1/2$ . A3 has the natural property that a lower price by a firm raises its probability of making the sale. By A4,  $\beta$  is weakly convex then weakly concave with the inflection point at  $\Delta = 0$ . It follows from A3 and A4 that the probability of purchase is most sensitive to the price difference when firms have identical prices:  $\beta'(0) \geq \beta'(\Delta), \forall \Delta$ . An example satisfying A1-A4 is the logistic,  $\beta(\Delta) = 1/(1 + e^{-\Delta})$ . It will simplify proofs if it is assumed the density function on a firm's cost,  $F'$ , is symmetric around its mean  $\mu$ .

Suppose both firms have the posted price format. A symmetric equilibrium price is defined by:

$$p^{pp} \in \arg \max(p - \mu)\beta(p^{pp} - p);$$

that is, given firm 2 prices at  $p^{pp}$  - so that firm 1's profit from pricing at  $p$  is  $(p - \mu)\beta(p^{pp} - p)$  - a price of  $p^{pp}$  is also optimal for firm 1. Assume the FOC is sufficient for an optimum:

$$\beta(0) - (p^{pp} - \mu)\beta'(0) = 0 \Rightarrow p^{pp} = \mu + \frac{\beta(0)}{\beta'(0)} = \mu + \frac{1}{2\beta'(0)}.$$

The second order condition (SOC) for firm 1 is:

$$-2\beta'(p_2 - p_1) + (p_2 - \mu)\beta''(p_2 - p_1) < 0.$$

Note that it holds in equilibrium as firms charge identical prices and  $\beta''(0) = 0$ . Furthermore, it holds if  $\beta$  is close to linear over the relevant domain (that is, price differences pertinent to determining whether a price pair is an equilibrium).

Next consider when firm 1 posts price and firm 2 quotes price. Define  $\varphi_2^{pQ}(p_1, c_2)$  as firm 2's best reply function given firm 1's price and firm 2's cost.

$$\varphi_2^{PQ}(p_1, c_2) \in \arg \max(p - c_2)[1 - \beta(p - p_1)].$$

The FOC is

$$1 - \beta(\varphi_2^{PQ}(p_1, c_2) - p_1) - (\varphi_2^{PQ}(p_1, c_2) - c_2)\beta'(\varphi_2^{PQ}(p_1, c_2) - p_1) = 0 \quad (5)$$

The SOC is

$$-2\beta'(p_2 - p_1) - (p_2 - c_2)\beta''(p_2 - p_1) < 0,$$

and again is satisfied when  $\beta$  is close to linear. Take the total derivative of (5) with respect to  $p_1$  to derive

$$\partial \varphi_2^{PQ}(p_1, c_2) / \partial p_1 :$$

$$\frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial p_1} = \frac{\beta'(\varphi_2^{PQ}(p_1, c_2) - p_1) + (\varphi_2^{PQ}(p_1, c_2) - c_2)\beta''(\varphi_2^{PQ}(p_1, c_2) - p_1)}{2\beta'(\varphi_2^{PQ}(p_1, c_2) - p_1) + (\varphi_2^{PQ}(p_1, c_2) - c_2)\beta''(\varphi_2^{PQ}(p_1, c_2) - p_1)}.$$

To ensure,

$$\frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial p_1} > 0,$$

it is assumed

$$\beta'(\varphi_2^{PQ}(p_1, c_2) - p_1) + (\varphi_2^{PQ}(p_1, c_2) - c_2)\beta''(\varphi_2^{PQ}(p_1, c_2) - p_1) > 0. \quad (6)$$

Note that it implies

$$\frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial p_1} \in (0, 1).$$

(6) can be shown to imply that firm 2's optimal price is increasing in its cost:

$$\frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial c_2} > 0.$$

A sufficient condition for (6) to hold is that  $\beta(\cdot)$  is not too far from being linear over the relevant price range.

Given firm 2's best reply function, consider firm 1's problem in the PQ-subgame:

$$p_1^{PQ} \in \arg \max \int_{\underline{c}}^{\bar{c}} (p_1 - \mu)\beta(\varphi_2^{PQ}(p_1, c_2) - p_1)F'(c_2)dc_2.$$

We want to show that, in equilibrium, firm 1's posted price is higher when firm 2 quotes price compared to when firm 2 posts price:  $p_1^{PQ} > p^{PP}$ . If that is the case then firm 2's expected profit is higher with the quoted price format - that is,  $\pi_2^{PQ} > \pi^{PP}$  - since its expected profit is increasing in its rival's posted price. Furthermore, firm 2 benefits from the quoted price format by being able to adjust its price to its cost. From this result we'll conclude that both firms choosing a posted price format is not part of a perfect Bayes-Nash equilibrium. The proof of the following lemma is in Appendix B.

**Lemma 2** *If (6) holds, then  $p_1^{PQ} > p^{PP}$ .*



Finally, we can use Lemma 2 to show that, given firm 1 has the posted price format, firm 2's expected profit is higher when it chooses the quoted price format. Note that firm 2's expected profit from the posted price format and price  $p_2$  is

$$(p_2 - \mu)[1 - \beta(p_2 - p^{PP})].$$

From choosing the quoted price format and price  $p_2$ , it is

$$(p_2 - \mu)[1 - \beta(p_2 - p_1^{PQ})].$$

The latter exceeds the former because  $p_1^{PQ} > p^{PP}$ . Under the quoted price format, firm 2's expected profit is actually even higher as it can condition its price on its cost, in which case expected profit is

$$\int_{p_2} \max(p_2 - c_2)[1 - \beta(p_2 - p_1^{PQ})]F'(c_2)dc_2.$$

**Theorem 3:** *Both firms having the posted price format is inconsistent with perfect Bayes-Nash equilibrium.*

While results were derived for when firms' costs are independent, they are likely to be strengthened if the more natural assumption of positive correlation is made.<sup>50</sup> Suppose firm 1 chose the posted price format and firm 2 chose the quoted price format. If costs are highly correlated then, when cost is not high (specifically, it is below firm 1's posted price), firm 2 will be able to undercut firm 1's price and with high probability win the sale at a profitable level. When cost is high (specifically, it exceeds firm 1's posted price), firm 2 - in pricing above its cost - will price above firm 1's price in which case firm 1 makes the sale with high probability but the sale is unprofitable. In other words, when costs are positively correlated, the firm that is quoting price will tend to make the sale when cost is low (and the sale is more profitable) and the firm that is posting price will tend to make the sale when cost is high (and the sale is less profitable). Hence, the relative profitability of the posted price format would seem to be reduced when firms' costs are positively correlated.

## VII. APPENDIX B: PROOF OF LEMMA 2

To prove  $p_1^{PQ} > p^{PP}$ , we'll show  $\frac{\partial \pi_1^{PQ}(p_1)}{\partial p_1} > 0$ ,  $\forall p_1 \leq p^{PP}$  and thus firm 1's optimal price exceeds  $p^{PP}$  when it

posts price and firm 2 quotes price. A lower bound on  $\frac{\partial \pi_1^{PQ}(p_1)}{\partial p_1}$  is derived by evaluating it when  $\frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial p_1}$  is

set equal to zero. In that case, the incentive of firm 1 to raise price in order to increase firm 2's price is neutralized.

We then show that this lower bound on  $\frac{\partial \pi_1^{PQ}(p_1)}{\partial p_1}$  is non-negative and, since in fact  $\frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial p_1} > 0$ , it follows

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<sup>50</sup> I thank a referee for this insight.

that  $\frac{\partial \pi_1^{PQ}(p_1)}{\partial p_1} > 0$ . In short, reasonable properties on the curvature of  $\beta(\cdot)$  preserve the first-mover effect to raise price which holds for the deterministic cost case.

Take the first derivative of firm 1's expected profit with respect to its price:

$$\frac{\partial \pi_1^{PQ}(p_1)}{\partial p_1} = \int_{\underline{c}}^{\bar{c}} [\beta(\varphi_2^{PQ}(p_1, c_2) - p_1) - (p_1 - \mu)\beta'(\varphi_2^{PQ}(p_1, c_2) - p_1) \left(1 - \frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial p_1}\right)] F'(c_2) dc_2. \quad (7)$$

A sufficient condition for  $p_1^{PQ} > p^{PP}$  is:

$$\frac{\partial \pi_1^{PQ}(p_1)}{\partial p_1} > 0, \quad \forall p_1 \in [\mu, p^{PP}]. \quad (8)$$

To prove (8), suppose  $\frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial p_1} > 0$  and  $\frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial c_2} > 0$ , both of which hold assuming (6).

First, note that if  $p_1 = \mu$  then

$$\frac{\partial \pi_1^{PQ}(p_1)}{\partial p_1} = \int_{\underline{c}}^{\bar{c}} \beta(\varphi_2^{PQ}(\mu, c_2) - \mu) F'(c_2) dc_2 > 0.$$

Hence, from hereon, assume  $p_1 > \mu$ . Since  $\frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial p_1} > 0$  then it follows from (7) that

$$\frac{\partial \pi_1^{PQ}(p_1)}{\partial p_1} > \int_{\underline{c}}^{\bar{c}} [\beta(\varphi_2^{PQ}(p_1, c_2) - p_1) - (p_1 - \mu)\beta'(\varphi_2^{PQ}(p_1, c_2) - p_1)] F'(c_2) dc_2. \quad (9)$$

Since  $\beta'(0) \geq \beta'(\Delta) \forall \Delta$  then it follows from (9) that

$$\frac{\partial \pi_1^{PQ}(p_1)}{\partial p_1} > \int_{\underline{c}}^{\bar{c}} [\beta(\varphi_2^{PQ}(p_1, c_2) - p_1) - (p_1 - \mu)\beta'(0)] F'(c_2) dc_2 \equiv \Omega(p_1). \quad (10)$$

Consider  $\Omega(p_1)$  evaluated at  $p_1 = p^{PP}$ :

$$\begin{aligned} \Omega(p^{PP}) &= \int_{\underline{c}}^{\bar{c}} [\beta(\varphi_2^{PQ}(p^{PP}, c_2) - p^{PP}) - (p^{PP} - \mu)\beta'(0)] F'(c_2) dc_2 \\ &= \int_{\underline{c}}^{\bar{c}} \left[ \beta(\varphi_2^{PQ}(p^{PP}, c_2) - p^{PP}) - \left( \mu + \frac{1}{2\beta'(0)} - \mu \right) \beta'(0) \right] F'(c_2) dc_2 \\ &= \int_{\underline{c}}^{\bar{c}} \left[ \beta(\varphi_2^{PQ}(p^{PP}, c_2) - p^{PP}) - \frac{1}{2} \right] F'(c_2) dc_2 \end{aligned} \quad (11)$$

where recall  $p^{PP} = \mu + \frac{1}{2\beta'(0)}$ . From (10), if  $\Omega(p^{PP}) \geq 0$  then  $\partial \pi_1^{PQ}(p^{PP}) / \partial p_1 > 0$ . By (11),  $\Omega(p^{PP}) \geq 0$  if and

only if

$$\int_{\underline{c}}^{\bar{c}} \beta(\varphi_2^{PQ}(p^{PP}, c_2) - p^{PP}) F'(c_2) dc_2 \geq \frac{1}{2} \quad (12)$$

To establish (12), we'll need to derive how firm 2's best reply responds to its cost. Take the total derivative of (5)

$$\partial \varphi_2^{PQ}(p_1, c_2) / \partial c_2$$

with respect to firm 2's cost and solve for

$$\frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial c_2} = \frac{\beta'(\varphi_2^{PQ}(p_1, c_2) - p_1)}{2\beta'(\varphi_2^{PQ}(p_1, c_2) - p_1) + (\varphi_2^{PQ}(p_1, c_2) - c_2)\beta''(\varphi_2^{PQ}(p_1, c_2) - p_1)} \quad (13)$$

Therefore,  $\frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial c_2} > 0$  if (6) holds. Since  $p^{PP} = \varphi_2^{PQ}(p^{PP}, \mu)$  and  $\frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial c_2} > 0$ , it follows that

$$\varphi_2^{PQ}(p^{PP}, c_2) - p^{PP} \begin{cases} < 0 & \text{if } c_2 < \mu \\ = 0 & \text{if } c_2 = \mu. \\ > 0 & \text{if } c_2 > \mu \end{cases} \quad (14)$$

Since

$$\beta''(\Delta) \begin{cases} \geq 0 & \text{if } \Delta < 0 \\ = 0 & \text{if } \Delta = 0 \\ \leq 0 & \text{if } \Delta > 0 \end{cases}$$

it follows from (14) that

$$\beta''(\varphi_2^{PQ}(p^{PP}, c_2) - p^{PP}) \begin{cases} \geq 0 & \text{if } c_2 < \mu \\ = 0 & \text{if } c_2 = \mu. \\ \leq 0 & \text{if } c_2 > \mu \end{cases} \quad (15)$$

Using (15), we can conclude from (13)

$$\frac{\partial \varphi_2^{PQ}(p^{PP}, c_2)}{\partial c_2} \begin{cases} \leq \frac{1}{2} & \text{if } c_2 < \mu \\ = \frac{1}{2} & \text{if } c_2 = \mu. \\ \geq \frac{1}{2} & \text{if } c_2 > \mu \end{cases} \quad (16)$$

By definition, we have

$$\varphi_2^{PQ}(p^{PP}, c_2) = \begin{cases} p^{PP} - \int_{c_2}^{\mu} \left( \frac{\partial \varphi_2^{PQ}(p^{PP}, c_2)}{\partial c_2} \right) dc_2 & \text{if } c_2 < \mu \\ p^{PP} & \text{if } c_2 = \mu \\ p^{PP} + \int_{c_2}^{\mu} \left( \frac{\partial \varphi_2^{PQ}(p^{PP}, c_2)}{\partial c_2} \right) dc_2 & \text{if } c_2 > \mu \end{cases} \quad (17)$$

Using (16) and (17), we have a lower bound on  $\varphi_2^{PQ}(p^{PP}, c_2)$ :

$$\varphi_2^{PQ}(p^{PP}, c_2) \begin{cases} \geq p^{PP} + \frac{1}{2}(c_2 - \mu) & \text{if } c_2 < \mu \\ = p^{PP} & \text{if } c_2 = \mu. \\ \geq p^{PP} + \frac{1}{2}(c_2 - \mu) & \text{if } c_2 > \mu \end{cases}$$

and therefore

$$\varphi_2^{PQ}(p^{PP}, c_2) - p^{PP} \geq \frac{1}{2}(c_2 - \mu).$$

Since  $\beta$  is increasing, we then have

$$\beta\left(\varphi_2^{PQ}(p^{PP}, c_2) - p^{PP}\right) \geq \beta\left(\frac{1}{2}(c_2 - \mu)\right). \quad (18)$$

We can now prove that (12) holds. By (18), a sufficient condition for (12) to be true is

$$\int_{\underline{c}}^{\bar{c}} \beta\left(\frac{1}{2}(c_2 - \mu)\right) F'(c_2) dc_2 \geq \frac{1}{2}. \quad (19)$$

Next note that

$$\begin{aligned} \int_{\underline{c}}^{\bar{c}} \beta\left(\frac{1}{2}(c_2 - \mu)\right) F'(c_2) dc_2 &= \int_{\underline{c}}^{\mu} \beta\left(\frac{1}{2}(c_2 - \mu)\right) F'(c_2) dc_2 + \int_{\mu}^{\bar{c}} \beta\left(\frac{1}{2}(c_2 - \mu)\right) F'(c_2) dc_2 \\ &= \int_{\mu}^{\bar{c}} \left[1 - \beta\left(\frac{1}{2}(c_2 - \mu)\right)\right] F'(c_2) dc_2 + \int_{\mu}^{\bar{c}} \beta\left(\frac{1}{2}(c_2 - \mu)\right) F'(c_2) dc_2 \\ &= \int_{\mu}^{\bar{c}} F'(c_2) dc_2 = \frac{1}{2} \end{aligned}$$

where the second equality follows from A1 and the symmetry of  $F'$ . Hence, (19) is true.

Having shown

$$\frac{\partial \pi_1^{PQ}(p^{PP})}{\partial p_1} > 0,$$

we still need to show that  $\frac{\partial \pi_1^{PQ}(p^{PP})}{\partial p_1} > 0, \forall p_1 \in [\mu, p^{PP})$ .

What we have is

$$\frac{\partial \pi_1^{PQ}(p_1^{PP})}{\partial p_1} > \Omega(p_1), \forall p_1 > \mu; \text{ and } \Omega(p^{PP}) \geq 0.$$

Since

$$\Omega'(p_1) = -\int_{\underline{c}}^{\bar{c}} \beta'\left(\varphi_2^{PQ}(p_1, c_2) - p_1\right) \left(1 - \frac{\partial \varphi_2^{PQ}(p_1, c_2)}{\partial p_1}\right) F'(c_2) dc_2 - \beta'(0) < 0$$

then  $\Omega(p^{PP}) \geq 0$  implies

$$\Omega(p_1) > 0, \forall p_1 \in [\mu, p^{PP}),$$

and, therefore

$$\frac{\partial \pi_1^{PQ}(p_1)}{\partial p_1} > 0, \forall p_1 \in [\mu, p^{PP}).$$

We conclude that firm 1's optimal posted price, given firm 2 quotes price, exceeds  $p^{PP}$ . This means that  $p_1^{PQ} > p^{PP}$  so that, given firm 1 posts price, firm 1's price is higher when firm 2 has the quoted price format than when firm 2 has the posted price format.