Advance Production, Inventories and Market Power: An Experimental Investigation

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Abstract

We report an experiment that assesses the effects of alterations in production conditions and product durability on market power in Bertrand-Edgeworth duopolies. Static equilibrium analysis predicts that advance (rather than ‘to demand’) production raises prices, but does not affect profits. The further addition of a simple inventory option causes prices to fall and seller earnings to increase. Contrary to these predictions, we observe similar prices in baseline and advance production treatments, but lower profits given advance production. An inventory option reduces both prices and earnings. Results are driven by the treatments’ effects on sellers’ capacities to tacitly collude.

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1. INTRODUCTION

Bertrand-Edgeworth games are an important part of any industrial organization economist’s toolkit. The unilateral market power created by capacity constraints represents one of economists’ primary methods for modeling supra-competitive prices as a static equilibrium outcome in a price setting game.\(^1\) The standard Bertrand-Edgeworth model, however, rather restrictively assumes that production is ‘to demand’ and that goods are immediately perishable. In the broad swath of modern economies that includes the production and sale of physical products, these assumptions are often not even approximately satisfied. Goods are routinely produced prior to being offered for sale at retail establishments. Similarly, while the effective shelf life of many products is quite short, relatively few products perish immediately, and many have effective shelf lives that extend throughout a sales season, if not longer.

This paper reports a laboratory experiment conducted to assess the effects of having sellers make production decisions in advance rather than to demand, and allowing sellers to carry unsold units across periods on market power in a Bertrand-Edgeworth pricing game. By way of preview, we find that both advance production and an inventory option prominently affect market outcomes: advance production reduces profits relative to a baseline condition, while an inventory option reduces both prices and profits. These results are important as they suggest that deviations from the standard oligopoly structures that routinely arise in natural contexts may fundamentally affect market performance.

We organize the paper as follows. Following a brief review of the pertinent literature in section 2, we outline equilibrium predictions for baseline, advance
production and inventory treatments in section 3. Section 4 describes the experimental design and procedures, and section 5 presents the experimental results. The paper concludes with a short sixth section.

II. BACKGROUND

Theoretical Literature

Economists have long recognized the restrictiveness of the standard price-setting oligopoly models. Shubik (1955), for example, argues that when evaluating price-setting duopolies economists should consider ‘price-quantity’ games where sellers simultaneously post prices and quantities in addition to games where price is the only decision variable.² Levitan and Shubik (1978) compute the mixed strategy equilibrium for a duopoly given advance production and unlimited capacities. More recently Tasnádi (2004) analyzes the case of advance production for capacity constrained duopolists pertinent to the present investigation. Tasnádi shows that under very general conditions, advance production raises prices but leaves seller profits unaffected.

The only theoretical work that analyzes the links between product durability and market prices of which we are aware is a stream of literature following Coase (1972) regarding the effects of product durability on monopoly power. Specifically, given sufficiently patient consumers, the ‘Coase Conjecture’ suggests that infinite durability will eliminate monopoly power. Analytical results are driven by consumers, who drive prices down by waiting for future discounts.³ To the best of our knowledge, no one has analyzed the effects of product durability on production and pricing incentives for capacity constrained, price-setting duopolists.
Experimental Literature

The relevant experimental literature consists of three strands. A first strand consists of a series of papers establishing that laboratory sellers recognize and exercise the unilateral market power induced by capacity constraints. Pertinent seminal references are Davis and Holt (1994) and Kruse et al. (1994), while some relevant related papers include Davis et al. (2002), Davis and Wilson (2000) and Wilson (1998). A second strand of the experimental literature studies the effects of advance production on posted price markets. Mestelman et al. (1987) and Mestelman and Welland (1988) examine advance production in a discrete-unit step-function environment where cost and demand conditions are not provided as full information. These authors report that relative to baseline posted-offer markets, advance production reduces efficiency and lowers prices in the equilibrium discovery process.

More closely related to the present study is Brandts and Guillen (2007), who examine the effects of advance production in simple symmetrical full information posted-offer pricing games, where sellers possess no unilateral market power. In their ‘price and quantity’ games with both two and three sellers Brandts and Guillen report high prices relative to Walrasian (‘competitive’) predictions, and numerous instances where sellers divided the market at the joint maximizing price, a result which can only be attributed to tacit collusion. Although their design was well suited for their intended research objective (of evaluating performance relative to ‘pure quantity’ and ‘pure price’ benchmarks), it is of limited use for identifying the incremental effects of advance production relative to standard posted offer markets, because the authors conduct no
baseline ‘to demand’ markets against which performance in their advance production markets can be compared.

A third strand of experimental literature consists of experiments in designs with durable goods. Although product durability is a feature of a diverse variety of experimental investigations, only a very few papers investigate the effects of durability on the incentives of sellers who both produce goods and carry inventories. Two papers merit comment. First, Mestelman and Welland (1991) examines the effects of inventory carryover on convergence in posted offer (as well as in double auction) markets. These were relatively thick markets with step function supply and demand configurations patterned after the advance production designs reported in Mestelman and Welland (1988). Sellers could costlessly carry inventories indefinitely. The focus of the investigation was on the extent to which inventories affected the equilibrium discovery process. These authors report that relative to baseline posted offer markets, inventory carryover reduces both prices and efficiency. Nevertheless, inventory carryover has little marginal effect on outcomes relative to the case of advance production.

In a second paper, Reynolds (2000) reports an experiment conducted to examine the effects of variations in product durability on monopoly pricing. Reynolds finds little evidence that increased product durability reduces prices, as would be consistent with the Coase conjecture. Reynolds’ experiment is related to our inventory treatment in that both experiments examine contexts where increased product durability generates predicted price reductions. However, in distinction to Reynolds we here study the effects of inventory on seller incentives vis-à-vis other sellers rather than with respect to buyers.
The present study adds to the experimental literature on both advance production and inventory. With respect to advance production, we develop a design that allows identification of static equilibrium predictions, and then we compare results to a series of baseline markets in a standard ‘to demand’ condition. These design features allow us to examine both the extent of tacit collusion in our markets and the incremental effects of advance production on prices and earnings. With respect to product durability, we report an inventory treatment that provides a first insight into the effects of inventory on seller interactions (as opposed to seller-buyer interactions) in an environment where performance can be evaluated relative to theoretical predictions.

III. ADVANCE PRODUCTION, INVENTORIES AND MARKET POWER

The addition of advance production and particularly an inventory option complicates significantly the analysis of the standard Bertrand-Edgeworth game. Advance production adds a quantity dimension to the pricing game, while the possibility of inventory carryover creates subgames that are dependent on actions in previous periods. For that reason, we focus here on a very simple stylized model.

Consider a market with two symmetric sellers, S1 and S2. Each seller may offer up to two units for sale at a constant unit cost c. Thus, in total a maximum of four units may be offered for sale, as shown in Figure 1. As is also shown in Figure 1, assume that a single buyer will purchase eight units at prices $p < v_L$ and three units in the range $v_L < p < v_H$. It facilitates our presentation to develop results in terms of our experimental design parameters. As Figure 1 indicates, we set $v_H =$6.00, $v_L =$3.50 and $c =$2.00.

*** Figure 1 about here ***
The market proceeds in a standard two step sequence. First, sellers simultaneously post prices. Second, once pricing decisions are complete, a fully revealing buyer makes purchase decisions, starting with the low pricing seller, and then proceeding to the high pricing seller. The buyer continues making purchases until either all units offered have been bought, or until prices no longer exceed unit values. In the case that the sellers post the same price, the buyer divides purchases as evenly as possible among the sellers. When necessary, the seller for a final odd unit is determined randomly.

In the following three subsections we develop static equilibrium predictions for three regimes: a baseline regime (‘BASE’) where production is to demand, an advance production regime (‘AP’) where sellers incur production costs on offered units, regardless of whether or not they subsequently sell, and an inventory regime (‘INV’) with both advance production and a single period carryover of unsold units to the next period. A fourth subsection offers comments regarding dynamic considerations.

**Static Predictions, BASE Treatment**

Standard production-to-demand conditions create unilateral market power. To see this, denote price choices by sellers S1 and S2 as \( p_1 \) and \( p_2 \), respectively. Further, for specificity, assume that seller S1 posts the weakly higher price. Observe that for any pair of prices \( (p_1, p_2) \) with \( v_L < p_2 \leq p_1 \leq v_H \), three of the four units supplied are purchased. Thus each seller is certain to sell at least one unit at price \( v_H \), and earn security profits \( v_H - c \). Following the standard reasoning, no equilibrium exists for this game in pure strategies. Rather, sellers randomize over the range \([p_{min}, v_H]\) where \( p_{min} \) is the price where sellers earn security profits from selling two units as the low pricing sellers, or
Using the parameters in our experimental design, $p_{\text{min}} = \frac{6.00+2.00}{2} = 4.00$.

For the symmetric equilibrium mixing distribution, calculate the cumulative pricing distribution $F_B(p)$ that seller $S2$ must post to make $S1$ indifferent to all prices in the support of her distribution, $p \in [p_{\text{min}}, v_H]$. That is,

$$v_H - c = F_B(p)(p - c) + (1 - F_B(p))(2p - 2c).$$

Solving

$$F_B(p) = \frac{(2p - v_H - c)(p - c)}{(p - c)} = \frac{2p - 8}{p - 2},$$

where the rightmost expression in (2) is the cumulative pricing distribution using our experimental parameters. Notice in (2) that given $p_{\text{min}}=4.00$ and $v_H=6.00$, $F_B(p_{\text{min}}) = 0$ and $F_B(v_H)=1$, implying that no probability mass exists at either end of $F_B(p)$. Columns (1) to (3) in the top row of Table 1 list expected transaction price, profit and consumer surplus predictions for the BASE treatment. As shown in the table, the mean expected transaction price is $\bar{p}_{\text{BT}} = 67.4$ , seller profits (here equal to security earnings, $v_H-c$) are $4.00$ and consumer surplus (the difference between buyer reservation values and the mean transaction price for the three units that sell in equilibrium, $3(v_H - \bar{p}_{\text{BT}})$) equals $4.00$. Anticipating results similar to other related experiments in this baseline case is a first conjecture.

**Conjecture 1:** Sellers recognize and exercise their unilateral market power. The mean of the symmetric static Nash Equilibrium mixing distribution organizes results in the BASE treatment.

We conduct BASE treatment markets primarily for purposes of calibration with other comparable environments where sellers exercised unilateral market power, such as
Davis and Holt (1994) and Kruse et al. (1994). BASE treatment results also provide a reference against which we can compare results of the other treatments.

*** TABLE 1 about here ***

**Static Predictions, AP Treatment**

Assume now that sellers must make both production and pricing decisions simultaneously. In the market game shown in Figure 1, sellers retain their market power with advance production in the sense that they can still be certain to sell a single unit at \( p = v_H \) and realize security earnings of \( v_H - c \). Further, the support of the mixing distribution is unchanged because sellers will still post prices down to the same minimum price \( p_{\text{min}} \), where the earnings from selling two units as the low pricing seller just equal security earnings. Now, however, sellers must make a quantity decision as well as a price choice. Consider the quantity choice. Observe first that when a seller restricts production to a single unit, (s)he will always post \( p = v_H \) because the seller is certain to sell a single unit at any admissible price. To find the distribution of quantity choices, let \( \theta \) denote the probability that a seller offers a single unit (at \( p = v_H \)), and let \( (1-\theta) \) denote the probability of an offer of two units at any price over the support of the mixing distribution. In order to induce indifference in seller \( S_1 \) between offering one and two units, seller \( S_2 \) must pick \( \theta \) so that

\[
\nu_H - c = 2\theta(v_H - c) + (1-\theta)(v_H - 2c) .
\]

Solving, \( \theta = c/v_H \) or, given our parameters, \( \theta = 1/3 \).

The equilibrium pricing distribution is derived similarly. To induce indifference in seller \( S_1 \) over the support of the pricing distribution \([p_{\text{min}}, v_H]\) seller \( S_2 \) must price according to a cumulative distribution \( G_A(p) \) so that
(4) \[ v_H - c = 2\theta(p - c) + (1 - \theta)[2(p - c)(1-G_A(p)) + (p - 2c)G_A(p)]. \]

Solving,

(5) \[ G_A(p) = (2p - v_H - c) / [(1 - \theta)p]. \]

Notice in (5) that \( \theta = 1/3 \) implies that \( G_A(p_{\text{min}}) = 0 \) and \( G(v_H) = 1 \). Thus, as long as seller \( S2 \) offers two units no probability mass exists over the support of the pricing distribution. Importantly, however, equation (5) reflects a seller’s pricing distribution, conditional on offering two units. The equilibrium distribution of observed prices consists of (5) weighted by the probability a seller offering two units, or

(6) \[ G(p) = (2p - v_H - c) / p. \]

Columns (1) to (3) in the second row of Table 1 summarize observed price, profit and consumer surplus predictions for the advance production treatment. Comparing across the BASE and AP treatments, observe that although advance production does not affect seller profits, it does raise substantially the expected mean transactions price, from $4.67 to $5.11. Due to the increased average prices, consumer surplus also falls by a third, from $4.00 to $2.67. The effects of advance production on outcomes form a second conjecture.

**Conjecture 2:** Static Nash predictions organize outcomes in AP markets. Relative to BASE markets, advance production raises transactions prices and reduces consumer surplus, but does not affect profits.

**Static Predictions, INV treatment**

Consider now a simple inventory option. Assume that in addition to making an advance production decision each period, sellers may carry unsold units as inventory for one period. Inventoried units carry over costlessly and are sold on a first-in-first-out
basis. Any unsold inventoried units become worthless at the expiration of the period. Finally, assume that the game repeats indefinitely, with a probability of continuation \( \delta \geq 0.77 \).

The appropriate solution concept for games like the inventory game, with variable states, is the Markov Perfect Equilibrium ("MPE"). Markov or ‘state space’ strategies are those in which the past influences current play only through its effect on a state variable that summarizes the direct effect of the past profile on the current equilibrium. Here inventories are the state variable, which we represent as ordered integer combinations \((I_1, I_2)\) for seller \(S_1\) and \(S_2\), respectively. A MPE is “a profile of Markov strategies that yields a Nash equilibrium in every proper subgame”.

To identify an MPE for the inventory game we first develop a candidate equilibrium, and then verify (numerically) that this candidate equilibrium is in fact a best response for each possible state. Here in the text we confine our attention only to an intuitive motivation of the candidate equilibrium and leave to an Appendix a more complete development.

The insight motivating our candidate equilibrium is that, given a sufficiently high discount factor, inventories can be an asset that improves profits by allowing sellers to service both the high value portion of the market at high prices in some periods and, after building up sufficient aggregate inventory, the low value portion of the market in others.

The following three period strategy represents an obvious sequence of plays that follows this intuition. In each period the seller produces two new units. Starting from an initial no-inventory condition the seller posts the limit price \(p = v_H\) in two initial periods and sells a single unit each period. Inventory increases from one then to two units. In a
third period, the seller clears inventory by posting the competitive price \( p=v_L \). Provided that the rival seller did not find profitable interference with this cycle of inventory accumulation/depletion, such a strategy would be repeatable. In fact, it is easily verified that the rival would not interfere with such a cycle. To the contrary, the above three period sequence is not an equilibrium because a rival may exploit a seller following such a strategy by selling two units at the minimum permissible increment below \( v_H \) in each of the initial two periods and then selling two units at \( p=v_L \) in the third.

To develop the candidate equilibrium, we follow the examples in equations (2) and (4) and calculate the cumulative pricing distributions that each seller must follow to induce indifference on the rival over every price in the support of the rival’s mixing distribution, for each period of the above three-period sequence. Calculations in this case are distinct, however, in that expected earnings must account for the future as well as the immediate consequences of pricing outcomes. Using the parameters in our experiment we establish in online Appendix A2 the following proposition.

**Proposition 1.** For the INV game with our experimental parameters and discount rate \( \delta \), a Markov Perfect Equilibrium consists of six (own-seller, other-seller) inventory states: \((0, 0), (1,0) \text{ and } (2,0), (0,1), (0,2) \text{ and } (1,1)\).

In state \((0, 0)\), the seller prices according to the cumulative distribution function

\[ F_{t1}(p) = \frac{6(p - p_{\min-t1})}{(3p - 6\delta - 7\delta^2)}, \text{ over the support } [p_{\min-t1}, \$6.00] \] where

\[ p_{\min-t1} = \frac{(18 + 6\delta + 7\delta^2)}{6}. \]

In state \((1,0)\) the seller prices according to the cumulative price distribution

\[ F_{t12}(p) = \frac{3(p - p_{\min-t2})}{(3p - 10.5\delta)} \text{ over the support } [p_{\min-t2}, \$6.00] \]

where \( p_{\min-t2} = \frac{(6 + 7\delta)}{3}. \)
In state (0,1) the seller prices according to the cumulative price distribution

\[ F_{12N}(p) = \frac{3(p - p_{\min-12})}{(2p - 7\delta)}. \]

In states (2,0), (1,1) and (0,2) the seller posts a price \( p = v_L = \$3.50 \), produces two units and sells all inventory.

Columns (1) to (3) in the bottom two rows of Table 1 list the mean transaction price, profit and consumer surplus predictions for the INV treatment, for \( \delta = 0.90 \) and in the limit, when \( \delta = 1.00 \). Looking at predictions across \( \delta \) values within the INV treatment, observe that both the mean transaction price and seller profits move directly with \( \delta \). Nevertheless, observe that even in the limit when \( \delta = 1.00 \), mean transaction prices per period for the INV treatment ($4.63) are slightly lower than in the BASE treatment ($4.67) and are much lower than in the AP treatment ($5.11). Further, as indicated by the mean per unit transaction price $4.28, predicted differences between the INV, BASE and AP treatments are considerably larger if an adjustment is made for the higher predicted sales volume in the low price periods. Second, and as a consequence of the lower prices, both profits and consumer surplus are higher in the INV treatment relative to other treatments. The predicted differences are particularly large relative to the AP treatment (at least $4.11 in the INV treatment vs. $2.67). Finally, neither the lower prices nor the increased consumer surplus adversely affect sellers. To the contrary, an inventory option represents a Pareto improving institutional alteration. These comparisons motivate a third conjecture.

**Conjecture 3:** MPE predictions organize outcomes in the INV treatment. Relative to static Nash BASE predictions inventory carryover reduces market power in the sense that
mean transaction prices fall. Further, inventories raise both seller profits and consumer surplus.

**Dynamic Considerations**

In standard indefinitely repeated games, repetition creates additional contingent strategy equilibria. As a practical matter, concerns about tacit collusion are often of particular relevance in duopoly contexts, and have been observed with some frequency in standard Bertrand-Edgeworth games. Some particularly well known examples include Dufwenberg and Gneezy (2000) and Fouraker and Seigel (1963). One way to assess the profitability of such contingent strategies is to consider the effect of changes in the institution on the well known ‘Friedman coefficient’, or the minimum discount factor (e.g., probability of continuation) necessary to support a contingent strategy equilibrium at the limit price $p = v_H$. Column (4) of Table 1 reports Friedman coefficients for the three treatments. Looking down the rows in Table 1, observe that moving from BASE to AP and then to INV, the Friedman coefficient increases from 0.50 to 0.62 and then to 0.69, reflecting a weakening of incentives to cooperate as institutional complexity increases.⁹

The listed changes in the Friedman coefficient, however, likely understate the effects of institutional alterations on the incidence of tacit collusion, because Friedman coefficient calculations ignore the changes in monitoring and implementation costs that successful tacit collusion in the AP and INV treatments requires. Going from the BASE to the AP regime, for example, sellers must shift from a relatively uncoordinated scheme of simply posting the limit price each period (in the BASE treatment) to a considerably more structured scheme of posting the limit price, but then rotating production quantities across periods in order to maximize joint profits. In the INV treatment sellers must again rotate
production quantities across periods. Further, however, sellers must trust their rivals to not (either purposely or inadvertently) carry inventories that the rival may feel compelled to clear at some point.

The above observations suggest that to the extent tacit collusion is a feature of our duopolies, it will more prominently impact the BASE markets than AP or INV. This is a fourth conjecture.

**Conjecture 4:** Tacit collusion will affect BASE markets most prominently, followed by AP and then INV markets.

In addition to providing a reason we might expect to reject any of the conjectures 1 to 3, conjecture 4 affects expectations regarding comparative static effects across treatments. A relatively higher propensity toward tacit collusion in the BASE and ADV markets should reinforce the predicted comparative static effects of these treatments relative to the INV treatment. At the same time, an increased propensity toward tacit collusion in the BASE markets relative to the AP markets will work against and may eliminate predicted static differences between the BASE and AP markets.

**IV. EXPERIMENT DESIGN AND PROCEDURES**

**Design**

To evaluate the effects of advance production and inventory on duopoly market power we conducted an experiment consisting of nine ten-person sessions. In each session the ten participants were grouped into a series of five duopolies, creating a total of 15 markets in each treatment. Due to an inadvertent recording error, however, data from one of the AP markets was lost. Thus, in total the data set consists of 44
independent markets; 15 markets each in the BASE and INV treatments and 14 markets in the AP treatment.

**Procedures**

At the outset of each session participants were randomly seated at computer terminals and handed sets of instructions. The instructions explained the market trading rules, the supply and demand conditions, as well as the number of certain periods and the stopping rule used to terminate sessions. Instructions were read aloud by a monitor, as participants followed along on printed copies of their own. To help clarify instructions we also projected color screen shots of the user interface on a screen at the front of the laboratory, and pointed to pertinent parts of the screen shots while reading the instructions. After completing the instructions participants completed a quiz of understanding, and completed an initial ten-period practice sequence for which they were not paid. Participants were invited to raise their hands and ask questions at any time during the instructions, quiz and practice periods.

Following the practice periods, participants were re-paired with new anonymous partners and the salient periods of the session commenced, with participants taking up to 90 seconds each trading period. Markets consisted of 40 periods with certainty followed by an indefinite number of periods which were terminated according to a $\delta=0.9$ probability of continuation each period. At the conclusion of the session, participants were privately paid the sum of their salient earnings and a $6$ appearance fee. Salient laboratory earnings were converted to U.S. currency at a rate of $10\text{lab} = 1\text{ U.S.}$ Participants were 90 undergraduate students enrolled in upper level business and economics courses at Virginia Commonwealth University in the Spring semester of 2009.
Earnings for the 60-75 minute sessions ranged from $12.25 to $45.25 and averaged $26.10.11

V. RESULTS

Overview

The mean transaction price, consumer surplus and profit paths for the 40 periods common to each session, shown as Figures 2, 3 and 4, provide an overview of results. Consider first the mean transaction price paths in Figure 2. Examination of the transaction price path for the BASE treatment relative to the BASE treatment Nash prediction, $\bar{p}_{BASE}$, reveals that tacit collusion very importantly affects the BASE markets. Further, as suggested by the general upward trend of the transaction price path for the BASE treatment, the effects of tacit collusion in these markets appear to increase over time.

*** FIGURE 2 about here ***

In contrast to the BASE treatment, tacit collusion does not so obviously carry over to the AP or INV markets. In the AP treatment the static Nash prediction, $\bar{p}_{AP}$, organizes mean results rather well for the last half of the session, following an initial convergence from below. In the INV treatment mean transaction prices fall consistently below the relevant static prediction, $\bar{p}_{INV}$ after period 10. Comparing across treatments, the separation between the INV price path and those for the BASE and AP treatments is particularly noticeable. Toward the end of the sessions, mean prices in the INV treatment are on the order of $1.00 lower than in the other treatments, or some 40% of the range between joint maximization and Walrasian (competitive) outcomes, $p_w$. 

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Turning next to the consumer surplus chart shown as Figure 3, observe that consumer surplus extraction rates are much higher in the INV treatment than in either the BASE or AP treatments. This is a consequence of the low prices in the INV treatment. Note also that due to the tacit collusion in the BASE markets, consumer surplus extraction rates tend to be below static Nash BASE predictions at the outset, with the differences between observed and predicted outcomes increasing over time.

*** FIGURE 3 about here ***

Looking finally at the seller earnings paths, shown in Figure 4, observe that the profit consequences for the BASE and AP series differ markedly, this despite the similarities in the mean prices and consumer surplus extraction rates for these two treatments. In the BASE treatment seller earnings trend far above static Nash equilibrium earnings predictions, reflecting profitable tacit collusion. In contrast, after starting low, mean seller earnings in the AP series tend to vacillate about static Nash predictions. Notice also in Figure 4 that the profit series for the INV treatment lies well below both static Nash predictions for the INV treatment, and, toward the end of the sessions, below the profit series for the AP and BASE treatments. Inventories clearly have the effect of reducing prices, but, contrary to static Nash predictions, rather than improving seller earnings, profits tend to fall.

*** FIGURE 4 about here ***

The remainder of this section establishes more formally the above observations, and then considers from less aggregated individual and market decisions some of the factors driving these results.
Evaluation of Conjectures.

**BASE Markets and Static Predictions.** The upper panel of Table 2 lists mean transaction prices, seller profits and consumer surplus extraction rates for the BASE treatment, both for the 40 periods common to all markets, and for the last 20 common periods (periods 21-40). Examining these outcomes in light of static the Nash predictions printed in the top row of the panel reveals that tacit collusion powerfully affects results. Mean transaction prices and profits exceed static Nash predictions, while consumer surplus falls below static Nash predictions. All differences are significant (e.g., $p<.05$) using a Wilcoxon test. This is a first result.

**Finding 1:** Static Nash predictions organize BASE treatment outcomes poorly because BASE markets are less competitive than predicted. Transaction prices and earnings significantly exceed static Nash predictions and consumer surplus falls significantly below the static Nash prediction.

*** TABLE 2 about here. ***

**AP Markets and Static Predictions.** The middle panel of Table 2 reports mean price, profit and consumer surplus results for the AP markets. In contrast to BASE treatment results, static Nash reference predictions organize mean outcomes for the AP treatment quite well. As suggested by the absence of ‘a’s, in the middle panel, neither transaction prices, profits nor consumer surplus extraction rates differ significantly from static AP predictions. Further, over the last 20 periods, predicted and observed mean outcomes overlap almost exactly. Finally, as indicated by the ‘b’s in the middle panel of Table 2, transaction prices significantly exceed and consumer surplus significantly falls below
reference BASE predictions. These outcomes are also both consistent with conjecture 2. Combined, these observations form a second result.

**Finding 2:** Static Nash predictions organize mean outcomes in the AP treatment quite well. Further, relative to BASE reference predictions, mean transactions prices increase and consumer surplus falls in the AP markets.

**INV Markets and Static Predictions.** The bottom panel of Table 2 illustrates mean transaction prices, profits and consumer surplus extraction rates for the INV markets (assuming the limiting case, $\delta = 1.00$). Comparing INV market results relative to MPE reference predictions indicates clearly the significantly less competitive than predicted nature of INV markets. As indicated by the ‘i’s, in the bottom panel, mean transaction prices and profits fall significantly below and consumer surplus significantly exceeds MPE predictions.

Despite the failure of MPE predictions to organize INV market outcomes, inventories do affect markets relative to BASE and AP reference predictions in some important respects. As indicated by the ‘b’s and ‘a’s, in the bottom panel of Table 2, the lower than predicted prices and the higher than predicted consumer surplus extraction rates in the INV markets actually reinforce predicted static differences between the INV markets and their AP and BASE counterparts.

On the other hand, contrary to equilibrium predictions, profit outcomes for the INV treatment fall not only below MPE predictions, but significantly below the (lower) predicted levels for the BASE and AP treatments as well. The prominent effects of inventories relative both to MPE predictions for the INV treatment and static Nash predictions for the BASE and AP treatments represents a third result.
Finding 3: MPE predictions organize outcomes in the INV treatment poorly because INV markets are more competitive than predicted. Although allowing sellers to inventory unsold units reduces prices and increases consumer surplus relative to static predictions for BASE and AP markets, inventories do not yield a Pareto improvement because seller profits fall.

Tacit Collusion and Comparative Static Effects. The significantly higher than predicted mean transaction prices and profits for the BASE treatment illustrate unambiguously a propensity for tacit collusion in BASE duopolies. At the same time, the conformity of AP market outcomes with static Nash predictions, and the generally less competitive than predicted outcomes in the INV markets reflect a tendency for the institutional modifications in the AP and INV treatments to undermine this propensity toward tacit collusion. This support for conjecture 4 is a fourth finding.

Finding 4: Tacit collusion powerfully affects outcomes in BASE duopolies. The addition of advance production undermines this propensity for tacit collusion observed in BASE markets. The further addition of a simple inventory option yields more competitive than predicted prices and profits.

The observed rank ordering of tacit collusion in the INV, AP and BASE treatments was as predicted in the discussion following conjecture 4. As the across-treatment differences shown in as columns (1) and (3) of Table 3 summarize, these dynamic effects increase the difference between the INV treatment and other treatments and diminish the difference between the BASE and AP treatments. While neither mean transaction prices nor consumer surplus extraction rates differ significantly across the AP and BASE
treatments, prices are significantly higher and consumer surplus extraction rates are significantly lower in both the BASE and AP treatments than in the INV treatment.

Turning to the earnings data, listed in column (2) of Table 3 note from the AP-BASE comparison in the upper panel of the table that BASE market profits significantly exceed AP market profits. It is this difference that distinguishes the tacitly collusive behavior from Nash play: despite the similarity in prices, BASE markets are more profitable. Moving down the column observe further that seller profits in the INV markets fall significantly below the BASE markets both overall and for the last 20 periods, and significantly below the AP markets for the last 20 periods. The earnings differences between the INV and BASE treatments are unsurprising given the less competitive than predicted behavior in the BASE markets and the more competitive than predicted behavior in the INV markets. More notable are the profit differences between the INV and AP markets over periods 21-40, because over those periods AP markets followed static Nash predictions quite closely. The more-competitive than predicted outcomes in the INV markets were not only strong enough to draw earnings under MPE predictions, but to levels even below static AP outcomes, where sellers simply bear the costs of unsold units.

*** TABLE 3 about here ***

Analysis of Individual Decisions

A less aggregated presentation of decisions provides insight into the behavioral factors underlying Findings 1-4. As can be readily seen from the price posting densities for the BASE, AP and INV treatments, shown in panels (a), (b) and (c) of Figure 5, the predicted equilibrium price distributions do a poor job organizing pricing decisions not
only in the BASE treatment, but in the AP and INV treatments as well.\textsuperscript{13,14} In all treatments, sellers tend to focus price choices on 25¢ nodes, and place particular weight on the even-dollar $6 and $5 prices. In the INV treatment sellers also price frequently at $4. Observe further in each panel that densities for the last 20 common periods (the dark bars) closely parallel pricing densities overall (the light bars), suggesting no obvious tendency for price choices to decay towards behavior that would be more consistent with randomization over the predicted continuous pricing distribution.

*** Figure 5 about here ***

Looking across panels observe that pricing decisions within treatments exhibit some distinguishing features not evident from the earlier discussion based on treatment means. Comparing panels (a) and (b) notice that advance production tends to increase price dispersion. Relative to the BASE treatment density at both the upper $6.00 mode and at the lower $3.50 and $4.00 modes rise in the AP treatment. (The density at $6.00 increases from about 30% of price choices in the BASE treatment to roughly 38% of price choices in the AP treatment. Similarly, the combined density weights at $3.50 and $4.00 increase from slightly above 8% in the BASE treatment to approximately 16% (overall) in the AP treatment.) Although AP sellers tended to choose $6 more frequently than is consistent with NE mixing distribution, the increased frequency of price choices at $6.00 in the AP treatment is both consistent with predicted changes in the underlying equilibrium pricing distributions and has some intuitive appeal. Posting at the upper limit price is a riskless way for AP sellers to maximize minimum earnings, if they also confine output to a single unit (as they did some 83% of the time).\textsuperscript{15} The increased density at $3.50 in the AP treatment also has some at least immediate intuitive appeal, because such
a posting offers a riskless way to offer and sell two units. Observe in panel (b) of Figure 5 that with experience, density at the $3.50 mode falls as sellers realize that they can increase earnings with higher prices.

Pricing densities for the INV treatment, in panel (c) of Figure 5, vary still more distinctly from behavior in either the AP or the BASE treatments, with considerably less density at $6 and increased density at $3.50, as is consistent with the change from the NE predictions for the BASE and AP treatments to the MPE prediction relevant for the INV treatment. Nevertheless, MPE predictions also largely fail to organize the empirical pricing densities. INV sellers posted the joint-maximizing price far more frequently than predicted (21% of observed decisions vs. the MPE prediction of 6%). Further, rather than clearing inventories at a price of $3.50 as frequently as predicted, sellers focus on the somewhat higher prices, particularly on $4.00, which accounted for some 17% of postings. We summarize these observations as a first comment.

**Comment 1:** Static Nash and MP equilibrium mixing distributions generally fail to organize pricing decisions in our duopolies. Contrary to equilibrium mixing predictions sellers focus price choices on even 50¢ price nodes. Further, in each treatment the frequency of choices at the upper limit price exceeds the pertinent equilibrium prediction.

Despite some movement of price choices across treatments in directions consistent with changes in the relevant equilibrium predictions, the strong modes at the upper bound of the pricing distribution in each treatment suggest that tacit collusion, and the effects of alterations in production and inventory decisions on the success of tacit collusion may provide a more useful perspective for gaining some insight into results than static NE and
$MPE$ mixing distributions. In the remainder of this subsection we consider how changes in production conditions and product durability affect sellers’ capacities to tacitly collude.

As an initial observation regarding tacit collusion, note that we rarely observed coordinated activity of the type that raises concern among antitrust authorities. Consider, Table 4, which summarizes the incidences of two standard indicators of tacit collusion, (a) the percentage of instances where sellers posted identical supra-competitive prices in consecutive periods, and (b) the percentage instances where sellers repeated a pattern of posting high then low supra-competitive prices (as would be consistent with a collusive scheme to rotate quantities). As is clear from entries in Table 4, the evidence for such organized behavior is generally quite weak. Notice in particular outcomes for the BASE treatment, where prices most strongly exceeded Nash predictions. In this treatment sellers coordinated on neither prices nor quantities in more than 5% of possible instances.

*** Table 4 about here ***

Rather than obvious coordination, less structured activity drives the tacitly collusive outcomes observed in our duopolies. The summary information on individual markets in each treatment reported in Tables 5(a), 5(b) and 5(c) provide some insight into these informal arrangements. The high variability of outcomes within treatments represents perhaps the most immediate result from perusing Tables 5(a) to 5(c). For example, from the mean transactions prices shown in column (1) of each table, observe that in each treatment the range of outcomes varies by at least $1.13$, or roughly half of the competitive to joint maximizing price range (e.g., $1.25$).

*** Tables 5(a), 5(b) and 5(c) about here ***
In addition to this heterogeneity, all treatments exhibit other common features. In particular, notice from the aggregate entry below the ‘T1’ measure in column (2) of each table that sellers tended to select a modal price choice frequently - about 30% of the time in each treatment (28%, 31% and 29% of price choices for the BASE, AP and INV treatments, respectively). Even beyond the modal choice, sellers tended to restrict attention to a fairly narrow set of prices. As seen by aggregate entries below the ‘T4’ measure in column (3) of each table, sellers picked among just four prices about 60% of the time in each treatment (59%, 61% and 63% of price choices in BASE, AP and INV treatments, respectively).

A third similarity across treatments regards the propensity for sellers to attempt to unilaterally raise prices by acting as a ‘price leader’. To measure sellers’ propensities toward price leadership, we calculate for each seller a ‘\( p_l \)’ index, which reflects the percentage of periods in which a seller posted a price that either strictly exceeded the maximum price posted in the preceding period, or weakly exceeded the $6 buyer limit value. The ‘\( p_{l_{\text{max}}} \)’ values reported in column (4) of each Table 5(a) – 5(c) are the higher of the \( p_l \) values for the two sellers in each duopoly. Looking at averages for the \( p_{l_{\text{max}}} \) values shown at the bottom of column (5) in each table, observe that the propensity for leadership varies little across treatments. In each treatment, the strongest leader tended to ‘lead’ in about half of the periods. (Mean \( p_{l_{\text{max}}} \) values are 0.53, 0.51 and 0.47 for the BASE, AP and INV treatments, respectively.)

Consider now the sort of informal activities that sellers might pursue to raise prices. One natural candidate explanation is that some sellers make unilateral efforts to raise prices. Although the overall propensity toward such leadership does not vary
importantly across treatments, we do note that within treatments the relationship between $p_{l_{\text{max}}}$ values and prices does vary. To see this we classify as ‘very collusive’ mean transaction prices in the upper quarter of the feasible price range (e.g., prices between $5.37$ and $6.00$).\(^{19}\) Observe in Table 5(a) that three of the four very collusive BASE sessions had $p_{l_{\text{max}}}$ values of 0.41 or below. In contrast, in Table 5(b) notice that both of the highly collusive AP markets ($AP_{13}$ and $AP_{14}$) had a strong price-leading seller, as reflected by the $p_{l_{\text{max}}}$ values of 0.85 and 0.74 for these markets, respectively. No highly cooperative outcomes were observed in the INV treatment. Notice further, however, that for the INV sessions with the most consistent price leaders (sessions $INV_{4}$ and $INV_{9}$, with respective $p_{l_{\text{max}}}$ values of 0.79 and 0.77), mean prices were not even in the upper half of the price space (e.g., mean transaction prices were below $4.75$, at $4.73$ and $4.43$). In summary then, in our experiment, successful tacit collusion in the AP treatment occurs only with strong price leadership. In the BASE treatment successful tacit collusion occurs both with and without strong price leadership, while in the INV treatment we never observe successful tacit collusion, even with strong price leadership.\(^{20}\)

A second type of unstructured behavior that has been associated with high prices in other experimental oligopolies is a sort of ‘weak cooperation’ in which sellers undercut each other frequently, but by small amounts, and also frequently raise prices.\(^{21}\) In the present context evidence of such weak cooperation is a combination of a high mean transaction price, a low $p_{l_{\text{max}}}$ and a small ‘spread’ or a small average difference between the high and low price each period.

Examining mean transaction prices and $p_{l_{\text{max}}}$ values in conjunction with the mean price spreads listed in column (5) of Tables 5(a) – 5(c) allows identification of instances
of such weak cooperation. Comparing across tables, observe that in the highly cooperative BASE sessions, spread values tend to be quite small (32¢ or less in three of four instances) despite low $p_{\text{max}}$ values in three instances, suggesting that ‘weak cooperation’ explains tacit collusion in these markets.\textsuperscript{22} In contrast, in the AP treatment no mean spread of less than 70¢ was observed absent a strong price leader. Observe finally that in the two INV markets with the highest $p_{\text{max}}$ values (INV4 and INV9) mean spreads were extremely large, at $1.63 in each case.

Looking at the average of mean price spread values for each treatment in the bottom rows of Tables 5(a)-5(c), observe that the price spread increases from 68¢ in the BASE treatment to 84¢ in AP treatment and then to 97¢ in the INV treatment. The increasing size of the spread in moving from the BASE to the AP and then to the INV treatments is consistent with a perceived increasing risk to sellers of following a price lead. In the BASE treatment, a seller shading under a standing price foregoes only the opportunity cost of selling a second unit in the case that her rival discounts still more deeply. In the AP treatment a seller who posts a price below $6.00 and offers two units bears the risk of producing a unit that may go unsold. Unless the seller is quite confident that his rival is a ‘strong leader’ (as in AP13 and AP14), she will offer a somewhat lower price relative to the BASE treatment to increase the chances of selling the second unit. In the INV treatment this spread increases still further, because a seller does not observe her rival’s inventories. A rival who posted a high price in the previous period may or may not have produced a single unit. In the event that a high pricing rival offered two units, he will carry forward at least one unit of inventory, in which case a seller will sell nothing
in the current period unless she either posts the lowest price in the current period, or posts the competitive price of $3.50.

A related consequence of changes in production conditions and product durability on pricing activity regards the price that sellers use as a primary reference. Looking at columns (6) of Tables 5(a)-5(c), notice that in the BASE treatment the modal price choice was either $6.00 or $5.99 in 10 instances and $5.75 in an eleventh market. Similarly, in the AP treatment, the modal price was either $6.00 or $5.99 in 12 instances. In the INV treatment, however, either $6.00 or $5.99 was the modal choice in only seven markets. In the remaining eight INV markets, $5.00 was a modal choice once, followed by $4.00 in three instances $3.50 in four instances. The propensity for sellers to adopt a lower reference price in the INV treatment is likely attributable to the same factors that drive high price spreads in that treatment. Sellers in the INV treatment do not observe the inventory status of their rivals. A seller is less likely to try ‘leading’ if she is uncertain to sell at least a single unit.

A simple OLS regression estimating for each treatment the effects of price leadership, the mean price spread and the modal price choice on mean transaction prices provides a succinct way to summarize the above observations regarding the differential effects of production and product durability on tacit collusion. Table 6 reports the pertinent regression results. Looking first at bottom of the table, observe that the $R^2$ for each treatment estimate is at least 0.65, indicating that in each case these three variables explain nearly two-thirds of the movement in mean transaction prices. Moving up rows to the last of the coefficient estimates, notice next that in all treatments, the modal price is a significant explainer of the mean transaction price, with coefficients of comparable
magnitude in each case (30¢, 22¢ and 26¢ for the BASE, AP and INV regressions, respectively). However, in the BASE treatment summarized in column (1) observe that only the mean spread estimate also deviates significantly from zero (because high prices occur in this treatment both with and without price leadership), while in the AP treatment summarized in column (2), only the coefficient on price leadership is also significant (because high prices occurred in this treatment only with a strong leader). Finally, for the INV treatment summarized in column (3) neither price leadership nor the mean price spread significantly affect mean transaction prices.

*** TABLE 6 about here ***

We summarize as a second comment the above observations regarding tacit collusion.

**Comment 2**: Advance production and an inventory option impede implementation of the varieties of informal tacit collusion that occurred in our markets. In the BASE treatment either strong price leadership or nonaggressive price competition may support tacit collusion. In the AP treatment the only tacitly collusive outcomes observed occurred with strong price leadership. In the INV treatment, successful tacit collusion was not observed even given a strong price leader.

V. CONCLUDING REMARKS

This paper reports an experiment conducted to evaluate the behavioral consequences of adding advance production and then inventory carryover on market power in a Bertrand-Edgeworth duopoly. Results indicate that, relative to a baseline condition, advance production yields lower profits, while the further addition of a simple inventory option lowers both profits and prices. Although aggregate results for the
advance production treatment match quite well the central moments of the pertinent static Nash equilibrium mixing distribution, closer consideration of price choices suggests that markets in this treatment, as well as those in the other treatments are more usefully viewed in terms of seller efforts to tacitly collude.

The tacit collusion we observe in our duopolies does not take on the sort of obvious coordination that is typically the focus of concern to antitrust authorities. Rather, we observe two informal types of cooperation: (a) a single seller acts as a strong price leader and (b) both sellers engage in a sort of ‘weak cooperation’, where the sellers undercut each other frequently, but reduce prices by fairly small margins, and also often raise prices. The changes in production conditions and product durability that are the focus of this investigation affect the success of these arrangements. In our BASE treatment both price leadership and ‘weak cooperation’ can elicit high prices. Given advance production, only strong price leadership elicits high prices. Finally in the INV treatment, neither strong price leadership nor weak cooperation generate high prices.

Importantly, we do not claim from our results that an inventory option eliminates tacit collusion, that advance production eliminates ‘weak cooperation’ as a method of tacit collusion, or even that the types of organized arrangements that are typically the focus of antitrust attention, such as common prices or quantity rotations will not be observed in the laboratory. With increased repetition sellers in all of our treatments may find ways to generate higher prices.\textsuperscript{23} Further, design alterations, such as a finer quantity grid, may facilitate more obvious varieties of seller coordination.\textsuperscript{24}

Our results do, however, suggest that the alterations in the standard Bertrand-Edgeworth game investigated here can very prominently affect both static equilibrium
predictions for such markets, and behavioral outcomes as well. Advance production and inventory are common elements of many naturally occurring contexts that policymakers might feel inclined to overlook in applying a model to a particular natural context. Our results suggest that glossing over such modifications can very substantially affect the predictive capacity of these models. Further investigation of the consequences of advance production and inventories on market performance, is clearly warranted.
REFERENCES


Manuscript, University of Arizona, 1997.


Shubik, M. “A Comparison of Treatments of a Duopoly Problem (Part II).”


## TABLE 1
Static Equilibrium Predictions and Friedman Coefficient Values

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(1) $\bar{p}_T^a$</th>
<th>(2) $\bar{\pi}$</th>
<th>(3) C.S</th>
<th>(4) $\delta^{ac}$</th>
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<tr>
<td>BASE</td>
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<td>$4.00$</td>
<td>$4.00$</td>
<td>0.50</td>
</tr>
<tr>
<td>AP</td>
<td>$5.11$</td>
<td>$4.00$</td>
<td>$2.67$</td>
<td>0.62</td>
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<tr>
<td>INV ($\delta=1.00$)</td>
<td>$4.63$ (4.28)$^b$</td>
<td>$4.70$</td>
<td>$4.11$</td>
<td>0.69</td>
</tr>
<tr>
<td>INV ($\delta=.90$)</td>
<td>$4.51$ ($4.20)^b$</td>
<td>$4.51$</td>
<td>$4.47$</td>
<td>0.69</td>
</tr>
</tbody>
</table>

a. Simulated in each case with $n=40,000$ pairs of observations.
b. Mean transaction price per unit. The (parenthetical) mean transaction price per unit is lower than the mean transaction price per period because of the increased sales volume in the low pricing periods.
c. Friedman Coefficient values ($\delta^c$) report the minimum discount factor necessary to support tacit collusion at the joint maximizing outcome with a threat to respond to any defection by with a permanent reversion to the static Nash equilibrium. For details of these calculations, see online Appendix A.3.
## TABLE 2
Market Outcomes and Nash Predictions

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\bar{p}_T$</th>
<th>$\pi$</th>
<th>C.S</th>
</tr>
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<td></td>
</tr>
<tr>
<td>Nash Prediction</td>
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<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>All</td>
<td>5.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.77&lt;sup&gt;ba&lt;/sup&gt;</td>
<td>2.46&lt;sup&gt;b1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Periods 21-40</td>
<td>5.28&lt;sup&gt;bb&lt;/sup&gt;</td>
<td>4.91&lt;sup&gt;ba&lt;/sup&gt;</td>
<td>2.16&lt;sup&gt;bi&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>AP</strong></td>
<td></td>
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</tr>
<tr>
<td>Nash Prediction</td>
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<td>All</td>
<td>4.96&lt;sup&gt;b1&lt;/sup&gt;</td>
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<tr>
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<td>4.08&lt;sup&gt;i&lt;/sup&gt;</td>
<td>2.65&lt;sup&gt;bi&lt;/sup&gt;</td>
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<tr>
<td><strong>INV</strong></td>
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<td>Nash Prediction</td>
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<td>Periods 21-40</td>
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<td>3.44&lt;sup&gt;bai&lt;/sup&gt;</td>
<td>5.26&lt;sup&gt;bai&lt;/sup&gt;</td>
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Notes: ‘b’s, a’s and i’s denote rejection of the null hypothesis that the variable does not differ from the static Nash prediction for the BASE, AP and INV treatments, respectively ($p<.05$, two-tailed Wilcoxon tests).
### TABLE 3
Differences Across Treatments

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<td></td>
<td>$\bar{p}_T$</td>
<td>$\pi$</td>
<td>$CS$</td>
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**AP – BASE**

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<tr>
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<td>0.49</td>
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**INV – BASE**

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<tbody>
<tr>
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<td>-1.48*</td>
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**INV – AP**

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<tbody>
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<td>-0.44</td>
<td>2.07*</td>
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<td>-0.64*</td>
<td>2.61*</td>
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</table>

**Key:** Asterisks denote rejection of the null hypothesis that observed mean outcomes across treatments do not differ significantly ($p<.05$, two-tailed Mann-Whitney tests).
## TABLE 4
Some Indicators of Tacit Collusion

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<th>BASE</th>
<th>AP</th>
<th>INV</th>
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<td><strong>Consecutive Periods with Identical Supra-Competitive Prices (% of Instances)</strong></td>
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<tr>
<td>All</td>
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<td>1%</td>
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<tr>
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<td>4%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td></td>
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<tr>
<td><strong>Repeated Supra-Competitive Price Rotations (% of Instances)</strong></td>
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<tr>
<td>All</td>
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<tr>
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<td>6%</td>
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TABLE 5(a)

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<tr>
<th>Market</th>
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<th>(2) $T1^b$</th>
<th>(3) $T4^c$</th>
<th>(4) $p_{l max}^d$</th>
<th>(5) $\bar{p}<em>{max} - \bar{p}</em>{min}^e$</th>
<th>(6) $p_{mode}^f$</th>
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<tr>
<td>Averages</td>
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<td><strong>0.28</strong></td>
<td><strong>0.59</strong></td>
<td><strong>0.53</strong></td>
<td><strong>0.68</strong></td>
<td><strong>5.68</strong></td>
</tr>
</tbody>
</table>

*Key:*

$a$. Mean per-period transaction price.

$b$. Modal price density.

$c$. Combined density of the four most frequent price choices.

$d$. ‘Price leadership index’, calculated as the percentage of price choices where the seller with the highest propensity to lead chose a supra-competitive price that either weakly exceeded $6 or was no lower than the previous period’s maximum price.

$e$. Mean price spread, or the average difference between the maximum and the minimum price.

$f$. Modal price choice.
### TABLE 5(b)
Summary Information for AP Markets, Periods 1-40

<table>
<thead>
<tr>
<th>Market</th>
<th>(1) $\bar{p}_T$</th>
<th>(2) $T^1$</th>
<th>(3) $T^4$</th>
<th>(4) $p_{T \text{ max}}$</th>
<th>(5) $\bar{p}<em>{\text{max}} - \bar{p}</em>{\text{min}}$</th>
<th>(6) $p_{\text{mode}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP14</td>
<td>5.89</td>
<td>0.44</td>
<td>0.89</td>
<td>0.85</td>
<td>0.15</td>
<td>5.99</td>
</tr>
<tr>
<td>AP 13</td>
<td>5.48</td>
<td>0.53</td>
<td>0.70</td>
<td>0.74</td>
<td>0.43</td>
<td>6.00</td>
</tr>
<tr>
<td>AP 9</td>
<td>5.14</td>
<td>0.35</td>
<td>0.76</td>
<td>0.51</td>
<td>0.91</td>
<td>6.00</td>
</tr>
<tr>
<td>AP 6</td>
<td>5.12</td>
<td>0.30</td>
<td>0.51</td>
<td>0.51</td>
<td>0.79</td>
<td>6.00</td>
</tr>
<tr>
<td>AP 4</td>
<td>5.11</td>
<td>0.26</td>
<td>0.44</td>
<td>0.36</td>
<td>0.70</td>
<td>6.00</td>
</tr>
<tr>
<td>AP 10</td>
<td>5.08</td>
<td>0.30</td>
<td>0.53</td>
<td>0.44</td>
<td>0.81</td>
<td>5.99</td>
</tr>
<tr>
<td>AP 5</td>
<td>5.03</td>
<td>0.30</td>
<td>0.50</td>
<td>0.51</td>
<td>0.98</td>
<td>6.00</td>
</tr>
<tr>
<td>AP 11</td>
<td>4.93</td>
<td>0.36</td>
<td>0.75</td>
<td>0.49</td>
<td>1.44</td>
<td>6.00</td>
</tr>
<tr>
<td>AP 12</td>
<td>4.89</td>
<td>0.31</td>
<td>0.50</td>
<td>0.56</td>
<td>0.83</td>
<td>6.00</td>
</tr>
<tr>
<td>AP 8</td>
<td>4.85</td>
<td>0.26</td>
<td>0.51</td>
<td>0.38</td>
<td>0.84</td>
<td>6.00</td>
</tr>
<tr>
<td>AP 7</td>
<td>4.73</td>
<td>0.20</td>
<td>0.30</td>
<td>0.46</td>
<td>0.91</td>
<td>6.00</td>
</tr>
<tr>
<td>AP 3</td>
<td>4.65</td>
<td>0.19</td>
<td>0.58</td>
<td>0.49</td>
<td>0.95</td>
<td>6.00</td>
</tr>
<tr>
<td>AP 2</td>
<td>4.30</td>
<td>0.53</td>
<td>0.89</td>
<td>0.38</td>
<td>0.74</td>
<td>3.50</td>
</tr>
<tr>
<td>AP 1</td>
<td>4.29</td>
<td>0.29</td>
<td>0.70</td>
<td>0.44</td>
<td>1.29</td>
<td>3.50</td>
</tr>
</tbody>
</table>

Averages: **4.96 0.31 0.61 0.51 0.84 5.64**

**Key:** a,b,c,d,e,f: see Table 5(a).
TABLE 5(c)

<table>
<thead>
<tr>
<th>Market</th>
<th>(1) $\bar{p}_r$</th>
<th>(2) T1 $^b$</th>
<th>(3) T4 $^c$</th>
<th>(4) $p_{t_{max}}$ $^d$</th>
<th>(5) $\bar{p}<em>{max} - \bar{p}</em>{min}$ $^e$</th>
<th>(3) $p_{mode}$ $^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>INV13</td>
<td>4.89</td>
<td>0.29</td>
<td>0.58</td>
<td>0.56</td>
<td>0.83</td>
<td>6.00</td>
</tr>
<tr>
<td>INV 4</td>
<td>4.73</td>
<td>0.30</td>
<td>0.56</td>
<td>0.79</td>
<td>1.63</td>
<td>6.00</td>
</tr>
<tr>
<td>INV 7</td>
<td>4.72</td>
<td>0.23</td>
<td>0.58</td>
<td>0.33</td>
<td>0.80</td>
<td>6.00</td>
</tr>
<tr>
<td>INV 12</td>
<td>4.55</td>
<td>0.06</td>
<td>0.21</td>
<td>0.36</td>
<td>0.77</td>
<td>6.00</td>
</tr>
<tr>
<td>INV 8</td>
<td>4.49</td>
<td>0.30</td>
<td>0.86</td>
<td>0.59</td>
<td>1.19</td>
<td>6.00</td>
</tr>
<tr>
<td>INV 9</td>
<td>4.43</td>
<td>0.36</td>
<td>0.93</td>
<td>0.77</td>
<td>1.59</td>
<td>6.00</td>
</tr>
<tr>
<td>INV 15</td>
<td>4.38</td>
<td>0.46</td>
<td>0.84</td>
<td>0.54</td>
<td>1.49</td>
<td>5.99</td>
</tr>
<tr>
<td>INV 5</td>
<td>4.34</td>
<td>0.19</td>
<td>0.58</td>
<td>0.56</td>
<td>0.58</td>
<td>5.00</td>
</tr>
<tr>
<td>INV 14</td>
<td>4.29</td>
<td>0.30</td>
<td>0.68</td>
<td>0.46</td>
<td>1.03</td>
<td>3.50</td>
</tr>
<tr>
<td>INV 3</td>
<td>4.20</td>
<td>0.23</td>
<td>0.64</td>
<td>0.31</td>
<td>1.06</td>
<td>4.00</td>
</tr>
<tr>
<td>INV 1</td>
<td>3.97</td>
<td>0.44</td>
<td>0.65</td>
<td>0.41</td>
<td>0.73</td>
<td>3.50</td>
</tr>
<tr>
<td>INV 6</td>
<td>3.90</td>
<td>0.29</td>
<td>0.68</td>
<td>0.33</td>
<td>1.14</td>
<td>4.00</td>
</tr>
<tr>
<td>INV 11</td>
<td>3.89</td>
<td>0.18</td>
<td>0.48</td>
<td>0.28</td>
<td>0.48</td>
<td>4.00</td>
</tr>
<tr>
<td>INV 10</td>
<td>3.87</td>
<td>0.46</td>
<td>0.64</td>
<td>0.31</td>
<td>0.69</td>
<td>3.50</td>
</tr>
<tr>
<td>INV 2</td>
<td>3.76</td>
<td>0.24</td>
<td>0.60</td>
<td>0.38</td>
<td>0.58</td>
<td>3.50</td>
</tr>
<tr>
<td>Averages:</td>
<td><strong>4.29</strong></td>
<td><strong>0.29</strong></td>
<td><strong>0.63</strong></td>
<td><strong>0.47</strong></td>
<td><strong>0.97</strong></td>
<td><strong>4.87</strong></td>
</tr>
</tbody>
</table>

Key: a,b,c,d,e,f. see Table 5(a).
## TABLE 6
Summary OLS Measures of Mean Transaction Prices: Coefficients
(Standard Errors)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(1) BASE</th>
<th>(2) AP</th>
<th>(3) INV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>3.75*</td>
<td>3.40*</td>
<td>3.01*</td>
</tr>
<tr>
<td></td>
<td>(0.63)</td>
<td>(0.47)</td>
<td>(0.23)</td>
</tr>
<tr>
<td>$\beta_{plmax}$</td>
<td>0.49</td>
<td>1.33*</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>(0.30)</td>
<td>(0.48)</td>
<td>(0.50)</td>
</tr>
<tr>
<td>$\beta_{Spread}$</td>
<td>-0.78*</td>
<td>-0.41</td>
<td>-0.095</td>
</tr>
<tr>
<td></td>
<td>(0.19)</td>
<td>(0.20)</td>
<td>(0.20)</td>
</tr>
<tr>
<td>$\beta_{mode}$</td>
<td>0.30*</td>
<td>0.22*</td>
<td>0.26*</td>
</tr>
<tr>
<td></td>
<td>(0.11)</td>
<td>(0.06)</td>
<td>(0.06)</td>
</tr>
<tr>
<td>N</td>
<td>15</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.65</td>
<td>0.81</td>
<td>0.69</td>
</tr>
<tr>
<td>F</td>
<td>9.82*</td>
<td>19.31*</td>
<td>11.25*</td>
</tr>
</tbody>
</table>

* Reject the null hypothesis that $\beta_i = 0$ at $p < .05$. 
FIGURE 1

Supply and Demand Arrays, Baseline and Advance Production Cases.
FIGURE 2

Mean Transaction Prices, BASE, AP and INV treatments.
FIGURE 3

Mean Consumer Surplus, BASE, AP and INV treatments.
FIGURE 4

Mean Seller Profits, BASE, AP and INV treatments.
FIGURE 5

Observed and predicted pricing densities for the BASE, AP and INV treatments. 
Key: Light bars: density, periods 1-40; dark bars: density, periods 21-40; dashes, equilibrium mixing distribution.
FOOTNOTES

* Thanks for helpful comments to Asen Ivanov, Oleg Korenok, Robert Reilly Roger Sherman, associate editor Yan Chen and two anonymous referees. The usual disclaimer applies. Thanks also to Matthew Nuckols for software development and to Michael Brown for help in conducting the laboratory sessions. Financial assistance from the National Science Foundation (SES 1034527) and the Virginia Commonwealth University Summer Research Grants Program is gratefully acknowledged. Instructions, experimental data and appendices are available at http://www.people.vcu.edu/~ddavis.

Author: Professor, Virginia Commonwealth University, Richmond VA 23284-4000. Phone 1-804-828-7140, Fax 1-804-828-9103, E-mail dddavis@vcu.edu

1 Capacity constraints are the only way to model non-competitive pricing as a static equilibrium in a full-information homogeneous-product price-setting market. Other variations, such as indefinite repetition, incomplete information and product differentiation may also generate supra-competitive equilibrium prices in price-setting games. Alternatively, in homogeneous product quantity setting Cournot games equilibrium prices increase above costs as the number of sellers falls (see e.g., Carleton and Perloff, 2005, chapters 6 and 7).

2 Both price and quantity are decision variables in an important branch of the Bertrand-Edgeworth literature that focuses on long run competition. In this literature, however, price and quantity decisions are sequential rather than simultaneous, with quantity (e.g., plant size) decisions preceding price choices. Given efficient rationing Kreps and
Scheinkman (1983) and others, show that the Cournot equilibrium is outcome of such a sequential quantity then price choice process. Davidson and Deneckere (1986) and others show that other rationing rules yield lower prices and higher quantities in equilibrium.

3 The formal analysis of monopoly pricing for durable goods focuses primarily on two cases. One case has a continuum of buyers who are individually unable to influence the market by withholding purchases. See Stokey (1981) and Gul, Sonnenschein and Wilson (1986). The other case has the seller facing a single buyer, whose value is a random draw unknown by the seller in advance. Pertinent papers include Sobel and Takahashi (1983) and Fudenberg, Levine and Tirole (1985). With some qualifications, the Coase conjecture holds in both cases. Reynolds (1997) shows that the Coase conjecture can also hold in an intermediate case involving a finite number of sellers whose value draws are randomly drawn and unknown to the seller.

4 Experiments featuring product durability include designs constructed to examine speculative pricing bubbles and information aggregation in asset markets. See, for example, Smith, Suchanek and Williams (1991), Forsythe, Palfrey and Plott (1982), and, Friedman, Harrison and Salmon (1988). Product durability is also a feature of designs that investigate the capacity of ‘middlemen’ to improve the efficiency of seasonally cyclical markets. Relevant papers here include Hoffman and Plott (1981), Miller, Plott and Smith (1977), and Williams and Smith (1984).

5 The expected mean transaction price is the quantity weighted expected maximum and expected price, or $E(\bar{p}_T) = \frac{1}{3}E(p_{\text{max}}) + 2E(p_{\text{min}})$. Simulating with $n=40,000$ ordered pairs,
\( E(p_{\text{max}}) = 5.09 \) and \( E(p_{\text{min}}) = 4.46 \). Online Appendix A1.1 reports details for simulating \( E(p_{\text{max}}) \) and \( E(p_{\text{min}}) \) for the BASE treatment.

6 Again simulating with \( n = 40,000 \) ordered pairs, \( E(p_{\text{max}}) = 5.64 \) and \( E(p_{\text{min}}) = 4.84 \), making the expected the transaction price \( \bar{p}_{SR} = 5.11 \). Online Appendix A1.2 reports details of the procedure for simulating maximum and minimum prices for the AP treatment. Parallel to calculations for the BASE treatment, seller earnings are security profits of $4.00 and consumer surplus, \( 2.67 = 3(v_u - \bar{p}_{SR}) \).

7 Fudenberg and Tirole (1991), p. 501. That this analysis confines dynamic effects to the inter-temporal consequences of inventories on pricing bears emphasis. In particular, we exclude from consideration contingent strategies consistent with tacit collusion. Incentives for tacit collusion in this and the other treatments are discussed below.

8 Inventory accumulation and the possibility of failing to sell inventoried units drive this sequence. In the first two periods of the cycle, the high pricing seller sells only one of the two units produced, leaving her with first one and then two units of inventory. In the third period, she posts price \( p = v_L \) to assure the sale of her inventoried units.

9 The pertinent calculations for these coefficients are developed in online Appendix A3. Intuitively, incentives to tacitly collude in the AP treatment weaken relative to the BASE treatment because the present value of deviating from the quantity rotation strategy needed to support symmetric joint profit maximizing tacit collusion in the AP treatment is somewhat lower than in the BASE treatment, where sellers can simply offer both units at the limit price each period and rely on the buyer purchasing procedure to allocate the odd unit. The increased profitability of the non-cooperative \( MPE \) relative to the BASE and AP treatments further weakens incentives to cooperate in the INV treatment.
Our combination of a definite number of initial periods followed by an indefinite number of periods using a probabilistic stopping rule creates some indeterminacy in the appropriate reference predictions for the \textit{INV} treatment, since $\delta$ is essentially 1 for periods 1 to 40 and then falls to .90 thereafter. Had we used a constant continuation probability in all periods, we would have achieved more precision in predictions, and (with relatively small $\delta$) larger differences in predicted outcomes across treatments. Such an approach however, would have made it impossible to create an experience profile for the \textit{INV} treatment that paralleled those in the \textit{BASE} and \textit{AP} treatments, because the distribution of expected session lengths is so highly skewed. For example, using a continuation of probability of $\delta=0.95$ yields a mean expected session length of only 20 periods. Further, only about 63% of sessions will have at least 20 periods. At the same time, the expected maximum session length in a sample of 15 sessions is almost 60 periods, and in many instances will exceed 90 periods. Higher $\delta$’s yield still greater variability in expected session lengths.

All markets in each session were terminated at the same time via a single application of the stopping distribution. Session lengths ranged from 42 to 57 periods, and averaged 49 periods.

As illustrated in Table 1, to the extent that the effective discount factor is below 1, mean transaction prices fall, seller earnings fall and consumer surplus increases. All differences shown in the bottom row of Table 2 remain significant with $\delta=0.9$.

The predicted density for the \textit{INV} treatment shown in Figure 5(c) is a weighted average of densities for the three stages of the \textit{MPE}.

10

11

12

13
Regressing individual price choices against own and other price choices in the immediately preceding period represents a standard way to show that sellers fail to randomize in laboratory Bertrand-Edgeworth oligopolies. Behavior is inconsistent with randomization if coefficients on either own or other previous price choices differ significantly from zero. Consistent with results of similar analyses in related contexts, such as Davis and Holt (1994), and Kruse et al. (1994), these coefficients are both large and significant for each of our duopoly treatments. We focus in the text on pricing densities to illustrate other features of pricing decisions inconsistent with randomization.

This aggregate percentage includes instances where \( q=1 \) and \( p=5.99 \) in sessions AP10 and AP14, where \$5.99 was effectively the limit price for sellers in these markets. In these two sessions sellers posted \$6.00 a total of 4 instances, while they posted \$5.99 in a total of 58 instances. Also, the bulk of instances where a sellers offered two units at the limit price occurred in a single instance (session AP13), where a single seller posted a price of \$6 in 29 of 40 periods, but restricted output only 3 times. Excluding session AP13, the average rate at which sellers restrict quantity when posting the limit price is 90%.

Denoting the price of seller \( j \) in period \( i \) as \( p_{ji} \), ‘consecutive periods of identical supra-competitive prices’ are periods \( i-j \) and \( i \) where, \( p_{1i-1} = p_{2i-1} \) and \( p_{ui} = p_{2i} \). ‘Instances of repeated supra-competitive price rotations’ are instances where (a) all prices strictly exceed \( p_c \), and (b) a ‘high-low’ price cycle is repeated at least once, e.g., \( p_{ui} > p_{2i} \), \( p_{1i-1} < p_{2i-1} \), \( p_{1i-2} > p_{2i-2} \), \( p_{3i-3} > p_{2i-3} \).

The patterns summarized in Table 4 are the sorts of organized behaviors that are the primary focus of antitrust authorities. See, e.g., the FTC/DOJ Horizontal Merger...
Guidelines, section 2.1. The failure of sellers in ‘tacitly collusive’ price-setting laboratory markets to engage in obviously organized behavior has been observed previously. See in particular Davis (2009).

For purposes of brevity, Tables 5(a) – 5(c) present averages based on the 40 periods common to all markets. All of the observations made in the text from these tables are robust to the use of periods 21-40, as can be verified by inspection of Tables A9, A10 and A11 in online Appendix A4. For the interested reader we also provide in online Appendix A5 price and quantity sequences for each market. Finally, and again for brevity we assess sellers’ propensity toward tacit collusions only in terms of mean transaction prices and not profits. Within treatments mean profits, are very highly correlated with transaction prices and add little extra information. For example, for the respective BASE, AP and INV treatments, the simple correlation between mean transaction prices and profits, are, 0.99, 0.92 and 0.81.

This definition of a ‘very collusive’ price range is offered only for purposes of specificity. As can be verified from inspection of Tables 5(a) to 5(c), our observations are qualitatively resilient to wide variations in this definition.

We are not, however, arguing that strong price leadership is sufficient for high prices in any treatment. Notice for example, BASE13. Here the mean transactions price is only $5.09, despite one seller acting as a price leader in 90% of the trading periods. That said, the strong leader in this session was ultimately able to raise prices toward the end of the session. Over periods 21-40 the mean transaction price in BASE13 rose to $5.54. A more expansive presentation of market results for periods 21-40 appears in Appendix A4.
See, for example, Davis, Korenok and Reilly (2010). The notion of ‘weak cooperation’ is admittedly somewhat elusive. Davis, Korenok and Reilly provide evidence suggesting that a propensity for such behavior persists within individuals across sessions. Dal Bó and Fréchette (2010) study the evolution of cooperation in a prisoners’ dilemma context and similarly find the phenomenon difficult to isolate. They do observe, however, that observation of cooperation early in a game tends to increase overall cooperation levels, a result consistent with the notion that agents decide on the basis of initial play how much to ‘invest’ in cooperation.

In market BASE15 the mean spread is somewhat larger, at 59¢. The relatively larger mean spread in this market is attributable to a relatively small number of instances where a seller made deep price cuts, perhaps in an effort to ‘punish’ his rival for cutting prices too deeply. For example, eliminating the five periods with the largest spreads reduces the average to 47¢.

Indeed, in one INV session (market INV15) sellers did coordinate on the limit price over the last 7 periods. See online Appendix A5 for an illustration of the sequence of price postings in this session.

Brandts and Guillen (2007) observe many instances where sellers share the market by posting the limit prices. One important difference between the Brandts and Guillen design and the one used here is the considerably finer grid of quantity choices available to sellers in their design.