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Dynamic Price Competition, Learning-by-Doing, and Strategic Buyers†

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We examine how strategic buyer behavior affects equilibrium outcomes in a model of dynamic price competition where sellers benefit from learning-by-doing by allowing each buyer to expect to capture a share of future buyer surplus. Many equilibria that exist when buyers consider only their immediate payoffs are eliminated when buyers expect to capture even a modest share of future surplus, and the equilibria that survive are those where long-run market competition is more likely to be preserved. Our results are relevant for antitrust policy and our approach may be useful for future analyses of dynamic competition. (*JEL* C73, D21, D43, D83, K21, L13, L40)

In many industries, producers' marginal costs tend to fall with their accumulated past output (learning-by-doing, LBD).[1] LBD creates a tension between achieving productive efficiency by concentrating production at a single producer, and sustaining meaningful competition, which may require spreading production across multiple producers. A range of dynamic models has been used to study whether, without regulation, market competition is likely to be sustained and whether outcomes are likely to be efficient.

Two literatures making different assumptions about buyers have reached qualitatively different conclusions. For example, Lewis and Yildirim (2002; henceforth, LY) consider a model where, in each period, two suppliers that benefit from LBD compete to sell a single unit to a long-lived, forward-looking monopsonist. LY's model has a unique Markov perfect equilibrium where the monopsonist spreads its purchases between the suppliers to maintain competition, even though this has

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[1] Industries with documented LBD include airframes (Alchian 1963; Benkard 2000), chemicals (Lieberman 1984; Lieberman 1987), semiconductors (Irwin and Klenow 1994; Dick 1991), shipbuilding (Thompson 2001; Thornton and Thompson 2001), power plant construction (Zimmerman 1982; Joskow and Rose 1985), and hospital procedures (Gaynor, Seider, and Vogt 2005; Dafny 2005).

the effect of raising prices.[2] On the other hand, some well-known models predict that a single seller may come to dominate the market when buyers are assumed to be atomistic. For example, Cabral and Riordan (1994; henceforth, CR) consider a model where duopolists sell differentiated products, LBD stops once a certain level of cumulative sales is reached, and there is an infinite sequence of short-lived buyers with idiosyncratic preferences over the sellers.[3] CR show, using an example, that if it is possible for sellers to exit, equilibria exist where the market may become a monopoly after initially intense competition. Besanko, Doraszelski, and Kryukov (2014; henceforth, BDK1) and Besanko, Doraszelski, and Kryukov (2019; henceforth, BDK2) show, using a richer version of CR's model (the BDK model), that this type of equilibrium exists for a broad range of parameters, and that these equilibria often coexist with equilibria where duopoly will be sustained and initial pricing is less aggressive. The possibility of monopoly tends to lower the discounted surplus of buyers, even if the initial buyers benefit from lower prices.

In practice, many industries with LBD, while not being monopsonies, have large, repeat buyers who are likely both to care about future competition and to recognize that their purchase choices may affect how competition evolves.[4] In this article, we extend the BDK model in a tractable way to cover cases that lie between atomistic buyers and monopsony. Specifically, we model buyers who expect to capture a particular share of future buyer surplus, and therefore partially internalize how their purchase choices affect how market structure evolves. We will describe an increase in this share as reflecting buyers behaving more "strategically." When monopoly will lower future buyer surplus, the response of strategic buyers will be to adjust their purchase choices in ways that will tend to preserve competition, which raises the question of whether equilibria where monopoly can occur will be eliminated.

We find that the multiplicity of equilibria is eliminated across a broad range of the parameter space as buyers become more strategic. The equilibria that survive have a higher probability, or certainty, of sustained long-run competition, and they tend to increase total surplus even though a softening of competition may leave buyers worse off. These qualitative results are sensible given that we expect strategic buyers to try to avoid monopoly outcomes, but a novel and less expected finding is that we observe these changes even when the degree of strategic behavior is fairly low. This reflects how, in the BDK model, a single sale may be enough to prevent a firm from ever wanting to exit. For example, for the parameters that BDK1 use as their leading example, there is a unique equilibrium with permanent duopoly once each buyer expects to capture 15 percent of future buyer surplus.

Our method and our results make several contributions. First, allegations of anticompetitive conduct often come from industries where LBD, network effects or switching costs can lead to an incumbent's high current market share creating a lasting competitive advantage. The decision to initiate an investigation will often

[2] The monopsonist also seeks to maintain competition in the related models of Lewis and Yildirim (2005) and Anton, Biglaiser, and Vettas (2014).

[3] CR also assume that sellers' costs are observed and that buyers' idiosyncratic preferences over sellers are private information, whereas LY assume that each seller's marginal cost contains an element that is idiosyncratic and private information.

[4] Even government procurement may not be a monopsony if different agencies or governments in different jurisdictions purchase from the same suppliers.

turn on whether the agency determines that features of the industry, including the sophistication of buyers (who may be large distributors, rather than final customers), are plausibly consistent with an exclusionary equilibrium.[5] While we consider a specific model of LBD that is not designed to capture the features of any particular market, our results suggest that a theory of inefficient exclusion may be less plausible when buyers are likely to be even moderately strategic.[6]

Second, we believe that our tractable formulation of how strategically buyers behave may be usefully applied to models where dynamics arise from other sources, such as network effects, or product durability or perishability. Existing models with strategic buyers (e.g., Gul, Sonnenschein, and Wilson 1986; Besanko and Winston 1990; Levin, McGill, and Nediak 2010; Jerath, Netessine, and Veeraraghavan 2010; Hörner and Samuelson 2011; Board and Skrzypacz 2016; Chen, Farias, and Trichakis 2019 for models with a monopolist seller; and under oligopoly, Levin, McGill, and Nediak 2009) allow buyers to choose when to buy and do not consider what happens as the degree to which buyers are strategic varies. In contrast, we vary buyer strategicness in a setting where buyers can influence future market structure. Our formulation may also be useful in extending the empirical literature on estimating games with dynamic competition (e.g., Benkard 2004 and Kim 2014 estimate games where sellers benefiting from LBD are dynamic but buyers are static).

Third, we make a methodological contribution with a new algorithm to identify equilibria. Following BDK, we use homotopies as our primary method for identifying Markov equilibria. However, homotopies are not guaranteed to find all equilibria, so we also use a new recursive algorithm that, under some plausible assumptions, can identify whether a particular type of equilibrium that may result in monopoly exists. While backwards recursion is widely used to solve finite horizon sequential games, or games that must end up in a single absorbing state (for example, CR's model when there is no exit), we believe that we are the first to use it to test whether or not a particular type of equilibrium exists.[7]

The rest of the paper proceeds as follows. Section I describes the extended version of BDK's model. Section II explains why strategic buyer behavior changes equilibrium outcomes using BDK's baseline parameters. Section III shows that we see qualitatively similar patterns for different degrees of LBD and different degrees of product differentiation. Sections II and III find equilibria using homotopies.

[5] United States Department of Justice (2008) discusses the issues involved in challenging allegedly anticompetitive conduct, although it was withdrawn as official policy in 2009.

[6] While BDK do not advocate for any particular antipredatory screen or policy, they use their results to suggest that predation is a real phenomenon that agencies should invest in trying to prevent. For example, BDK1 (p. 892): "Our analysis suggests that guiding these expectations toward 'good' equilibria by creating a business environment in which firms anticipate that predatory pricing 'does not work' (by issuing general guidelines about how allegations of predation are handled, speaking out against predation, pursuing high-profile cases, etc.) can be a powerful tool for antitrust policy"; and p. 894: "Behavior resembling conventional notions of predatory pricing–aggressive pricing followed by reduced competition–arises routinely. This casts doubt on the notion that predatory pricing is a myth and does not have to be taken seriously by antitrust authorities." We agree with both of these statements, and view our work as highlighting that, in assessing alleged predation, it may be more important than previously recognized to account for how strategically buyers behave.

[7] We thank a referee for pointing out the novelty of our approach. Iskhakov, Rust, and Schjerning (2016) show that recursive algorithms can be used to identify equilibria in stochastic Markov equilibrium games where all movements through the state space must satisfy a directional property. One can view our approach as using recursion to identify the existence of a specific type of equilibrium where movements through parts of the state space are directional.

Section IV provides supporting evidence about how strategic buyer behavior affects the types of equilibria that exist using our recursive algorithm, and examines the robustness of our results to changing several of the model's assumptions. Section V concludes. The online Appendices contain details of the methods used, as well as additional figures and results. The programs to replicate our results are available online (Sweeting et al. 2022).

I. Model

In this section we briefly describe the model. BDK1 and BDK2 provide additional motivation.

Overview.—Two ex ante symmetric but differentiated sellers and a set of symmetric strategic buyers play an infinite horizon, discrete time, discrete state dynamic game. Each seller i has a publicly observed state variable e_i, and is either a potential entrant ($e_i = 0$), or active with $e_i \in \{1, 2, \ldots, M\}$, which represents the seller's "know-how." Every period, active sellers set prices to compete for the unit demand of a buyer. An active seller's marginal cost is $\kappa \rho^{\log_2(\min(e_i, m))}$ where $\rho \in [0, 1]$ is the "progress ratio." For states below m, a doubling of know-how implies a $100(1-\rho)$ percent marginal cost reduction, but there is no marginal cost reduction when know-how increases above m. Marginal costs are constant for $e_i \geq m$, and $e_i \leq M$ constrains the state space to be finite. We follow BDK1 and BDK2 in assuming $\kappa = 10, M = 30, m = 15$ and a discount factor of $\beta = \frac{1}{1.05}$.

A buyer's flow indirect utility if it buys from seller i is $v_i - p_i + \sigma \epsilon_i$, where $v_1 = v_2 = 10$, p_i is i's price, and σ parameterizes the degree of product differentiation. The no purchase option (0) has $v_0 - p_0 = 0$. We model strategic buyers by assuming that the chosen buyer in each period is drawn, with replacement, from a pool of symmetric potential buyers, and that each buyer expects to be the buyer in any future period with probability $0 \leq b^p \leq 1$. The ϵ_is are private information type I extreme value payoff shocks that are i.i.d. across buyers, options and periods, and do not depend on a buyer's past purchases. Buyers and sellers cannot sign multi-period contracts, and we ignore the effects that possible downstream competition between buyers may have on purchase behavior.

Timing, State Transitions and Entry/Exit.—Figure 1 summarizes within-period timing. Active sellers simultaneously set prices, without knowing the buyer's ϵs. A sale raises a seller's state by one, unless it is already at M. There is no know-how depreciation. Sellers make simultaneous exit and entry choices. Sunk entry costs and scrap values are drawn independently from symmetric triangular distributions, with cumulative distribution functions F_{enter} and F_{scrap}, and supports $[\overline{S} - \Delta_S, \overline{S} + \Delta_S]$ and $[\overline{X} - \Delta_X, \overline{X} + \Delta_X]$, respectively, with $\Delta_X, \Delta_S > 0$. The finite supports mean that entry may be certain or never optimal, and that exit may never be optimal.[8] We will use BDK's baseline parameter values, $\overline{S} = 4.5$, $\overline{X} = 1.5, \Delta_S = \Delta_X = 1.5$.

[8] When the support of the scrap value is wide enough, a seller that draws a low scrap value will always prefer to remain in the market.

A. Buyer is selected from pool. Its tastes are private information.

B. Active sellers simultaneously set prices.

C. Buyer makes purchase choice.

D. Successful seller's experience increases by 1 (up to M).

E. Private info. seller entry costs and scrap values are revealed and sellers make simultaneously entry/exit choices.

F. State space evolves given entry/exit choices.

FIGURE 1. WITHIN-PERIOD TIMING

Equilibrium.—We consider symmetric and stationary Markov perfect Nash equilibria (MPE) (Ericson, and Pakes 1995; Maskin and Tirole 2001). Existence of at least one MPE follows from Doraszelski and Satterthwaite (2010). An equilibrium will consist of, for each state $\mathbf{e} = (e_1, e_2)$, active seller prices $(p(\mathbf{e}))$ and seller continuation probabilities $(\lambda(\mathbf{e}))$, and the values of the sellers and a representative buyer in the pool defined at the start of the period $(V^S(\mathbf{e}), V^B(\mathbf{e}))$ and before private entry/exit decisions are taken $(V^{S,INT}(\mathbf{e}), V^{B,INT}(\mathbf{e}))$.

Equilibrium values and strategies will solve the following equations, where symmetry implies that we can express the equations in terms of seller 1's strategies and values only.[9]

Beginning of period value for seller 1 (V_1^S)**:**

$$V_1^S(\mathbf{e}) - D_1(p(\mathbf{e}), \mathbf{e})(p_1(\mathbf{e}) - c_1(e_1)) - \sum_{k=0,1,2} D_k(p(\mathbf{e}), \mathbf{e}) V_1^{S,INT}(\mathbf{e}'_k) = 0, \tag{1}$$

where $\mathbf{e}'_1 = (\min(e_1 + 1, M), e_2)$, $\mathbf{e}'_2 = (e_1, \min(e_2 + 1, M))$ and $\mathbf{e}'_0 = (e_1, e_2)$, i.e., the states that the game will transition to if there is a purchase from seller 1 or seller 2, or no purchase, respectively.[10] The sale probabilities, D, will be defined below.

Value for seller 1 before entry/exit stage $(V_1^{S,INT})$**:**

$$\begin{aligned} V_1^{S,INT}(\mathbf{e}) - \big(&\beta\lambda_1(\mathbf{e})\lambda_2(\mathbf{e}) V_1^S(\mathbf{e}) + \beta\lambda_1(\mathbf{e})(1 - \lambda_2(\mathbf{e})) V_1^S(e_1, 0) \\ &+ (1 - \lambda_1(\mathbf{e}))E(X|\lambda_1(\mathbf{e}))\big) = 0, \end{aligned} \tag{2}$$

for $\mathbf{e} = (e_1, e_2)$ where $e_1, e_2 > 0$, with similar equations when a seller is a potential entrant. The expected scrap value when seller 1 chooses to exit is $E(X|\lambda_1(\mathbf{e}))$.

[9] For example, symmetry implies that $\lambda_2(e_1, e_2) = \lambda_1(e_2, e_1)$, $p(\mathbf{e}) = (p_1(e_1, e_2), p_1(e_2, e_1))$, $V^B(e_2, e_1) = V^B(e_1, e_2)$ and $V^{B,INT}(e_2, e_1) = V^{B,INT}(e_1, e_2)$.

[10] The Bellman equation at the price-setting stage is $V_1^S(\mathbf{e}) = \max_{p_1} D_1(p_1, p_2(\mathbf{e}), \mathbf{e})(p_1(\mathbf{e}) - c_1(e_1)) + \sum_{k=0,1,2} D_k(p_1, p_2(\mathbf{e}), \mathbf{e}) V_1^{S,INT}(\mathbf{e}'_k)$, from which equation (1) can be derived by substituting in the prices implied by the first-order conditions. Similarly, equation (2) can be derived from a Bellman equation that determines the continuation choice.

First-order condition for seller 1's price (p_1) *if* $e_1 > 0$:

$$D_1\big(p(\mathbf{e}),\mathbf{e}\big) + \sum_{k=0,1,2} \frac{\partial D_k\big(p(\mathbf{e}),\mathbf{e}\big)}{\partial p_1} V_1^{S,INT}(\mathbf{e}_k') + \big(p_1(\mathbf{e}) - c_1(e_1)\big)\frac{\partial D_1\big(p(\mathbf{e}),\mathbf{e}\big)}{\partial p_1} = 0. \tag{3}$$

Seller 1's continuation probability in entry/exit stage (λ_1):

$$\lambda_1(\mathbf{e}) - F_{\text{enter}}\Big(\beta\big[\lambda_2(\mathbf{e})\, V_1\big(1,\max(1,e_2)\big) + \big(1-\lambda_2(\mathbf{e})\big)\, V_1(1,0)\big]\Big) = 0 \text{ if } e_1 = 0, \tag{4}$$

$$\lambda_1(\mathbf{e}) - F_{\text{scrap}}\Big(\beta\big[\lambda_2(\mathbf{e})\, V_1\big(e_1,\max(1,e_2)\big) + \big(1-\lambda_2(\mathbf{e})\big)\, V_1(e_1,0)\big]\Big) = 0 \text{ if } e_1 > 0. \tag{5}$$

Buyers' values and choice probabilities are defined by the following equations.

Beginning of period representative buyer value (V^B):

$$V^B(\mathbf{e}) - b^p\,\sigma\log\left(\sum_{k=0,1,2}\exp\left(\frac{v_k - p_k + V^{B,INT}(\mathbf{e}_k')}{\sigma}\right)\right) - (1-b^p)\sum_{k=0,1,2} D_k\big(p(\mathbf{e}),\mathbf{e}\big)\, V^{B,INT}(\mathbf{e}_k') = 0, \tag{6}$$

where the last term is the continuation value for a nonchosen buyer, and the second term is the expected surplus, reflecting both the expected flow utility and the continuation value, for a chosen buyer.

Value for representative buyer before entry/exit stage ($V^{B,INT}$):

$$V^{B,INT}(\mathbf{e}) - \beta\Big(\sum_{\mathbf{e}'}\Pr\big(\mathbf{e}'|\,\mathbf{e},\lambda_1(\mathbf{e}),\lambda_2(\mathbf{e})\big)\, V^B(\mathbf{e}')\Big) = 0, \tag{7}$$

where $\mathbf{e}'$ are the states the game can evolve to depending on the entry and exit choices of the sellers.

Choice/sale probabilities ($D_i(p,\mathbf{e})$), *including for the outside option* ($i = 0$):

$$D_i(p,\mathbf{e}) = \frac{\exp\left(\frac{v_i - p_i + V^{B,INT}(\mathbf{e}_i')}{\sigma}\right)}{\sum_{k=0,1,2}\exp\left(\frac{v_k - p_k + V^{B,INT}(\mathbf{e}_k')}{\sigma}\right)}. \tag{8}$$

Discussion of b^p.—The variable b^p is a buyer's expected share of future buyer surplus, or, equivalently, the proportion of a purchase choice's effect on future buyer surplus that a buyer internalizes. If $b^p = 0$, $V^B = V^{B,INT} = 0$ for all states and the model is equivalent to the BDK model. If $b^p = 1$, the model is consistent with LY's assumption of a single repeat buyer. If $\frac{1}{b^p}$ is an integer, the model is consistent with a pool of this number of symmetric buyers from which a buyer is chosen with replacement each period (e.g., five buyers if $b^p = 0.2$). However, we will vary b^p continuously, and one can rationalize values where $\frac{1}{b^p}$ is not an integer using a behavioral interpretation where all buyers over- or underestimate their future importance.

The variable b^p only affects purchase probabilities in states where the purchase choice that is made can affect the state that the industry will be in the next period. In particular, the $V^{B,INT}$ terms will cancel in (8) in states $(M,0)$ and (M,M) and any buyer will maximize its current flow utility.

Types of Equilibria.—It is useful to distinguish different types of equilibria. Following BDK, equilibria where sellers never exit from duopoly states are "accommodative."

DEFINITION 1: *An equilibrium is* ***accommodative*** *if* $\lambda_1(e_1,e_2) = \lambda_2(e_1,e_2) = 1$ *for all states* (e_1,e_2) *where* $e_1 > 0$ *and* $e_2 > 0$.

As active sellers always have a positive probability of making a sale, a game that begins with duopoly must end up in absorbing state (M,M) when an equilibrium is accommodative. It is theoretically possible for more than one accommodative equilibrium to exist, although we have never found an example of this type of multiplicity.[11]

Non-accommodative equilibria may take many forms. For policy purposes, one might be particularly interested in equilibria where one seller can become a permanent monopolist (i.e., $(M,0)$ or $(0,M)$ are absorbing states that can be reached with positive probability). We will pay particular attention to a subset of this type of equilibria.

DEFINITION 2: *A symmetric equilibrium has the "some exit leads to permanent monopoly" (SELPM) property if there is some state* $e_1^* > 1$, *where (i)* $\lambda_1(e_1,e_2) = 1$ *for all* $e_1 \geq e_1^*$[12] *and* $\forall e_2$, *including* $e_2 = 0$; *(ii)* $\lambda_2(e_1^*,e_2) < 1$ *for some* e_2 *where* $0 < e_2 < e_1^*$, *and* $\lambda_2(e_1,0) = 0$ *for all* $e_1 \geq e_1^*$.

In words, an equilibrium is SELPM if the leader will not exit for the rest of the game once it has attained a certain level of know-how (e_1^*) (condition (i)), but there is a nonzero probability that a laggard seller 2 will exit in which case there will be no re-entry (condition (ii)). Therefore, once e_1^* has been reached the game will either evolve, with both sellers accumulating know-how, to (M,M), and stay there, or seller 2 may exit in which case the game will evolve, with seller 1 accumulating know-how, to $(M,0)$, and stay there.[13] As noted previously, purchase choices in

[11] However, the form of demand implies that accommodative equilibrium prices in state (M,M) must be unique for all b^p.

[12] Note that as we are only looking at symmetric equilibria, this condition implies that $\lambda_2(e_1,e_2) = 1$ for all $e_2 \geq e_1^*$.

[13] In a SELPM equilibrium the game must eventually end up in one of these two absorbing states unless $(0,0)$ is also an absorbing state, in which case the game could end with a completely inactive industry. We have not found an equilibrium where $(0,0)$ is absorbing for any of the parameterizations considered in this paper.

states $(M, 0)$ and (M, M) will not change the state, so firms will set static Nash prices in these states for all values of b^p.[14]

In Sections II and III we will note that, for the parameters considered, all of the non-accommodative equilibria identified using homotopies are SELPM. In Section IVA we will use a recursive algorithm that can identify if SELPM equilibria exist.

II. The Effects of Strategic Buyers on Equilibrium Outcomes: An Illustration

In this section, we use the parameter values assumed by BDK in their leading example, including $\sigma = 1$ and $\rho = 0.75$, to examine how varying b^p from 0 to 1 changes incentives and equilibrium outcomes.[15] BDK1 argue that these parameters are empirically plausible, although they are not intended to match any particular industry.[16] We will call these the "illustrative parameters." The methods that we use to find equilibria are described in online Appendix A.

Table 1 shows equilibrium strategies, for a subset of states, for the three equilibria ("baseline equilibria") that both our analysis and BDK identify when $b^p = 0$. One equilibrium is accommodative and the other two are SELPM.[17] The three equilibria differ only in states where at least one firm is in states 0 or 1, with lower SELPM duopoly prices, consistent with the sellers recognizing that a seller that has made no sales may exit.

BDK measure long-run market structure using the long-run Herfindahl-Hirschman index (HHI^∞):

$$HHI^\infty = \sum_{\mathbf{e} \neq (0,0)} \frac{\mu^\infty(\mathbf{e})}{1 - \mu^\infty(0,0)} HHI(\mathbf{e}) \tag{9}$$

where

$$HHI(\mathbf{e}) = \sum_{i=1,2} \left(\frac{D_i(p, \mathbf{e})}{D_1(p, \mathbf{e}) + D_2(p, \mathbf{e})} \right)^2,$$

where $\mu^\infty(\mathbf{e})$ is the probability that a game beginning in state $(1,1)$ will be in state $\mathbf{e}$ after 1,000 periods, approximating the long-run, given equilibrium strategies. The long-run expected price (P^∞) is defined similarly with the sale probabilities weighting the prices of the active sellers. In an accommodative equilibrium $\mu^\infty(M, M)$ is essentially one, so $HHI^\infty = 0.5$ and $P^\infty = 5.24$. In either of the SELPM equilibria, the game may alternatively end up in absorbing states $(M, 0)$ or $(0, M)$, where the $HHI(\mathbf{e})$ is 1 and prices are 8.54, so that HHI^∞ and P^∞ reflect the probabilities of permanent duopoly and permanent monopoly outcomes.

Increasing b^p.—We now consider the effect of increasing b^p. We first consider buyer behavior, and how changes in buyer behavior affect seller incentives, and then equilibrium outcomes.

[14] Note that a monopolist would still set a static price in state $(M, 0)$ even if there was a possibility of re-entry so that $(M, 0)$ was not absorbing.

[15] All of the other parameters take the values noted in Section I.

[16] Ghemawat (1985) reports the average estimated ρ across 97 empirical studies to be 0.85, with 79 estimates between 0.75 and 0.9.

[17] Any $e_1 = 2, .., 30$ meets the SELPM definition of e_1^* in both cases.

TABLE 1—BASELINE EQUILIBRIUM STRATEGIES FOR A SUBSET OF STATES FOR THE ILLUSTRATIVE PARAMETERS WHEN $b^p = 0$

States	High-HHI equilibrium				Mid-HHI equilibrium			
	$HHI^{\infty} = 0.96$, $P^{\infty} = 8.26$				$HHI^{\infty} = 0.58$, $P^{\infty} = 5.74$			
(e_1,e_2)	p_1	p_2	λ_1	λ_2	p_1	p_2	λ_1	λ_2
(1,1)	−34.78	−34.78	0.9996	0.9996	3.27	3.27	1	1
(2,1)	0.08	3.63	1	0.7799	3.62	4.65	1	0.9998
(3,1)	0.56	4.15	1	0.7791	3.44	4.95	1	0.9874
(3,2)	5.61	5.94	1	1	5.61	5.94	1	1
(4,1)	0.80	4.41	1	0.7787	3.38	5.12	1	0.9767
(4,2)	5.55	6.06	1	1	5.55	6.06	1	1
(4,4)	5.65	5.65	1	1	5.65	5.65	1	1
(10,1)	1.21	4.86	1	0.7778	3.38	5.46	1	0.9586
(10,2)	5.44	6.28	1	1	5.44	6.28	1	1
(10,10)	5.32	5.32	1	1	5.32	5.32	1	1
(29,1)	1.24	4.90	1	0.7777	3.39	5.49	1	0.9577
(29,2)	5.42	6.30	1	1	5.42	6.30	1	1
(30,1)	1.24	4.90	1	0.7777	3.39	5.49	1	0.9577
(30,2)	5.42	6.30	1	1	5.42	6.30	1	1
(30,29)	5.24	5.24	1	1	5.24	5.24	1	1
(30,30)	5.24	5.24	1	1	5.24	5.24	1	1
(1,0)	8.80	—	1	0	7.55	—	1	0.1357
(2,0)	8.72	—	1	0	8.72	—	1	0
(10,0)	8.56	—	1	0	8.56	—	1	0
(0,0)	—	—	0.9583	0.9583	—	—	0.9698	0.9698
(0,1)	—	8.80	0	1	—	7.55	0.1357	1
(0,2)	—	8.72	0	1	—	8.72	0	1
(0,3)	—	8.68	0	1	—	8.68	0	1
(0,4)	—	8.65	0	1	—	8.65	0	1
(0,10)	—	8.56	0	1	—	8.56	0	1
(0,29)	—	8.54	0	1	—	8.54	0	1
(0,30)	—	8.54	0	1	—	8.54	0	1

(*Continued*)

As $\lambda_2(e_1, e_2 > 1) = 1$ in the SELPM equilibria, a buyer in a state $(e_1 > 1, 1)$ can guarantee long-run duopoly if it buys from seller 2 (the laggard). The large difference (79.58) in the present value of buyer surpluses in the absorbing duopoly and monopoly states, (M,M) and $(M,0)$, implies that the incentive for even a moderately strategic buyer to buy from the laggard may be substantial.[18]

Figure 2 panel A shows seller 2's demand in state (3,1), holding seller strategies fixed at their baseline equilibrium values, for different values of b^p.[19] As b^p rises, seller 2's demand increases significantly in the SELPM mid-HHI and high-HHI equilibria even for low values of b^p.[20] For example, at the high-HHI baseline equilibrium price (4.15), the probability that seller 2 wins the sale increases from 0.027

[18] Recall that the value of b^p does not affect equilibrium prices in absorbing states. The present value of buyer surplus in state (M,M) is 114.57 $\left(\frac{\ln(2\times\exp(10-5.242)+\exp(0))}{1-\frac{1}{1.05}}\right)$ and the present value in state $(M,0)$ is 34.99 $\left(\frac{\ln(\exp(10-8.543)+\exp(0))}{1-\frac{1}{1.05}}\right)$. Of course, the fact that prices in states such as $(4,1)$ are lower than in states such as $(4,2)$ in the SELPM equilibria partially offsets this incentive.

[19] The figure is drawn varying $p_2(3,1)$ only in the current period, i.e., the buyer assumes that p_2 will have its baseline equilibrium value if the game is in state (3,1) in any future period. p_1, λ_1, and λ_2 are held fixed at their baseline equilibrium values in all states.

[20] There is also a small shift in demand towards the laggard in the accommodative equilibrium as accommodative prices are lower when states are more symmetric.

Table 1—Baseline Equilibrium Strategies for a Subset of States for the Illustrative Parameters When $b^p = 0$ (Continued)

States	Accommodative equilibrium $HHI^{\infty} = 0.5$, $P^{\infty} = 5.24$			
(e_1,e_2)	p_1	p_2	λ_1	λ_2
(1,1)	5.05	5.05	1	1
(2,1)	5.34	6.29	1	1
(3,1)	5.45	6.65	1	1
(3,2)	5.61	5.94	1	1
(4,1)	5.51	6.82	1	1
(4,2)	5.55	6.06	1	1
(4,4)	5.65	5.65	1	1
(10,1)	5.59	7.12	1	1
(10,2)	5.44	6.28	1	1
(10,10)	5.32	5.32	1	1
(29,1)	5.58	7.15	1	1
(29,2)	5.42	6.30	1	1
(30,1)	5.58	7.15	1	1
(30,2)	5.42	6.30	1	1
(30,29)	5.24	5.24	1	1
(30,30)	5.24	5.24	1	1
(1,0)	8.19	—	1	0.8816
(2,0)	8.45	—	1	0.5233
(10,0)	8.55	—	1	0.2953
(0,0)	—	—	0.9552	0.9552
(0,1)	—	8.19	0.8816	1
(0,2)	—	8.45	0.5233	1
(0,3)	—	8.52	0.4227	1
(0,4)	—	8.54	0.3739	1
(0,0)	—	8.55	0.2953	1
(0,29)	—	8.54	0.2899	1
(0,30)	—	8.54	0.2899	1

Notes: The variables p_i and λ_i are the equilibrium price and equilibrium probability of being in the industry in the next period of seller i. The calculations of HHI^{∞} and P^{∞} are described in the text. Marginal costs for experience states 1, 2, 3, 4, 10, 29 and 30 are 10, 7.50, 6.34, 5.63, 3.85, 3.25, and 3.25 respectively.

to 0.306 as b^p increases from 0 to 0.1 (seller 1's probability falls from 0.973 to 0.694).

This shift in buyer demand increases seller 2's value. Figure 2 panel B shows $V_2^S(3,1)$ holding seller strategies fixed at their baseline equilibrium values but allowing demand to change. If $\beta V_2^S(3,1)$ is greater than $\left(\overline{X} + \Delta_X\right)$ (maximum scrap value) then seller 2 will never choose to exit in state (3,1). The buyer-demand adjusted $V_2^S(3,1)$s for the high-HHI and mid-HHI equilibria cross this threshold when $b^p \approx 0.16$ and 0.05 respectively.

The change in demand also affects the sellers' pricing incentives. BDK1 define two dynamic incentives for a seller.

DEFINITION 3: *Seller 1's* ***advantage-building*** *(AB) incentive is* $V_1^{S,INT}(e_1+1,e_2) - V_1^{S,INT}(e_1,e_2)$, *and its* ***advantage-denying*** *(AD) incentive is* $V_1^{S,INT}(e_1,e_2) - V_1^{S,INT}(e_1,e_2+1)$.

BDK1 identify the AD incentive as particularly important in sustaining equilibria that can result in monopoly. Figure 2 panel C shows how seller 1's incentives

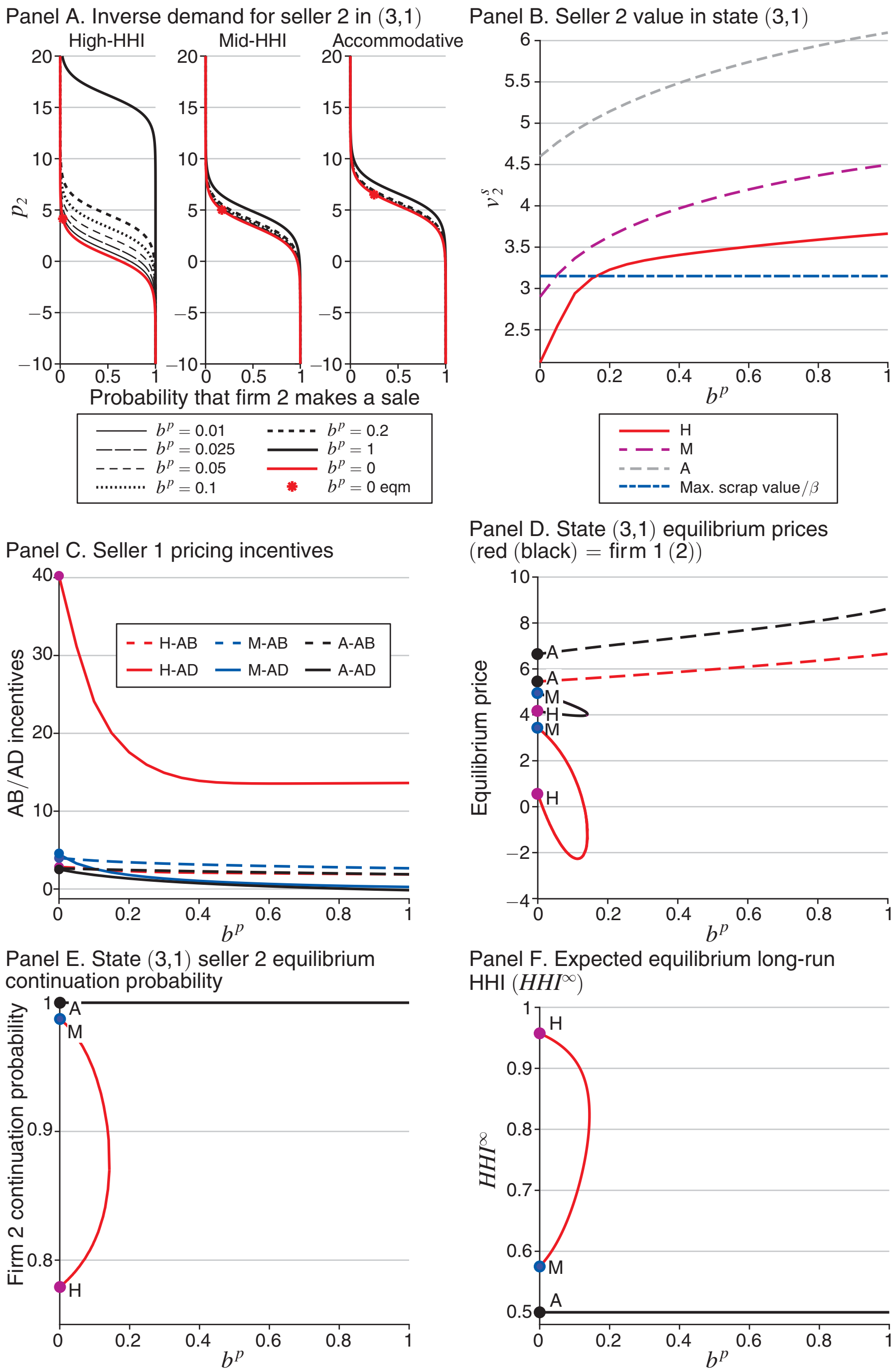

Figure 2. Demand, Dynamic Incentives, Equilibrium Strategies, and Long-Run Market Concentration for the Illustrative Parameters

Notes: H: high-HHI, M: mid-HHI, and A: accommodative baseline equilibria, and AB: advantage-building and AD: advantage-denying incentives. Panels A–C hold seller strategies fixed at baseline equilibrium values, and panels D–F show equilibrium strategies and implied HHI^∞ along b^p-homotopy paths from the A equilibrium (black lines) and overlapping paths from the H and M equilibria (red lines).

change in state $(3,1)$ as b^p increases, holding seller strategies fixed so that changes reflect only changes in demand. Even though seller 2 is still likely to exit if it does not make the sale, seller 1's high-HHI equilibrium AD incentive, which is large when $b^p = 0$, falls rapidly as b^p increases, reflecting how seller 2 is more likely to make a sale in future periods if it remains. The other incentives decline only slightly, and more linearly, as b^p increases.

Figure 2 panels D–F show state (3,1) prices, seller 2's continuation probability in state (3,1) and the HHI^{∞}s implied by equilibria when we follow the equilibrium correspondence using b^p-homotopies from each baseline equilibrium (see online Appendix F.1 for what happens to incentives). The high (H)- and mid (M)-HHI baseline equilibria lie at the two ends of a loop (i.e., the homotopies trace the same path in opposite directions) in the equilibrium correspondence that does not extend beyond $b^p = 0.142$ (approximately seven symmetric buyers). All of the equilibria on this loop are SELPM. The homotopy path from the accommodative equilibrium extends to $b^p = 1$, and all equilibria on this path are accommodative (i.e., $\lambda = 1$ for all duopoly states, and $HHI^{\infty} = 0.5$). We only ever find one accommodative equilibrium so that we have a unique equilibrium for $b^p > 0.142$. We will provide additional evidence that there are no SELPM equilibria for $b^p > 0.142$ in Section IVA. The decline in seller 1's demand causes equilibrium prices to initially fall as b^p increases from zero from the H and M equilibria, but sellers' prices rise on the path from the accommodative equilibrium as both sellers' incentives to gain an advantage are weakened by how strategic buyers tend to favor the laggard.

Figure 3 shows what happens to the present value of equilibrium expected total surplus (PV TS) and buyer surplus (PV CS) for a game starting in state (1,1). The long-run values of both measures are higher in the accommodative equilibrium, but lower initial prices can raise present values in the SELPM equilibria. The accommodative equilibria have higher PV TS, but, when multiple equilibria exist, the PV CS of the accommodative equilibrium lies between the PV CSs of the SELPM equilibria.[21] Therefore, strategic buyer behavior can actually eliminate a type of equilibrium that produces more surplus for buyers, and, within the type of equilibrium that survives, increasing b^p can lower buyer welfare, as prices rise, and lower total surplus, as discounted production costs increase when the sellers are kept relatively symmetric (see online Appendix Figure F.3(a)).[22]

III. Results across Values of ρ and σ

In this section, we examine whether strategic buyer behavior changes equilibrium outcomes in similar ways for different values of ρ, the progress ratio, and σ,

[21] Online Appendix F.2 further explores the welfare patterns by examining what happens to the number of sales and production costs, in the long run and in the first ten periods of the game. Even though one seller is likely to exit, expected surplus is highest in the high-HHI equilibrium in the first ten periods because duopoly prices are so low.

[22] These results are potentially relevant for whether buyers who do not compete downstream might have an incentive to merge before the game starts in order to prevent the upstream industry possibly ending up in monopoly. Even ignoring possible costs of agreeing to a merger, there would be no incentive for all buyers to merge in this example if, absent a merger, the mid-HHI equilibrium would be played. If the high-HHI equilibrium would be played, there would not be an incentive to merge to monopsony, as this would lower PV CS, and it might not be attractive for a subset of buyers to merge, without a subsidy from the remaining buyers who might capture many of the benefits from the merger.

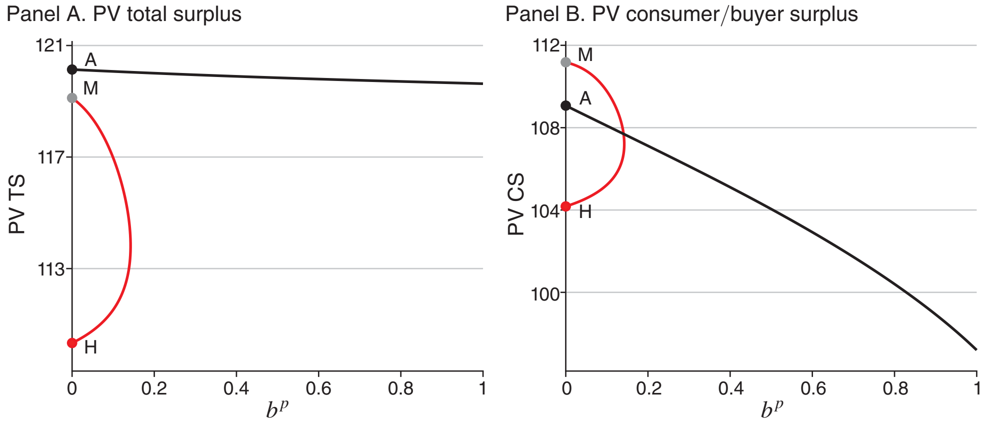

FIGURE 3. PRESENT VALUE OF SURPLUS FOR THE ILLUSTRATIVE PARAMETERS ALONG b^p-HOMOTOPY PATHS

Notes: H: high-HHI, M: mid-HHI, and A: accommodative baseline equilibria. The black line traces the homotopy path from the A baseline equilibrium. The red line traces the overlapping paths from the H and M baseline equilibria.

the degree of product differentiation. Lower σ reduces long-run duopoly prices and profits, which tends to lead to more exit, while slightly increasing monopoly profits, which may increase the competition to become a monopolist. Lower ρ tends to raise duopoly profits but it also gives the seller that makes the first sale a larger cost advantage, so that the effect on the incentives of a laggard to exit are ambiguous. We find equilibria by running σ- and ρ-homotopies for different, discrete, values of b^p, holding all of the other parameters fixed at their illustrative values.[23]

Figure 4 panels A and B show the values of HHI^∞ and P^∞ implied by the equilibria on σ-homotopy paths $(\rho = 0.75)$ for 11 different values of b^p.[24] All of the equilibria identified are accommodative or SELPM, and we only ever find one accommodative equilibrium for given parameters. The "ALL b^p" lines identify outcomes associated with accommodative equilibria that exist for all 11 values of b^p that we consider.[25] For $b^p = 0$ (black solid line, shown on its own in online Appendix F.3 for clarity), we find a single, accommodative equilibrium when $\sigma > 1.12$ (high differentiation), but for lower σ, we find that at least one equilibrium exists where a duopolist may exit and for some values there are many equilibria. For example, there are 23 equilibria for $\sigma = 0.8$, all of which have $HHI^\infty \geq 0.95$ and very similar $P^\infty > 8.5$. When accommodative and SELPM equilibria coexist, the accommodative equilibrium has the lowest P^∞.

The σ-homotopy paths unwind as b^p rises, which tends to reduce multiplicity but also leads to accommodative equilibria existing for lower σ. The probability of

[23] Varying other parameters may also generate interesting effects. However, we think it is natural to focus on the progress ratio, which measures the extent of LBD, and product differentiation, which distinguishes the CR and BDK models from earlier analyses of LBD and market structure, such as Dasgupta and Stiglitz (1988).

[24] For all b^p, we begin the path at $\sigma = 1.3$ where we find what appears to be a unique equilibrium by solving the equilibrium equations.

[25] This does not imply that the accommodative equilibria are identical in all states for all values of b^p, just that these equilibria generate essentially identical values of HHI^∞ and P^∞.

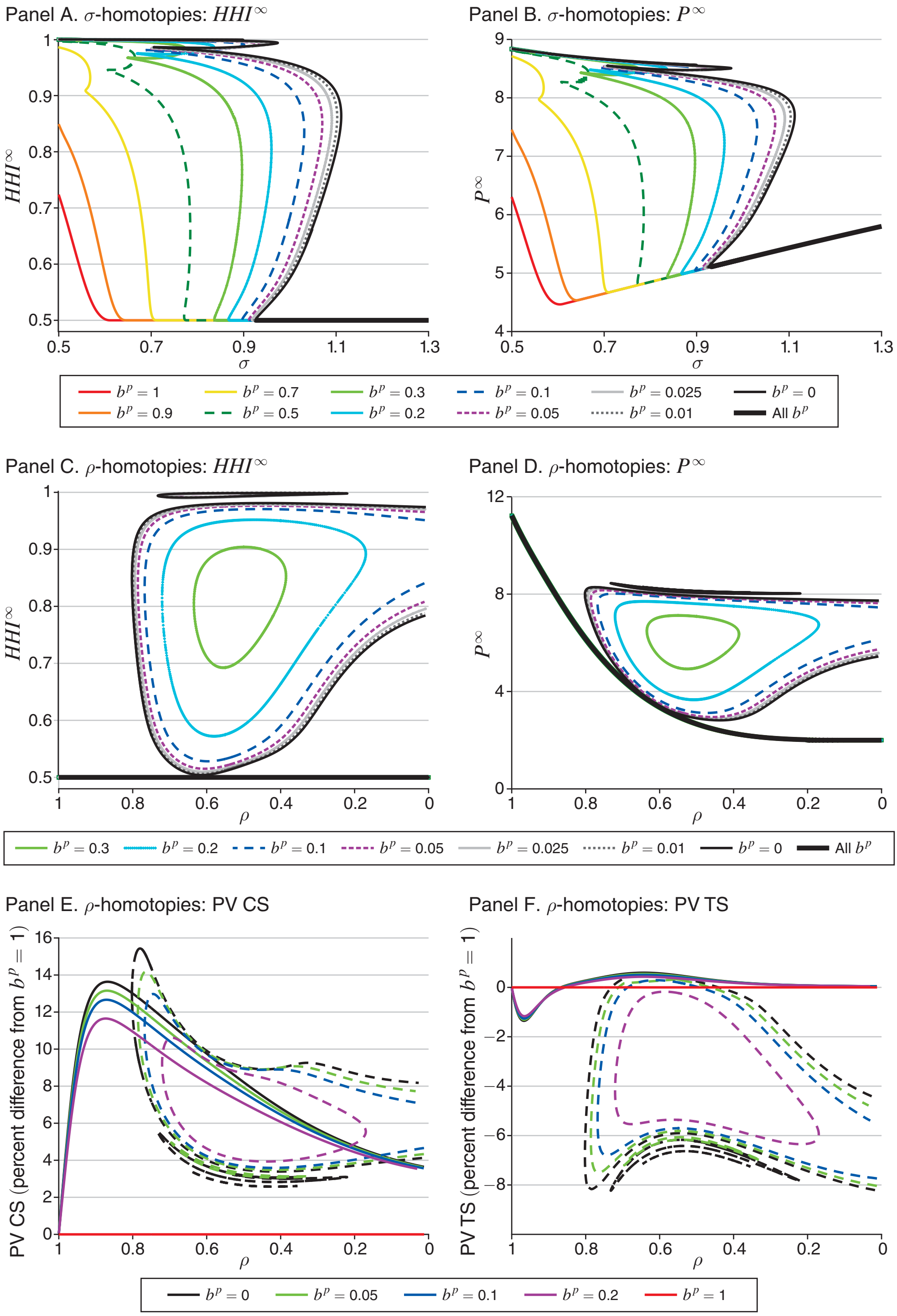

FIGURE 4. EQUILIBRIUM HHI^{∞}, P^{∞}, AND PRESENT VALUE OF SURPLUS ON σ OR ρ-HOMOTOPY PATHS FOR DIFFERENT b^p, WITH OTHER PARAMETERS AT THEIR ILLUSTRATIVE VALUES

Notes: Surplus in panels E and F is measured relative to surplus in the accommodative equilibrium when $b^p = 1$, and solid (dashed) lines indicate accommodative (non-accommodative) equilibria. The solid "ALL b^p" lines indicates where lines for all of the b^p values that we consider (0, 0.01, 0.025, 0.05, 0.1, 0.2, 0.3, 0.5, 0.7, 0.9, and 1) would overlap.

monopoly, reflected in HHI^{∞}, in the SELPM equilibria tends to fall. While multiplicity was eliminated when $b^p > 0.142$ for $\sigma = 1$, we find a similar result, but with a higher b^p threshold, when there is less differentiation. For example, we find a unique (accommodative) equilibrium for $\sigma = 0.8$ only when $b^p \geq 0.5$.

Figures 4 panels C and D show similar plots for ρ-homotopy paths, with the other parameters at their illustrative values, including $\sigma = 1$. The x-axis is ordered so that LBD increases to the right. We find one accommodative equilibrium for all ρ and for all b^p. All identified non-accommodative equilibria are SELPM. For $\rho > 0.803$, which is very relevant empirically (see footnote 16), we find only an accommodative equilibrium for all b^p. For lower ρ, we find that SELPM and accommodative equilibria coexist when b^p is small enough. For $b^p = 0$, the SELPM equilibrium correspondence has (in this dimension) two disconnected loops. The loop with the highest HHI^{∞}/P^{∞}s is eliminated for $b^p \geq 0.05$, and the second loop contracts as b^p rises, disappearing entirely for $b^p > 0.3$, so that only accommodative equilibria remain.

Figures 4 panels E and F show PV CS and PV TS for the ρ-homotopies (online Appendix F.4 shows the figures for the σ-homotopies). The patterns are broadly consistent with the illustrative parameter example. When accommodative and SELPM equilibria coexist, the accommodative equilibrium has higher PV TS, while its PV CS lies between the values of the SELPM equilibria. BDK2 argue that equilibria are quite efficient in the BDK model, and this conclusion tends to be strengthened when buyers are strategic in the sense that less efficient types of equilibria are eliminated. Increasing b^p lowers PV CS in accommodative equilibria, as initial price competition is softened, and it tends to lower PV TS for $\rho \leq 0.9$. For high ρ the pattern is different, as costs are sufficiently high that the probability that nonstrategic buyers make no purchase is not negligible, which inefficiently slows the industry's progress down. This probability tends to fall when buyers are strategic.[26]

IV. Robustness Checks, Extensions, and Discussion

The results presented so far suggest that, for empirically relevant progress ratios, moderately strategic buyer behavior eliminates the multiplicity of equilibria that is common when buyers are atomistic and, in particular, tends to eliminate equilibria that are likely to result in long-run industry domination by a single seller. However, the limitations of the method used to find equilibria and the simplicity of the model may provide reasons for caution. In this section, we explore and discuss the robustness of our results.

A. *Alternative Method for Identifying SELPM Equilibria*

Homotopies are only guaranteed to be able to find all equilibria under particular restrictions that our model does not satisfy (Judd, Renner, and Schmedders 2012), so our results could potentially reflect a systematic failure to find non-accommodative equilibria when buyers are strategic. As a check, we therefore use an alternative

[26] For example, when $\sigma = 1$, $\rho = 0.925$ and $b^p = 0.2$, the probability that the buyer chooses the outside option in state $(1,1)$ is around 0.272. When $b^p = 1$, this probability falls to 0.241 (a 10 percent decrease).

algorithm that can identify whether SELPM equilibria exist for given parameters, exploiting the feature that, in a SELPM equilibrium, once a state e_1^* has been reached, the state will transition to either (M,M) or $(M,0)$ without returning to a previously visited state. This feature implies that an algorithm that works backwards from (M,M) and $(M,0)$ will be able to find an e_1^* state, if one exists, as long as we can find all SELPM-consistent equilibria in a given state given continuation values if a state changes. Online Appendix D describes the algorithm and the conditions under which it will work.[27] Online Appendix E describes a simpler algorithm that can identify if an accommodative equilibrium exists.

To be clear, the algorithm cannot determine if non-SELPM non-accommodative equilibria exist. However, recall that all of the non-accommodative equilibria identified in Section II and III are SELPM. If, across a much broader range of parameters, all or almost all non-accommodative equilibria are SELPM, then finding that no SELPM equilibria exist for particular parameters provides at least highly suggestive evidence that an accommodative equilibrium, if one exists, is likely unique.

Figure 5 shows the types of equilibria that we find exist for a grid of values of (b^p, ρ, σ) with the other parameters at their illustrative values. We highlight three results. First, for $\rho = 0.75$ or $\sigma = 1$, the results are completely consistent with those presented in Sections II and III suggesting that homotopies are an effective way to find SELPM and accommodative equilibria for all b^p. Second, there is a small set of parameters with no LBD and low differentiation $(\rho = 1, \sigma \leq 0.65)$ where equilibria must be non-accommodative and non-SELPM. For these parameters, the present value of perpetual duopoly profits in state (M,M) is less than the highest possible scrap value, so (M,M) cannot be an absorbing state. Third, for the remaining combinations, the qualitative pattern is consistent with our earlier findings. Accommodative and SELPM equilibria coexist over a wide range of the parameter space when $b^p = 0$. Accommodative (SELPM) equilibria are supported for wider (narrower) ranges of parameters as b^p rises. However, for $0.2 < \rho < 0.9$, SELPM equilibria can exist even when $b^p = 1$ when there is minimal product differentiation.

B. *Mixture of Strategic and Nonstrategic Buyers*

The Section I model assumes that all buyers are equally strategic, whereas it may be more common that there are some repeat purchasers and some buyers that expect to be in the market only once. To investigate how our results may change if strategic and nonstrategic buyers coexist, we solve, for the illustrative parameters, an extended version of our model with four symmetric strategic buyers.[28] Nature chooses a nonstrategic buyer each period with probability $(1 - \gamma)$, and otherwise randomly chooses one of the strategic buyers. Sellers can set different prices depending on the buyer's type. If $\gamma = 0$ then the model is equivalent to the original BDK model, with prices equal to those in the baseline equilibria. The details of this extension, and the next three extensions, are provided in online Appendix G.

[27] Note that the algorithm does not identify how many SELPM equilibria there may be, partly because the recursive algorithm cannot find equilibrium strategies in parts of the state space where there can be exit followed by re-entry.

[28] Patterns are qualitatively similar for different numbers of strategic buyers.

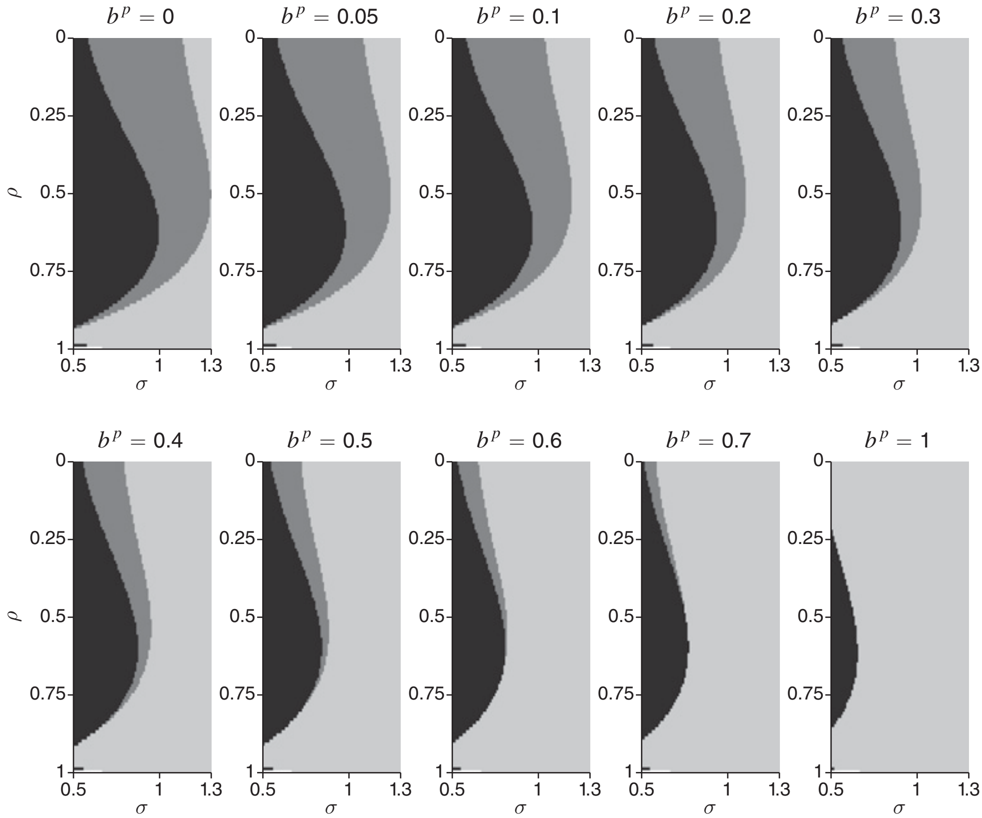

FIGURE 5. CLASSIFICATION OF THE TYPES OF EQUILIBRIA THAT EXIST FOR (b^p, ρ, σ) COMBINATIONS WITH REMAINING PARAMETERS AT THEIR ILLUSTRATIVE VALUES

Notes: ρ and σ are varied in steps of 0.01. The algorithm for identifying if SELPM (accommodative) equilibria exist is described in online Appendix D (E). *White:* neither SELPM nor accommodative equilibria exist; *light gray:* an accommodative equilibrium exists, no SELPM equilibria exist; *dark gray:* an accommodative equilibrium and SELPM equilibria coexist; *black:* SELPM equilibria exist, no accommodative equilibrium exists.

Figure 6 panel A shows the HHI^{∞} implied by the equilibria on γ-homotopy paths that start from the $\gamma = 0$ equilibria. We find accommodative equilibria for all γ and non-accommodative equilibria, all of which are SELPM, when $\gamma \leq 0.79$. If $\gamma = 0.79$, each strategic buyer expects to be the buyer with probability $\frac{\gamma}{4} = 0.198$ in future periods. This is greater, but not too much greater, than the threshold probability of 0.142 which eliminated SELPM equilibria in the Section I model, suggesting that the existence of nonstrategic buyers may require strategic buyers to behave "more strategically" to eliminate SELPM equilibria.

C. *Buyers with Persistent Preferences over Sellers*

The Section I model also assumes that all buyers have identical preferences over sellers up to i.i.d. preference shocks. In reality, some buyers may have systematic

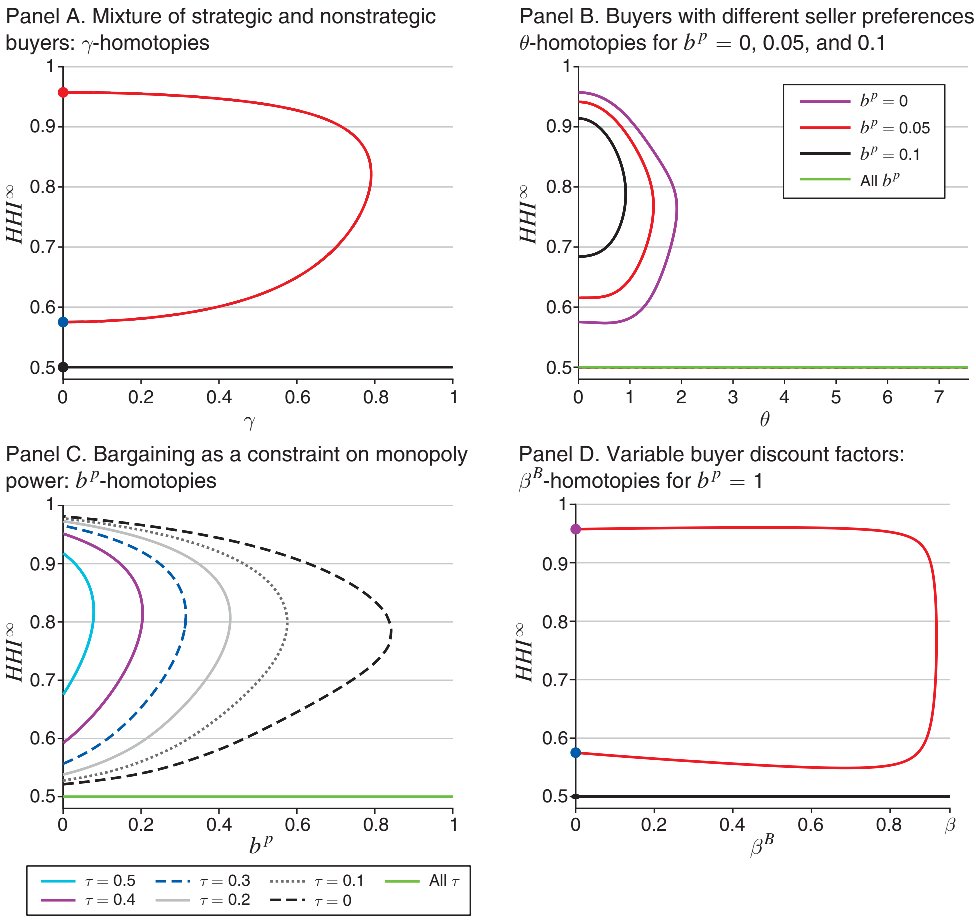

FIGURE 6. EQUILIBRIUM EXPECTED LONG-RUN HHI (HHI^{∞}) FOR VARIOUS EXTENSIONS

Notes: Panel A: red line indicates paths from non-accommodative equilibria. Black line indicates the path from the accommodative equilibrium. Panel B: the "ALL b^p" line indicates where lines for all of the b^p values shown in the diagram (0, 0.05, 0.1), as well as values of b^p above 0.15, would overlap. Panel C: τ is the Nash bargaining parameter that indicates the buyer's share of surplus. The "ALL τ" lines indicates where lines for values of τ = 0, 0.1, 0.2, …, 0.9, 1 would overlap. Panel D: red line indicates paths from non-accommodative equilibria. Black line indicates path from accommodative equilibrium.

preferences for a particular seller (for example, because of geographic location or compatibility with existing equipment). We therefore extend the Section I model by assuming that there are equal numbers of two types of buyers. Type 1's indirect utility when it purchases from sellers 1 and 2 respectively are $v_1 + \frac{\theta}{2} - p_1 + \epsilon_1$ and $v_2 - \frac{\theta}{2} - p_2 + \epsilon_2$. For type 2 buyers, the signs on the $\frac{\theta}{2}$ terms are reversed. Sellers recognize the type of the buyer before setting prices. The model is equivalent to the Section I model when $\theta = 0$. Intuitively, as θ increases it will become more attractive for a seller that has a marginal cost disadvantage to remain in the market as it will still have an advantage when selling to one-half of the market.

Figure 6 panel B shows, for the illustrative parameters, the HHI^{∞} implied by equilibria on θ-homotopy paths that start at the $\theta = 0$ equilibria for $b^p = 0, 0.05,$

and 0.1, values that support multiple equilibria when $\theta = 0$.[29] There are accommodative equilibria for all θ, but the non-accommodative equilibria, all of which are SELPM, are eliminated for relatively low θs, especially when buyers are strategic.[30] Therefore, less strategic behavior may be required to generate our qualitative results than in our simple model when buyers have persistent preferences.

D. *Bargaining as a Constraint on Monopoly Power*

When a low know-how laggard may exit, a strategic buyer has an incentive to buy from the laggard in order to reduce the probability that it will be exposed to monopoly power in future periods. However, at least two considerations might make a large buyer less concerned about a monopoly outcome. First, in the spirit of Aghion and Bolton (1987); Rasmusen, Ramseyer, and Wiley (1991); and Segal and Whinston (2000), the leader might sign multi-period contracts with large buyers, which simultaneously protect these buyers from future monopoly power while also making it less profitable for the laggard to remain in the market. We view the relaxation of the period-by-period price competition assumption of BDK, CR, and LY to allow for contracts as an important next step in this research, although contracts may provide imperfect protection from a monopolist when products are complicated and/or customized.

Second, even if we assume period-by-period competition, it is possible that a buyer would be able to negotiate with a monopoly seller rather than being faced with a take-it-or-leave-it price. If negotiations partially protect buyers this could make them less concerned with preserving competition, but it could also provide a leader with less incentive to try to become a monopolist. To provide a preliminary assessment of how these forces play out, we adjust the Section I model by assuming that, in monopoly states, a strategic buyer and a monopolist play a complete information Nash bargaining game (i.e., the buyer ϵ preferences become observed) where, in each period, the buyer receives a share τ of the surplus from trade. The change in the assumed information structure means that BDK's model is no longer a special case even when $b^p = 0$. However, as a comparison, the expected transaction price in state (30,0) is approximately the same as in the baseline equilibria when τ is slightly greater than 0.2.

Figure 6 panel C shows, for the illustrative parameters, the HHI^{∞} implied by equilibria on b^p-homotopy paths for different values of τ. An accommodative equilibrium exists for all considered (τ, b^p) combinations, and we find only accommodative equilibria when $\tau \geq 0.6$. When a monopolist seller and a buyer have equal bargaining power (i.e., $\tau = 0.5$), we find only accommodative equilibria when $b^p \geq 0.08$, which is a lower threshold than we identified for our basic model.

[29] The interpretation of b^p is still the unconditional probability with which a given buyer expects to be the chosen buyer in any future period, so that a model with a single buyer of each type would have $b^p = 0.5$.

[30] To put the magnitude of θ in context, a seller's marginal cost drops by 1.5 with its first sale for these parameters.

E. *Buyer Discount Factors*

It may be tempting to believe that b^p can also be interpreted as buyer patience, as the $b^p = 0$ equilibria would still be equilibria if there was a myopic monopsonist.[31] However, increasing a buyer discount factor (call this β^B) from zero has a different effect to increasing b^p because, for low β^B, the buyer will care primarily about surplus in the immediate future, and, in non-accommodative equilibria, this is often increased by buying from the leader. This is illustrated in online Appendix Figure G.1 which shows that, for baseline equilibrium seller strategies, increasing β^B when $b^p = 1$ tends to move demand away from seller 2 in state (3,1) in the mid- and high-HHI equilibria, until $\beta^B \geq 0.5$, reflecting how prices are significantly lower in state (4,1) than state (3,2). This is the opposite of the pattern when b^p increases from zero (Figure 2 panel A).

Figure 6 panel D shows the HHI^{∞} implied by equilibria on the β^B-homotopy paths from the baseline equilibria when we assume $b^p = 1$, limit $\beta^B \leq \beta = \frac{1}{1.05}$ and other parameters have their illustrative values. Accommodative and non-accommodative equilibria coexist until β^B is almost equal to β, which is a qualitatively different pattern to the elimination of these equilibria for low b^p in our model. While there may be industries where buyers are less patient than sellers, it seems plausible that buyers and sellers have similar time preferences in most industries where LBD has been identified, even if each buyer knows it will only account for a proportion of future demand.

F. *Forgetting*

Our model follows CR and BDK in assuming that sellers can only lose know-how by exiting the industry. However, Benkard (2000) and Thompson (2007) provide empirical evidence that know-how can also depreciate when production slows ("forgetting"). Besanko et al. (2010) (BDKS) show that a model where duopolists can stochastically forget but cannot exit also has multiple equilibria that result in different expected levels of long-run industry concentration. One might expect strategic buyer behavior to have less effect on equilibria in the BDKS model because depreciation may eliminate the know-how that a laggard gains through a sale. However, our working paper, Sweeting et al. (2021) shows that for many values of ρ and alternative forgetting probabilities, multiplicity of equilibria and equilibria that tend to lead to the most asymmetric long-run market structures are eliminated for lower values of b^p than in the BDK model, although we also identify small groups of parameters where increases in b^p can increase the number of equilibria.

V. Conclusion

We have provided a tractable framework for analyzing how equilibrium strategies and market outcomes change when buyers partially internalize how their purchase decisions affect future surplus, in the context of a well-known dynamic

[31] We thank David Besanko for asking a question that led us to realize that one should not interpret b^p in terms of buyer patience.

model where sellers benefit from LBD. Our framework allows for an investigation of what happens between the polar cases of short-lived atomistic buyers and monopsony, motivated by the fact that many industries where cost-side dynamics are important have at least some large and repeat customers. Our main finding is that, for many empirically relevant parameters, even moderately strategic buyer behavior can eliminate equilibria where the market may come to be dominated by a single firm.

We view this result as having implications for antitrust policies that aim to combat predation which have to strike a delicate balance between the potentially large benefits of preserving competition and the risk that intervention will deter pro-competitive pricing. Our results suggest that the existence of equilibria where an industry may become a monopoly will depend on the incentives of customers to offset predatory behavior, and it may be appropriate to treat claims of predation more skeptically when there are several large, repeat customers.

We believe that our framework can be usefully applied to investigate the effects of strategic behavior in settings where incumbents' advantages may arise from other sources, such as network effects or switching costs, or where dynamics arise from the durable or perishable nature of products. While we have investigated some alternative specifications, we view understanding how the ability of sellers to offer multi-period contracts to some customers would affect our results as an important next step of this research. We also believe that, in some settings, it may be useful to include strategic buyers in empirical models of dynamic competition, as doing so may not only make these models more realistic but also help to reduce concerns that multiple equilibria may make it hard to interpret counterfactuals.

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