Product Switching Cost and Strategic Flexibility

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This paper examines the equilibrium degree of flexibility adopted by firms competing in oligopolistic product markets in which the value of flexibility arises from the initial presence of uncertainty over consumer preferences and its eventual resolution. The equilibrium choice of flexible mode depends on the following factors: (1) the cost of switching product design in response to revealed consumer preferences, (2) the difference in the acquisition costs of the flexible and dedicated modes, and (3) the precision of the ex ante information held by the firms regarding consumer preferences. The relationship between these factors and the equilibrium choice of modes is fully characterized.

1. Introduction

It is widely recognized that a firm's performance in an uncertain market environment depends critically on its ability to respond to newly available information and adapt itself to the revealed environment. This view is well captured in the following statement by scholars of manufacturing strategy:

> In a stable environment, competitive strategy is about staking out a position, and manufacturing strategy focuses on getting better at the things necessary to defend that position. In turbulent environment, however, the goal of strategy becomes *strategic flexibility*. Being world-class is not enough; a company also has to have the capability to switch gears . . . relatively quickly and with minimal resources. (Hayes and Pisano, 1994, p. 78)

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While certain aspects of flexibility may be inherent in many organizations independent of any conscious design, nevertheless, a significant amount of flexibility can be embedded deliberately in a firm's operational mode through choices made *ex ante*. In this vein, the degree of flexibility can be treated as a decision variable in the initial state when the firms must invest in a long-term mode of operation.

This paper examines the equilibrium degree of flexibility adopted by firms operating in an oligopolistic product market in which the value of flexibility arises from both the initial presence of uncertainty over consumer preferences and its eventual resolution. As can be inferred from the existing literature on manufacturing flexibility,[1] there are many ways in which one can define the "flexibility" of a firm. In this paper, flexibility is defined as a firm's ability to switch, over time, the product orientation of its operation so as to respond optimally to market demand information that is generated externally.[2]

Given the conceptual framework, the most straightforward indication of a firm's flexibility is the cost of switching the product orientation of the manufacturing operation adopted initially by the firm. The strategic significance of the product switching cost is well

1. Recent works include Fine and Freund (1990), Milgrom and Roberts (1990), Röller and Tombak (1990), Chang (1993), Mansfield (1993), Röller and Tombak (1993), de Groote (1994), Eaton and Schmitt (1994), Milgrom and Roberts (1995), and Athey and Schmutzler (1995). Also, see Gerwin and Kolodny (1992) for an excellent survey of modern manufacturing technologies and various types of flexibility that are embedded in them. Two papers that are closest in spirit to the present work are Chang (1993) and Röller and Tombak (1993). Chang (1993) uses a similar model of product switching cost to address an incumbent monopolist's incentive to use flexible technology as an entry-deterring mechanism. Röller and Tombak (1993) look at the equilibrium choice of flexible technology in an oligopolistic market, even though they define flexibility differently from the present paper: their definition is associated with economies of scope under certainty.

2. As Milgrom and Roberts (1990, 1995) have shown, flexibility in manufacturing is the result of combining a group of production activities that are complementary to one another: (1) physical production technologies such as CAD/CAM (computer-aided design/computer-aided manufacturing), CIM (computer-integrated manufacturing), and FMS (flexible manufacturing systems), (2) shorter product cycles, (3) low finished-goods inventory, (4) organizational structure that entails parallel team approaches rather than a rigid vertical hierarchy, and (5) incentive mechanisms that promote multiskilled workers. Complementarities among these activities support their adoption in clusters, because a change in a parameter value that causes a shift in one activity triggers a series of optimal adjustments in other related activities. In this paper, I abstract away from addressing the exact linkages between these activities and the resulting level of flexibility. I take the conclusions reached by Milgrom and Roberts (1990) as given and instead concentrate on firms' equilibrium choices of flexibility (assuming implicitly that the chosen degree of flexibility can be implemented centrally by combining the previously mentioned activities).

recognized in the business community:

> Japan's No. 2 car maker [Nissan] has high hopes that the flexible-manufacturing techniques at the new Kyushu plant will give it a jump on rivals.... The primary goal of the new flexible techniques, Nissan officials say, is improving the company's ability to respond quickly and efficiently to consumer demands. Mr. Kobatake says shifting to production of a completely new model will take less time at Kyushu-style plants because there's no need to replace the jigs on robots used there. In conventional Japanese car plants, retooling for production of a new model usually requires at least 10 months. But he says reprogramming software for the robots at the Kyushu plant will take only three months. (*Wall Street Journal*, July 6, 1992, p. 11)

> Formerly the company [Stoves, the cooker manufacturing arm of Yale & Valor] would make cooker chassis using heavy presses and welding methods. Design changes took months to implement and were very costly as new dies were made. It now uses CNC [computer numerically controlled] equipment to bend, cut and punch the metal struts... and water pressure to shape the sheet metal.... Installing the new production equipment took longer than expected, but it now gives the company far greater flexibility in developing new products. Introducing a new cooker design using old tooling could take two years and cost £100,000 but the company can now design a new cooker in just five weeks at a cost of £2,000. (*Financial Times*, November 10, 1992, p. 11)

A given operational mode is then *more flexible* than another if its cost of switching the product design is lower. Linking flexibility with the product switching cost in this fashion, the following questions are asked: (1) what are the external factors that influence the firms' choice of flexibility in equilibrium, given that they are aware of the mutual interactions in the oligopolistic product market, (2) is it possible that an equilibrium exists in which differential degrees of flexibility are chosen, and, if so, (3) how is the equilibrium proportion of the flexible firms affected by the external factors identified in (1)?

In providing answers to the questions raised above, a stylized two-period model is considered in which the firms commit to their operational modes (''dedicated'' or ''flexible'') in the first period, based on commonly held beliefs with respect to the probability that consumers will prefer one of two potential product designs. In between period 1 and period 2, the firms learn which product design is, in fact, preferred by the consumers. They then attempt to adapt in period 2 to the revealed information. The firms that chose initially a flexible mode are able to adapt at *zero* cost, thereby switching their operational modes toward the preferred product design. The firms that committed themselves to a mode dedicated to the less preferred product must incur a positive fixed cost of switching their product design, if they wish to adapt to the new information. While, once installed, the flexible mode strictly dominates the dedicated mode, there is a trade-off to be faced by the firms *ex ante* in that the acquisition cost of the flexible mode is higher than that of the dedicated mode.

In this framework, I first derive a subgame perfect equilibrium in a duopoly and show that the equilibrium choice of an operational mode in the initial period depends on the following factors: (1) the difference in cost of adopting a flexible versus a dedicated mode, (2) the probability that consumers will prefer one product design over another, and (3) the cost of subsequently switching the product design. I further show that there exists an equilibrium in which *ex ante* identical firms deliberately choose to embed different degrees of flexibility in their operational mode, i.e., one firm chooses a dedicated mode and another firm chooses a flexible mode.[3] The intuition is that flexibility is beneficial for one firm, but not for both, as the second firm considering the adoption of flexible mode must share the market with the first one. Given the *ex ante* cost of acquiring flexibility, there exists a range of parameter values for which equilibrium choices are heterogeneous. These heterogeneous choices lead to an *ex post* intra-industry differential in the ability of the firms to respond to newly revealed information about their market environment. These results are then extended to an N-firm oligopoly.

The model emphasizes an aspect of flexibility that is different from other existing models in a nontrivial manner. Broadly, the existing theoretical literature on manufacturing flexibility consists of two distinct approaches. The first and more traditional approach restricts its attention to homogeneous goods markets in which the firms face uncertainty over the volume of output demanded by the consumers. The degree of flexibility chosen by the firms is then

3. Röller and Tombak (1990) also obtain a similar result with respect to the existence of the mixed-modes equilibrium. However, their model is substantially different in that flexibility is modeled as the firms' ability to generate multiple products in the absence of uncertainty and without any switching costs.

represented by the curvature of the average cost curve. Stigler (1939), Mills (1984), and Vives (1986, 1989) are representative of this branch of inquiry. The second and more recent approach associates flexibility with the firm's ability to produce simultaneously a diverse array of products in a static framework with no uncertainty. The demand for product diversity arises either from the representative consumer's preference for diversity in the consumption basket or from a group of consumers with heterogeneous tastes. The firm's problem is then reduced to choosing between a single product technology and a multiproduct technology. This approach does not, therefore, address the issue of uncertainty or the firm's response to it. Both Röller and Tombak (1990, 1993) and Eaton and Schmitt (1994) belong to this category. My model combines these two approaches: although it recognizes the importance of uncertainty in the firm's desire for flexibility, its concern is with uncertainty over consumers' preference for product design rather than production volume. This shift in emphasis is motivated by the fact that a major concern of modern business firms is how to respond to the uncertainty generated by the frequent and random shifts in consumer tastes and preferences. Through the use of a stylized model that incorporates the product switching cost, I am able to derive and characterize fully, in the simplest possible manner, the equilibrium choice of flexibility.

The paper is organized as follows. Section 2 describes the model. In Section 3, the subgame perfect equilibrium in pure strategies for a duopoly is analyzed through backward induction: Section 3.1 presents the Nash equilibrium product selection supported in period 2, and Section 3.2 derives and characterizes equilibrium in the operational mode. Section 4 briefly looks at the possibility of allowing the duopolists to choose mixed strategies. Section 5 extends the results to N-firm oligopoly. Section 6 concludes.

2. The Model

Initially, two firms are assumed to exist, each of which produces and markets only one product at any given time with a particular operational mode (to be defined shortly) that it possesses. The analysis will be extended later to an oligopoly setting in which the number of firms exceeds two.

There exists a set, X, of competing product varieties that are feasible with the available operational modes. For the sake of analytical tractability, I assume that there are only two such products, A and B: $X \equiv \{A, B\}$. A natural way to think about such a set in our framework is to imagine A and B to be two competing designs of a new product that the firm is planning to launch, both of which are technologically feasible and perceived initially by the firm to have some appeal to the consumers.

Consumers are assumed to be homogeneous and thus to have identical tastes. Furthermore, when presented with the set of products, X, we assume that the consumers exhibit inherent (and stable) preferences for one product over another. Under consumer homogeneity, this implies that everyone either prefers A to B or prefers B to A, and if both products are offered at the same price, all consumers will purchase the preferred product.[4] Let us then define $E \equiv \{e_A, e_B\}$, as the set of possible preference orderings over the products A and B, namely,

- e_A: All consumers prefer product A to product B.
- e_B: All consumers prefer product B to product A.

Let $v(i, j)$ be the single-period sales profit to a firm if it produces and sells product i ($i = A, B$) and its rival produces and sells product j ($j = A, B$). It is assumed that this profit is symmetric under both e_A and e_B. Given the symmetry in profit, let k be the index for the preferred product and l the index for the nonpreferred product for *any* realization of market environment, $e \in E$. We may then write the reduced-form profits as follows:

$v(k, k) =$ single-period sales profits to a firm producing the *preferred* product (k) when its rival also produces the *preferred* product (k) $[v(k, k) \equiv v(A, A)$ under $e_A = v(B, B)$ under $e_B]$,
$v(k, l) =$ single-period sales profits to a firm producing the *preferred* product (k) when its rival produces the *nonpreferred* product (l) $[v(k, l) \equiv v(A, B)$ under $e_A = v(B, A)$ under $e_B]$,
$v(l, k) =$ single-period sales profits to a firm producing the *nonpreferred* product (l) when its rival produces the *preferred* product (k) $[v(l, k) \equiv v(B, A)$ under $e_A = v(A, B)$ under $e_B]$,

4. One may think of this phenomenon as a consequence of some *perceived* quality differential upon which all consumers agree, or simply of every consumer's desire to conform to what is accepted by the rest of society (as in the case of fashion trends). In the case of the former, the emphasis is on perceived quality differential rather than actual: I assume that the marginal costs are identical whether the firm produces A or B. In order to concentrate on the effect of consumer preferences on the choice of flexibility, I intentionally abstract away from the possibility of vertical product differentiation, which might introduce into our analysis the issue of how the cost difference among products (caused by *actual* quality differential) may affect firms' strategic choices.

$v(l, l) =$ single-period sales profits to a firm producing the *nonpreferred* product (l) when its rival also produces the *nonpreferred* product (l) $[v(l, l) \equiv v(B, B)$ under $e_A = v(A, A)$ under $e_B]$.

The following assumption is made on these payoffs:

A.1: $0 < v(k, k) - v(l, k) \leq v(k, l) - v(l, l), \quad k, l = A, B$ and $k \neq l$.

For expository convenience, let us define $\hat{v}(1) \equiv v(k, k) - v(l, k)$ and $\hat{v}(0) \equiv v(k, l) - v(l, l)$. Here $\hat{v}(1)$ is the extra gain in a duopolist's profit from selling the preferred variety (k) over the nonpreferred variety (l) when its rival sells the *preferred* variety (k), and $\hat{v}(0)$ is the same measure when its rival sells the *nonpreferred* variety (l).[5] That $\hat{v}(1) > 0$ and $\hat{v}(0) > 0$ implies a firm always earns a greater sales profit by selling the preferred product (k) rather than the nonpreferred product (l), regardless of which product the rival chooses. Recall that what differentiates the two products, A and B, is which design better caters to the tastes of consumers. Since the ultimate position of a product has more to do with the realization of consumer preferences than some inherent quality differential, any difference in sales profit is likely to be induced by demand-side rather than cost-side considerations. In view of this formulation, it is then reasonable to assume that a firm always benefits more from selling the preferred variety, even if it may have to share the market with the rival in doing so: since it does not have any cost advantage from supplying the less-preferred variety and consumers have homogeneous preferences, a firm is better off meeting its competition by jumping into the market for the favored variety than by facing the same competition with a less-preferred variety. Finally, the second inequality in the assumption, $\hat{v}(1) \leq \hat{v}(0)$, implies that the extra gain in profit from selling the preferred variety is larger when its rival sells the nonpreferred variety than when it sells the preferred variety —the benefits to selling the popular product are larger if the firm does not face direct competition from a rival.

An operational mode is a production function that combines broadly three major types of inputs that are complementary to one another: (1) production technology in the form of physical capital and the organization of production processes, such as the design of plant

5. In a more general N-firm oligopoly model, $\hat{v}(r)$ is defined as the extra gain in a firm's profit from selling the preferred product (k) rather than the nonpreferred product (l) when r rivals are also selling the preferred variety. Hence, in the case of duopoly, $r = 1$ if the rival sells k, or $r = 0$ if the rival sells l.

layout, (2) organizational structure of the administrative hierarchy,[6] and (3) human resources. Together these elements yield a particular degree of flexibility in an organization. I define a set, M, of feasible operational modes, which contains three elements: $M \equiv \{F, D_A, D_B\}$. Here F refers to a flexible mode that allows the firm to produce any product, $i \in X$. Switching between products is accomplished costlessly with this mode. D_A (D_B), on the other hand, represents a mode that is dedicated to the production of A (B) only. If a firm currently possessing mode D_A wishes to produce product B instead of A, it must incur a fixed cost of switching, f, which consists of the costs of retooling and redesigning the factory and production process, reorganizing the administrative hierarchy that can efficiently support the production of B, and finally reeducating and retraining the workforce. This composite cost f is assumed to be strictly positive.

Once the operational mode is in place, the marginal costs of producing A or B at any given time are assumed to be constant and identical whether they are produced by F, D_A, or D_B. Consequently, the flexible mode, once adopted, is strictly superior to the dedicated mode in that it is perfectly capable of switching from one product to another. However, this *ex post* flexibility comes at a cost incurred *ex ante*. The flexible mode (F) requires a one-time fixed investment that is strictly greater than that of a dedicated mode (D_A or D_B). For the sake of analytical simplicity and without any loss of generality, I assume that the acquisition cost of a dedicated mode is zero and denote by Δ the acquisition cost of the flexible mode. More accurately, Δ is then the acquisition-cost differential between F and D_A (D_B) and is assumed to be strictly positive.[7]

The two firms interact with one another on a timeline composed of two discrete periods. At $t = 1$, they simultaneously choose and invest in their respective operational modes, $m_i \in M$, by incurring the one-time acquisition cost, Δ if F is chosen and 0 if D_A (or D_B) is chosen. Design and implementation of the operational mode takes one period. In period 2, given the operational mode that they have chosen at $t = 1$, the firms simultaneously select a product, x, from X. If the firm has committed at $t = 1$ to a dedicated mode and the product chosen at $t = 2$ is different from the one for which the mode

6. For the organizational aspect of flexibility, see Byrne (1993), Emshoff (1993), Scheffman (1993), and Tully (1993). Also, see Chapter 6 of Gerwin and Kolodny (1992).

7. This is a standard assumption made in many other works (see Röller and Tombak, 1993; Chang, 1993). In discussing the economic value of FMS (flexible manufacturing systems) relative to conventional systems, Economic Commission for Europe (1986, p. 115) attributes the cost differential to "the cost of computers and material-handling equipment [which] are usually considerably higher in FMS."

is designed, then the firm incurs a fixed cost of switching, f, in order to adapt itself. Selection of a product is instantly accompanied by its production and sale, and each firm receives a corresponding payoff from the sale of the product, $v(\cdot,\cdot)$.

A special feature of the model is that the first period of the firms' horizon is distinguished from the second period by the existence of uncertainty. To be specific, the firms in period 1, while aware that the consumers have certain preferences over products A and B, are uncertain as to which of the two preference orderings in E will be realized. This uncertainty is assumed to be resolved exogenously at the close of period 1, when consumer preferences are revealed (costlessly) to the firms. At $t = 1$, the firms then hold a (common) subjective probability distribution over the set E: They believe that $e = e_A$ with probability β and $e = e_B$ with probability $1 - \beta$. The choice of operational mode is thus made at $t = 1$, given the firms' subjective belief about the true state of consumer preferences.[8] Since the analysis and the equilibrium outcomes are symmetric around $\beta = \frac{1}{2}$, the exposition is restricted to $\frac{1}{2} \leq \beta \leq 1$ in this paper. The case of $0 \leq \beta < \frac{1}{2}$ is simply the mirror image of what is obtained here.

Finally, given the trade-off between the *ex ante* acquisition cost and the potential value of *ex post* flexibility, I restrict the analysis to the following range of Δ values only:

A.2: $0 < \Delta < \frac{1}{2}\hat{v}(1)$.

Note that the expected value of the flexibility for a firm facing a *flexible* rival is $\min\{\beta, 1 - \beta\} \cdot \hat{v}(1)$, which reaches its maximum value of $\frac{1}{2}\hat{v}(1)$ at $\beta = \frac{1}{2}$. A.2 simply states that the extra cost of acquiring flexibility over dedication *ex ante* must not exceed its *maximal* expected benefit, $\frac{1}{2}\hat{v}(1)$, given that the firm's rival is flexible. This condition ensures that there exists a range of parameter values for which both firms' adopting F is a Nash equilibrium. If Δ is excessive, so that A.2 is violated, then the simultaneous adoption of F is entirely ruled out as an equilibrium under *all* parameter values. Since I am interested in investigating the strategic value of the flexible mode as a function of various parameters, A.2 is imposed so as to retain the mutual adoption of F as an equilibrium for at least *some* range of parameter values. For the sake of completeness, however, I

8. One may alternatively view the level of β as the degree of precision in the firms' information about the state of consumers' preferences *ex ante*. When β is close to either 0 or 1, it represents relatively precise information. Those values of β that are close to $\frac{1}{2}$ represent imprecise information. The degree of precision hence declines monotonically as β moves toward $\frac{1}{2}$ from either side.

shall briefly consider the consequences of relaxing this assumption at the end of Section 3.2.

At any given period t, the firms maximize the expected present value of the current and future payoffs with no discounting.[9] Given the sequential structure of the game, the appropriate solution concept is subgame perfect equilibrium in which a pair of strategies—one for each firm—must form mutual best responses in both $t = 1$ and $t = 2$. Firms are initially restricted to choosing pure strategies only. In Section 4, however, the analysis is extended to allow the firms to choose mixed strategies: a symmetric subgame perfect equilibrium in mixed strategies is shown to exist and characterized for the case of duopoly.

3. Duopoly Equilibrium

3.1 Equilibrium Product Selection (in Period 2)

The operational modes chosen at $t = 1$, along with consumer preferences revealed at the end of the period, jointly define the initial state within which the firms must make their product selections.

Proposition 1:

(1) *For all $f < \hat{v}(1)$, both firms produce the preferred product, regardless of the operational modes that they possess.*
(2) *For $\hat{v}(1) \leq f \leq \hat{v}(0)$, when both firms possess operational modes that are dedicated to the nonpreferred product, one (and only one) of the firms will switch the orientation of its mode and produce the preferred product. Otherwise, the firm with a flexible mode produces the preferred product, and the firm with a dedicated mode produces the mode-specific product independent of the revealed consumer preferences.*
(3) *For all $f > \hat{v}(0)$, the firm with a flexible mode produces the preferred product, and the firm with a dedicated mode produces the mode-specific product, independent of the revealed consumer preferences.*

Under A.1, a firm with a flexible mode always selects the preferred product: Regardless of the product chosen by the rival firm, its payoff from selling the preferred product is always superior to that from selling the nonpreferred product. Similarly, the firm with a mode dedicated to the product that is revealed to be preferred by consumers will also find it optimal to produce and sell the preferred product.

9. While it is straightforward to allow discounting, the role of the discount factor in this model is entirely obvious and of no intrinsic interest. It is with no loss of generality that we assume the discount factor to be one.

The choice of product for a firm with a mode dedicated to the *nonpreferred* product, however, depends on the cost of switching, f. First, consider $f < \hat{v}(1)$: The cost of switching is strictly lower than the gains from selling the preferred variety, regardless of the rival's choice of product. The optimal strategy for the firm is then to offer the preferred product. In contrast, for sufficiently high cost of switching such that $f > \hat{v}(0)$, the gains from switching are strictly dominated by its cost: the firm with a mode dedicated to the nonpreferred product never finds it optimal to switch. It prefers to offer the product for which its mode was initially designed, even though that product is not preferred by the consumers.

The interesting case is for the intermediate range of f values, $\hat{v}(1) \leq f \leq \hat{v}(0)$. By A.1, as long as at least one of the firms has either a flexible mode or a mode dedicated to the preferred product, Nash equilibrium in product selection entails both firms offering the product for which their operational modes are originally designed (with the flexible firm always offering the preferred product). An exception occurs when *both* firms are committed to the operational mode dedicated to the nonpreferred product: given $\hat{v}(1) \leq f \leq \hat{v}(0)$, the equilibrium entails exactly one firm switching. There then exist multiple pure-strategy Nash equilibria in this case, depending on which of the two firms switches to the preferred product. I arbitrarily pick firm 1 as the one that switches to the preferred product in equilibrium. It will be shown in Section 4 that a symmetric mixed strategy Nash equilibrium also exists for this set of parameter values, in which each firm chooses A and B with corresponding probabilities.

3.2 Equilibrium Adoption of Operational Mode (in Period 1)

We proceed to analyze the firms' choice of operational mode at $t = 1$, given their uncertainty over consumer preferences and recognizing that the equilibrium selection of products at $t = 2$ is characterized by Proposition 1. We consider the three separate ranges of f values as identified previously.

3.2.1 Case 1: The Cost of Switching is Sufficiently Low That $f < \hat{V}(1)$ From Proposition 1, we know that the firms always offer the preferred product at $t = 2$ for this range of f values. Hence, the expected payoff at $t = 1$ may be written as

$$V(F, \cdot) = -\Delta + v(k, k), \tag{1}$$

$$V(D_A, \cdot) = v(k, k) - (1 - \beta)f, \tag{2}$$

$$V(D_B, \cdot) = v(k, k) - \beta f. \tag{3}$$

Given $\beta \geq \frac{1}{2}$, D_B is strictly dominated by D_A and hence never adopted. The choice between F and D_A then depends on the comparison between Δ and $(1-\beta)f$. Notice that the expected value of D_A reaches its minimum at $\beta = \frac{1}{2}$: $v(k,k) - \frac{1}{2}f$. If the expected value of F is lower than this minimum, then it can be concluded that F is simply not a viable option. This case is observed for $f \leq 2\Delta$, and the dominant strategy equilibrium is then (D_A, D_A). Flexibility is a viable option in equilibrium if, and only if, $f > 2\Delta$. The following proposition characterizes the equilibrium choice of operational mode when the cost of switching *ex post* is sufficiently low.

Proposition 2:

(1) *For $0 < f \leq 2\Delta$, the subgame perfect equilibrium in operational mode, $m^* \equiv (m_1^*, m_2^*)$, entails*

$$m^* = (D_A, D_A) \qquad \text{for} \quad \tfrac{1}{2} \leq \beta \leq 1.$$

(2) *For $2\Delta < f < \hat{v}(1)$, the subgame perfect equilibrium in operational mode, $m^* \equiv (m_1^*, m_2^*)$, entails*

$$m^* = \begin{cases} (D_A, D_A) & \text{for} \quad 1 - (1/f)\Delta < \beta \leq 1, \\ (F, F) & \text{for} \quad \frac{1}{2} \leq \beta \leq 1 - (1/f)\Delta. \end{cases}$$

When both firms expect A to be the preferred product with a sufficiently high probability, the equilibrium entails that they both choose D_A. In contrast, when both A and B are expected to be preferred approximately equally (i.e., β close to $\frac{1}{2}$), the resulting equilibrium entails that both firms invest in a flexible mode, if $f > 2\Delta$.

3.2.2 Case 2: The Cost of Switching is Moderate, So That $\hat{v}(1) \leq f \leq \hat{v}(0)$ This is the region in which a unilateral switching of product orientation occurs in period 2, when both firms are committed to the operational mode dedicated to the nonpreferred product.

Proposition 3: *For $\hat{v}(1) \leq f \leq \hat{v}(0)$, the subgame perfect equilibrium in operational mode entails*

$$m^* = \begin{cases} (D_A, D_A) & \text{for} \quad 1 - (1/f)\Delta < \beta \leq 1, \\ (F, D_A); (D_A, F) & \text{for} \quad 1 - [1/\hat{v}(1)]\Delta \leq \beta \leq 1 - (1/f)\Delta, \\ (F, F) & \text{for} \quad \frac{1}{2} \leq \beta < 1 - [1/\hat{v}(1)]\Delta. \end{cases}$$

Proof. See Appendix. □

Note that there exists an intermediate region of β values in which the firms choose different operational modes in period 1. To be specific, for $1 - [1/\hat{v}(1)]\Delta \leq \beta \leq 1 - (1/f)\Delta$, one of the firms chooses a flexible mode, while the other firm prefers to dedicate itself to the production of A.

In order to better understand the intuition behind the mixed-modes equilibrium, let us rearrange the condition on β. The second inequality can be rewritten as $\Delta \leq (1 - \beta)f$. The implication is that spending the extra cost, Δ, of acquiring F over D_A is justified for one of the firms, since it allows the firm to save the *ex post* switching cost, f, which is incurred in equilibrium with probability $1 - \beta$.[10] Similarly, the first inequality can be rewritten as $\Delta \geq (1 - \beta)\hat{v}(1)$: The extra cost of acquiring F for the second firm exceeds the extra gain in profit from being able to sell the preferred product along with the flexible rival. This condition hence justifies the second firm's choice of a dedicated mode. The intuition is that flexibility pays for one firm but not for both: the second firm considering adoption cannot reap the gain of being the only producer of the preferred good, because it must then share the market with its rival in period 2.

3.2.3 Case 3: The Cost of Switching is Sufficiently High that $f > \hat{v}(0)$

For these values of f, the firm with a dedicated mode in period 2 always produces the mode-specific product, independent of the revealed consumer preferences. Product switching thus never occurs for a dedicated firm.

Proposition 4: *For $f > \hat{v}(0)$, the subgame perfect equilibrium in operational mode entails*:

$$m^* = \begin{cases} (D_A, D_A) & \textit{for} \quad 1 - [1/\hat{v}(0)]\Delta < \beta \leq 1, \\ (F, D_A); (D_A, F) & \textit{for} \quad 1 - [1/\hat{v}(1)]\Delta \leq \beta \leq 1 - [1/\hat{v}(0)]\Delta, \\ (F, F) & \textit{for} \quad \frac{1}{2} \leq \beta < 1 - [1/\hat{v}(1)]\Delta. \end{cases}$$

Proof. See Appendix. □

Once again, it is found that for some intermediate ranges of β values, there exist mixed-modes equilibria. The intuition behind these equilibria is similar to that in case 2.

10. If both firms choose the dedicated mode, there is a probability, $1 - \beta$, that they are dedicated to producing the wrong product. In such a case, the period-2 equilibrium for $\hat{v}(1) \leq f \leq \hat{v}(0)$ entails one of the firms switching its mode to the preferred product. It is precisely this switching cost that can be avoided, if a firm chooses to be flexible in period 1.

3.2.4 Discussion Propositions 2 through 4 characterize fully the period-1 equilibrium in operational mode. Figure 1 depicts the equilibrium in terms of f and β. While the propositions were restricted to the case of $\frac{1}{2} \leq \beta \leq 1$ for ease of exposition, Figure 1 includes the equilibria for $0 \leq \beta < \frac{1}{2}$ as well. As noted earlier, the case of $0 \leq \beta < \frac{1}{2}$ is simply the mirror image of the case of $\frac{1}{2} \leq \beta \leq 1$, where the choice of a dedicated mode is D_B rather than D_A. The shaded regions represent the set of (f, β) combinations that support the mixed-modes equilibrium. The existence of the mixed-modes equilibrium is assured under appropriate conditions as long as $\hat{v}(1) \leq \hat{v}(0)$, which is satisfied by A.1.

Recalling that a flexible mode is a viable option if and only if $f > 2\Delta$, we observe the following properties from the various cases and Figure 1.

Property 1: *When the product-switching cost is low to moderate so that $2\Delta < f \leq \hat{v}(0)$, a firm's choice of an operational mode in equilibrium is dependent upon the actual value of f. More specifically, the firms adopt a flexible mode in equilibrium for a larger range of β values as f increases.*

The intuition behind this property is as follows. The range of f values between 2Δ and $\hat{v}(0)$ can be divided into two subranges, $2\Delta < f < \hat{v}(1)$ and $\hat{v}(1) \leq f \leq \hat{v}(0)$. Recall from Section 3.1 that for $2\Delta < f < \hat{v}(1)$, a firm with a dedicated mode will *always* switch its product if consumers turn out to favor a different product in period 2. Firms' choice of an operational mode in period 1 is then influenced directly by this (rational) expectation, and their incentive to choose a

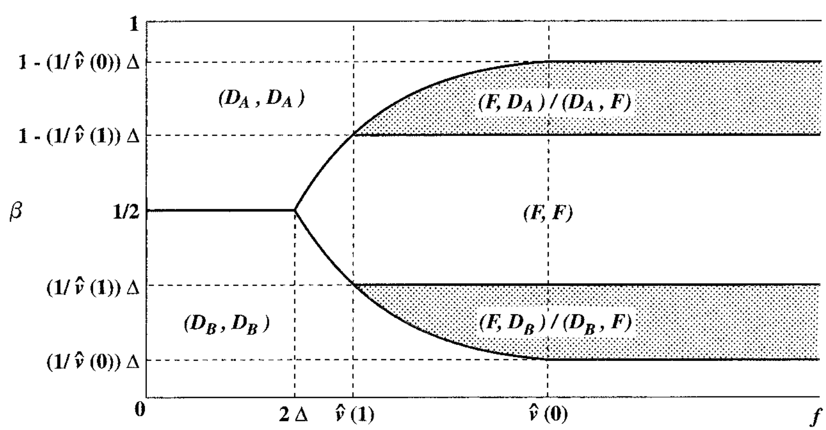

FIGURE 1. EQUILIBRIUM IN OPERATIONAL MODE

flexible mode is strengthened as f rises. For the second range, $\hat{v}(1) \leq f \leq \hat{v}(0)$, a firm with a mode dedicated to the nonpreferred product will switch the orientation of its mode and produce the preferred product if and only if its rival is dedicated to the nonpreferred product. Again, anticipating this possibility of incurring the switching cost, a firm's incentive to adopt the flexible mode *ex ante* grows with a rising value of f. Finally, when f is sufficiently high that $f > \hat{v}(0)$, the firms find the cost of product switching to be excessive and hence never switch their product orientation, regardless of the revealed consumer preferences. Since the firms never expect to switch their product, their initial choice of an operational mode in equilibrium is independent of f in this region.

PROPERTY 2: *More firms adopt the flexible mode in equilibrium when (1) β approaches $\frac{1}{2}$ and (2) Δ declines.*

The implications are straightforward: (1) the more imprecise the information (i.e., the more β approaches $\frac{1}{2}$), the more valuable is the possession of flexibility; and (2) the narrowing gap between the acquisition costs of the flexible mode and the dedicated mode encourages the firms to choose the flexible mode.

It should be noted that all of the above comparative static properties are directly observable from Figure 1. These properties are fully general in that they continue to hold when the current model is extended to an N-firm oligopoly (see Section 5 below).

3.2.5 WHEN THE ACQUISITION-COST DIFFERENTIAL IS HIGH: $\Delta \geq \frac{1}{2}\hat{v}(1)$ Let us now consider the implications of relaxing A.2. When Δ is sufficiently high that $\Delta \geq \frac{1}{2}\hat{v}(1)$, (F, F) is no longer an equilibrium attainable under any parameter values. This can be seen by rewriting the inequality $\Delta \geq \frac{1}{2}\hat{v}(1)$ as follows: $-\Delta + v(k, k) \leq \frac{1}{2}v(k, k) + \frac{1}{2}v(l, k)$. Given that the rival firm produces the preferred product (k), the left-hand side of the inequality captures the net gain to investing in F in stage 1. The right-hand side, on the other hand, is the expected net gain to investing in D_A. These expected net gains are evaluated under the conditions that are most favorable to F: $\beta = \frac{1}{2}$ and f sufficiently large so that the firm, when committed to the wrong product, will not be able to switch its mode to the preferred product. The above inequality then implies that F is *never* a best response to the rival choosing F, and hence (F, F) is never an equilibrium for all values of β and f, if $\Delta \geq \frac{1}{2}\hat{v}(1)$. This result is intuitive and is a natural extension of Property 2 in that a higher value of Δ makes F less attractive, and consequently fewer firms will adopt it in equilibrium.

In addition to the fact that (F, F) is never an equilibrium, another interesting phenomenon is that for sufficiently high values of Δ there emerges a new equilibrium for β sufficiently close to $\frac{1}{2}$ and f sufficiently high, in which the firms choose *dedicated differentiation*, i.e., (D_A, D_B).[11] Even though $\beta \geq \frac{1}{2}$, so that A is more likely to be the preferred product, a firm prefers to dedicate its operational mode to producing B if β is sufficiently close to $\frac{1}{2}$. The intuition is that a firm may prefer to have a smaller chance at being the monopoly provider of B when it is the preferred variant, rather than have a larger chance of being a duopoly provider of A when it is the preferred variant.[12] In this case, D_B is a better response to D_A than D_A is, provided that f is sufficiently large and β is sufficiently close to $\frac{1}{2}$.[13]

4. Subgame Perfect Equilibrium in Mixed Strategies

The subgame perfect equilibria observed previously were in pure strategies. In this section, I investigate the existence of symmetric subgame perfect equilibrium in mixed strategies, especially for those parameter values that gave rise to multiple asymmetric pure-strategy equilibria in Section 3.

Since multiple asymmetric pure-strategy equilibria existed in the period-2 subgame as well as in the period-1 operational-mode game, the possibility of a mixed strategy equilibrium in period 2 needs to be addressed first. It was shown in Section 3.1 that for $\hat{v}(1) \leq f \leq \hat{v}(0)$ and when both firms possess operational modes that are dedicated to the nonpreferred product, there exist two pure-strategy Nash equilibria, (A, B) and (B, A): for any realization of consumer preferences, one, and only one, firm switches to the preferred product. It can be shown that a symmetric mixed-strategy Nash equilibrium also exists in this case.

11. I thank a referee and the coeditor for pointing out the existence of the dedicated-differentiation equilibrium under the alternative assumption of $\Delta \geq \frac{1}{2}\hat{v}(1)$. While the existence of dedicated differentiation is an interesting phenomenon on its own right, I do not go into a full characterization of it here, since the focus in this paper is mainly on the strategic value of flexibility, and assuming a high acquision cost such as $\Delta \geq \frac{1}{2}\hat{v}(1)$ rules out the viability of F as an equilibrium choice altogether.

12. I owe the coeditor a debt of gratitude for this intuition.

13. It should be noted that A.1 and A.2 jointly rule out dedicated differentiation in my model, because D_B is always strictly dominated by F for $\frac{1}{2} \leq \beta \leq 1$. See the proofs of Propositions 3 and 4 in the Appendix.

Proposition 5: *When $\hat{v}(1) \le f \le \hat{v}(0)$ and both firms possess operational modes dedicated to the nonpreferred product, the period-2 subgame has a symmetric Nash equilibrium in mixed strategies in which the firms, with positive probability, switch the orientation of the operational mode to produce the product revealed preferred by the consumers.*

Proof. See Appendix. □

Given the above symmetric mixed strategy Nash equilibrium in period 2 for $\hat{v}(1) \le f \le \hat{v}(0)$, it is now possible to solve for the symmetric subgame perfect equilibrium in mixed strategies in period 1 for all $f \ge \hat{v}(1)$ [for $f < \hat{v}(1)$, the mixed-strategy equilibria degenerate into the pure-strategy equilibria identified in Section 3 for all values of β]:

Proposition 6: *For sufficiently high switching cost $f \ge \hat{v}(1)$, the period-1 game has a symmetric subgame perfect equilibrium in mixed strategies in which a firm chooses its operational mode from (F, D_A, D_B) with corresponding probabilities $(q^*, 1 - q^*, 0)$:*

$$q^* = \begin{cases} 0 & \text{for} \quad 1 - \dfrac{1}{\phi(f)}\Delta < \beta \le 1, \\[2ex] \dfrac{-\Delta + (1-\beta)\phi(f)}{(1-\beta)[\phi(f) - \hat{v}(1)]} & \text{for} \quad 1 - \dfrac{1}{\hat{v}(1)}\Delta \le \beta \le 1 - \dfrac{1}{\phi(f)}\Delta, \\[2ex] 1 & \text{for} \quad \dfrac{1}{2} \le \beta < 1 - \dfrac{1}{\hat{v}(1)}\Delta, \end{cases}$$

where

$$\phi(f) \equiv \begin{cases} f + \dfrac{\hat{v}(0) - f}{\hat{v}(0) - \hat{v}(1)}[v(k,l) - v(k,k)] & \text{for} \quad \hat{v}(1) \le f \le \hat{v}(0), \\[2ex] \hat{v}(0) & \text{for} \quad f > \hat{v}(0). \end{cases}$$

Proof. See Appendix. □

Given A.1 and A.2, it can be shown that D_B is always strictly dominated by F. Hence, D_B is chosen with zero probability for all relevant parameter values, while F and D_A are chosen with respective probabilities q^* and $1 - q^*$. Note that q^* is a function of β, f, and Δ. It is straightforward to show that q^* is decreasing in β, increasing in f [for $\hat{v}(1) \le f \le \hat{v}(0)$], and decreasing in Δ: a firm assigns a high probability to choosing F in equilibrium, when (1) β is low (close to $\frac{1}{2}$) so that the information on consumer preferences is imprecise, (2) the potential *ex post* cost, f, of being dedicated to a wrong product is high, and, finally, (3) the relative cost of acquiring a flexible mode over a dedicated mode, Δ, is low. These observations are consistent with the properties of the pure-strategy equilibria derived in Section 3.

5. Oligopoly Equilibrium

The analytical results obtained for the case of duopoly in Section 3 are now extended to N-firm oligopoly. Suppose there exists a total of N firms, $N > 2$, each of which can produce and market only one product at any given time with a particular operational mode that it possesses. I retain all of the modeling assumptions and the structures of the game used previously, with the exception of the reduced-form payoffs that must be modified in order to accommodate the N-firm oligopoly. Firms are again restricted to choosing pure strategies only.

Let $v(k; r, s)$ be the profits to a firm from selling the preferred product (k) when there are r rivals also selling k and s rivals selling the nonpreferred product (l), where $l, k = A, B$ and $k \neq l$. Likewise, $v(l; r, s)$ is the sales profits to the firm selling a nonpreferred product when r of its rivals sell the preferred product and s of its rivals sell the nonpreferred product. Since $r + s$ is the total number of rivals that a firm faces and hence is equal to $N - 1$, we shall save on notation by simply noting that $s = N - 1 - r$. Let $\hat{v}(r) \equiv v(k; r, s) - v(l; r, s)$. Then $\hat{v}(r)$ is the marginal gain in profits from selling the preferred product, k, over that from selling the nonpreferred product, l, given that r rivals sell the preferred product and s rivals sell the nonpreferred product. The following assumption is made:

$$A.3: \quad 0 < \hat{v}(N-1) \leq \hat{v}(N-2) \leq \cdots \leq \hat{v}(r) \leq \hat{v}(r-1) \leq \cdots \leq \hat{v}(1) \leq \hat{v}(0).$$

Note that $\hat{v}(r)$ is positive for all values of r: no matter what the rivals produce, it is always more profitable to produce the preferred product than the nonpreferred product. The implications are: (1) those firms with the flexible mode always produce the product that is revealed to be preferred by the consumers, and (2) the firms with a mode that is dedicated to the product revealed to be preferred always produce the preferred product. That $\hat{v}(r) \leq \hat{v}(r-1)$ for all r from $N - 1$ to 1 implies that the gain from selling the preferred product is larger, the fewer the rival firms selling the same product.

Finally, in order to ensure that there exist at least some parameter values for which full flexibility may be an equilibrium, the following assumption is employed as an oligopoly analog of A.2:

A.4: $0 < \Delta < \frac{1}{2}\hat{v}(N-1)$.

The main objective is to show that there exists an integer m between 0 and N such that m firms choosing a flexible mode and $N-m$ firms choosing a dedicated mode form a subgame perfect equilibrium. For simplicity, let us concentrate only on that range of f values sufficiently high such that no wrongly dedicated firm wants to switch its product. It is sufficient to assume the following:

A.5: $f > \hat{v}(0)$.

Again, since the outcome is symmetric around $\beta = \frac{1}{2}$, I shall restrict attention to those $\beta \geq \frac{1}{2}$. Also note that D_B is strictly dominated by F and hence never chosen for $\frac{1}{2} \leq \beta \leq 1$, given A.4.[14]

Given that m firms chose F and $N-m$ firms chose D_A in period 1, A.3 implies that all N firms will produce product A in period 2 if e_A is realized. Alternatively, if e_B is realized, then m flexible firms will produce B, and $N-m$ dedicated firms will produce A, by A.5. In supporting $(m, N-m)$ as the subgame perfect equilibrium, it is necessary to show that none of the m flexible firms should have any profit incentive to change its mode to a dedicated mode and none of the $N-m$ dedicated firms should have any profit incentive to change its mode to a flexible mode. The corresponding conditions are

$$\Delta \leq (1-\beta)\left[v(k; m-1, N-m) - v(l; m-1, N-m)\right], \tag{4}$$

$$\Delta \geq (1-\beta)\left[v(k; m, N-m-1) - v(l; m, N-m-1)\right]. \tag{5}$$

Inequality (4), defined for and applied identically to each and every one of the m flexible firms, states that the gain in acquisition cost from choosing D_A over F is dominated by the expected loss incurred in the event that product B is preferred by the consumers in period 2. Conversely, inequality (5) is defined for each and every one of the $N-m$ dedicated firms and states that the extra cost of acquiring the flexible mode (F) outweighs the potential gain in profits that may be realized in the event that product B is preferred. Combined together,

14. Note that F dominates D_B if and only if $-\Delta + \beta v(k; N-1, 0) + (1-\beta)v(k; m, N-m-1) > \beta v(l; N-1, 0) + (1-\beta)v(k; m, N-m-1)$. This simplifies to $\beta\hat{v}(N-1) > \Delta$, which is true for $\beta \geq \frac{1}{2}$, given A.4.

(4) and (5) can be written as

$$\hat{v}(m) \leq \frac{\Delta}{1-\beta} \leq \hat{v}(m-1), \tag{6}$$

where $\hat{v}(m) \equiv v(k; m, N-m-1) - v(l; m, N-m-1)$ and $\hat{v}(m-1) \equiv v(k; m-1, N-m) - v(l; m-1, N-m)$. Hence, an N-firm oligopoly that consists of m flexible firms and $N-m$ dedicated firms forms a subgame perfect equilibrium if and only if inequality (6) is satisfied.

Note that (6) is a condition imposed on two parameters: Δ and β. Figure 2 illustrates the equilibrium operational modes for various levels of $\Delta/(1-\beta)$. When $\Delta/(1-\beta)$ is sufficiently low, all firms choose to be flexible. As $\Delta/(1-\beta)$ rises in value, the proportion of flexible firms in the total population declines monotonically. Eventually, for sufficiently high values of $\Delta/(1-\beta)$, the equilibrium contains no flexible firms. All firms prefer to be dedicated to the production of A. Letting λ represent the equilibrium proportion of flexible firms such that $\lambda = m/N$, it is observed that the properties identified previously under duopoly extend fully to N-firm oligopoly: (1) λ declines in Δ, and (2) λ rises as β approaches $\frac{1}{2}$ from above.

6. Concluding Remarks

This study has investigated the equilibrium degree of flexibility chosen by firms that compete in a duopolistic product market. It was found that there exists an equilibrium in which *ex ante* identical firms deliberately choose to embed differential degrees of flexibility in their operational mode. This leads to an *ex post* intra-industry differential in the ability of the firms to respond to newly revealed information about their market environment. It was further shown that the equilibrium choice of flexible mode depends on three factors: (1) the cost of switching product design, (2) the difference in the acquisition costs of the flexible and dedicated modes, and (3) the precision of the *ex ante* information held by the firms regarding consumer preferences. The precise relationship between these factors and the equilibrium choice of modes was fully characterized and then extended to N-firm oligopoly.

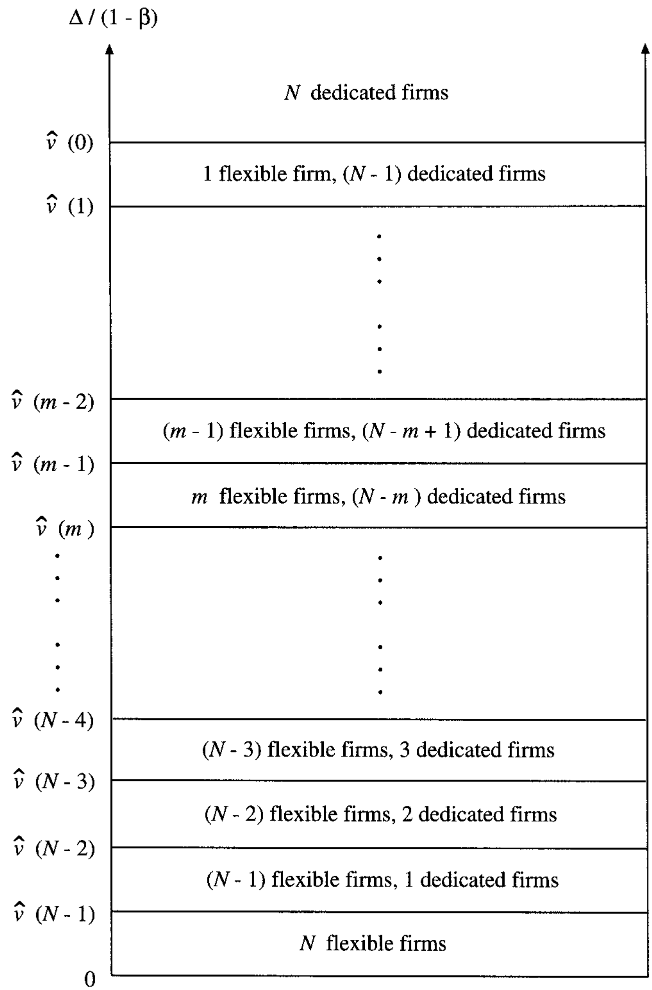

FIGURE 2. EQUILIBRIUM OPERATIONAL MODES IN N-FIRM OLIGOPOLY WITH $\beta > \frac{1}{2}$

APPENDIX

Proof of Proposition 3. The following equations describe the expected payoffs in period 1 for firms 1 and 2, given that $\hat{v}(1) \leq f \leq \hat{v}(0)$ and that the period-2 game is characterized by the Nash equilibrium derived in Proposition 1:

$$V(F,F) = -\Delta + v(k,k), \tag{A.1a}$$

$$V(D_A,F) = \beta v(k,k) + (1-\beta)v(l,k), \tag{A.1b}$$

$$V(D_B,F) = \beta v(l,k) + (1-\beta)v(k,k), \tag{A.1c}$$

$$V(F,D_A) = -\Delta + \beta v(k,k) + (1-\beta)v(k,l), \tag{A.2a}$$

$$V(D_A,D_A) = \beta v(k,k) + (1-\beta)[v(l,k) - f], \tag{A.2b}$$

$$V(D_B,D_A) = \beta v(l,k) + (1-\beta)v(k,l), \tag{A.2c}$$

$$V(F,D_B) = -\Delta + \beta v(k,l) + (1-\beta)v(k,k), \tag{A.3a}$$

$$V(D_A,D_B) = \beta v(k,l) + (1-\beta)v(l,k), \tag{A.3b}$$

$$V(D_B,D_B) = \beta[v(k,l) - f] + (1-\beta)v(k,k). \tag{A.3c}$$

Note that the expected profits are symmetric for both firms. Let $x \in M$ denote the rival firm's chosen mode. It is straightforward that $V(F, x) > V(D_B, x)$ for all $x \in M$: D_B is always strictly dominated by F. Defining the best response function of a firm as $\psi(x) = \text{Argmax}_{y \in M} V(y, x)$, we obtain

$$\psi(F) = \begin{cases} D_A & \text{for } 1 - [1/\hat{v}(1)]\Delta < \beta \leq 1, \\ F & \text{for } \frac{1}{2} < \beta \leq 1 - [1/\hat{v}(1)]\Delta, \end{cases} \tag{A.4}$$

$$\psi(D_A) = \begin{cases} D_A & \text{for } 1 - (1/f)\Delta < \beta \leq 1, \\ F & \text{for } \frac{1}{2} < \beta \leq 1 - (1/f)\Delta, \end{cases} \tag{A.5}$$

$$\psi(D_B) = \begin{cases} D_A & \text{for } 1 - [1/\hat{v}(1)]\Delta < \beta \leq 1, \\ F & \text{for } \frac{1}{2} < \beta \leq 1 - [1/\hat{v}(1)]\Delta. \end{cases} \tag{A.6}$$

The above best response functions imply that (D_A, D_A) is a pair of equilibrium operational modes for $1 - (1/f)\Delta < \beta \leq 1$, and (F, F) is a pair of equilibrium operational modes for $\frac{1}{2} < \beta \leq 1 - [1/\hat{v}(1)]\Delta$. However, for $1 - [1/\hat{v}(1)]\Delta < \beta \leq 1 - (1/f)\Delta$, multiple asymmetric equilibria arise. Both (D_A, F) and (F, D_A) can be supported as subgame perfect equilibria for this range of β values. □

Proof of Proposition 4. The following equations describe the expected payoffs in period 1 for firms 1 and 2, given $f > \hat{v}(0)$ and that the period-2 game is characterized by the Nash equilibrium derived in

Proposition 1:

$$V(F,F) = -\Delta + v(k,k), \tag{A.7a}$$

$$V(D_A,F) = \beta v(k,k) + (1-\beta)v(l,k), \tag{A.7b}$$

$$V(D_B,F) = \beta v(l,k) + (1-\beta)v(k,k), \tag{A.7c}$$

$$V(F,D_A) = -\Delta + \beta v(k,k) + (1-\beta)v(k,l), \tag{A.8a}$$

$$V(D_A,D_A) = \beta v(k,k) + (1-\beta)v(l,l), \tag{A.8b}$$

$$V(D_B,D_A) = \beta v(l,k) + (1-\beta)v(k,l), \tag{A.8c}$$

$$V(F,D_B) = -\Delta + \beta v(k,l) + (1-\beta)v(k,k), \tag{A.9a}$$

$$V(D_A,D_B) = \beta v(k,l) + (1-\beta)v(l,k), \tag{A.9b}$$

$$V(D_B,D_B) = \beta v(l,l) + (1-\beta)v(k,k). \tag{A.9c}$$

As in the proof of Proposition 3, it is straightforward to show that D_B is strictly dominated by F. Defining the best response function in the same way, we obtain

$$\psi(F) = \begin{cases} D_A & \text{for } 1 - [1/\hat{v}(1)]\Delta < \beta \leq 1, \\ F & \text{for } \frac{1}{2} < \beta \leq 1 - [1/\hat{v}(1)]\Delta, \end{cases} \tag{A.10}$$

$$\psi(D_A) = \begin{cases} D_A & \text{for } 1 - [1/\hat{v}(0)]\Delta < \beta \leq 1, \\ F & \text{for } \frac{1}{2} < \beta \leq 1 - [1/\hat{v}(0)]\Delta, \end{cases} \tag{A.11}$$

$$\psi(D_B) = \begin{cases} D_A & \text{for } 1 - [1/\hat{v}(1)]\Delta < \beta \leq 1, \\ F & \text{for } \frac{1}{2} < \beta \leq 1 - [1/\hat{v}(1)]\Delta. \end{cases} \tag{A.12}$$

Given $\frac{1}{2} < 1 - [1/\hat{v}(1)]\Delta < 1 - [1/\hat{v}(0)]\Delta \leq 1$, it is straightforward that (D_A, D_A) forms an equilibrium for $1 - [1/\hat{v}(0)]\Delta < \beta \leq 1$, and (F,F) forms an equilibrium for $\frac{1}{2} < \beta \leq 1 - [1/\hat{v}(1)]\Delta$. For $1 - [1/\hat{v}(1)]\Delta < \beta \leq 1 - [1/\hat{v}(0)]\Delta$, multiple asymmetric equilibria exist. Both (F, D_A) and (D_A, F) can be supported. □

Proof of Proposition 5. Given that both firms possess the identical operational modes dedicated to the nonpreferred product, the period-2 profits are then symmetric for both firms. Let p_i denote the probability that firm i chooses to produce the mode-specific product. Then $1 - p_i$ is the probability that firm i reorients its operational mode and switches to the production of the preferred product. The expected profit for firm i can be written as

$$EV_i(p_i, p_j) = p_i\big[p_j v(l,l) + (1-p_j)v(l,k)\big]$$
$$+(1-p_i)\{p_j[v(k,l)-f] + (1-p_j)[v(k,k)-f]\},$$
$$i, j = 1,2 \text{ and } i \neq j. \quad \text{(A.13)}$$

Denote by $\omega_i(p_j)$ firm i's best response to p_j. From (A.13) it is straightforward to show that

$$\omega_i(p_j) = \begin{cases} 1 & \text{for} \quad 0 \leq p_j < [f - \hat{v}(1)]/[\hat{v}(0) - \hat{v}(1)], \\ [0,1] & \text{for} \quad p_j = [f - \hat{v}(1)]/[\hat{v}(0) - \hat{v}(1)], \\ 0 & \text{for} \quad [f - \hat{v}(1)]/[\hat{v}(0) - \hat{v}(1)] < p_j \leq 1. \end{cases} \quad \text{(A.14)}$$

Let p_i^* be the Nash equilibrium in mixed strategies such that $EV_i(p_i^*, p_j^*) \geq EV_i(p_i, p_j^*)$ for all $p_i \in [0,1]$. From (A.14), it can be seen that there are three mixed strategy equilibria: (1) $(p_i^*, p_j^*) = (1,0)$, (2) $(p_i^*, p_j^*) = (0,1)$, and (3) $p_i^* = p_j^* = [f - \hat{v}(1)]/[\hat{v}(0) - \hat{v}(1)] \equiv p^*$. The first two coincide with the pure-strategy equilibria identified in Proposition 1. The third is the symmetric mixed-strategy Nash equilibrium, in which, with probability $1 - p^*$, the firms reorient the operational mode and switch to the preferred product. □

Proof of Proposition 6. The proof consists of two parts: part A for $\hat{v}(1) \leq f \leq \hat{v}(0)$ and part B for $f > \hat{v}(0)$.

Part A: Given that the symmetric mixed strategy equilibrium $(p^*, 1 - p^*)$ is played in period 2 for $\hat{v}(1) \leq f \leq \hat{v}(0)$ as described in Proposition 5, one can write the period-1 expected sales profits $V_i(m_i, m_j)$ of firm i $(i = 1,2)$ from choosing the operational mode m_i, as its rival chooses m_j $(i \neq j)$:

$$V_i(F, F) = -\Delta + v(k,k), \quad \text{(A.15)}$$

$$V_i(F, D_A) = -\Delta + \beta v(k,k) + (1-\beta)v(k,l), \quad \text{(A.16)}$$

$$V_i(F, D_B) = -\Delta + \beta v(k,l) + (1-\beta)v(k,k), \quad \text{(A.17)}$$

$$V_i(D_A, F) = \beta v(k,k) + (1-\beta)v(l,k), \quad \text{(A.18)}$$

$$V_i(D_A, D_A) = \beta v(k,k) + (1-\beta)\{(p^*)^2 v(l,l) + p^*(1-p^*)v(l,k) + (1-p^*)p^*[v(k,l) - f] + (1-p^*)^2[v(k,k) - f]\}, \tag{A.19}$$

$$V_i(D_A, D_B) = \beta v(k,l) + (1-\beta)v(l,k), \tag{A.20}$$

$$V_i(D_B, F) = \beta v(l,k) + (1-\beta)v(k,k), \tag{A.21}$$

$$V_i(D_B, D_A) = \beta v(l,k) + (1-\beta)v(k,l), \tag{A.22}$$

$$V_i(D_B, D_B) = \beta\{(1-p^*)^2[v(k,k) - f] + (1-p^*)p^*[v(k,l) - f] + p^*(1-p^*)v(l,k) + (p^*)^2 v(l,l)\} + (1-\beta)v(k,k). \tag{A.23}$$

Comparing equations (A.15), (A.16), and (A.17) with (A.21), (A.22), and (A.23), respectively, it is straightforward to show that $V_i(F, m_j) > V_i(D_B, m_j)$ for all $m_j \in M$ under assumptions A.1 and A.2. Hence, D_B is strictly dominated by F and is chosen with zero probability by both firms. Letting $q_i, 1 - q_i, 0$ be the mixed strategy of firm i $(i = 1,2)$ defined over F, D_A, D_B respectively, the expected sales profits of firm i can be written as

$$\begin{aligned} EV_i(q_i, q_j) = q_i\{&q_j[-\Delta + v(k,k)] \\ &+(1-q_j)[-\Delta + \beta v(k,k) + (1-\beta)v(k,l)]\} \\ &+(1-q_i)\big[q_j[\beta v(k,k) + (1-\beta)v(l,k)] \\ &+(1-q_j)\big(\beta v(k,k) + (1-\beta) \\ &\times\{(p^*)^2 v(l,l) + p^*(1-p^*)v(l,k) \\ &+(1-p^*)p^*[v(k,l) - f] + (1-p^*)^2[v(k,k) - f]\}\big)\big]. \end{aligned} \tag{A.24}$$

Differentiating (A.24) with respect to q_i and after much simplification, we obtain

$$\frac{\partial E V_i}{\partial q_i} = -\Delta + (1-\beta)\phi(f) - q_j(1-\beta)[\phi(f) - \hat{v}(1)], \tag{A.25}$$

where $\phi(f) \equiv f + \{[\hat{v}(0) - f]/[\hat{v}(0) - \hat{v}(1)]\}[v(k,l) - v(k,k)]$. The best response function of firm i, $\omega_i(q_j)$, is then

$$\omega_i(q_j) = \begin{cases} 1 & \text{for} \quad 0 \le q_j < \dfrac{-\Delta + (1-\beta)\phi(f)}{(1-\beta)[\phi(f) - \hat{v}(1)]}, \\ [0,1] & \text{for} \quad q_j = \dfrac{-\Delta + (1-\beta)\phi(f)}{(1-\beta)[\phi(f) - \hat{v}(1)]}, \\ 0 & \text{for} \quad \dfrac{-\Delta + (1-\beta)\phi(f)}{(1-\beta)[\phi(f) - \hat{v}(1)]} < q_j \le 1. \end{cases} \tag{A.26}$$

There are three mixed-strategy equilibria: (1) firm 1 chooses (F, D_A, D_B) with probabilities $(1,0,0)$, and firm 2 with $(0,1,0)$, (2) the exact opposite of (1), and (3) both firms choose (F, D_A, D_B) with respective probabilities of $(q^*, 1-q^*, 0)$, where $q^* = [-\Delta + (1-\beta)\phi(f)]/\{(1-\beta)[\phi(f) - \hat{v}(1)]\}$ and $0 \le q^* \le 1$ for $1 - [1/\hat{v}(1)]\Delta \le \beta \le 1 - [1/\phi(f)]\Delta$. The first two coincide with the pure-strategy equilibria identified in Section 3, in which both (F, D_A) and (D_A, F) are supported. The third is the symmetric mixed-strategy equilibrium for $\hat{v}(1) \le f \le \hat{v}(0)$.

Part B: For $f > \hat{v}(0)$, the period-1 expected sales profits, $V_i(m_i, m_j)$, of firm i $(i = 1,2)$ from choosing the operational mode m_i as its rival chooses m_j have the expressions in (A.7) through (A.9) in the proof of Proposition 4. Once again, it is straightforward to show that $V_i(F, m_j) > V_i(D_B, m_j)$ for all $m_j \in M$ under assumptions A.1 and A.2. Letting $(q_i, 1-q_i, 0)$ be the mixed strategy of firm i $(i = 1,2)$ defined over (F, D_A, D_B) respectively, the expected sales profits of firm i are written as

$$\begin{aligned} EV_i(q_i, q_j) = q_i\{&q_j[-\Delta + v(k,k)] + (1-q_j) \\ &\times[-\Delta + \beta v(k,k) + (1-\beta)v(k,l)]\} \\ &+(1-q_i)\{q_j[\beta v(k,k) + (1-\beta)v(l,k)] \\ &+(1-q_j)[\beta v(k,k) + (1-\beta)v(l,l)]\}. \end{aligned} \tag{A.27}$$

Differentiating (A.27) with respect to q_i and after much simplification, we obtain

$$\frac{\partial E V_i}{\partial q_i} = -\Delta + (1-\beta)\hat{v}(0) - q_j(1-\beta)[\hat{v}(0) - \hat{v}(1)]. \tag{A.28}$$

The best response function of firm i, $\omega_i(q_j)$, is then

$$\omega_i(q_j) = \begin{cases} 1 & \text{for} \quad 0 \le q_j < \dfrac{-\Delta + (1-\beta)\hat{v}(0)}{(1-\beta)[\hat{v}(0) - \hat{v}(1)]}, \\ [0,1] & \text{for} \quad q_j = \dfrac{-\Delta + (1-\beta)\hat{v}(0)}{(1-\beta)[\hat{v}(0) - \hat{v}(1)]}, \\ 0 & \text{for} \quad \dfrac{-\Delta + (1-\beta)\hat{v}(0)}{(1-\beta)[\hat{v}(0) - \hat{v}(1)]} < q_j \le 1. \end{cases} \tag{A.29}$$

There are three mixed-strategy equilibria: (1) firm 1 chooses (F, D_A, D_B) with probabilities $(1,0,0)$, and firm 2 with $(0,1,0)$, (2) the exact opposite of (1), and (3) both firms choose (F, D_A, D_B) with respective probabilities of $(q^*, 1-q^*, 0)$, where $q^* = [-\Delta + (1-\beta)\hat{v}(0)]/\{(1-\beta)[\hat{v}(0) - \hat{v}(1)]\}$ and $0 \le q^* \le 1$ for $1 - [1/\hat{v}(1)]\Delta \le \beta \le 1 - [1/\hat{v}(0)]\Delta$. The first two coincide with the pure-strategy equilibria identified in Section 3, in which both (F, D_A) and (D_A, F) are supported. The third is the symmetric mixed-strategy equilibrium for $f > \hat{v}(0)$. □

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