Switching Costs and Bidding Parity in Government Procurement of Computer Systems

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The issue in dispute . . . began with HGOC's [House Government Operations Committee] resistance to allowing consideration of full costs for converting computer programs from the form used by incumbent computers to the form needed for equipment of prospective new vendors. HGOC correctly believes that considering full conversion costs tends to restrict competition to vendors of equipment compatible with incumbent machines.

P. R. Werling, Ph.D. dissertation

1. INTRODUCTION

Since the late 1960s, the General Services Administration (GSA) has supervised acquisitions of computer equipment of high value by federal agencies.[1] GSA's policies governing bidding procedures have frequently been a focal point of controversy.

One issue of debate concerned the GSA's policies for determining the winning bidder to supply a computer system when the new acquisition is subject to "conversion costs," that is, costs incurred as a consequence of

A substantial portion of this work was completed when both authors were associated with the Center for Economic Policy Research at Stanford University. We would like to thank Tim Bresnahan, Roger Noll, Mike Riordon, two anonymous referees, and Oliver Williamson for many useful remarks. We are solely responsible for any remaining errors.

1. See GAO (1977a) for a summary of the structure of computer procurement.

Journal of Law, Economics, and Organization vol. 6, no. 2 Fall 1990
 ISSN 8756-6222

switching suppliers of a mainframe computer system.[2] In the late 1970s, many computer users complained that the GSA had no systematic policy for accounting for "conversion costs" when choosing among competing bids from alternative suppliers. As a consequence, the GSA was generally underaccounting for them. A Government Accounting Office (GAO) report inquired, "Would including conversion costs in computer procurement result in selecting the (computer mainframe) system that would cost the government the least over the lifetime of the system?" (GAO, 1980:ii).

Most government analyses, including the report just cited, have focused on subsets of the economic issues.[3] Through careful analysis of many actual conversions, the GAO established that switching costs could be large and could influence procurement (and that there existed methods for estimating those costs). However, the GAO reports implicitly assume that bids should fully account for switching costs under all circumstances[4] and, hence, that establishing the existence of switching costs justifies accounting for them.[5]

In contrast to the GAO report, this paper shows why this assumption is not appropriate: There may be plausible circumstances in which it is best not to account for switching costs—even when those costs are large and can influence procurement.

We compare two stylized procurement systems in which the winner is chosen either by a third party, who strictly follows GSA's policies and does not account for switching costs, or by the eventual user, who does (correctly) account for switching costs. We call the first "centralized" procurement and the latter "decentralized" procurement.[6] We focus on whether the benefits of extra competitive bidding in a procurement that ignores switching costs outweigh the losses from occasionally switching to nonincumbent suppliers whose computers actually cost the buyer more in the end. That is, could ignoring switching costs result in such aggressive bidding behavior that a buyer may still want to switch vendors?

Consider situations where federal-agency computer users are "locked-in" to one of two bidders; that is, users have made idiosyncratic investments that are complementary with the incumbent's equipment, and these investments would have to be made again with any new vendor. From the perspective of the central budgeting agency, the Office of Management and Budget (OMB), centralized procurement can be optimal for the federal government as a budgetary unit when most agencies are "locked-in" to the low-cost bidder. Centralized procurement will elicit more competitive behavior from the bidder, who already has a competitive advantage, without causing the purchasing agency much added expense from switching suppliers. On the other hand, when most agencies are "locked-in" to the high-cost bidder, decentralized procurement will be favored over centralized procurement because lower costs from switching vendors more than make up for the higher prices paid.

We also show that bidding using an underestimate of switching costs—or only partly accounting for them—will involve the same trade-offs. In some circumstances, underestimates will even be preferable to the extreme cases of "centralized" and "decentralized" procurement. Partially ignoring switching costs could elicit more aggressive bidding, which makes up for the costs of switching vendors, even if the switch does not appear economically sensible when viewed in isolation.

We will not argue that the procurement policies of the 1970s and 1980s were right or wrong. Such an analysis requires both empirical research and further theoretical extensions beyond the scope of this paper. Rather, we will show that a simple economic analysis highlights many issues that arise in the debate over changes in the procurement policy. Our analysis will have several concrete implications, including one related to our original motivation: the policy of ignoring switching costs, or partially accounting for them, has a sensible economic rationale that the GAO never considered. Hence, the old procurement policy was abandoned without a full consideration of its economic merits.

In related work, economists have attempted to understand the influence of switching costs, sunk costs, and "lock-in" on competitive behavior. Much

2. "Switching costs" refer to the costs associated with moving to a new supplier. These are not to be confused with conversion expenses that would be incurred irrespective of the identity of the new supplier (i.e., expenses associated with technically "orphaned systems"—systems with no available compatible upgrade).

3. Two issues that received much attention were (1) What principles should guide the implementation of policies for incorporating switching costs into procurement?; and (2) What can be done to aid agency managers in reducing the costs of conversion? See GAO (1977b, 1980).

4. For example, when the GAO (1980) discusses the GSA's newly proposed guidelines for the "inclusion of most conversion costs in the evaluation of vendor proposals," it concludes that "GSA's proposed regulation, as it covers the treatment of conversion costs, is sound." GSA's new proposal was a response to the complaints about the absence of any systematic treatment of conversion expenses. (See GAO 1980:8.)

5. The GAO's presumption that switching costs should always be accounted for is related to the presumption (implicit in its case studies) that correctly accounting for switching costs does not alter pricing behavior. That is, in their study the GAO (1980:5) considered what would have happened if they "adjusted costs used in selecting the winning vendor by including conversion costs we believe should have been considered and correcting for significant underestimates." In effect, the GAO reconsiders the bids by altering the evaluation of the costs of conversion, while not altering their assumptions about pricing behavior. If the basic price of the system does not change, it is not surprising that procurement decisions that account fully for conversion costs appear better than procurement decisions that do not account fully for conversion costs.

6. While we could imagine a centralized procurement system that accounts for switching costs, we maintain this terminology for simplicity.

of the focus has been on understanding pricing, vertical integration, contracting, and entry when incumbent firms are at an apparent advantage relative to nonincumbents. This paper is closest in spirit to those that try to understand the actions of "sophisticated buyers" (i.e., buyers whose behavior is best represented as something more than a simple demand curve).[7] A second related research line has been devoted to understanding second sourcing in government procurement. It focuses on the trade-offs facing policymakers when there is a choice between two alternative vendors, only one of whom has a previous history with the buyer or has progressed down a learning curve.[8] While these theoretical investigations provide useful descriptions of the possible behavioral dynamics, we think that the concrete policy problem we describe here helps clarify the issues involved in an important economic trade-off and renders its implications more concrete.

2. THE DEBATE SURROUNDING COMPUTER PROCUREMENT PROCEDURES

Changes in computer procurement policy in the 1970s potentially had major effects. Virtually every civilian agency and military installation possesses one, if not many, general-purpose mainframes to keep records, process checks, and perform calculations.

By the late 1970s, agencies had reasons to worry about conversion costs and their impact on procurement decisions. Many federal agencies feared that moving to alternative suppliers would result in a large loss in the value of their previous investments, especially if users had to convert idiosyncratic complementary assets, such as large programming packages, to work on the new system from an incompatible supplier.[9] Moreover, switching costs could possibly be large enough to affect the outcomes of bids. The 1980 GAO report mentioned in the Introduction was one of several to show this.[10]

7. For discussions of the variety of possible buyer and seller behaviors when buyers invest in supplier-specific assets, see Farrell (1987), Farrell and Shapiro (1988, 1989), Klemperer (1987a,b), Scherer and Ross (1980: chapter 14), Scheffman and Spiller, and Williamson (1975, 1979).

8. See Anton and Yao; Demski, Sappington, and Spiller; Farrell and Gallini; Laffont and Tirole; and Riordan and Sappington.

9. Several mainframe system manufacturers had developed compatible families of systems and offered upgrades—the IBM 360 and 370 families being the most popular—that were compatible with each other but not with systems made by other firms. By the 1970s, many agency offices had built a substantial library of software investment that was compatible with only one firm's systems and potentially very costly to replace. See Greenstein (chapter 2), for more technical detail.

10. The GAO report brought to light examples where the procurement procedures did not reflect the full costs of switching between alternative suppliers. GAO publications (1977b, 1980) are the best sources. For other useful retrospective studies see GSA (1983, 1986), and National Bureau of Standards (NBS) (1980a,b). Also see Werling (1983).

Computer procurement by federal agencies was also shaped by the nature of supervision. The acquisition and use of computers in the federal government had been guided by the public law 89-306, "The Brooks Act," named for Congressman Jack Brooks (D, Texas) of the House Government Operations Committee, who had long been interested in the procurement and use of federal information technologies. The Brooks Act delegated to the GSA the authority to decide the winner of computer competitive bids.[11] The GSA could delegate to agencies the authority to decide the winner, and did so when the procurement was small in value. Often when the procurement was large in value the delegation of authority was made, although with careful stipulation of the policies governing the procurement.[12] As a consequence, procurement decisions could be tightly circumscribed, and the user's choice could always be reviewed for approval (or reviewed if there was a protest).[13]

The deemphasis of switching costs in GSA policies was not a written policy, but one assumed to be de facto in place. The GAO (1980:28) diplomatically stated that the problem was "traceable to a lack of clarity in government regulations. Some policies are unwritten, while others are unclear." Congressman John N. Erlenborn was more direct. He wrote in an October 3, 1978 letter (quoted in GAO, 1980:7), "In practice GSA has stipulated . . . that certain costs involved in the acquisition process, notably conversion costs, must be treated in such a manner as to not be prejudicial to free and open competition. In actuality, conversion costs are not duly considered, even though they are in many instances extremely costly to the government."

It was believed that Brooks was partially responsible for this situation because he sought to make procurement procedures more "competitive," seeking to eliminate "sole source" procurement of systems, primarily from incumbent suppliers.[14] As a result, the GSA was not initially sympathetic to arguments that the costs of switching to incompatible computer suppliers justified limiting the number of competitors. In the GSA's defense, the GSA

11. Among its directives, the Brooks Act also delegated authority for computer procurement policy- and decision-making to several federal agencies, the GSA, the NBS, and the Bureau of the Budget [later to become the Office of Management and Budget (OMB)].

12. Guidelines used to be set at $50,000 for sole-source procurement and $300,000 for competitive procurement. See NBS (1983).

13. It was also widely believed that Congressman Brooks held ultimate authority over the purchase of any large computer system to which he turned his attention, although he never retained any formal authority to veto a computer procurement (Petrillo). Paul Werling, who wrote a thesis on the Brooks Act, alleges that Brooks especially targeted IBM, the dominant system supplier in the early 1970s.

14. A sole-source contract is one in which an agency contracts with a single vendor. If the supplier possessed a "unique capability and experience," agencies could justify bypassing solicitation of competitive bids or at least restricting bidding to compatible suppliers. See the quote at the start of this paper (Werling).

In contrast, switching costs are taken into account in each purchase in a decentralized procurement. We consider two possible cases, depending on whether s is greater or smaller than the difference $s^* = c^h - c^l$. If $s > s^*$, then the incumbent firm (i.e., the firm to which the buyer is locked-in) has a sufficiently large strategic advantage that it sells even if it has a higher cost. The price charged by the incumbent is given by the cost of the other firm plus the value of s. Average benefit, conditional on s being greater than s^*, is then given by

$$B^{dh} = u - m \cdot (c^l + s^h) - (1 - m) \cdot (c^h + s^h), \tag{2}$$

where $s^h \equiv E(s|s > s^*)$.

If, on the other hand, $s < s^*$, then the low-cost firm has a sufficiently large cost advantage that it sells even if it is not incumbent. The price charged by the low-cost firm is $c^h + s$, if it is incumbent, and $c^h - s$, if it is not. Average benefit conditional on s being lower than s^* is then

$$B^{dl} = u - m \cdot (c^h - s^l + s^l) - (1 - m) \cdot (c^h + s^l), \tag{3}$$

where $s^l \equiv E(s|s < s^*)$.

Average benefit per office under the decentralized procurement regime is

$$B^d = (1 - F^*)\, B^{dh} + F^* B^{dl}, \tag{4}$$

where $F^* = F(s^*)$, the proportion of offices with sufficiently low switching costs. Substituting (2) and (3) into (4) and doing some algebraic manipulation, we get

$$B^d = u - c^h - E(s) + mK, \tag{5}$$

where $K = (1 - F^*)\,(c^h - c^l) + F^* s^l > 0$.

The benefit function under decentralized procurement is increasing in m. The greater the proportion of offices locked-in to the high-cost firm, the fewer the firms that switch, and the lower the total expenditure the entire government spends on switching costs.

The main result of this section can be summarized as follows.

Proposition 1. If m is sufficiently small (large), then the regime of centralized procurement (decentralized procurement) yields higher net benefit.

The result follows straightforwardly by comparing (1) and (5). The intuition behind the proposition is quite simple, and most easily understood for the extreme cases. When m is small, the low-cost firm has the advantage in a bidding game, whether or not procurement is centralized. When switching costs are taken into account (i.e., under the decentralized regime), the low-cost firm, if incumbent, has one less cost associated with its systems than its competitor. This manifests itself in a higher price and, thus, a lower benefit to the buyer. When m is large, on the other hand, switching costs will quite often be incurred in a centralized regime. The total switching costs will more than make up for the lower prices induced by bidding parity. In other words, the two regimes trade off the gains from a more competitive behavior with the consequent costs of switching suppliers.

One of the peculiarities of a centralized regime is that behavior that appears to be suboptimal on a local level can be optimal when viewed globally. In this case, agencies commit to an evaluation procedure that is not subgame perfect when viewed in isolation, because the agency does not act on information that it might be better off not switching to a nonincumbent. Yet, the commitment is globally optimal because it induces lower prices as a result of more aggressive bidding.

This feature of the model is related to similar notions found in the theoretical economic literature on auctions—namely, if the buyer can commit to a course of action, irrespective of the information he receives later that may reveal that his strategy is suboptimal, then he may be better off. Commitment to one type of action leads other players to change their behavior in a manner that may be favorable to the buyer. Usually, observations of this type are problematic, because there is no practical method of ensuring the commitment of the first decision-maker. We have much less trouble here, since the situation motivating our investigation provides evidence that an institutional mechanism enforces the commitment—namely, administrative law regulates procedures, and losing vendors can protest a decision (to the Comptroller General or GAO) if decision-making noticeably deviates from publicly stated GSA policies or federal laws. The appeals process was (and still is) sufficiently painful and slow that an agency closely followed GSA regulations to reduce the probability of a protest. Following policies closely also protected the agency in the event that it would have to justify its activities in an oversight hearing.[21]

We should mention that there are various ways one can depart from the simple common-knowledge model presented here. For example, one can assume that production costs are each firm's private information. The model would then be isomorphic to an auction with a discriminating factor z (McAfee and McMillan), z being zero when switching costs are ignored. This and other possible departures from the common-knowledge assumption

21. We recognize as well that Congressman Brooks historically played a role in enforcing any equilibrium. An agency that wanted to avoid the scrutiny of the House Government Operations Committee had to follow GSA's directives.

make the model more difficult to solve (sometimes impossible to solve analytically), but do not change the basic points brought out by the analysis of the simple case.

On the other hand, one must recognize that, in its simplicity, our model leaves out some aspects of potential interest. For example, we could discuss the case in which s is the buyer's private information, and see what incentives he or she has to reveal that information.[22] We could also discuss the case in which s is known to the buyer and the incumbent firm to see how this affects the trade-off between the two regimes.[23] In addition, when an agency's (unobserved) actions affect the level of switching costs incurred in a procurement, we could also investigate an agency's incentives to make an effort to keep s low (as functions of procurement regimes, oversight's effectiveness, and the extent of public information).[24]

4. CHOICES AMONG PROCUREMENT REGIMES

The analysis implies that the existence of switching costs associated with a purchase does not, per se, provide a compelling reason for adopting a system that fully accounts for them. Centralized procurement is optimal for the federal government as a budgetary unit (e.g., from OMB's perspective) when most agencies are "locked-in" to the low-cost bidder; decentralized procurement will be favored when most agencies are "locked-in" to the high-cost bidder. The analysis also implies that a system that did not fully account for switching costs in the 1970s was optimal if the dominant incumbent suppliers, such as IBM and Univac, had lower costs than the new entrants. We note that nothing similar to this condition was discussed in the records of the debate.

An optimal centralized system will result in switches between manufacturers that would not occur in a decentralized system. That is, there are situations in which a bid could be awarded to a low-cost nonincumbent supplier in a centralized regime and to an incumbent supplier in a decentralized regime. Moreover, in a centralized regime, awarding the bid to the nonincumbent will appear very costly and uneconomic once the switching costs are incurred, if the acquisition is viewed in isolation of the global gains from aggressive pricing behavior.

We conclude that one should observe in a centralized regime some acquisitions from a nonincumbent vendor which would not be made if switching costs were fully accounted for. This is important because the GAO (1980) showed that for two of six cases studied, procurement choices would have changed if switching costs were properly estimated and accounted for. In our model, these occurrences do not provide sufficient reason to alter the procurement regime. Yet, the GAO offered these cases as substantive evidence of the problems of a system that did not account for switching costs.

This analysis does not entirely vitiate the force of complaints against a centralized regime. A centralized system could result in complaints if appropriate side payments do not solve equity problems not modeled here. The costs and benefits of a centralized system may not be equally borne by all offices, since any particular office may benefit from more competitive pricing under the centralized regime. However, the offices locked in to the high-cost supplier may do more switching and bear more of those switching costs. If each office is constrained by a budget, then one can expect complaints from the offices whose switching costs were ignored. Thus, complaints may arise in a centralized regime whether or not partly accounting for switching costs is optimal for the entire government as a budgetary unit.

We now consider a more general procurement regime in which a portion of the switching costs are taken into account. This is equivalent to a situation in which switching costs are systematically underestimated.[25] Let us assume that the procurement authorities commit to taking into account a fraction, p, of the switching costs.[26] In order to discover whether the optimal p will always be 0 or 1, we performed calculations, summarized in Appendix A, which show that the total benefit for the government under this "flexible regime" policy is

$$B^f = u - c^h + (1 - F^*) \cdot m \cdot \delta - p \cdot E(s) - (1 - 2p) \cdot F^* \cdot m \cdot s^l, \quad (6)$$

22. Basically, if sellers have approximately the same cost and s is low, then it is in the buyer's interest to reveal that information, assuming that switching costs are to be taken into account in the bidding process. However, it is unclear whether there could ever be any credible information disclosure, for a high-s buyer would also benefit by convincing sellers that his or her s is low. We could also investigate the incentives for an agency with foresight to report technical specifications that favor one supplier over another. We have presumed that the central authority can elicit truthful information about the agency's needs. See Greenstein (chapter 2) for more analysis of the latter issue.

23. Our first guess is that the centralized mechanism would be relatively more favored in this case, because, in addition to the switching costs, the incumbent firm would have an information advantage relative to its rival.

24. The GAO (1980) discusses at length agency practices that contribute to raising or lowering conversion expenses.

25. We believe that this is a relevant issue because any definition of a switching cost is in practice somewhat arbitrary, and, thus, can systematically underestimate the true switching cost the agency incurs. The GAO (1980) documents several cases where switching costs were underestimated partly because not all the components of switching costs were accounted for.

26. In practice, this could be done through rules that limit what features an office may require in its technical specifications and, thus, what expenses a seller must cover in each procurement. This ignores the incentives of an agency with foresight to misrepresent the level of "allowable" switching costs, as a means to favor an incumbent supplier. We presume that the central authority can elicit truthful information about the level of switching costs. For related discussion, see Greenstein (chapter 2).

where $\delta \equiv c^h - c^l$, $s^* \equiv (c^h - c^l)/p$, $s^l \equiv E(s|s < s^*)$, and $F^* \equiv F(s^*)$.[27]

Although a systematic characterization of the optimal solution is not possible, we can state the following general results (see Appendix B for the proof).

Proposition 2. There exist parameter values such that $p^* = 0$ is optimal, $p^* = 1$ is optimal, and $p^* \in (0,1)$ is optimal. The following are examples.

(i) If m is very small, then the optimal solution corresponds to $p = 0$.

(ii) If m is very large, then $p = 1$ yields a higher benefit than $p = 0$, but it may be the case that the optimal solution lies strictly between 0 and 1.

(iii) If there is an interior solution and $p^* < \frac{1}{2}$, then an increase in m implies an increase in the optimal p.

(iv) If there is an interior solution and both $p^* < \frac{1}{2}$ and $m < \frac{1}{2}$, then an increase in δ implies an increase in the optimal p.

The proposition provides some insight into the comparative statics of the optimal choice. Even with the simple structure of our model, however, the derivation of the optimal p turns out to be fairly complex.

Through numerical stimulations we have found that p^* is strictly between 0 and 1 generally for cases where m is neither very large nor very small. As an illustration, in Figure 1 B^p is plotted as a function of p, assuming that $c^h = 1.1$, $c^l = 1$, $m = 0.5$, $u = 2$, and s is uniformly distributed between 0 and 1. As can be seen, $p = .215$ maximizes the government's total benefit.

This analysis illustrates that underestimating switching costs also trades off the costs of switching to nonincumbent vendors (more frequently in a centralized regime) with the more competitive pricing behavior induced from vendors (lower pricing in a centralized regime). In some circumstances, the intermediate solution may be better than the extreme solutions of not accounting or fully accounting for switching costs.

5. FINAL REMARKS

Our main finding is that complaints about the GSA's procedures for accounting for switching costs failed to take into account all the relevant economic issues. We have shown that there may be economic merit to ignoring those costs, because the increased competitiveness in response to bidding parity can outweigh the costs of switching between suppliers.

We have also argued that the 1980 GAO report should not have presumed that proof of the existence of switching costs was sufficient to justify accounting for them fully and systematically in all computer procurement. In our view, before making that assumption the authors of the report also should

27. Note that s^*, s^l, and F^* are functions of p.

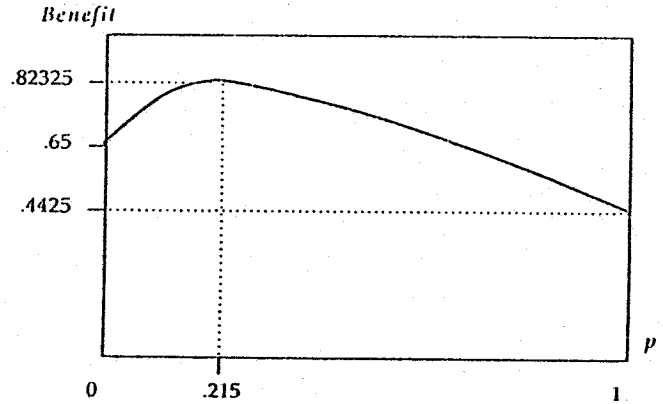

Figure 1. The benefits of a partial regime as a function of p.

have investigated the degree to which the earlier procedures were eliciting more competitive bidding from incumbent vendors, as well as the degree to which federal offices expended funds on switching costs, when they otherwise would not have under a procurement system with full accounting.[28] Such an investigation would have to account fully for the extent to which agencies were locked into the systems provided by incumbent vendors and would have to try to estimate the competitive positions of these vendors.[29] We are not arguing that the policies of the 1970s and 1980s were correct or incorrect, only that changing them required giving full consideration to several fundamental economic issues underlying related questions.[30]

We have noted a number of areas for further useful work. Private information about the level of switching costs or imperfect estimation about the costs of switching could alter the relevant trade-offs between regimes. Conflicts between the supervising and supervised agencies over management prac-

28. One complicating historical factor was that the GSA did not have in place a general facility for performing conversions nor for estimating switching costs. Hence, some allowance must be made for the higher switching costs that were incurred due to the absence of appropriate technical expertise.

29. For example, suppose the largest incumbent mainframe vendor during the 1970s, IBM, was at a cost disadvantage relative to competitors; then there would be economic justification for accounting for switching costs. For information about the installed base of systems in federal agencies, see the *Automatic Data Processing Activities Summary in the United States Government*, published each year from 1972 to 1982 by the GSA.

30. We also note that the relative benefits of the two regimes would differ if central authorities wanted to develop a more "competitive" computer industry by using government procurement to "subsidize" several nondominant (and nonincumbent) industry suppliers—which was commonly alleged when federal agencies purchased non IBM equipment.

tices that influence the level of switching costs could also alter the trade-offs between alternative policy rules. We suspect that useful insights may also be gained through investigating oversight agencies and the routine procedures they use as a means to monitor and elicit control over subagencies (see McCubbins, Noll, and Weingast). How did the GSA prevent offices from "loading up" on switching-cost estimates? How did the GSA induce agencies to incur present expenses that decreased switching costs later? The relative merits of alternative procurement policies will depend on the efficacy of the administrative solutions to these questions.

APPENDIX A: THE EXPECTED BENEFITS UNDER THE FLEXIBLE REGIME

We suppose that a fraction p of the switching costs is taken into account. The crucial value of s is now $s^* \equiv (c^h - c^l)/p$.

If $s > s^*$, then the incumbent always sells at price

$$\begin{aligned} &c^l + p \cdot s, && \text{with probability } m,\\ &c^h + p \cdot s, && \text{with probability } 1 - m. \end{aligned}$$

If $s < s^*$, then the low-cost firm always sells at price

$$\begin{aligned} &c^h + p \cdot s, && \text{with probability } m,\\ &c^l + p \cdot s, && \text{with probability } 1 - m, \end{aligned}$$

and a switching cost s is paid with probability m.

Total benefits are, therefore,

$$\begin{aligned} B^f = u &- (1 - F^*) \cdot [m \cdot (c^l + p \cdot s^h) + (1 - m) \cdot (c^h + p \cdot s^h)]\\ &- f^* \cdot [m \cdot (c^h - p \cdot s^l + p \cdot s^l) + (1 - m) \cdot (c^h + p \cdot s^l)], \end{aligned} \tag{A1}$$

which can be simplified into the expression in the text.

APPENDIX B: PROOF OF PROPOSITION 2

(i) Substituting $m = 0$ in (3), we get

$$B^f = u - c^h - p \cdot E(s) \tag{B1}$$

and the result follows straightforwardly.

(ii) The first part of the result corresponds to Proposition 1. The ambiguity of the optimal solution is evident by computing the derivative $\partial B^f/\partial p$ (done below) for $m = p = 1$. One can find functions $F(\,)$ for which this is negative, which implies an interior optimal solution.

(iii, iv) We make use of the following useful lemma (see, e.g., Varian).

Lemma. Suppose $z(y) = \operatorname{argmax} f(x,y)$. Then

$$\operatorname{sgn}\left(\frac{\partial z}{\partial y}\right) = \operatorname{sgn}\left(\frac{\partial^2 f}{\partial x\, \partial y}\right). \tag{B2}$$

Differentiating (3) with respect to p, we get

$$\begin{aligned} \frac{\partial B^f}{\partial p} = &f\left(\frac{\mu}{p}\right) \cdot \frac{\mu}{p^2} \cdot m \cdot \mu - E(s) + 2 \cdot F\left(\frac{\mu}{p}\right) \cdot m \cdot s^l\\ &+ (1 - 2p) \cdot f\left(\frac{\mu}{p}\right) \cdot \frac{\mu}{p^2} \cdot m \cdot s^l\\ &+ (1 - 2p) \cdot F\left(\frac{\mu}{p}\right) \cdot m \cdot \frac{\mu^2}{p^3} \cdot f\left(\frac{\mu}{p}\right), \end{aligned} \tag{B3}$$

where we use the fact that

$$s^{el} = \int_0^{s^*} s \cdot dF(s)$$

and therefore

$$\frac{\partial s^l}{\partial p} = \frac{\partial s^*}{\partial p} \cdot s^* \cdot f(s^*) = -\frac{\mu}{p^2} \cdot \frac{\mu}{p} \cdot f\left(\frac{\mu}{p}\right).$$

Taking the derivative of (B3) with respect to m and μ, and applying the above lemma, the results follow.

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