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Technological Tying

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Abstract

This paper explores a firm's incentive to technologically tie when R&D is important and finds that technological tying increases innovation, which is an efficiency not considered in other tying models. Intuitively, technological tying protects the seller from aftermarket entry, ensuring that the seller internalizes the full effect of increased investment in technology on system profits. More importantly, the additional innovation, associated with technological tying, may benefit consumers more than anticompetitive effects hurt them, suggesting that innovation efficiency should be an important consideration in technological tying cases.

[1] The views expressed herein are my own and do not purport to represent the views of the Federal Trade Commission or any Commissioner, or The Brattle Group, Inc. I thank Preston McAfee, Patrick DeGraba, Douglas Rathbun, and Eric Edmondson for helpful comments. Any errors or omissions are the responsibility of the author.

A monopolist engages in technological tying when it designs one product so that it functions only when used in conjunction with its own complementary products. For example, a camera system producer introducing a new camera body that will only work with its own line of lenses has technologically tied its lenses with its camera body. Such a dependency between products may be a necessity of engineering a better product[2] or it may represent the producer's attempt to artificially close the camera system from competition. When a technological tie artificially closes an inherently open system, the tying behavior may be subject to antitrust scrutiny. While claims of technological tying have been before the courts since the early 1970s, little has been said regarding a firm's incentives to technologically tie, the effects of a technological tie on the firm's decision to innovate, and ultimately how consumers are affected by such tying behavior.

This paper addresses each of these issues for a class of tying situations in which the tying firm relies on the tied product market to serve as a metering device. Specifically, a simple two-component system consisting of a foremarket and an aftermarket good is presented. Only owners of the foremarket product consume the aftermarket good. The paper considers the case where the quantity of the aftermarket good can vary as opposed to earlier studies where both products are consumed in fixed proportions. Thus, the model is better suited to an aftermarket good like zip discs and a foremarket good of a zip drive; the number of zip discs can vary. The model assumes that a monopolist produces the foremarket product and that the quality of the system is a function of investment in research and development. Further, it is assumed that all R&D occurs and investments are incurred at the foremarket development stage. In addition to the fixed cost of developing a system of a given quality, there is also an additional fixed cost associated with tying technologically.

The model shows that if the fixed cost of engineering the technological tie is sufficiently small relative to the probability of entry into the aftermarket by a competing firm, the monopolist has an incentive to technologically tie. The tie permits the monopolist to use the tied aftermarket purchases to price discriminate among different

[2] For example, Nikon's 50 and 90 series cameras offer 3D Advanced Matrix Metering with Distance Data Detection only when one of Nikon's own D-type lenses are mounted on the camera body. This dependency on D-type lenses is a technical necessity, however, because the D-type lenses include an "encoder" that relays camera-to-subject distance information from the lens to the camera's microcomputer.

consumer types. The model also finds that investment in system development, and therefore overall system quality, is greatest when the monopolist ties technologically (regardless of whether or not it is optimal for the profit-maximizing monopolist to do so). Finally, the paper shows that social welfare in general and consumer surplus in particular may be improved through technological tying, even in cases where the monopolist would not restrict output of the tying product in the absence of the tie.

While this paper relies on a fictitious camera/lenses system example, the model presented in this paper resembles many high technology systems markets of the real world. One example is the 8-bit Nintendo Entertainment System (NES).

When Nintendo introduced the NES to the U.S. in 1986, the system's hardware component included the 10NES security chip whose only function was to prevent non-Nintendo authorized games from being used with the Nintendo hardware.[3] This security chip was a technological tie that permitted Nintendo to generated additional system revenue through sales of the Nintendo System's software component.

Understanding why a firm may choose to tie technologically and under what circumstances consumers may benefit from such behavior is important to the courts treatment of tying cases in general and to cases of alleged technological tying in particular. This is especially true in light of the district and circuit court rulings in the recent Microsoft trial in which the software giant was accused of technologically tying its browser (Internet Explorer) to the Windows operating system. The finding of liability by the District Court and subsequent remand of the verdict by the Appeals Court is representative of both the court's desire to address issues of technological tying and at the same time, the uncertainty over how to do so.

The courts are faced with a difficult balancing act regarding technological tying claims. On the one hand they are reluctant to become enmeshed "in a technical inquiry into the justifiability of product innovations"[4]. On the other hand, the courts do not want technological tying to become a safe haven for otherwise illegal tying practices.

In the recent District Court case against Microsoft, Judge Penfield Jackson was willing to enter into such a technical inquiry in an attempt to answer the seemingly basic

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[3] Atari Games Corp. v. Nintendo of America Inc., 975 F.2d 832
[4] Response of Carolina v. Leasco Response, 537 F.2d 1307, 1330.

question: In the absence of the technological tie, would consumers have been able to create the same bundle on their own?

The reasonableness of this question is hardly objectionable. Yet, it raises the question: In the absence of the technological tie, would consumers be combining the same components to form the bundle? In the present model they would not. A unique feature of technological tying is that the decision to tie must occur early on at the design stage. Therefore, there is an inescapable connection between the firm's decision to tie technologically and its decision of how much to invest in system development. If a firm designing a new camera system can earn greater profits by designing the camera so that it will work only with its own lenses, the firm will invest more in R&D and create a better camera system. What is the effect on consumers when forcing them to buy lenses from a monopolist allows them to take better pictures?

Two features that distinguish this model of technological tying from the existing literature on contractual tying are the link between the (technological) tying behavior and the level of investment in system quality, and the uncertainty of entry into the tied goods market (aftermarket) in the absence of a (technological) tie. The link between investment and tying is appropriately omitted from traditional models of contractual tying because contractual tying is typically considered a marketing decision and as such occurs ex post of system development. In this paper, technological tying can be used as a tool to prevent aftermarket entrants from free-riding on the investments of the system developer. As this paper shows, preventing this free-riding behavior through a technological tie may benefit consumers. While free-riding on investment arguments are not new to antitrust, the economics literature on the subject is limited.[5]

II. A Model of Technological Tying

Consider a two-component system consisting of a foremarket product and an aftermarket good where the quantity of the aftermarket good can vary. Thus, our camera system may consist of a camera body (the foremarket good) and one or more lenses (the aftermarket good). Alternatively, one could consider a home entertainment system: the foremarket good is the system hardware and the aftermarket goods are game cartridges, or a satellite television system: the satellite represents the foremarket good and the satellite stations are the aftermarket products. To simplify the analysis, the model assumes there are only two quantities of the aftermarket good consumers can choose from.

Consumer Behavior:

In this framework, consumers decide between two alternative systems: A basic system consisting of the foremarket product and the low quantity of the aftermarket good, or an extended system which consists of the same foremarket good but the higher quantity of the aftermarket product.[6]

Consumers are indexed by their values per unit of quality, θ, for the basic system. Assume θ has cumulative distribution F, with continuous density f, and that the distribution has support $[0, \bar{\theta}\,]$. The additional value, per unit of system quality, that a type θ consumer receives from consuming the extended system, rather than the basic system, is given by the function $\alpha(\theta)$. A consumer of type θ is represented by the value function:

$$V_\theta(\mathbf{P},s) = \text{Max}\left\{ \theta\, s - P_B\, ,\ \theta\, s + \alpha(\theta)\, s - (P_B + P_A) \right\}.$$

The variable, s, represents the quality, or state of technology, of the system; P_B is the cost of the basic system; and P_A is the additional cost of the extended system (over and above the cost of the basic system). The transformation function, $\alpha(\theta)$, is increasing, convex, and zero valued at θ equal to zero; $\alpha'(\theta) > 0$, $\alpha''(\theta) > 0$, and $\alpha(0) = 0$. The second and third of these assumptions on $\alpha(\theta)$ are sufficient to guarantee that, absent the threat of entry into its aftermarket, the system developer would find it optimal to offer both the basic system and the extended system.[7]

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[5] See Salop (1993) for a survey of the legal and academic literature on "free-riding".
[6] Quantity and quality are somewhat interchangeable in the context of differentiating the aftermarket choices available to consumers. For example the basic camera system could consist of a camera body and a 28-50 mm lens while the extended camera system could consist of either a camera body and a single 28-200mm zoom lens, or a camera body and two lenses; a 28-50 mm and a 50-200 mm. I have chosen to refer to this distinction in terms of quantity in order to avoid confusing this measure with a key variable of the model, system quality, which is an endogenous measure for the state of technology.
[7] Intuitively, the conditions imply that if the system producer was to set the basic system price and the price of the additional aftermarket good (contained in the extended system) independently at their monopoly levels, some consumers of the basic system would choose not to consume the additional aftermarket

It is worth noting that the assumption that all consumers share the same transformation function, $\alpha(\theta)$, restricts the set of possible outcomes and, thus, detracts from the generality of the model. Retuning to our earlier camera/lens discussion, for example, it is possible to imagine a set of consumers who value the camera system only for zoom photography: For this set of customers, as the price of zoom lenses (the add-on product) is increased, beyond their values for the lenses, it is likely that these customers will chose to abandon the camera system altogether rather than consume the basic camera system that lacks zoom capabilities. Under my assumption, and increase in the price of the zoom lens (ceteris paribus) could only cause customers to switch to buying the camera without the zoom lens.

Despite the loss of generality associated with the assumptions on the transformation function, $\alpha(\theta)$ (most notably that all consumers share the same transformation function) the assumptions provide a simple framework that allows for second degree price discrimination to exist in the model and the model remains representative of many modern systems platform markets.

According to this specification, for a given level of technology, s, consumers who have higher valuations for the basic system have more than proportionally higher valuations for the extended system. In this sense, high value users are more constrained by the limitations of the basic system than lower value users.

Producer Behavior:

On the producer side, consider a monopolist who develops the two-component system and assume developing a system is costly, requiring a fixed expenditure for research and development. The research and the associated investment required to develop the technology are incurred at the foremarket development stage. That is to say that the monopolist cannot develop the technology for the foremarket product without also developing the complementary technology of the aftermarket good. Because the basic system and the extended system differ only in the quantity of the aftermarket good, the state of technology incorporated in both systems is the same. Therefore, the fixed

quantity. See Gaynor (2001), "Non-Exclusionary Bundling of Aftermarket Products" for an explanation of these assumptions. That these assumptions assure that both systems would be offered in the absence of a threat of entry is also shown by Proposition I of the current paper.

cost of developing the basic system and the extended system is the same. Assume this fixed cost of development, ϕ, is an increasing and convex function of the quality (or technology), s, of the system; $\phi'(s) > 0$, $\phi''(s) > 0$. Once developed, the model assumes that the systems components are produced without cost.[8]

In addition to the cost of developing the system, the monopolist may choose to incur an additional fixed cost, z, to design the system so that the foremarket good only works with the monopolist's own aftermarket products. This technological tie artificially closes the system preventing entry into the aftermarket. By leveraging the monopoly power in the foremarket to maintain its monopoly status in the aftermarket, the monopolist is able to price discriminate among consumers according to their preferences for high versus low quantity aftermarket consumption.

Absent the technological tie-in, entry will occur into the aftermarket with probability $(1-\lambda)$. If a competitor enters the aftermarket, the rivals' aftermarket products are substitutes and competition in the aftermarket is Bertrand.[9] In this environment, the monopolist is unable to make profits on aftermarket purchases (and therefore cannot price discriminate) if entry does occur. The model assumes that the monopolist is unable to change his prices once entry has (or has not) occurred. This price commitment may be due to reputation considerations or because of the timing of consumers' purchases – aftermarket entry may not occur until consumers have already purchased the foremarket component from the monopolist.

Given this environment, the monopolist chooses among three optimal strategy candidates when deciding how to design and market the system. The monopolist may: (1) technologically tie, (2) risk separation, or (3) be forced to bundle.[10] The monopolist's strategy space is divided into three regions, which correspond to these three alternatives,

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[8] Alternatively, one could assume that production of each component entails some positive but constant marginal cost *per unit of quality* and reinterpret prices as being net of these marginal costs. An alternative cost assumption is considered at the end of this section.

[9] Thus, in this model only a single entrant is required to drive aftermarket prices to their competitive levels.

[10] Strictly speaking, these three alternatives are not 'strategies'. The monopolist has a continuum of strategies each consisting of prices, a level of system quality, and a choice of the binary tying variable. However, the monopolist's strategy space can be divided into these three regions according to the outcomes they produce. Within each region there is a unique optimal strategy (or local maximum). It is these three 'regional' optimum strategies that that I refer to as the monopolist's strategies in this paper.

and the optimal strategy is obtained by comparing the local maxima of the different regions.

Before proceeding, it is helpful to re-write the probability that aftermarket entry will not occur, λ, to be a function of the binary technology tying variable, z, and the parameter, λ, such that:

$$\lambda(z, \lambda) = 1 \text{ and}$$
$$\lambda(0, \lambda) = \lambda.$$

Therefore, if the system developer incurs the fixed cost of the technological tie, z, he will monopolize the aftermarket with probability one. However, if the developer chooses not to invest in the technological tie, aftermarket entry will occur with probability 1-λ.

Technological Tying Problem

For a given probability of entry into the aftermarket, the monopolist may not want to risk losing aftermarket profits and decide to incur the additional fixed cost, z, of the technological tie. The monopolist's technological tie-in strategy is denoted by the subscript, T. The system developer's optimization problem associated with the technological tying region is:

$$\text{Max } \pi_T = P_B D_B + \lambda P_A D_A - \phi(s) - z$$
$$\text{s.t.} \quad D_i = 1\text{-}F(\theta_i),\ P_B = \theta_B\, s,\ P_A = \alpha(\theta_A)\, s$$
$$\theta_A > \theta_B$$
$$\lambda(f, \lambda) = 1 \text{ and } z = z.$$

D_B is the demand for basic system components – this includes both consumers of the basic system and consumers of the extended system (i.e. every consumer of the extended system is also a consumer of the basic system). D_A is the demand for extended systems and P_A is the additional cost required to make the extended system (the cost of the additional aftermarket quantity). Because θ_B is the marginal consumer of the basic system, the demand for the basic system, D_B, is equal to 1-F(θ_B) and the price of the basic system, P_B, is θ_B s (the marginal consumer's value per unit of quality for the basic system times the quality of the basic system). Similarly, the demand for the extended system and the additional cost of the extended system can be expressed in terms of the marginal consumer of the extended system, θ_A: $D_A = 1\text{-}F(\theta_A)$, $P_A = \alpha(\theta_A)$ s.

Substituting the probability constraint, the monopolist's tying problem reduces to:

$$\text{Max } \pi_T = P_B D_B + P_A D_A - \phi(s) - z$$
$$\text{s.t.} \quad D_i = 1\text{-}F(\theta_i),\ P_B = \theta_B s,\ P_A = \alpha(\theta_A) s$$
$$\theta_A > \theta_B$$

The price of the basic system, P_B, the price for the extended system, $P_B + P_A$, and the level of system quality (R&D) that are optimal under the technological tying strategy solve the following three first order conditions.[11]

$$(1) \qquad \frac{d\pi_T}{dP_B} = 1 - F(\theta_B^*) - \theta_B^* f(\theta_B^*) = 0$$

$$(2) \qquad \frac{d\pi_T}{dP_A} = 1 - F(\theta_A^*) - \left\{\frac{\alpha(\theta_A^*)}{\alpha'(\theta_A^*)}\right\} f(\theta_A^*) = 0$$

$$(3) \qquad \frac{d\pi_T}{ds} = \theta_B^{*2} f(\theta_B^*) + \left\{\frac{\alpha(\theta_A^*)^2}{\alpha'(\theta_A^*)}\right\} f(\theta_A^*) - \phi'(s^*) = 0$$

Using equations (1) and (2) equation (3) can be rewritten as:

$$(3.a) \qquad \frac{d\pi_T}{ds} = \theta_B^* [1 - F(\theta_B^*)] + \alpha(\theta_A^*) [1 - F(\theta_B^*)] - \phi'(s^*)$$

To guarantee the existence of a unique solution to this problem, assume that equations (1) and (2) are decreasing for all values in the support of θ. These conditions are equivalent to the standard hazard rate assumptions requiring that marginal revenue curves are downward sloping.

Having solved for the technological tying optimization problem it is possible to show the monopolist's preference for separation versus bundling in the absence of the threat of entry.

[11] Note that in solving for this local optimum, I assume that the last constraint, $\theta_A > \theta_B$, is satisfied, and then proof that this must be the case in Proposition 1.

Proposition 1: *In the absence of entry into its aftermarket, the monopolist will earn more system gross profits*[12] *by selling both a basic and an extended system rather than by only selling the extended system for any given state of technology.*

Proof: To prove that it is optimal to sell both systems, it is sufficient to show that the first order condition given by equation (1) evaluated at the marginal consumer of the extended system is negative:

$$1- F(\theta_A^*) - \theta_A^* f(\theta_A^*) < 0 .$$

Using equation (2) this condition can be re-expressed as:

$$\left\{\left(\alpha(\theta_A^*) / \alpha'(\theta_A^*)\right) - \theta_A^*\right\} < 0.$$

Given the model's assumptions: $\alpha(\underline{\theta}) = \underline{\theta} = 0$, and $\alpha(\theta)$ convex, this condition for separation is satisfied. It is because proposition 1 holds that this paper considers the choice of the monopolist to bundle to be forced – the threat of entry forces the bundling.

<u>*Risking Separation Problem*</u>

Alternatively, the threat of entry may not be sufficiently large to warrant the fixed cost of eliminating the threat with the tie. In this case the monopolist's strategy may be to continue offering both a basic system and an extended system and hope that entry into the aftermarket does not occur. Such strategies are referred to as risking separation strategies, denoted by subscript R, because if entry does occur, the monopolist collects profits only on basic system sales since the additional services (or additional quantity of the aftermarket product), that when added to the basic system comprise the extended system, are now available for free (or at a price equal to the constant marginal cost per unit of quality if marginal costs are non-zero).[13] The optimization problem associated with the *risking separation* region of the monopolist's strategy space is:

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[12] Revenues minus variable costs.

[13] One may ask: If the basic system is comprised of a foremarket and aftermarket product, and the price of the aftermarket good is zero when entry occurs (or equal to the constant MC if non-zero), why don't basic system profits fall as well? The answer lies in the functional relationship between the products. Because the aftermarket good has value only when consumed with the foremarket good, and because the minimal system is the basic system, one can think of charging the full basic system price for the foremarket good and giving the low quantity of the aftermarket good away for free. This is a very common occurrence in systems markets: a Zip drive ships with two Zip disks, Computer entertainment systems typically ship with one or two free games, most low to mid-priced SLR camera bodies ship with a starter lens.

$$\text{Max } \pi_R = P_B D_B + \lambda P_A D_A - \phi(s) - z$$

$$\text{s.t.} \quad D_i = 1\text{-}F(\theta_i),\ P_B = \theta_B\, s,\ P_A = \alpha(\theta_A)\, s$$

$$\theta_A > \theta_B$$

$$\lambda(0, \lambda) = \lambda, \text{ and } z = 0.$$

Substituting the last two constraints, the risking separation problem reduces to:

$$\text{Max } \pi_R = P_B D_B + \lambda P_A D_A - \phi(s)$$

$$\text{s.t.} \quad D_i = 1\text{-}F(\theta_i),\ P_B = \theta_B\, s,\ P_A = \alpha(\theta_A)\, s$$

$$\theta_A > \theta_B$$

The first order conditions associated with the risking separation optimization problem are:

$$(4) \qquad \frac{d\pi_R}{dP_B} = 1 - F(\tilde{\theta}_B) - \tilde{\theta}_B\, f(\tilde{\theta}_B) = 0$$

$$(5) \qquad \frac{d\pi_R}{dP_A} = \lambda \left\{ 1 - F(\tilde{\theta}_A) - \left[\frac{\alpha(\tilde{\theta}_A)}{\alpha'(\tilde{\theta}_A)} \right] f(\tilde{\theta}_A) \right\} = 0$$

$$(6) \ \frac{d\pi_R}{ds} = \tilde{\theta}_B^2\, f(\tilde{\theta}_B) + \lambda \left\{ \frac{\alpha(\tilde{\theta}_A)^2}{\alpha'(\tilde{\theta}_A)} \right\} f(\tilde{\theta}_A) - \phi'(\tilde{s}) = 0$$

Using first order equations (4) and (5), equation (6) can be rewritten as:

(6.a)

$$\frac{d\pi_R}{ds} = \left\{ \tilde{\theta}_B\, [1\text{-}F(\tilde{\theta}_B)] + \alpha(\tilde{\theta}_A)\, [1\text{-}F(\tilde{\theta}_A)] \right\} - (1\text{-}\lambda) \left\{ \alpha(\tilde{\theta}_A)\, [1\text{-}F(\tilde{\theta}_A)] \right\} - \phi'(\tilde{s})$$

Forced Bundling Problem

Finally, if the cost of engineering the technological tie is too large to make the tying strategy optimal, but the probability of entry is too large to follow the optimal risk separation strategy, the monopolist may decide to offer only the extended system. This is referred to as a forced bundling strategy, denoted F, because rather than selling two systems which differ only in the quantity of the aftermarket product, the monopolist sells only one system; the extended system. According to proposition 1, this bundling is 'forced' because without the threat of entry, the monopolist's optimal strategy would be to sell two separate systems. The optimization problem associated with the *forced bundling* region of the monopolist's strategy space is:

$$\text{Max } \pi_F = P_B D_B + \lambda P_A D_A - \phi(s) - z$$

$$\text{s.t.} \quad \theta_{\mathbf{B}} = \theta_A = \theta_{AB}$$

$$P_B = P_{AB} = s[\theta_{AB} + \alpha(\theta_{AB})]$$

$$P_A = 0$$

$$\lambda(0, \lambda) = \lambda, \text{ and } z = 0.$$

The first constraint indicates that there is only one marginal consumer and therefore a single consumer type; extended system consumers. The second and third constraints show that the marginal consumer is charged a basic system price equal his value for the extended system and then given the extended system features free of charge. Therefore, in the forced bundling region of the monopolist's strategy space, the monopolist is indifferent to aftermarket entry.

Substituting constraints the monopolist's forced bundling optimization problem becomes:

$$\text{Max } \pi_F = P_{AB} D_{AB} - \phi(s)$$

$$\text{s.t.} \quad D_{AB} = 1\text{-}F(\theta_{AB}),\ P_{AB} = s[\theta_{AB} + \alpha(\theta_{AB})].$$

P_{AB} and D_{AB} represent the price and demand for the extended system when only that one system is available to consumers.

Because the forced bundling problem involves only one system, there are only two first order conditions associated with the forced bundling strategy:

$$(7) \qquad \frac{d\pi_F}{dP_{AB}} = 1 - F(\hat{\theta}_{AB}) - \left\{\frac{\hat{\theta}_{AB} + \alpha(\hat{\theta}_{AB})}{1 + \alpha'(\hat{\theta}_{AB})}\right\} f(\hat{\theta}_{AB}) = 0$$

$$(8) \qquad \frac{d\pi_F}{ds} = \left\{\frac{\left[\hat{\theta}_{AB} + \alpha(\hat{\theta}_{AB})\right]^2}{1 + \alpha'(\hat{\theta}_{AB})}\right\} f(\hat{\theta}_{AB}) - \phi'(\hat{s}) = 0$$

Substituting equation (7) into (8) yields,

$$\text{(8.a)} \quad \frac{d\pi_F}{ds} = \left[\hat{\theta}_{AB} + \alpha(\hat{\theta}_{AB})\right]\left[1 - F(\hat{\theta}_{AB})\right] - \phi'(\hat{s}).$$

<u>*Comparing Local Maxima*</u>

Having solved for the monopolist's three optimal strategy candidates, it is now possible to make comparisons among the alternative outcomes as well as explore the conditions in which the monopolist will prefer the tying strategy to the others.

Proposition 2: *If ex post entry into the aftermarket does not occur, the consumers' choices of which system to consume is unaffected by whether the monopolist technologically tied or chose to risk separate system sales. If, however, entry does occur, the number of extended systems sold under the risk separation strategy is equal to the demand for basic systems under the tying strategy.*

Proof: Comparing first order condition (1) with (4) and first order condition (2) with (5), it is clear that for non-zero λ, both strategies involve the same marginal consumers: $\theta^*_B = \tilde{\theta}_B$ and $\theta^*_A = \tilde{\theta}_A$. Therefore, if entry does not occur demand for the two systems is the same under the optimal risk separation strategy as under the optimal technological tying strategy. If ex post entry does occur, competition in the aftermarket drives the price of the aftermarket good to zero when marginal costs of production are zero (or to the non-zero constant marginal cost of production for the given state of technology when marginal costs are non-zero). Thus every consumer of the basic system will also receive the aftermarket features.[14]

Proposition 3: *R&D investment and system quality are always higher from following the technological tying strategy candidate, even in situations where tying technologically is not the monopolists profit maximizing strategy.*

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[14] If marginal costs are constant and non-zero $\alpha(0)=0$ & $\alpha'(\theta) > 0$ guarantee that all consumers of the basic system will also purchase the extended system features if entry occurs: Again, reinterpreting θ as consumer value per unit quality minus constant margin cost per unit of quality, these assumptions imply that every consumer's value per unit of quality of the extended system is no less than the marginal cost per unit of quality of the extended system. The assumption that the marginal consumer's value for a unit of add-on quality exceeds the marginal cost of producing a unit of add-on quality simplifies the welfare calculations that follow at the end of the section.

Because the cost of technological tying is represented by a fixed cost in this model, system quality is an increasing function of gross profits,[15] but not necessarily profits. Revenues are higher with technological tying than from following a risk separation strategy because the tie protects the monopolist from aftermarket entry, and are higher than forced bundling revenues by definition.[16]

Proof of proposition 3 requires: (a) that quality is greater when the aftermarket is technologically tied than when the monopolist risks separation, and (b) that system quality following a technological tie is greater than when the monopolist is forced to bundle.

(a) From Proposition 2, the marginal consumers associated with a technological tying strategy are the same marginal consumers considered in the risk separation strategy. This permits the first order condition for system quality, associated with the risk separation strategy, (6.a), to be rewritten as:

$$\frac{d\pi_R}{ds} = \left\{ \theta_B^* [1-F(\theta_B^*)] + \alpha(\theta_A^*) [1-F(\theta_A^*)] \right\} - (1-\lambda)\left\{ \alpha(\theta_A^*) [1-F(\theta_A^*)] \right\} - \phi'(\tilde{s}).$$

Substituting equation (3.a) into the expression above yields the following:

$$\text{(9)} \qquad \phi'(s^*) - (1-\lambda)\left\{ \alpha(\theta_A^*) [1-F(\theta_A^*)] \right\} = \phi'(\tilde{s})$$

Equation (9) implies $\phi'(s^*) > \phi'(\tilde{s})$. Because the investment function, ϕ, is convex in quality the above condition implies that system quality associated with the technological tie, s^*, is higher than system quality that results when the monopolist risks separation.

(b) Following Proposition 1, in the absence of entry the monopolist will earn higher revenues by offering separate systems, rather than a single system for any state of technology, s. This implies that revenues per unit of quality are greater with separate system sales. Or that:

In Section IV we consider an alternative assumption in which production entails constant marginal costs per unit of production and is independent of the units quality. As Section IV will show, this alternative assumption introduces an additional efficiency associated with technological tying.

[15] Revenue or revenue minus variable cost (contribution margin) for non-zero constant marginal costs per unit of quality.

[16] Otherwise, bundling is not forced (violating Proposition 1).

$$(10) \qquad \theta_B^* [1 - F(\theta_B^*)] + \alpha(\theta_A^*) [1 - F(\theta_B^*)] \; > \; \left[\hat{\theta}_{AB} + \alpha(\hat{\theta}_{AB})\right] \left[1 - F(\hat{\theta}_{AB})\right]$$

Substituting equations (3.a) and (8.a) into the left-hand and right-hand side of (10), respectively, yields the following condition;

$$\phi'(s^*) \; > \; \phi'(\hat{s})$$

Again, because the investment function, ϕ, is convex, it follows that technology is greater when the monopolist ties than when the monopolist is forced to sell only the 'bundled' extended system: $s^* > \hat{s}$.

While propositions 1-3 provide useful insights into the effects of the monopolist's alternative strategies, they say nothing about how the monopolist chooses between the three alternative strategies (i.e. which of the three local maxima is the global optimum). Specifically, how does the monopolist decide to technologically tie rather than risk separation or be forced to bundle?

Begin by considering the question: When is it more profitable for the monopolist to tie technologically rather than risk separation – when is $\pi_T^* > \tilde{\pi}_R$? This profit comparison can be expressed in terms of the optimal system qualities and the marginal consumers (which from proposition 2 are the same whether the monopolist ties or risks separation).

$$(s^*-\tilde{s})\left\{ \theta_B^*[1-F(\theta_B^*)] + \alpha(\theta_A^*)[1-F(\theta_A^*)] \right\} - \{\phi(s^*)-\phi(\tilde{s})\} + (1-\lambda)\left\{ \alpha(\theta_A^*)[1-F(\theta_A^*)] \right\} \tilde{s} > z$$

Using first order condition (3.a) this condition becomes:

$$(11) \qquad \left\{ (s^* -\tilde{s})\, \phi'(s^*) - [\phi(s^*)-\phi(\tilde{s})] \right\} + (1-\lambda)\left\{ \alpha(\theta_A^*) [1 - F(\theta_A^*)] \right\} \tilde{s} > z.$$

The first term in brackets in equation (11) represents the additional profits from greater provision of quality that the technological tie allows relative to risking separation. Notice that the convexity of the function $\phi(s)$ assures that this term in positive. The second expression on the left-hand side of equation (11) represents the expected loss in aftermarket profits from entry that are avoided with the technological tie. This term is clearly positive as well. Therefore, if the sum of these two positive terms, representing the benefits from tying technologically, exceeds the fixed cost, z, associated with engineering the tie, then the monopolist will choose technological tying over risking separation.

It is clear from equation (11) that the smaller is the fixed cost of a technological tie, the more likely it will be for the monopolist to choose to tie rather than risk separation. What is less clear is how changes in the probability of aftermarket entry affect the monopolist's choice of whether to tie or risk separation.

In determining how changes in the probability of entry affect the monopolist's tying choice it is helpful to first make a couple of observations. Because changes in the probability of entry, λ, will have no affect on tying profits, it is only necessary to consider how such changes affect profits when the monopolist risks separation (i.e. one only needs to consider first order conditions associated with the risk separation strategy). The second observation is that of the three first order conditions for the risk separation strategy (4)-(6), only equation (6) is a function of the parameter λ. Equation (6.a) implicitly defines system quality, $\tilde{s}$, as a function of λ. An expression showing how changes in λ affect (risk separation) system quality, $\tilde{s}$, is found by invoking the implicit function theorem.

$$(12) \qquad \frac{d\tilde{s}}{d\lambda} = \frac{\alpha(\theta_A^*)[1 - F(\theta_A^*)]}{\phi''(\tilde{s})}.$$

To determine how profits associated with the risk separation strategy change in response to changes in the probability λ, take the derivative of risk separation profits with respect to the parameter λ (noting that system quality is a function of λ).

(13)

$$\frac{d\pi_R}{d\lambda} = \tilde{s}\,\alpha(\tilde{\theta}_A)\,[1-F(\tilde{\theta}_A)] + \frac{d\tilde{s}}{d\lambda}\left\{\tilde{\theta}_B\,[1-F(\tilde{\theta}_B)] + \lambda\,\alpha(\tilde{\theta}_A)\,[1-F(\tilde{\theta}_A)]\right\} - \frac{d\tilde{s}}{d\lambda}\,\phi'(\tilde{s})$$

Using equation (12) and equation (6.a) to simplify equation (13) yields:

$$(14) \qquad \frac{d\pi_R}{d\lambda} = \tilde{s}\,\alpha(\tilde{\theta}_A)\,[1-F(\tilde{\theta}_A)]$$

Equation (14) is clearly positive. This implies that risk separation profits fall as the probability of aftermarket entry, 1-λ, rises. Therefore, it follows that the greater the threat of entry, the more likely the monopolist is to tie technologically rather than risk separation.

$$\frac{d\{\pi_T - \pi_R\}}{d(1-\lambda)} > 0.$$

Similarly, because forced bundling profits are not affected by changes in the probability of entry (although the decision of whether to bundle obviously is) the greater the threat of aftermarket entry, the more likely it is that the monopolist will choose to bundle rather than risk separation.

$$\frac{d\{\pi_F - \pi_R\}}{d(1-\lambda)} > 0$$

Finally, we consider when the monopolist will find it more profitable to tie technologically rather than adopt a forced bundling strategy: $\pi_T^* > \tilde{\pi}_F$. A comparison of profits reveals the following condition that must be satisfied if the monopolist is to prefer technological tying over forced bundling:

$$(15) \quad \hat{s}\left\{\phi'(s^*) - \phi'(\hat{s})\right\} + \left\{(s^* - \hat{s})\,\phi'(s^*) - [\phi(s^*) - \phi(\hat{s})]\right\} > z$$

The first term of this inequality represents the additional profits that the monopolist can earn on quality $\hat{s}$ systems from selling both systems. That is, taking the forced bundling level of technology ($\hat{s}$) as given, how much more profits could the monopolist earn if he could use aftermarket purchases to price discriminate? The second term in brackets represents the additional profits that the greater provision of system quality, associated with the technological tie, permits the monopolist to earn from selling a basic and an extended system. Convexity of the investment function, ϕ, is sufficient to guarantee that both of these terms are positive.

Welfare effects from tying technologically:

Most of Section III has focused on the monopolist's choice to tie technologically and the effect of such tying on the state of technology and on the monopolist's revenue. Section III concludes by considering the effects of technological tie-ins on consumers. Here, the focus is on the case where the monopolist's optimal strategy is to technologically tie and the most profitable alternative is to risk separation.

We focus on the more interesting case where the monopolist's next best strategy is to risk separation rather than to be forced to bundle because the existing literature on tie-in sales, whereby the tied good permits second degree price discrimination, clearly admits to the possibility that consumer surplus may be improved when tying is permitted if in the absence of the tie-in the monopolist serves fewer consumers.[17] In the current model, this is the case where the monopolist's best alternative to tying is the forced bundling strategy. Because the current model endogenizes the level of system technology (introducing a tying efficiency), it becomes even more likely that technological tying could improve consumer welfare in such cases.

Alternatively, in cases where prohibiting a tie-in does not result in any low value consumers being excluded from the market, the existing literature predicts that consumer surplus must be reduced by tying[18]. In this paper's model, this situation resembles cases in which the monopolist's best alternative to tying is to risk separation: the marginal consumers are identical in both cases. However, claims that welfare must fall if ties are permitted, in these cases, depend on the assumption that the monopolist's investment in technology and, accordingly, the state of technology are exogenous. When quality is a choice variable for the monopolist, as it is in this paper, a technological tie may increase consumer surplus even in cases where prohibiting the tie does not lead to exclusion of consumers from the market.

When the monopolist technologically ties, consumer surplus is determined by the following equation:

$$(16) \qquad CS_T = s^* \left\{ \int_0^{1-F(\theta_A^*)} \alpha[F^{-1}(1-q)]dq + \int_0^{1-F(\theta_B^*)} F^{-1}(1-q)dq - \phi'(s^*) \right\}$$

The second integral represents the total surplus associated with basic system sales. The first integral accounts for the additional total surplus that extended system aftermarket

[17] See McAfee (Damaged Goods) or Tirole (pg 147). Varian (1985) discusses an analogous result for 3[rd] degree price discrimination that extends earlier work by Schmalensee. Varian finds that under rather general conditions, increased output is a necessary condition for price discrimination to increase welfare – defined as consumer plus producer welfare by Varian.

[18] See Tirole (pg 147-148) for an explanation. Intuitively, in the existing literature, the potential welfare benefit to consumers from tying exist only if tying results in the producer selling basic systems to a low value group of consumers who would not have purchases the complete extended system if only extended systems were offered to the market.

purchases provide. Calculating the consumer surplus when the strategy is to risk separation is more difficult, because the consumers' realized surplus depends on whether or not entry occurs. When the monopolist risks separation, expected consumer surplus is given by:

$$(17) \qquad CS_R = \lambda\, \tilde{s} \left\{ \int_0^{1-F(\theta_A)} \alpha[F^{-1}(1-q)]dq + \int_0^{1-F(\theta_B)} F^{-1}(1-q)dq - \phi'(s^*) \right\} +$$

$$(1-\lambda)\, \tilde{s} \left\{ \int_0^{1-F(\theta_B)} \alpha[F^{-1}(1-q)]dq + \int_0^{1-F(\theta_B)} F^{-1}(1-q)dq - \tilde{\theta}_B\, [1-F(\tilde{\theta}_B)] \right\}$$

Equation (17)can be simplified slightly yielding equation (18).

$$(18) \qquad CS_R = \tilde{s} \left\{ \int_0^{1-F(\theta_A)} \alpha[F^{-1}(1-q)]dq + \int_0^{1-F(\theta_B)} F^{-1}(1-q)dq - \phi'(\tilde{s}) \right\} + \tilde{s}\,(1-\lambda) \int_{1-F(\theta_A)}^{1-F(\theta_b)} \alpha[F^{-1}(1-q)]dq$$

Using equations (16) and (18), consumer surplus from technological tying exceeds consumer surplus from risking separation when the following holds:

(19)

$$(s^* - \tilde{s}) \left\{ \int_0^{1-F(\theta_A)} \alpha[F^{-1}(1-q)]dq + \int_0^{1-F(\theta_B)} F^{-1}(1-q)dq - \phi'(s^*) \right\} > \tilde{s}\,(1-\lambda) \left\{ \int_{1-F(\theta_A)}^{1-F(\theta_b)} \alpha[F^{-1}(1-q)]dq + \alpha(\tilde{\theta}_A)[1-F(\tilde{\theta}_A)] \right\}.$$

Determining the general conditions under which technological tying can improve consumers' welfare without changing the quantity of systems demanded is complicated and beyond the scope of the current paper. One complicating factor is that, when satisfied, equation (19) guarantees that consumers are better off if the monopolist chooses to tie technological rather than risk separation. However, in addition to equation (19), it is also necessary to show: (a) that the monopolist's optimal strategy is to tie technologically (i.e. inequality (11) must hold) and (b) if tying is prohibited the monopolist's best alternative is to risk separation (a condition similar to (11) must hold).

However, to disprove the claim that tying only improves welfare when it increases the number of customers served (i.e. if prohibiting tying leads to forced bundling), it is sufficient to provide an example to the contrary.

Example: Let consumers value for basic systems be distributed uniformly on the unit interval; $\theta \sim [0\ 1]$. Assume that both the transformation function, $\alpha(\theta)$, and the technology function, $\phi(s)$, are constant convexity functions of the form: $\alpha(\theta) = d\theta^2$ and $\phi(s) = bs + cs^2$.

Given this specification of the model, there exist parameterizations such that the profit-maximizing monopolist's optimal strategy is to technologically tie and his next best strategy is to risk separation, and at the same time, consumers' welfare is higher with the tie. One such parameterization is summarized in the table below.

Parameters		Profits		Consumer Surplus	
λ	0.90	Tech. tying	0.052102		
z	0.02	Risk separation	0.046944	CS_T	0.498085
b	0.30	Forced bundling	0.046212	CS_R	0.433032
c	0.01	$\%\Delta$ (π_T vs. π_R)	11%	$\%\Delta$ (CS_T vs. CS_R)	15%
d	0.70	$\%\Delta$ (π_R vs. π_F)	2%		

Table 1.

Hence, it is possible for consumers to benefit from a technological tie even in situations where if tying is prohibited the monopolist serves the same group of consumers.

IV. <u>Alternative Cost Structure</u>

The model developed in the previous section assumed that the marginal costs of production per unit of quality were constant or zero. That is to say, given some state of technology, the model assumed that the marginal cost of producing a basic system or an extended system was constant, but that these constant marginal production costs were increasing in the level of technology, or quality, incorporated in the systems.

While the constant marginal cost per unit of quality is likely to be appropriate in many situations, in other cases, particularly in high technology industries, it is often more appropriate to assume that the marginal costs of producing the foremarket and aftermarket products are constant but independent of the level of technology incorporated in the product: That the only costs associated with quality are fixed.

Software products markets or markets for programmable devices are candidates for this alternative cost assumption. For example, the marginal cost of producing a software title is often little more than the cost of the software distribution medium (CD or bandwidth). While the fixed cost of creating a superior word processor is increasing in quality (or technology), the marginal costs of producing a good word processor versus a bad word processor are identical (assuming either could fit on the same number of CDs). Similarly, between the first Gulf War and the second Gulf War, Raytheon claims to have made significant improvements to its Patriot Missile System. Many of the improvements are software improvements that entailed significant fixed programming costs but likely had a negligible affect on the marginal cost of producing a Patriot System.[19]

Changing the original model to reflect the alternative marginal cost assumption produces the following first order conditions associated with technological tying

$$(20) \qquad \frac{d\pi_T}{dP_B} = 1 - F(\theta_B^*) - \theta_B^* f(\theta_B^*) + \frac{C_B}{s^*} f(\theta_B^*) = 0$$

$$(21) \qquad \frac{d\pi_T}{dP_A} = 1 - F(\theta_A^*) - \left\{\frac{\alpha(\theta_A^*)}{\alpha'(\theta_A^*)}\right\} f(\theta_A^*) + \frac{C_A}{\alpha(\theta_A^*)\, s^*} f(\theta_A^*) = 0$$

$$(22) \qquad \frac{d\pi_T}{ds} = \theta_B^{*2} f(\theta_B^*) + \left\{\frac{\alpha(\theta_A^*)^2}{\alpha'(\theta_A^*)}\right\} f(\theta_A^*) - \phi'(s^*) = 0$$

where C_A and C_B are the constant marginal costs of producing a system components. Similarly, the first order conditions associated with risking separation strategies become

$$(23) \qquad \frac{d\pi_R}{dP_B} = 1 - F(\tilde{\theta}_B) - \tilde{\theta}_B f(\tilde{\theta}_B) + \frac{C_B}{\tilde{s}} f(\tilde{\theta}_B) = 0$$

$$(24) \qquad \frac{d\pi_R}{dP_A} = \lambda \left\{ 1 - F(\tilde{\theta}_A) - \left[\frac{\alpha(\tilde{\theta}_A)}{\alpha'(\tilde{\theta}_A)}\right] f(\tilde{\theta}_A) + \frac{C_B}{\alpha(\tilde{\theta}_A)\, \tilde{s}} f(\tilde{\theta}_B) \right\} = 0$$

$$(25) \qquad \frac{d\pi_R}{ds} = \tilde{\theta}_B^2 f(\tilde{\theta}_B) + \lambda \left\{\frac{\alpha(\tilde{\theta}_A)^2}{\alpha'(\tilde{\theta}_A)}\right\} f(\tilde{\theta}_A) - \phi'(\tilde{s}) = 0.$$

[19] In reality, the Patriot System's improvements included hardware as well as software improvements. Thus, to the extent that some of the software improvements may have required complementary hardware improvements, it is likely that some of the Patriots software improvements resulted in higher marginal costs of producing a system.

Equations (22) and (25) are identical to their associated first order conditions from the original model; equations (3.a) and (6.a) respectively.[20] Following the proof of Proposition 3, $\phi'(s^*) > \phi'(\tilde{s})$ and the convexity of the investment function, ϕ, implies that system quality associated with the technological tie, s^*, is higher than system quality that results when the monopolist risks separation. Following similar logic, it is straightforward to show that technology is higher when the monopolist ties than when the monopolist is forced to sell only the 'bundled' extended system: $s^* > \hat{s}$. Thus, ***Proposition 3*** remains valid under this alternative cost structure.

However, ***Proposition 2*** does not hold under this alternative cost structure. When the marginal cost of producing a basic or extended system is constant and independent of the level of quality built into the system, there is an additional efficiency associated with technological tying in the model that results in increased output of systems under technological tying relative to a risking separation strategy.

Proposition 4: *When marginal costs of system production are constant per unit of production and independent of the level of technology, more consumers will consume some system (either basic or extended) under a technological tying outcome than from a risking separation outcome. Furthermore, if ex post entry into the aftermarket does not occur, more consumers will purchase extended systems if the monopolist follows a technological tying strategy than would consume if the monopolist follows a risking separation strategy .*

Proof: Because $s^* > \hat{s}$ it follows that $\{C_B/s^*\} < \{C_B/\hat{s}\}$. Using equations (20) and (23) this condition yields

$$\theta_B^* - \left(\frac{1-F(\theta_B^*)}{f(\theta_B^*)}\right) < \tilde{\theta}_B - \left(\frac{1-F(\tilde{\theta}_B)}{f(\tilde{\theta}_B)}\right).$$

Which given the standard *hazard rate* assumptions of Section III, implies $\theta_B^* < \tilde{\theta}_B$. Thus, more consumers purchase the basic system components (either as a basic system or as

[20] In the original model, θ_B and θ_A defined a consumer's value per unit of quality of the basic system and the extended system (respectively), or as a consumer's value net of marginal cost per unit of quality if positive constant marginal costs per unit of quality are assumed. In the present model, because marginal

part of an extended system) when the monopolist ties technologically than when the monopolist followed a risk separation strategy, $D_B^* > \tilde{D}_B$.

Similarly, because $\{c_A/s^*\} < \{c_A/\hat{s}\}$ substitution using equations (21) and (24) yields the following relationship between θ_A^* and $\tilde{\theta}_A$;

$$\alpha(\theta_B^*) - \alpha'(\theta_B^*)\left(\frac{1-F(\theta_B^*)}{f(\theta_B^*)}\right) < \alpha(\tilde{\theta}_B) - \alpha'(\tilde{\theta}_B)\left(\frac{1-F(\tilde{\theta}_B)}{f(\tilde{\theta}_B)}\right).$$

Again, the hazard rate assumption discussed in Section III, implies that $\theta_A^* < \tilde{\theta}_A$ and that $D_A^* > \tilde{D}_A$.

Thus, in situations where it is more appropriate to model marginal costs of production as being constant per unit of system component produced but independent of the level of technology, it is even more likely that technological tying will benefit consumers than in the original model (where marginal costs are constant per unit of production and increasing in the level of technology). In addition to the innovation effect, identified in the original model, when marginal costs of production do not vary with the level of technology incorporated in the system, there is an additional efficiency of scale in the distribution of quality that is realized by bundling larger quantities of technology into a system.

V. <u>Conclusion</u>

The above model of aftermarket tying reveals an efficiency effect not found in other models of tying – technological tying increases innovation. While similar variable-proportion models illustrate how tying aftermarket purchases may facilitate second-degree price discrimination (or metering) by a primary product monopolist, the existing literature does not consider how the additional revenue from metering affects the monopolist's investment decisions. This paper focuses on the connection between a primary good monopolist's choice to tie technologically and its decision of how much to invest in system technology. Intuitively, the technological tie protects the seller from

cost is modeled explicitly, θ_B and θ_A are only interpreted as a consumer's value per unit of quality of the respective good.

aftermarket entry and therefore ensures that the seller internalizes the full effect of increased investment in technology on system profits.

Perhaps even more importantly, this increase in system quality afforded by the technological tie may benefit consumers more than anticompetitive effects hurt them. Therefore, while any analysis of tying policy necessarily involves other efficiency as well as anticompetitive effects, these results suggest that innovation efficiency should be an important consideration in cases involving technological ties.

Given its suggestive nature, this paper raises more questions than it answers. Future research should go beyond showing that the innovation efficiency associated with tying is potentially significant and characterize the conditions in which this effect is most likely to dominate. Despite its suggestive nature, however, an important conclusion from this paper remains: The analysis shows that when evaluating the welfare effects of tying one should consider innovation effects, as such efficiencies can be large enough that consumers benefit from a technological tie.

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Appendix: Technological Tying Example

Given $\alpha(\theta) = d\,\theta^2$ and $\phi(s) = b\,s + c\,s^2$, equation (19), the condition which guarantees that consumers are better off if the monopolist chooses to technological tie rather than risk separation, reduces to:

i) $\left[\frac{(1-\lambda)\,d}{139968\,c}\right][14364\,b + 896\,d - 2295 - 2128\,d\,\lambda] > 0.$

Equation (11), which must be satisfied in order for the monopolist to favor technological tying over risking separation, is:

ii) $\left[\frac{(1-\lambda)}{1458\,c}\right][27(4b-1)d - 8d^2(1+\lambda)] > z.$

Finally, the condition for the monopolist to prefer risking separation over forced bundling is derived. It is straightforward to show that $\pi_R > \pi_F$ iff $S_R > S_F$. Therefore, the monopolist will prefer to risk separation rather than be forced to bundle whenever $S_R - S_F > 0$. For the functional forms used in the example, this implies the following condition:

iii) $\left[\frac{8 - 8\sqrt{d^2+d+1} + d(12-8\sqrt{d^2+d+1}) + d^2(15-8\sqrt{d^2+d+1}) + 8d^3(-1+2\lambda)}{216\,d^2\,c}\right] > 0$

As table 1 indicates, conditions (i)-(iii) are simultaneously satisfied with the following parameterization of the model: $\{\lambda = 0.9, z = 0.02, b = 0.3, c = 0.01, d = 0.7\}$.