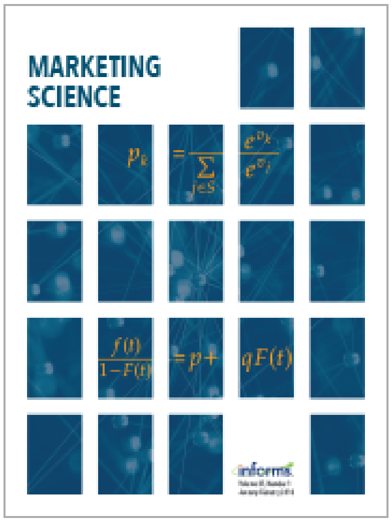

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Innovation and the Durable Goods Monopolist: The Optimality of Frequent New-Version Releases

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When an improvable durable good (such as packaged software) saturates the market, the seller could be tempted to release new versions too frequently, hurting her profit. A novel contractual device, which I term as a Free New Version Rights warranty (free NVR warranty), can help the seller overcome this temptation. In a two-period game-theoretic model involving a monopolist firm facing heterogeneous consumers, I derive conditions under which a rational monopolist can act suboptimally: She could face a commitment problem and offer the new version, even if doing so lowers her overall profit. Profit is hurt because when consumers expect a new version, (a) fewer consumers buy the initial version, and (b) the monopolist is forced to charge a lower price for the initial version. I show how the free NVR warranty, which requires the monopolist to offer consumers the right to receive the new version for free for a limited period, can solve her commitment problem. This is a new, surprising finding: By bundling new-version rights with the initial version, the monopolist at first appears to be denying herself future revenue. I derive conditions under which this apparently unprofitable action is optimal, which is my main contribution. When free NVR is offered, consumer surplus decreases and social surplus increases. This work extends prior literature on durable goods and the Coase conjecture to innovative durable goods with network externalities. The findings have important practical implications for firms selling new versions of innovative durable goods subject to network effects, as well as for their consumers.

Key words: high-tech marketing; game theory; innovation; marketing strategy; product development; product life cycles; product policy; signaling
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1. Introduction

When an improvable durable good reaches a high level of market penetration, at some point the firm looks for revenue mainly from selling improved versions of the good to the existing customer base, rather than revenue from new consumers. This is more so if the firm has a monopoly or near-monopoly position, because then it cannot expand its market share at the expense of competitors. (Some software vendors such as Microsoft, for Office and Windows, and Oracle, for database software, are in this position today.) In such situations, the company faces incentives to offer newer versions too frequently for its own good. This paper demonstrates analytically how even a rational monopoly firm selling a high-technology product could end up offering newer versions too frequently due to a commitment problem, and achieve suboptimal profitability. Next, this paper shows how a novel contractual warranty can effectively cure this problem. This cure is our main contribution.

The analytical model is motivated using packaged software products. The worldwide market for packaged software was estimated at $179 billion (2004) by International Data Corp. Large vendors such as Microsoft and Oracle have already achieved high levels of market penetration, with the result that a significant portion of their revenue now comes from new version releases (major upgrades) and maintenance. When selling a new version, their most significant competition is from prior versions that consumers are already using. New version release policy is therefore a critical component of such firms' marketing strategy, and has significant implications for their profitability.

A monopoly firm selling innovative durable goods subject to network effects must decide its new version release policy in order to maximize profits. If new versions are released too slowly, the firm clearly foregoes profits, and in the long run, the firm may lose market share to competing firms. However, executives driven by short-term financial goals could face incentives to release new versions too soon, which we show could also lead to lost profits, because the new version can compete with the existing version. Surprisingly, a firm could be fully aware of the profit consequences and yet offer new versions too soon and realize suboptimal profits because of a commitment problem (Coase 1972, Ellison and Fudenberg 2000). In a two-period setting, a monopolist may initially find it optimal to sell her good in the first period but not in the second period, but because of the Coasian commitment problem, she is later unable to commit to her optimal decision, and ends up selling the good in the second period at a lower price, because at the start of the second period (ignoring the first period), selling the good is profitable. This hurts her overall profitability over both periods. A similar commitment problem exists with respect to the release of new versions of an innovative good: after releasing the current version, the firm may be better off not releasing a new version in the second period, but sometimes becomes impatient to release the new version (for reasons such as meeting the next year's sales targets), and is unable to commit to the optimal release policy that would maximize its long-term profitability. The frequent new-version problem is particularly rampant in the software industry, according to industry observers (Greenbaum 2005). In such cases, the firm needs a remedial mechanism to prevent it from offering new versions too frequently.

This paper contributes one such remedy. We analyze a two-period game-theoretic model of a monopolist firm selling an innovative durable good that exhibits network externalities to a set of consumers with heterogeneous valuations of quality. The firm can produce the "initial version" in period 1, and the "new version" in period 2. (Releasing the new version in period 1 is not an option because it involves time-consuming R&D.) Consumers in period 1 strategically decide whether to buy the initial version or wait for the new version. In period 1, the firm sells the initial version to some consumers. Also in period 1, the firm realizes that under some conditions, not releasing the new version in period 2 is more profitable than releasing it: i.e., a no-new-version policy is best. However, at the start of period 2, the firm is unable to commit to its no-new-version policy (this is the commitment problem), because the firm now finds it optimal to sell the new version.[1] In period 1, the firm is able to contemplate its optimal product-release policy over both periods, whereas in period 2, the firms finds only period 2 to be relevant. Consumers anticipate the new version and expect to use the initial version only for the first period. As a result, (i) some consumers delay their purchase: They avoid buying the initial version in period 1, and buy the new version in period 2; (ii) moreover, consumers' willingness to pay for the initial version decreases, forcing the monopolist to lower the price for the initial version in period 1. Therefore, the firm is shown to earn lesser profit over both periods when she offers the old version in period 1 and new version in period 2, than when she offers the old version only and withholds the new version. The firm's commitment problem can be solved if, in period 1, the firm can take an action that would render producing the new version unprofitable in period 2. The new version will be unprofitable if there is an insufficient number of consumers willing to pay for it. There will be fewer paying consumers if consumers who buy the initial version are contractually entitled to the new version (if produced) for free, because then the firm cannot expect revenue from selling the new version to such consumers in period 2. A lower consumer base for the new version successfully decreases the firm's incentive to produce the new version in period 2. When the firm contractually sells the initial version with bundled rights to the new version, that entitles consumers who buy the initial version to receive the new version for free, if the firm releases the new version within the time interval specified in the contract. (The contract, however, does not require the firm to product the new version.) Such a contract paradoxically ensures that the firm does not release the new version. Rational consumers will take such a free new-version rights (Free NVR) warranty as a credible signal that the new version will not be released, and so they won't expect the new version and overpay.[2] The firm prices the bundle of the initial version and rights to the new version expecting that the initial version will be used over both periods, withholds the new version, and is shown to realize optimal profits.

The fact that the durable good exhibits network externalities plays an important role in this model. The presence of significant network externalities ensures that consumers who bought the old version in period 1 will be inclined to buy the new version when it is released in period 2, thereby providing the motivation to the monopolist to release the new version. However, this limits the use of the old version to one period, thereby restricting the surplus that the monopolist can extract, while at the same time inducing the monopolist to incur the additional fixed cost of producing the new version.

There is evidence that elements of the proposed solution are in use in the software industry. For instance, the vendor Wolfram Research offers two licensing options for Mathematica: "Educational Unlimited program" and the "Comprehensive program," which allow a consumer to license Mathematica for a period of one year, and entitles the consumer to any updates released during that year for free. Enterprise software vendors Oracle and SAP routinely require consumers to prepay annual maintenance fees, for which

[1] We use a discrete two-period setting, and do not model the exact timing of release of the new version.

[2] This notion is akin to that of a replacement warranty, wherein the seller promises to replace a defective product, as a credible signal of product quality.

consumers are entitled to minor updates (technical patches fixing bugs, or in response to periodic changes in tax, regulatory, or business practices) as and when Oracle or SAP release the updates. Precollecting annual maintenance does not hinder the release of these updates, because these updates are essential and critical, and not providing them could seriously damage the reputation of the vendor. This paper suggests the extension of this contractual mechanism to major upgrades (i.e., new versions) by firms prone to offering new versions too frequently. This will ensure that such firms release only essential updates, but do not release new versions meant to enhance revenue for short-term gain at the cost of long-term profitability.

Although the analytical model has been motivated using the example of packaged software products, the results may give some insight into the question of excessive innovation and optimal timing of new-version releases for a range of high-technology durable goods (such as PDAs, video game consoles, and computing hardware), because (a) all these products are durable goods subject to innovation; (b) as the products become mature, the innovation becomes incremental rather than major; and (c) network effects may force consumers to upgrade nevertheless. In the case of video games, PDAs, and computer hardware, network effects could manifest in the form of game and software publishers' willingness to write programs for the newer console or platform, rather than for the older one, which will eventually force consumers to abandon the earlier platform.

This paper is built upon two main notions: (A) In a two-period setting, a monopolist firm selling innovative durable goods that exhibit network effects can face a commitment problem, forcing the firm to release a new version too frequently, when not releasing the new version may be more profitable. (B) When a firm gives its consumers a future right to a new version without requiring those consumers to pay in the future, the firm loses the incentive to produce the new version. This paper shows how firms prone to releasing new versions excessively can use the insight from observation (B) to mitigate the problem outlined in (A).

Observation (B) above may have some bearing on a recent event involving Microsoft. In May 2002, Microsoft changed its licensing terms for enterprise software (*BusinessWeek*, October 21, 2002, p. 68). Consumers buying a specific software product (such as Microsoft SQL Server) could buy the Software Assurance contract, which entitled them to "free" new versions (if any) of Microsoft SQL Server for a period of two years. At the time, consumers expected Microsoft to produce major upgrades in those two years, and subscribed to Software Assurance. However, significant new-version releases (e.g., SQL Server "Yukon," Microsoft .NET "Whidbey") were postponed beyond this two-year window, and consumers who subscribed to Software Assurance were dismayed because they paid for new versions that ultimately did not materialize. What happened with Microsoft and its consumers is not inconsistent with notion (B) above: When a firm precollects payments for a future new version, the firm gives its consumers a right to the new version, without requiring those consumers to pay in the future. The firm then faces lesser incentives to produce the new version, especially in the absence of a contractual obligation to produce the new version.[3]

The insights in this paper can help marketers optimize their new-version release policy. Often, firms are under intense pressure to meet the next quarter's targets, which could force them to release new versions too soon. This can hurt the firms' long-term profitability. This paper shows how such firms can get around this problem. Also, this paper can enable consumers to make better-informed decisions on purchasing new versions. It is important for consumers to realize that prepaying for future versions could sometimes decrease the likelihood of those new versions, as demonstrated by the Microsoft example.

This paper builds upon prior literature on innovation, durable goods, and new product introductions. The literature on innovation (Kamien and Schwartz 1975) has highlighted the interplay of technology and economic progress: Technological innovation does not just affect economic progress, but is also affected by the influence of economic institutions and the game-theoretic interaction among economic agents (Reinganum 1984). In the literature on durable goods, Coase (1972) conjectured that the monopolist could face a commitment problem leading to excessive sales. Researchers have looked at the conditions under which this conjecture holds (Stokey 1981, Gul et al. 1986, Ausubel and Deneckere 1989), and at conditions under which this conjecture does not hold, such as when the durable good depreciates (Bond and Samuelson 1984) or when production costs increase (Kahn 1986).

As pointed out by Waldman (2003), Coase's commitment problem has broader implications beyond the context of excessive sales, because it could apply to any future action that could affect the future value of goods already sold. One such context where the commitment problem influences the profitability

[3] However, this statement should not be construed to imply anything with respect to Microsoft per se, because several factors beyond a company's control could affect the timing of release of an upgrade.

of firms is when firms introduce improved durable goods (Levinthal and Purohit 1989, Waldman 1993, Dhebar 1994, Choi 1994, Ellison and Fudenberg 2000), where the action of introducing the improved version could affect the value of the previous version of the product. Due to this commitment problem, a monopolist releases new versions too frequently, which hurts her profit. No solution has been proposed for this problem so far. Our paper addresses this gap and proposes bundling free new-version rights (free NVR) as a cure.

We now discuss other cures proposed for the commitment problem, and compare them with the cure we propose. The Coasian commitment problem as applicable to excessive sales can be cured through leasing (Bulow 1982), planned obsolescence (Bulow 1986), offering a best-price provision (Butz 1990), and using a production technology with a higher marginal cost in the first period (Karp and Perloff 1996). In the context of improving durable goods, when the commitment problem leads a monopolist to make a new version backward-incompatible with the older version, Choi (1994) shows that building sufficiently high quality into the initial version in the first period can be a cure. When the commitment problem leads a monopolist to make excessively high R&D investments into producing the new version, Waldman (1996) shows that leasing the initial version in the first period can be a cure.

We now discuss each of the above cures in more detail, beginning with leasing.

Leasing helps cure excessive sales (the Coasian commitment problem) because at the end of the lease period the lessees are back in the market, along with the consumers who did not lease. Therefore, at the end of the lease period, the monopolist regains ownership of the goods and again faces the same demand curve she faced at the start of the period. This implies that the monopolist will internalize the value of goods, choose the profit-maximizing monopoly (lease) price, and not face a temptation to lower this price. This cures her excessive-sales commitment problem.

Our model shows that leasing can cure the frequent new-version problem as well, but leasing may be ineffective when it is possible for the monopolist to produce a new version before the lease expires. Offering free NVR does not suffer from this limitation, and also results in lesser transaction costs than leasing. This is discussed in more detail in §5.

We now discuss the other cures. Decreasing the durability of a product through planned obsolescence (Bulow 1986) may not always be possible for some products (e.g., computer software) that do not experience any significant wear and tear. (For certain classes of computer software, durability decreases naturally with time—e.g., antivirus software becomes less useful when new viruses emerge, and tax software becomes less useful when tax laws change; but these are exogeneous events that the monopolist does not control.) A best-price provision (Butz 1990) requires that if, after selling the good in the initial period, the monopolist sells it later at a lower price, she must reimburse earlier consumers for the difference in prices. In the case of improved durable goods, a best-price provision is not appropriate, because the earlier good is not being sold at a lower price. Karp and Perloff (1996) suggest a commitment mechanism of using an inferior production technology to produce the durable good, even though the monopolist may have access to a superior production technology. Inferior (superior) production technology results in a higher (lower) marginal cost of production. This is clearly not applicable to our focus where the product itself is improved (as opposed to the technology used to produce the product).

The marketing literature has a rich stream of work on durable goods, innovation (Hauser et al. 2006), network externalities, and product release timing. Prior work has studied the pricing of successive generations of durable goods (Bayus 1992), the relationship between new and used durable goods (Purohit 1992), the optimal timing of entry for a company selling an innovative product in a duopolistic setting (Bayus et al. 1997), the optimal use of leasing versus selling in durable goods marketing (Desai and Purohit 1999), the role of expectations about network externalities in shaping contractual terms between a technology vendor and retailer (Li 2005), and the role of alliances in new product development (Amaldoss and Rapoport 2005). Further research has more specifically looked at the causes and consequences of releasing successive versions of a durable good. Padmanabhan et al. (1997) discuss how a firm can use its new-version release policy to signal the presence of a large consumer base, when the firm has asymmetric information about the size of the market (and the resulting network externalities). On the other hand, Levinthal and Purohit (1989) look at some consequences of releasing successive versions: When a monopoly firm is ready to sell an improved version of a durable good, the earlier version could compete with and hinder adoption of the new version. They find that the firm could either phase out the sales of the earlier version, or implement a buy-back policy for the earlier version, depending on the extent of the new version's improvement. However, their work does not explore whether the improved version could itself have a detrimental effect on the firm's overall profitability. That issue is partially addressed by Dhebar (1994), who studies situations where the new version is too improved compared to the earlier version, in which case rational forward-looking consumers avoid (or regret) buying the earlier version, leading to suboptimal profits for the monopolist. Our work addresses a related problem of too-frequent new-version releases, and contributes by proposing a remedy.

Set in the context of a two-period setting, the remedy we propose for excessively frequent new-version releases is to bundle the new-version rights (NVR) with the initial version sold in period 1. When this cure works, the new version is not produced in period 2, and rational consumers do not expect it either. Consumers pay at the start of period 1 to use version 1 in both periods. In this case, the bundled NVR is a credible promise by the monopolist that she will not introduce the new version in period 2. On the other hand, when this cure does not work, the new version is produced in period 2, and rational consumers do expect it in period 2. Consumers then pay at the start of period 1 to use version 1 in period 1, and version 2 in period 2.

In our model the firm is assumed to be a monopolist (Shugan 2002) in order to focus better on the commitment problem and its cure. Moreover, there are significant examples where one vendor is dominant enough almost to be considered a monopoly firm (e.g., Microsoft in the market for personal productivity software). Arya and Mittendorf (2006) discuss how channel discord can alleviate the excessive-sales commitment problem of a durable goods monopolist; our paper does not model channel relationships. Mitra and Golder (2006) find a time lag between a change in actual quality of a product, and consumers' perception of this change; our model does not capture this time lag, because consumers expect a new version (by definition) to have improved features.

Bundling NVR with the initial version may be seen as a form of advance selling (Shugan and Xie 2000, 2005; Xie and Shugan 2001), wherein the new version that will be released in period 2 is sold in advance, in period 1. In the advance selling literature, when buyers are uncertain about future valuations, advance selling increases the seller's profitability by decreasing her information disadvantage, or by increasing her ability to price discriminate. However, in our model, buyers are not uncertain about future valuations, and advance selling the new version improves the seller's profitability when it prevents the seller from releasing the new version.

The rest of this article is organized as follows. Section 2 specifies the modeling framework. Section 3 proves the existence of conditions in which a monopolist firm could face a commitment problem. Section 4 discusses how providing free new-version rights could alleviate the firm's commitment problem. Section 5 discusses managerial implications and suggests further research.

2. The Model

The model analyzes the monopolist's commitment problem when selling to a mass of consumers. Motivating the model using a packaged software product (such as a word-processing software), a monopolist firm M offers a software product over two periods to a heterogeneous mass of consumers, normalized to unity. In the first period, M produces a relatively lower-quality version L of the software, whose intrinsic value is V_L. In the second period, she can produce a higher-quality version H (also referred to as "upgrade"), whose intrinsic value (determined exogenously) is V_H. Each consumer consumes at most one unit of each version of the software. Consumers vary in their valuation of intrinsic software quality, depending on their type. Consumer type is denoted by θ, assumed to be uniformly distributed in the interval $[0, 1]$. In each period, a consumer of type θ who uses software i derives a utility of θV_i, and a network externality benefit of αx, where x is the total number of users of the software in the period (the network size). In line with prior literature (Katz and Shapiro 1985), rational consumers are assumed to form identical expectations about network size when deciding to buy software, and these expectations are fulfilled in equilibrium. The software is backward compatible but not forward compatible: If x_L and x_H is the number of consumers of versions L and H in a period, then the network externality benefit to each consumer using L is αx_L, whereas the network externality benefit to each consumer using H is $\alpha(x_H + x_L)$. M can sell version L in period 1, and versions L and H in period 2. There is no discount factor in the model.

The analysis formulates software prices, revenues, and profits in terms of the consumer type θ, software qualities V_L and V_H, and network coefficient α. Each consumer's action satisfies the Nash equilibrium, subject to the abovementioned fulfilled expectations condition. The following assumptions attempt to characterize products with low relative network benefits:

$$V_H > V_L > 4\alpha; \tag{1}$$

$$V_H - V_L < \alpha. \tag{2}$$

Here, α is the network benefit enjoyed by an individual consumer when all other consumers consume the same version or a compatible version. These assumptions enable us to focus on goods for whom (a) the network benefit is significantly less than intrinsic value (Assumption 1), but (b) the network effect benefit dominates the incremental quality differential between the new version and the previous version (Assumption 2). Both assumptions enable us to focus on a subset of the parameter space and help make the analysis tractable. Prior related work has made similar limiting assumptions (for instance, Ellison and Fudenberg 2000, p. 264; Fudenberg and Tirole 1998, p. 238). The assumptions apply to mature technology products (e.g., Microsoft Word, Excel, PowerPoint, Intuit Inc's Quicken, etc.) wherein a consumer uses the product to produce and/or consume documents, spreadsheets, presentations, personal financial statements, etc. For such products, (a) the product can provide significant value when used in isolation—e.g., one can create a document in Microsoft Word and print it out, and derive value even if one is not sharing the document electronically with anyone else; (b) a consumer enjoys network externalities when sharing documents with others; (c) because the product is mature, most consumers converge to one product that becomes a de facto standard (e.g., Excel for spreadsheets); and (d) the monopolist seller controls this standard (e.g., Microsoft controls the Excel spreadsheet file format; Intuit controls the Quicken file format). For such products, when compared to the pure network benefit α (from sharing documents), the intrinsic value V_L is significantly higher (it is difficult to think of life without Microsoft Word, even if one does not share documents much), which we capture with $V_L > 4\alpha$. In contrast, for products such as e-mail software and mobile phones, the network benefit dominates intrinsic benefit: With a mobile phone, being able to communicate with others (network benefit) is far more important than having an address book or calculator functionality (intrinsic benefit).

Because such products are at a mature stage in the product life cycle, any improvements in new versions are of incremental (and not substantial) value to consumers. For example, Microsoft Office Word 2003, compared to earlier versions of Word, includes some new features such as editing/formatting restrictions (lock down portions of a word document to prevent others from editing or reformatting those portions only), and restrictions on copying, forwarding, or printing documents, etc. It also includes some improvements to existing features, such as the use of digital signatures to confirm authenticity, and file password encryption to deter hacking. These improvements increase the intrinsic value of the product somewhat (so that $V_H > V_L$), but from anecdotal evidence it appears that for most consumers, these improvements by themselves are not valuable enough to justify an upgrade; on the other hand, if one's colleagues are using the newer version, that appears to be a more compelling reason to upgrade. In a university setting, Stenzel (1997) discusses the limited incremental value of new features offered by a new version of Microsoft Word, and documents how some users of a previous version of Word feel compelled to upgrade when other users start using the newer version.

That the increase in intrinsic quality is sometimes not significant compared to the network benefit is captured by $V_H - V_L < \alpha$, so that if everyone else upgrades to version H, an individual consumer gets a higher value from the network effect than from the incremental improvement in intrinsic quality. In the case of Microsoft Word, if a new version of Word is adopted by most users, then users of the old version will be unable to read word documents created using the new version. In such a situation, being able to read documents sent by colleagues (which drives α) is perhaps more valuable than having little-used features like the editing/formatting restrictions described above. This is not the case with some other products such as computer monitors: Compared to a 17" CRT monitor, a 17" LCD monitor confers positive intrinsic benefits such as less eyestrain, less power consumption, and less space requirement, but no network benefit.

We now discuss the nature of the commitment problem faced by the monopolist M. In deciding to introduce version H in period 2, M could face a commitment problem: At the start of the first period, producing and selling L and never producing H could be the most profitable alternative. However, at the start of the second period, producing and selling H could be profitable. M is therefore tempted to produce and sell H in period 2. Consumers in period 1 anticipate that M will produce and sell H in period 2, and will pay for version L accordingly, leaving M with suboptimal profit overall. To show that M could face a commitment problem, her profitability is compared in the following two cases: case (a): M produces version H in period 2, and case (b): M does not produce version H in period 2. Let profits be denoted by π, revenues by R, and the fixed cost of producing a version of software by c (assumed to be constant and identical for versions L and H).[4] Section 3.1 discusses case (a), in which M's profit from producing versions L and H is denoted by $\pi_a = R_a - 2c$. Section 3.2 discusses case (b), in which M's profit from producing version L alone is denoted by $\pi_b = R_b - c$. Under some parameterizations it can be shown that $\pi_a < \pi_b$, i.e., it is better for M to refrain from offering the upgrade. However, at the start of the second period, M finds it more profitable to offer H than not: i.e., $R_2 > c$, with the result that M does offer the upgrade. This demonstrates the existence of the commitment problem (§3.3). (The Technical Appendix B.1, available at http://mktsci.pubs.informs.org, contains a table summarizing the variables in the model.)

[4] The results do not change if we assume the fixed costs for versions L and H to be c_L, c_H where $c_L \neq c_H$, because c_H is the only relevant fixed cost. (See proofs of Propositions 2 and 3).

3. Monopolist Faces Commitment Problem

This section describes the conditions when the monopolist (hereafter denoted by M) can face a commitment problem, whereby M produces a new version of software in each period, even though ex ante it is more profitable for M to produce one version in period 1 only. To show this, M's overall profitability (over both periods) is compared in two alternative scenarios: when M produces both versions, and when M produces only one version. Section 3.1 (i.e., case (a)) derives the firm's overall profitability from producing both versions (version L in period 1, and version H in period 2). Section 3.2 (i.e., case (b)) derives the firm's overall profitability from producing only one version (version L in period 1). Section 3.3 compares the firm's profitability from cases (a) and (b). Under some conditions, overall profitability is higher for case (b) (i.e., not producing version H). However, in the second period, M finds it profitable to produce version H. M ends up producing version H (i.e., chooses case (a)), earning lesser profit overall.

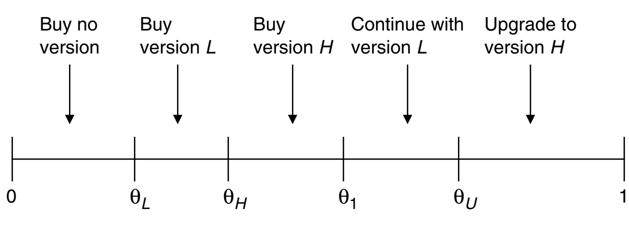
3.1. Case (a): M Offers Both Versions

This section derives the firm's overall profitability from producing version L in period 1, and version H in period 2.

Explaining Figure 1, when M produces version L in period 1, her pricing scheme P_1 will segment consumers into two categories $(0, \theta_1)$, and $(\theta_1, 1)$ so that all consumers whose type is greater (lesser) than a cutoff θ_1 will buy (not buy) version L in period 1. In the second period there are two kinds of consumers—those who bought version L in period 1, whose type lies in $(\theta_1, 1)$ (the patrons), and those who did not (the nonpatrons), whose type lies in $(0, \theta_1)$. When M produces version H in period 2, she could (a) offer version H as an upgrade to patrons, (b) offer version H at a regular price to nonpatrons, and (c) offer version L to nonpatrons. Any pricing scheme chosen by M in period 2 will segment consumers into the five categories shown in Figure 1.

The analysis proceeds backwards—period 2 analysis is followed by period 1 analysis. In period 2, Proposition 1 shows that (i) all consumers who bought version L in period 1 (whose type lies within $[\theta_1, 1]$) upgrade to H in period 2 at the upgrade price P_U; (ii) consumers who did not buy version L in period 1 (whose type lies within $[\theta_H, \theta_1)$) buy version H at regular price P_H; (iii) interestingly, M stops selling version L in period 2, even though some consumers would have bought it. This is consistent with commonly observed practice in the software industry. (In Figure 1, this is equivalent to saying that θ_U converges to θ_1, and θ_L converges to θ_H.)

Figure 1 **Customer Segmentation When Monopolist M Offers Both Versions**



In the period 1 analysis, Lemma 1 shows the existence of an interval of first-period consumers of type $[\theta_1, 1]$ who buy version L in period 1. Lemma 2 shows the existence of an interval of consumers $[\theta_H, \theta_1)$ who did not buy version L in period 1, and buy version H in period 2.

Proposition 1 and Lemmas 1 and 2 form the basis for deriving the monopolist's revenue over both periods from producing versions L in period 1 and H in period 2, which is the goal of this section.

3.1.1. Second-Period Analysis. Given a cutoff type θ_1 from period 1, at the start of period 2 M has to decide on selecting the upgrade price P_U, regular price P_H for version H, and price P_L for version L so that her revenue is maximized. The rest of this section expresses prices P_U, P_L, P_H in terms of cutoff consumer types θ_U, θ_L, θ_H, and formulates and solves for the monopolist's second-period choice of $\theta_U, \theta_H, \theta_L$ as a constrained optimization problem.

(a) If P_U is the price charged for each upgrade, and all consumers in $(\theta_U, 1)$ upgrade, then the revenue to M from selling upgrades is $R_U = P_U(1-\theta_U)$. P_U satisfies the condition

$$\theta_U V_H + \alpha(1-\theta_L) - P_U \geq \theta_U V_L + \alpha(\theta_U - \theta_1 + \theta_H - \theta_L). \quad (3)$$

The price P_U leaves the consumer with type θ_U indifferent between upgrading and continuing with version L in period 2. Discussing the expression on the left of the inequality 3 when the consumer of type θ_U uses the version H, (i) her intrinsic utility is $\theta_U V_H$; (ii) because all consumers in the interval $(\theta_L, 1)$ use either L or H in period 2, and because H is backward compatible, her utility from network externalities is $\alpha(1-\theta_L)$. Her total utility from upgrading and paying a price P_U is therefore given by $\theta_U V_H + \alpha(1-\theta_L) - P_U$. Discussing the expression on the right of inequality (3), when the consumer of type θ_U declines the upgrade and continues to use L in period 2, (i) her intrinsic utility is $\theta_U V_L$,; (ii) network utility is $\alpha(\theta_U - \theta_1 + \theta_H - \theta_L)$ because $(\theta_U - \theta_1 + \theta_H - \theta_L)$ represents the mass of consumers using L in period 2, and L is not forward compatible with H; and (iii) the consumer does not pay any price to continue to use L in period 2.

$$P_U = \theta_U(V_H - V_L) + \alpha(1 - \theta_U + \theta_1 - \theta_H); \quad (4)$$

$$R_U = (\theta_U(V_H - V_L) + \alpha(1 - \theta_U + \theta_1 - \theta_H))(1 - \theta_U). \quad (5)$$

(b) If P_L is the price per copy of version L in period 2, and all consumers in (θ_L, θ_H) buy version L in period 2, then the revenue to M from selling version L in period 2 is $R_L = P_L(\theta_H - \theta_L)$. Following a reasoning similar to (a) above,

$$P_L = \theta_L V_L + \alpha(\theta_U - \theta_1 + \theta_H - \theta_L); \tag{6}$$

$$R_L = (\theta_L V_L + \alpha(\theta_U - \theta_1 + \theta_H - \theta_L))(\theta_H - \theta_L). \tag{7}$$

(c) If the monopolist charges a price P_H to a mass of consumers (θ_H, θ_1), she earns a revenue $R_H = P_H(\theta_1 - \theta_H)$, where

$$P_H = (\theta_H V_H + \alpha(1-\theta_L)) + \theta_L V_L - \theta_H V_L \tag{8}$$

$$R_H = ((\theta_H V_H + \alpha(1-\theta_L)) + \theta_L V_L - \theta_H V_L)(\theta_1 - \theta_H). \tag{9}$$

Based on the above formulation, the monopolist's second-period problem reduces to finding the optimal cutoff values of $(\theta_L^*, \theta_H^*, \theta_U^*)$ to maximize the second-period revenue $R_2 = R_L + R_H + R_U$. Solving this three-variable inequality constrained optimization problem (Proposition 1) shows that (i) M will not sell L in period 2, and (ii) M will sell upgrades to all period 1 consumers. The resulting revenue is therefore a function of θ_H and θ_1 alone. At the start of the second period, M takes θ_1 as a given and selects the optimal θ_H^* that maximizes second-period revenue (Equation (14)). Next, the first-period revenue and total revenues are stated in terms of θ_1, and solved for optimal θ_1^* (Lemma 1) to represent overall revenue in terms of the intrinsic software qualities V_H and V_L, and network effect α.

Formally, M's optimization problem can be stated as follows:

$$\begin{aligned}
&\max R_2(\theta_L, \theta_H, \theta_U)\\
&\quad = (\theta_L V_L + \alpha(\theta_U - \theta_1 + \theta_H - \theta_L))(\theta_H - \theta_L)\\
&\qquad + (\theta_H V_H + \alpha(1-\theta_L) + \theta_L V_L - \theta_H V_L)(\theta_1 - \theta_H)\\
&\qquad + (\theta_U(V_H - V_L) + \alpha(1 - \theta_U + \theta_1 - \theta_H))(1-\theta_U) \qquad (10)\\
&\quad \text{s.t.} \quad 1 - \theta_U \geq 0 \qquad (11)\\
&\qquad\qquad \theta_U - \theta_1 \geq 0\\
&\qquad\qquad \theta_1 - \theta_H \geq 0\\
&\qquad\qquad \theta_H - \theta_L \geq 0\\
&\qquad\qquad \theta_L \geq 0.
\end{aligned}$$

Proposition 1.[5] *At the optimum, the monopolist M* (a) *sets the upgrade price for the newer version H so that all consumers who bought the older version L in period* 1 *will upgrade to H in period* 2; (b) *offers version H in period* 2 *to consumers who did not buy version L in period* 1; *and* (c) *withdraws version L from the market in period* 2.

[5] Proofs for all propositions and lemmas are in Appendix A.

Substituting $(\theta_U, \theta_H) = (\theta_1, \theta_L)$,

$$\begin{aligned}
R_2 = {} & \theta_1 V_H - \theta_1^2 V_H - \theta_1 V_L + \theta_1^2 V_L + \alpha - 2\alpha\theta_L\\
& + \theta_L V_H \theta_1 - \theta_L^2 V_H + \alpha\theta_L^2
\end{aligned}$$

If $\theta_H = \theta_L$, then the interval (θ_H, θ_1) now merges with the interval (θ_L, θ_1) and denotes the mass of consumers who do not buy version L in period 1, but buy version H in period 2 at the regular price P_H. To denote such buyers, notationally it is appropriate to use (θ_H, θ_1) instead of (θ_L, θ_1).

Therefore, substituting θ_L with θ_H and collecting all terms of θ_H^2 and θ_H,

$$\begin{aligned}
R_2 = {} & (-V_H + \alpha)\theta_H^2 + (-2\alpha + V_H\theta_1)\theta_H + V_H\theta_1\\
& - V_H\theta_1^2 - V_L\theta_1 + V_L\theta_1^2 + \alpha.
\end{aligned} \tag{12}$$

M's problem remains one of finding the optimal θ_H^* to maximize second-period revenue R_2. The first-order condition is as follows:

$$\frac{\partial R_2}{\partial \theta_H} = -2\alpha + V_H\theta_1 - 2\theta_H V_H + 2\alpha\theta_H = 0. \tag{13}$$

Solving the first-order condition for θ_H,

$$\theta_H^* = \frac{1}{2}\frac{V_H\theta_1 - 2\alpha}{V_H - \alpha}. \tag{14}$$

By Assumption 1, $V_H > 4\alpha$, and so $V_H - \alpha > 0$. Further, $V_H\theta_1 + 2\alpha(1-\theta_1) > 0 \; \forall \theta_1 < 1$. Therefore, it can be seen that $\frac{1}{2}(V_H\theta_1 - 2\alpha)/(V_H - \alpha) < \theta_1$, and so $\theta_H^* < \theta_1$. It remains to be shown that $\theta_H^* > 0$, for which θ_1^* is first derived in the next section.

Substituting for θ_H^* in the expression for the second-period revenue R_2,

$$\begin{aligned}
R_2 = {} & \tfrac{1}{4}\big(-3V_H^2\theta_1^2 - 8V_H\theta_1\alpha + 4V_H^2\theta_1 + 4V_H\theta_1^2\alpha + 4V_L\theta_1\alpha\\
& - 4V_L\theta_1 V_H - 4V_L\theta_1^2\alpha + 4V_L\theta_1^2 V_H + 4V_H\alpha\big)\\
& \cdot (V_H - \alpha)^{-1}.
\end{aligned} \tag{15}$$

3.1.2. First-Period Analysis. This section derives the first-period revenue R_1 in terms of V_H, V_L, α, and θ_1, formulates total revenue $R_a = R_1 + R_2$ in terms of V_H, V_L, α, and θ_1, and solves for the optimum θ_1^*. (θ_1^* and θ_H^* are then shown to satisfy the constraint $0 < \theta_H^* < \theta_1^* < 1$.) Total revenue R_a is formulated in terms of V_H, V_L, and α.

From the earlier analysis, substituting $\theta_U = \theta_1$, $\theta_L = \theta_H$, and (from Equation (14)) $\theta_H = \frac{1}{2}(V_H\theta_1 - 2\alpha)/(V_H - \alpha)$ in the expressions for prices P_U and P_H based on Equations (4) and (6),

$$P_U = \frac{1}{2}\frac{2\theta_1 V_H^2 - 3\theta_1 V_H\alpha - 2\theta_1 V_L V_H + 2\theta_1 V_L\alpha + 2V_H\alpha}{V_H - \alpha}; \tag{16}$$

$$P_H = \frac{1}{2}\theta_1 V_H. \tag{17}$$

If P_1 is the price charged for each copy of version L in period 1, and all consumers in $(\theta_1, 1)$ buy L in period 1, then the revenue to M from selling version L in period 1 is $R_1 = P_1(1-\theta_1)$. P_1 therefore satisfies

$$P_1 = 2V_L\theta_1 + \alpha - \alpha\theta_1 - V_H\theta_1 + \theta_H V_H, \tag{18}$$

where $\theta_H = \frac{1}{2}(V_H\theta_1 - 2\alpha)/(V_H - \alpha)$ (from Equation (14)). The first-period revenue from sale of version L is given by $R_1 = P_1(1-\theta_1)$:

$$R_1 = \frac{1}{2}\frac{(-4V_L\theta_1\alpha + 4V_L\theta_1V_H - 2\alpha^2 + 2\alpha^2\theta_1 - V_H^2\theta_1)}{V_H - \alpha}(1-\theta_1). \tag{19}$$

Total revenue $R_a = R_1 + R_2$. From Equations (15) and (19), R_a is given by

$$R_a = \frac{1}{4}\left(\frac{4V_L\theta_1\alpha - 4V_L\theta_1^2\alpha - 4V_L\theta_1V_H + 4V_L\theta_1^2V_H + 4\alpha^2 - 8\alpha^2\theta_1}{\alpha - V_H}\right) + \frac{1}{4}\left(\frac{4\alpha^2\theta_1^2 - 2V_H^2\theta_1 + V_H^2\theta_1^2 + 8V_H\theta_1\alpha - 4V_H\theta_1^2\alpha - 4V_H\alpha}{\alpha - V_H}\right). \tag{20}$$

Lemma 1. *There exists an optimal first-period cutoff type θ_1^* such that $0 < \theta_1^* < 1$, where $\theta_1^* = ((V_H - 2\alpha)^2 + 2V_L(V_H - \alpha))/((V_H - 2\alpha)^2 + 4V_L(V_H - \alpha))$.*

It is also possible to show that $\theta_H^* > 0$:

Lemma 2. *Optimally, the monopolist M prices the newer version H so that there exists a marginal consumer of type θ_H^* who has not bought the older version L in period 1, and is indifferent to buying version H and buying nothing in period 2.*

It is now possible to compute the total (two-period) revenue R_a (from Equation (20)) to the monopolist from the sale of version L in period 1 and version H in period 2:

$$\begin{aligned} R_a = {} & \tfrac{1}{4}\big(-4V_L\alpha V_H^2 - 8V_L^2\alpha V_H + 4V_H^2\alpha^2 + 4V_L^2\alpha^2 + 4V_L^2V_H^2 \\ & + 4V_LV_H^3 - 4V_H^3\alpha + V_H^4\big) \\ & \cdot ((V_H - \alpha)(-4V_L\alpha + 4V_LV_H + 4\alpha^2 + V_H^2 - 4V_H\alpha))^{-1}. \end{aligned} \tag{21}$$

3.2. Case (b): M Produces Only Version L

If M does not produce version H in period 2, there are two possible cases: (i) M could offer version L only in period 1 and not in period 2; and (ii) M could offer version L in both periods, at a higher price in the first period for higher-type consumers, and lower price in the second period for lower-type consumers. Lemma 3 below shows that alternative (i) is superior for the monopolist by establishing that higher revenues accrue to the monopolist by selling version L in period 1 only, as opposed to selling it in both periods. The resulting installed base and revenue from producing version L only is obtained, in both cases—when the monopolist commits to not selling L in period 2, as well as when she is unable to commit and sells L in both periods.

Lemma 3. *If the monopolist produces only version L, she earns more revenue overall by selling version L in the first period, as opposed to selling version L in both periods; in this case, consumers of type $(\theta_b, 1)$ buy version L in period 1, where $\theta_b = \frac{1}{2}(V_L - 2\alpha)/(V_L - \alpha)$, and yield a revenue $R_b = \frac{1}{2}V_L^2/(V_L - \alpha)$. When the monopolist sells version L in both periods* (*Coase's commitment problem*), *consumers of type $(\theta_x, 1)$ buy version L in period 1, where $\theta_x = \frac{1}{5}(3V_L - 5\alpha)/(V_L - \alpha)$; and consumers of type (θ_y, θ_x) buy version L in period 2, where $\theta_y = (3V_L - 10\alpha)/10(V_L - \alpha)$. The revenue over both periods $R_{xy} = 9V_L^2/20(V_L - \alpha)$. $(R_b > R_{xy})$*

3.3. The Commitment Problem Exists

Comparing the monopolist's profits from cases (a) and (b) above, we show that the commitment problem exists: i.e., there exists a set of parameters when M should optimally refrain from producing version H in period 2, but finds at the start of the second period that producing version H is profitable. In the case when the monopolist offers version H (compared to the case when she sells only version L), consumers anticipate the version H, as a result of which (I) fewer consumers buy version L in period 1, and (II) consumers who buy version L in period 1 pay less.

Elaborating on (I), we compare (i) θ_1, where $(1-\theta_1)$ is the number of consumers who buy version L in period 1 when the monopolist offers version H in period 2, to (ii) θ_x, where $(1-\theta_x)$ is the number of consumers who buy version L in period 1 when the monopolist sells version L in period 1 as well as period 2. (Here the monopolist suffers from the excessive-sales related commitment problem identified by Coase 1972.) We find that $\theta_1 > \theta_x$. (Similarly, $\theta_1 > \theta_b$, when the excessive-sales commitment problem does not exist.) Therefore, one reason for the commitment problem from frequent upgrades is that some consumers delay purchase of the initial version in anticipation of the newer version.

Elaborating on (II), we compare (i) P_1 which is the optimal price consumers pay for version L in period 1, when the monopolist offers version H in period 2, to (ii) P_x which is the optimal price consumers pay for version L in period 1 when the monopolist sells version L in both periods (the excessive-sales commitment problem exists). We find that $P_1 < P_x$ (and $P_1 < P_b$, when the excessive-sales commitment problem does not exist).

This is stated in the following lemma:

Lemma 4. *The seller sells version L* (i) *to fewer consumers*, (ii) *at a lower price, in period* 1 *if* (A) *she introduces* *the new version H in period* 2, *than* (B) *if she sells the older version L only and does not introduce the new version*. *This holds in the case* (B.1), *where she sells the older version in periods* 1 *and* 2 (*i.e., when Coase's commitment problem exists*) *as well as in* (B.2), *where she sells the older version in period* 1 *only.*

As a result of fewer consumers buying in period 1 at lower prices, the monopolist is sometimes left with less than optimal profit over both periods. Proposition 2 below states and proves this formally.

Proposition 2. *There exists a range of values for fixed cost c* (*whether or not the monopolist suffers from Coase's commitment problem*) *such that the monopolist M faces a commitment problem*: (i) *Over both periods, M is better off not offering the newer version H in period* 2, *but* (ii) *M finds offering H attractive at the start of period* 2.

From Proposition 2, the lower and upper bounds of fixed cost c are $[c_{MIN}, c_{MAX}]$:

$$c_{MIN} = R_a - R_b \tag{22}$$

or

$$c_{MIN(COASE)} = R_a - R_{xy}. \tag{23}$$

Because $R_{xy} < R_b$, we have $c_{MIN(COASE)} > c_{MIN}$.

R_a is given by Equation (21), and R_b and R_{xy} are given by Lemma 3.

$$c_{MAX} = R_2 \tag{24}$$

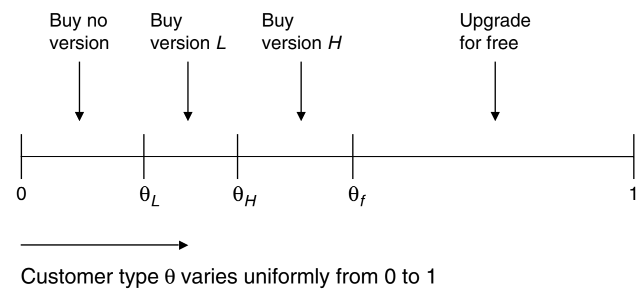
where, substituting θ_1 from equation Lemma 1, (§3.1.2) into the expression for R_2 from Equation (15) (§3.1.1), we have

$$R_2 = \frac{-(V_H^2(-2\alpha+V_H)^4)+12(\alpha-V_H)V_H^2(-2\alpha+V_H)^2V_L}{4(\alpha-V_H)((-2\alpha+V_H)^2-4(\alpha-V_H)V_L)^2} + \frac{4(\alpha-V_H)^2(8\alpha^2-3V_H(4\alpha+V_H))V_L^2-16(\alpha-V_H)^3V_L^3}{4(\alpha-V_H)((-2\alpha+V_H)^2-4(\alpha-V_H)V_L)^2}. \tag{25}$$

4. Free New-Version Rights Can Alleviate the Commitment Problem

Proposition 2 shows the existence of a commitment problem, when M (a) could earn higher profit overall if she refrains from offering the newer version, but (b) finds it profitable to offer the new version at the start of the second period and ends up with reduced profitability. This section discusses how offering free NVR can solve M's commitment problem. If M offers a free NVR bundled with the sales of V_L in period 1, then buyers of V_L will be entitled to a free new version H in period 2 (provided M chooses to produce version H). By bundling free NVR with version L, M effectively forfeits second-period version H sales revenue from first-period consumers. Is this revenue loss sufficient to deter M from producing version H? (In the second period there is a mass of consumers who bought no software in the first period who might still be willing to buy version H.) If M finds producing version H unattractive, then the free NVR is successful in solving her commitment problem. The corresponding parameters are identified in this section.

Figure 2 **Customer Segmentation When Monopolist *M* Offers Free NVR**



If the monopolist bundles free NVR in period 1 and sells it to consumers $(\theta_f, 1)$ in period 1, then in period 2 she can sell version H to consumers (θ_H, θ_f) and sell version L to consumers (θ_L, θ_H). This is depicted in Figure 2. Lemma 5 establishes that optimally, the monopolist does not sell version L in period 2 (in Figure 2, θ_L converges to θ_H). Lemma 6 establishes the existence of a set of consumers (θ_H, θ_f) who pay for and buy version H in period 2 (but have bought nothing in period 1). Proposition 3 shows that the revenue from this sale can sometimes be insufficient to cover the monopolist's fixed costs, inducing the monopolist to refrain from producing version H, and solving her commitment problem.

In the following analysis, M produces version L in period 1, and sells it bundled with free NVR to some $(\theta_f, 1)$, at a price P_1. In period 2, M sells version L at price P_L to consumers of type (θ_L, θ_H), and sells version H in period 2 to some (θ_H, θ_f). Analyzing the second period first, M's second-period revenues are:

$$R_2 = P_L(\theta_H - \theta_L) + P_H(\theta_f - \theta_H), \tag{26}$$

where P_L, the price of version L in period 2, satisfies $\theta_L V_L + \alpha(\theta_H - \theta_L) - P_L \geq 0$, and so

$$P_L = \theta_L V_L + \alpha(\theta_H - \theta_L).$$

P_H, the price of version H in period 2, satisfies $\theta_H V_H + \alpha(1-\theta_L) - P_H \geq \theta_H V_L + \alpha(\theta_H - \theta_L) - P_L$, so that

$$P_H = \theta_H(V_H - V_L) + \alpha(1-\theta_L) + \theta_L V_L$$

Therefore, the total revenue R_2 from the second-period sale of L to (θ_L, θ_H) and H to (θ_H, θ_f) is given by

$$R_2 = (\theta_L V_L + \alpha(\theta_H - \theta_L))(\theta_H - \theta_L) + (\theta_H(V_H - V_L) + \alpha(1-\theta_L) + \theta_L V_L)(\theta_f - \theta_H). \tag{27}$$

The monopolist faces the problem of choosing θ_H, θ_L to maximize R_2, subject to the following constraints:

$$\begin{aligned} \theta_f - \theta_H &\geq 0 \\ \theta_H - \theta_L &\geq 0 \\ \theta_L &\geq 0. \end{aligned} \tag{28}$$

Lemma 5. *If M bundles free NVR with version L for a subset of consumers* $(\theta_f, 1)$ *in the first period, and produces version H in period two,* (i) *she never sells version L in period two;* (ii) *she sells only version H to a fraction of consumers* (θ_H, θ_f) *and earns a revenue* R_H *in the second period, where*

$$\theta_H = \frac{1}{2}\left(\frac{2V_L - 5\alpha + V_H}{4V_L - 5\alpha + V_H} - \frac{\alpha}{V_H - \alpha}\right), \quad \theta_f = \frac{2V_L - 5\alpha + V_H}{4V_L - 5\alpha + V_H}.$$

The existence of θ_H, θ_f is shown:

Lemma 6. *Both* θ_H *and* θ_f *exist*: $0 < \theta_H < \theta_f < 1$.

Considering the range of fixed-cost values (c_{MIN}, c_{MAX}) over which the commitment problem exists, Proposition 3 below shows that $c_{MIN} < R_H < c_{MAX}$, or in the case where the monopolist suffers from the Coasian commitment problem, that $c_{MIN(COASE)} < R_H < c_{MAX}$, where R_H is the revenue from selling version H in period 2. In other words, (a) when the fixed cost of producing the new version is sufficiently large, the revenue R_H from selling version H to lower-type consumers is insufficient to cover the fixed cost, and so the monopolist does not produce version H. In this case, bundling the NVR with version L in period 1 succeeds in preventing the monopolist from selling excessive upgrades. Because no upgrades are forthcoming, rational consumers won't pay extra for the bundled NVR. On the other hand, (b) when the fixed cost of producing the new version is lower, the revenue from selling the new version to lower-type consumers is sufficient to cover the fixed cost. In this case the monopolist produces the new version despite bundling the NVR with version L in period 1. Therefore, in this case free NVR carries an extra price and is merely a mechanism to collect revenues earlier. This can be summarized in the following proposition.

Proposition 3. *If the monopolist bundles free NVR with version L in period one, there exist some values of fixed cost c when revenue from sale of version H is unprofitable*: (a) *Free NVR will solve M's commitment problem when the fixed cost is relatively high*: *c lies between* (R_H, c_{MAX}), *whether or not M faces the Coasian commitment problem.* (b) *Free NVR will not solve her commitment problem and will only help collect revenues earlier when the fixed cost is relatively low*: *c lies between* (c_{MIN}, R_H). *This range is* $(c_{MIN(COASE)}, R_H)$, *when the monopolist suffers from the Coasian commitment problem.*

Proposition 3 shows that $\forall c \in (c_{MIN}, R_H)$ even if the monopolist forfeits revenue from $(\theta_f, 1)$ consumers, the revenue R_H from (θ_H, θ_f) consumers is sufficient to cover the cost c of producing version H, and the commitment problem is unsolved. However $\forall c \in (R_H, c_{MAX})$ the commitment problem is solved: The revenue R_H is insufficient to cover the production cost c, and so M will not produce the new version. First-period consumers expect this and the resulting prices and outcomes are identical to those of §3.2 above. More specifically, Proposition 3 shows that producing new versions is unattractive $\forall c \in (R_H, c_{MAX})$, whether or not the monopolist suffers from the Coasian commitment problem and offers version L for sale in both periods, when not producing version H.

We now illustrate our results with a numerical example in the context of computer software. Assuming that $V_L = 100$, $V_H = 110$, based on our assumptions (inequalities (1) and (2)), α can range between 10 and 25. We choose $\alpha = 15$. Substituting these values in Equations (24) and (25), we have $c_{MAX} = 20.3$, $c_{MIN} = 0.3$, and $R_H = 11.57$. In the model we assumed a unit mass of consumers. Rescaling the figures by assuming a total consumer population of 10 million,[6] we have $c_{MAX} = \$200$ million, $c_{MIN} = \$3$ million, and $R_H = \$115$ million. Our model suggests that when the fixed cost of producing a good (say a word-processing software) is between \$3 million and \$200 million, a monopolist[7] is likely to suffer from the commitment problem, leading to excessively frequent new versions. When the fixed cost is higher than \$115 million but lower than \$200 million, the monopolist's commitment problem can be cured by bundling free NVR with the initial version. When the fixed cost is lower than \$115 million, free NVR will not be a cure.

We wish to emphasize that our model does not suggest that the monopolist can or should derive higher revenue by duping consumers into thinking that a new version is forthcoming and available for free when it is not. Our model suggests that in the two-period setting, if the free NVR is bundled with the initial version, and if the equilibrium outcome is that the monopolist finds it unprofitable in the second period to offer the new version (which happens $\forall c \in (R_H, c_{MAX})$), then rational forward-looking consumers in our model anticipate that no new version is forthcoming, and that will affect consumers' willingness to pay and the firm's profitability. When the monopolist finds no incentive in the second period

[6] From the 2003 U.S. Census estimates, 62% of U.S. households had access to a computer. This translates to approximately 45 million computers. Based on this, a figure of 10 million is perhaps a conservative estimate of the installed base of any widely used productivity software, such as word-processing software.

[7] The use of the term "monopolist" in this paper merely denotes that the vendor does not have a rival for the product being sold, and should not be construed to denote that the vendor is or is not engaging in any form of predatory or aggressive behavior.

for producing the new version, she has successfully cured her commitment problem.

Consumer surplus is higher when free NVR is not offered than when it is offered. Further, when free NVR is offered, consumer welfare is higher when (a) the monopolist suffers from the Coasian commitment problem and sells version L in period 1 and 2, than (b) when she sells version L in period 1 only.

Social welfare (the sum of seller's profit and consumer surplus) is higher when free NVR is offered than when it is not. When free NVR is offered, the increase in seller's profit offsets the decrease in consumer surplus. When free NVR is offered, as with consumer surplus, social welfare is higher when (a) the monopolist suffers from the Coasian commitment problem and sells version L in periods 1 and 2, than (b) when she sells version L in period 1 only. The seller earns less profit in (a) than in (b) (based on Lemma 3), but the increase in consumer surplus offsets the decrease in the seller's profit.

(Proofs for consumer surplus and social welfare are provided in the technical appendix at http://mktsci.pubs.informs.org.)

5. Discussion

The premise of this article is that releasing innovative products frequently need not always be a profit-maximizing strategy—sometimes a less frequent release of innovation is more profitable. This article extends prior research showing how the commitment problem can result in excessively frequent new-version releases. It analyzes a stylized two-period dynamic model of a monopolist firm selling a durable good exhibiting network effects to a set of consumers with heterogeneous valuations of quality. First, it finds that the firm should never sell the initial version in the second period, even if there are consumers willing to buy it. (This is consistent with the Coase theorem.) Next, under some conditions the firm is shown to achieve a higher profit overall by not introducing the new version. However, in period 2 the firm nevertheless finds it profitable to introduce the new version (the commitment problem). This causes the firm to achieve suboptimal profitability, because when consumers anticipate the new version, fewer consumers buy the initial version, and the firm is forced to charge a lower price for the initial version. Finally, this paper shows how the firm can mitigate this commitment problem by bundling the free NVR with the initial version when selling to consumers. This solution for excessive innovation is the main contribution of this paper. We also find that when free NVR is offered, consumer surplus actually decreases, whereas social surplus increases.

The insights of this paper could be important for (a) managers in charge of strategic product-release decisions, as well as (b) individual consumers and managers in charge of product upgrade decisions. With regard to (a), companies may be prone to release new versions too frequently for various reasons, such as the pressure to meet the current period's sales targets, expectations from Wall Street, and so on. Executives in charge of strategic marketing decisions in such companies could offer the free NVR to send a credible signal to consumers that they are committed to offering fewer, higher-quality new versions, thereby increasing their overall profitability. As a practical matter, if a company bundles the free NVR with the initial version, it is important for the company to manage consumers' expectations with regard to the new version. If the firm does not intend to produce the new version (barring any minor upgrades, such as security patches in the context of software products), it should make this clear so that consumers do not form unrealistic expectations, which could lead to loss of goodwill when consumers later discover that the new version will not be released after all (as happened with Microsoft in the example described in the introduction). Bundling free NVR serves as a credible signal that the monopolist will indeed refrain from releasing the new version. With regard to (b), individual consumers and managers in charge of making product upgrade decisions for their organizations might want to keep in mind an important implication of this article—when a firm offers free NVR before the new version is released, it might not release the new version. When a sufficiently large number of consumers enjoy the free NVR, the firm faces a diminished incentive to actually bring out the new version, because the firm cannot earn future revenue from such consumers.

Offering free NVR is like offering a manufacturer's warranty, wherein the manufacturer offers to repair or replace a product free of charge if the good is found to be defective. This does not imply that the good will be defective. The warranty is just a credible signal of quality, meant to reassure consumers and encourage them to buy the product.

We now compare offering free NVR with leasing in more detail. Leasing is not a cure if the new version can be produced before the lease expires. In the context of our two-period model, if the monopolist leases version L to consumers for two periods, then that does not cure her temptation to release a new version H at the start of period 2. However, if the monopolist leases L to consumers for the first period only, then leasing can mitigate the frequent new-version commitment problem. In this scenario, in the second period when the fixed cost of producing version H is sufficiently high, leasing L to consumers again is more profitable (because there is no fixed cost to incur) than producing and leasing H to consumers, even though revenues from sale of H are higher. This helps the monopolist commit to not producing the new version H. (A detailed proof is given in Appendix B.)

Based on the above discussion, there are two reasons why offering free NVR may be better than leasing: (a) A monopolist seeking to cure her commitment problem can offer free NVR for a longer duration than she can offer a lease. If offering a lease, she must restrict the duration of the lease to the shortest possible time before which she can produce the new version. Practically speaking, deciding the lease term is problematic when the monopolist cannot exactly predict when the new version will be ready. There is no such restriction to offering free NVR. (b) Additionally, by offering free NVR, the monopolist needs to transact only once, at the start of period 1, and can collect a price based on the consumer's valuation of the product over both periods. When leasing for one period at a time, the monopolist is forced to transact twice and collect each period's valuation in that period only. By offering free NVR, the monopolist avoids two transactions (one lease in each period) and saves on transaction costs.

Our model has several limitations. For one, our model applies to mature products, where the number of new consumers entering the market is not significant compared to the existing installed base. Because our model's key intuition is that offering free NVR decreases the number of potential buyers of the new version for the monopolist, if new consumers (who have not bought the previous version, and hence do not hold free new-version rights) arrive in significant numbers, that strengthens the monopolist's incentive to produce the new version, and so our model's results may not apply. Additionally, the products covered by our model must be improvable durable goods subject to network effects, among other assumptions. More research is needed to examine whether the results apply to other types of durable goods. More elaborate aspects such as a duopoly, a multiperiod setting with overlapping generations of consumers, and endogenizing the timing of release of the new versions, are interesting areas for future research. In applying the model, care must be taken to limit the duration of time for which the free NVR warranty is offered. Offering the warranty for too long could cause the monopolist to delay needed upgrades, thereby inviting competition and hurting the monopolist.

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Appendix A. Proofs of Propositions and Lemmas

Proposition 1. At the optimum, the monopolist M (a) sets the upgrade price for the newer version H so that all consumers who bought the older version L in period 1 will upgrade to H in period 2, (b) offers version H in period 2 to consumers who did not buy version L in period 1, and (c) withdraws version L from the market in period 2.

Mathematically, this proposition can be restated as: $\theta_U = \theta_1$, and $\theta_H = \theta_L$. It can be seen that $\partial^2 R_2/\partial\theta_U^2 = -2V_H + 2V_L + 2\alpha > 0$, because $\alpha > V_H - V_L$ by Assumption 2. Therefore, at the global optimum $(\theta_U^*, \theta_H^*, \theta_L^*)$ that maximizes R_2, the value of θ_U^* must be a corner point; i.e., $\theta_U^* = 1$ or $\theta_U^* = \theta_1$. Likewise, $\partial^2 R_2/\partial\theta_H^2 = -2V_H + 2V_L + 2\alpha > 0$. Therefore, $\theta_H^* = \theta_1$ or $\theta_H^* = \theta_L$. Evaluating $R_2(\theta_L)$ when (θ_U, θ_H) take on each of the following pairs of values $((1, \theta_1), (1, \theta_L), (\theta_1, \theta_1), (\theta_1, \theta_L))$, it can be seen that $R_2(\theta_L)$ is greatest when $(\theta_U, \theta_H) = (\theta_1, \theta_L)$:

$[R_2(\theta_L)]_{(\theta_U, \theta_H)=(1,\theta_1)} = (\theta_L V_L + \alpha(1-\theta_L))(\theta_1 - \theta_L)$

$[R_2(\theta_L)]_{(\theta_U, \theta_H)=(1,\theta_L)} = (\theta_L V_H + \alpha(1-\theta_L))(\theta_1 - \theta_L)$

$[R_2(\theta_L)]_{(\theta_U, \theta_H)=(\theta_1,\theta_1)} = (\theta_1(V_H - V_L) + \alpha(1-\theta_1))(1-\theta_1) + (\theta_L V_L + \alpha(\theta_1 - \theta_L))(\theta_1 - \theta_L)$

$[R_2(\theta_L)]_{(\theta_U, \theta_H)=(\theta_1,\theta_L)} = (\theta_1(V_H - V_L) + \alpha(1-\theta_L))(1-\theta_1) + (\theta_L V_H + \alpha(1-\theta_L))(\theta_1 - \theta_L)$

$[R_2(\theta_L)]_{(\theta_U, \theta_H)=(\theta_1,\theta_L)} - [R_2(\theta_L)]_{(\theta_U, \theta_H)=(1,\theta_1)} = (\theta_1 - \theta_L)\cdot(\theta_L V_H - \theta_L V_L) + (\theta_1(V_H - V_L) + \alpha(1-\theta_L))(1-\theta_1) > 0$

$[R_2(\theta_L)]_{(\theta_U, \theta_H)=(\theta_1,\theta_L)} - [R_2(\theta_L)]_{(\theta_U, \theta_H)=(1,\theta_L)} = (\theta_1(V_H - V_L) + \alpha(1-\theta_L))(1-\theta_1) > 0$

$[R_2(\theta_L)]_{(\theta_U, \theta_H)=(\theta_1,\theta_L)} - [R_2(\theta_L)]_{(\theta_U, \theta_H)=(\theta_1,\theta_1)} = 2\alpha(1-\theta_1)\cdot(\theta_1 - \theta_L) + \theta_L(V_{Hn} - V_L)(\theta_1 - \theta_L) > 0$

M's period 2 revenue is highest when she sells only version H as (a) upgrades to all consumers who bought version L in period 1, and (b) regular-priced products to all consumers who did not buy version L in period 1. Of particular note is the implication that M will not sell version L in period 2, which is in line with observed industry practice.

Lemma 1. There exists an optimal first-period cutoff type θ_1^* such that $0 < \theta_1^* < 1$, where $\theta_1^* = ((V_H - 2\alpha)^2 + 2V_L(V_H - \alpha))/((V_H - 2\alpha)^2 + 4V_L(V_H - \alpha))$.

Formulating the first-order condition to determine optimal θ_1^* that maximizes R_a,

$$\frac{\partial R_a}{\partial \theta_1} = 0. \tag{29}$$

Solving the above FOC for θ_1^*,

$$\theta_1^* = \frac{(V_H - 2\alpha)^2 + 2V_L(V_H - \alpha)}{(V_H - 2\alpha)^2 + 4V_L(V_H - \alpha)}. \tag{30}$$

Because $V_H > 4\alpha$, it is always the case that $0 < \theta_1^* < 1$.

Lemma 2. Optimally, the monopolist M prices the newer version H so that there exists a marginal consumer of type θ_H^* who has not bought the older version L in period 1, and is indifferent to buying version H and buying nothing in period 2.

Mathematically, there exists some θ_H^* such that $0 < \theta_H^* < \theta_1^* < 1$. From Equation (14), $\theta_H = \frac{1}{2}(V_H\theta_1 - 2\alpha)/(V_H - \alpha)$. It is to be shown that $\frac{1}{2}(V_H\theta_1 - 2\alpha)/(V_{Hn} - \alpha) > 0$. By Assumption 1, $V_H - \alpha > 0$. Therefore, it is to be shown that $V_H\theta_1 - 2\alpha > 0$. From Lemma 1, substituting $\theta_1 = ((V_H - 2\alpha)^2 + 2V_L(V_H - \alpha))/((V_H - 2\alpha)^2 + 4V_L(V_H - \alpha))$, it is to be shown that

$$V_H \frac{(V_H - 2\alpha)^2 + 2V_L(V_H - \alpha)}{(V_H - 2\alpha)^2 + 4V_L(V_H - \alpha)} - 2\alpha > 0.$$

The denominator is positive. The numerator can be rewritten as: $(V_H - 2\alpha)^3 + (V_H - 4\alpha)(2V_L)(V_H - \alpha)$. Because by Assumption 1 $V_H > V_L > 4\alpha$, it is verified that the numerator is positive. Hence, $\theta_H^* > 0$.

LEMMA 3. *If the monopolist produces only version L, she earns more revenue overall by selling version L in the first period, as opposed to selling version L in both periods; in this case, consumers of type $(\theta_b, 1)$ buy version L in period 1, where $\theta_b = \frac{1}{2}(V_L - 2\alpha)/(V_L - \alpha)$, and yield a revenue $R_b = \frac{1}{2}V_L^2/(V_L - \alpha)$. When the monopolist sells version L in both periods (Coase's commitment problem), consumers of type $(\theta_x, 1)$ buy version L in period 1, where $\theta_x = \frac{1}{5}(3V_L - 5\alpha)/(V_L - \alpha)$, and consumers of type (θ_y, θ_x) buy version L in period 2, where $\theta_y = (3V_L - 10\alpha)/10(V_L - \alpha)$. The revenue over both periods $R_{xy} = 9V_L^2/20(V_L - \alpha)$. $(R_b > R_{xy})$*

(a) If M offers version L in period 1 only, M sets a price P_b and a cutoff type θ_b so that all consumers belonging to types $(\theta_b, 1)$ buy version L in period 1, and consumers in $(0, \theta_b)$ do not use the software in either period. M's revenue $R_b = (1 - \theta_b)P_b$. The price P_b satisfies the constraint: $\theta_b V_L + \alpha(1 - \theta_b) + \theta_b V_L + \alpha(1 - \theta_b) - P_b \geq 0$. The θ_b consumer pays price P_b to purchase software version L in period 1 and derives identical value of $\theta_b V_L + \alpha(1 - \theta_b)$ in both periods.

Revenue is given by

$$R_b = 2(\theta_b V_L + \alpha(1 - \theta_b))(1 - \theta_b). \tag{31}$$

To derive the optimum θ_b that maximizes R_b, the first-order condition is given by

$$\frac{\partial R_b}{\partial \theta_1} = 2V_L - 4\theta_b V_L - 4\alpha + 4\alpha\theta_b = 0. \tag{32}$$

Solving the FOC,

$$\theta_b = \frac{1}{2}\frac{V_L - 2\alpha}{V_L - \alpha}. \tag{33}$$

Note that $0 < \theta_b < 1$ because by Assumption 1, $V_L > 4\alpha$. Substituting for θ_b^* in Equation (31),

$$R_b = \frac{1}{2}\frac{V_L^2}{V_L - \alpha}. \tag{34}$$

(b) If M offers version L in both periods: In the first period, consumers $(\theta_x, 1)$ buy version L at price P_x to yield revenue R_x. In the second period, consumers (θ_y, θ_x) buy version L at price P_y to yield revenue R_y. The following analysis first expresses prices P_x, P_y in terms of cutoff types θ_x, θ_y. Proceeding backwards in time, the optimal second-period cutoff θ_y^* is formulated in terms of θ_x, V_L, α. This helps express overall revenues (over both periods) in terms of θ_x, V_L, α. The first-order condition for overall revenues yields optimal (θ_x^*, θ_y^*) and yields an expression for overall revenues in terms of V_L, α.

The second-period price P_y satisfies $\theta_y V_L + \alpha(1 - \theta_y) - P_y \geq 0$ so that the cutoff consumer θ_y buys version L in period 2. Solving, we have

$$P_y = \theta_y V_L + \alpha(1 - \theta_y). \tag{35}$$

Second-period revenue is $R_y = P_y(\theta_x - \theta_y)$, which can be rewritten as

$$R_y = (\theta_y V_L + \alpha(1 - \theta_y))(\theta_x - \theta_y). \tag{36}$$

Because the monopolist maximizes revenue in the second period, solving the first-order condition $\partial R_y/\partial \theta_y = 0$ for θ_y yields

$$\theta_y^* = \frac{1}{2}\frac{V_L\theta_x - \alpha\theta_x - \alpha}{V_L - \alpha}. \tag{37}$$

First-period price P_x satisfies $\theta_x V_L + \alpha(1 - \theta_x) + \theta_x V_L + \alpha(1 - \theta_y) - P_x \geq \theta_x V_L + \alpha(1 - \theta_y) - P_y$. (The reasoning is similar to that for P_1 in Equation (18), §3.1.2.) Substituting for P_y and θ_y yields

$$P_x = \tfrac{3}{2}(\theta_x(V_L - \alpha) + \alpha). \tag{38}$$

First-period revenue $R_x = P_x(1 - \theta_x)$, which can be rewritten as

$$R_x = \left(\tfrac{3}{2}V_L\theta_x + \tfrac{3}{2}\alpha - \tfrac{3}{2}\alpha\theta_x\right)(1 - \theta_x). \tag{39}$$

Total revenue

$$R_{xy} = R_x + R_y. \tag{40}$$

Because the monopolist sets prices (i.e., chooses θ_x^* and θ_y^*) to maximize total revenue, solving for θ_x from the first-order condition $\partial R_{xy}/\partial \theta_x = 0$ yields

$$\theta_x^* = \frac{1}{5}\frac{3V_L - 5\alpha}{V_L - \alpha}. \tag{41}$$

Substituting for θ_x^* in Equation (37) yields

$$\theta_y^* = \frac{3V_L - 10\alpha}{10(V_L - \alpha)}. \tag{42}$$

Total revenue $R_{xy} = R_x + R_y = P_x(1 - \theta_x) + P_y(\theta_x - \theta_y)$. Substituting for P_x, P_y, θ_x^*, θ_y^* yields

$$R_{xy} = \frac{9V_L^2}{20(V_L - \alpha)}. \tag{43}$$

Comparing, $R_{xy} < R_b$:

$$\frac{9V_L^2}{20(V_L - \alpha)} < \frac{1}{2}\frac{V_L^2}{V_L - \alpha}. \tag{44}$$

Hence, if the monopolist produces only version L, she earns higher revenues if she offers this version for sale in period 1, and refrains from selling it in period 2.

LEMMA 4. *The seller sells version L (i) to fewer consumers, (ii) at a lower price, in period 1 if (A) she introduces the new version H in period 2, than (B) if she sells the older version L only and does not introduce the new version. This holds in the case (B.1) where she sells the older version in periods 1 and 2 (i.e., when Coase's commitment problem exists) as well as (B.2) where she sells the older version in period 1 only.*

(i) There are fewer consumers: From Lemma 1, we have $\theta_1 = ((V_H-2\alpha)^2+2V_L(V_H-\alpha))/((V_H-2\alpha)^2+4V_L(V_H-\alpha))$. If the seller does sell the older version in period 2, then from Lemma 3, we have $\theta_x = \frac{1}{5}(3V_L-5\alpha)/(V_L-\alpha)$. We show that $\theta_1 > \theta_x$: i.e.,

$$\frac{(V_H-2\alpha)^2+2V_L(V_H-\alpha)}{(V_H-2\alpha)^2+4V_L(V_H-\alpha)} > \frac{1}{5}\frac{3V_L-5\alpha}{V_L-\alpha}.$$

Simplifying the above inequality reduces to:

$$2V_L(V_H(V_H-V_L)+V_H\alpha+\alpha(V_L-\alpha))>0,$$

which is true because $V_L > \alpha$ and $V_H > V_L$. Hence, $\theta_1 > \theta_x$. In other words, the monopolist loses consumers in period 1 due to excessively frequent release of innovation, over and above consumers lost due to excessive sales. If the seller does not sell the older version in period 2, then from Lemma 4, we have $\theta_b = \frac{1}{2}(V_L-2\alpha)/(V_L-\alpha)$. We show that $\theta_1 > \theta_b$: i.e.,

$$\frac{(V_H-2\alpha)^2+2V_L(V_H-\alpha)}{(V_H-2\alpha)^2+4V_L(V_H-\alpha)} > \frac{1}{2}\frac{V_L-2\alpha}{V_L-\alpha}.$$

Simplifying the above inequality reduces to $V_L V_H^2 > 0$, which is true. Hence, $\theta_1 > \theta_b$. Again, fewer consumers buy because some low-type consumers wait until the second period to buy version V_H.

(ii) Price of version V_L in period 1 is lower:

From (19), $P_1 = \frac{1}{2}(-4V_L\theta_1\alpha + 4V_L\theta_1 V_H - 2\alpha^2 + 2\alpha^2\theta_1 - V_H^2\theta_1)/(V_H-\alpha)$.

From (38), $P_x = \frac{3}{2}(\theta_x(V_L-\alpha)+\alpha)$.

From (31), $P_b = 2(\theta_b V_L + \alpha(1-\theta_b))$.

Substituting for θ_1 in P_1, and θ_x in P_x, and comparing, it can be algebraically verified that $P_1 < P_x$, and $P_1 < P_b$.

Proposition 2. There exists a range of values for fixed cost c (whether or not the monopolist suffers from Coase's commitment problem) such that the monopolist M faces a commitment problem: (i) over both periods, M is better off not offering the newer version H in period 2, but (ii) M finds offering H attractive at the start of period 2.

(I) When the monopolist sells version L in period 1 only: The task is to prove that, simultaneously, (i) $R_a - 2c < R_b - c$, and (ii) $R_2 > c$; i.e. $R_2 > c > R_a - R_b$, or equivalently, $R_b > R_1$ (because $R_a = R_1 + R_2$ from Equation (20)).

$$R_b = \frac{1}{2}\frac{V_L^2}{V_L-\alpha};$$

$$R_1 = \frac{1}{2}(-4V_L\theta_1\alpha+4V_L\theta_1V_H-2\alpha^2+2\alpha^2\theta_1-V_H^2\theta_1)\frac{1-\theta_1}{V_H-\alpha},$$

where $\theta_1 = ((V_H-2\alpha)^2+2V_L(V_H-\alpha))/((V_H-2\alpha)^2+4V_L(V_H-\alpha))$.

To prove:

$$\frac{1}{2}\frac{V_L^2}{V_L-\alpha} > \frac{1}{2}\big(-4V_L\theta_1\alpha+4V_L\theta_1V_H-2\alpha^2 + 2\alpha^2\theta_1-V_H^2\theta_1\big)\frac{1-\theta_1}{V_H-\alpha}. \tag{45}$$

Equivalently, to prove:

$$-(V_L-\alpha)(2\alpha^2)\theta_1^2+(V_L-\alpha)\big(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha\big) \cdot\theta_1\big(1-\theta_1\big)+V_HV_L^2-\alpha(V_L-\alpha)^2-\alpha^3>0.$$

Because $-(V_L-\alpha)(2\alpha^2)\theta_1^2<0$, and $\max(\theta_1)=1$, it is sufficient to prove that

$$-(V_L-\alpha)(2\alpha^2)(1)^2+(V_L-\alpha)\big(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha\big) \cdot\theta_1(1-\theta_1)+V_HV_L^2-\alpha(V_L-\alpha)^2-\alpha^3>0.$$

Simplifying, it is sufficient to prove that $(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha)\theta_1(1-\theta_1)+V_L^2(V_H-\alpha)>0$. Because $V_H>\alpha$ the second term is always true. With respect to the first term, the following two cases are possible:

Case (i): $(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha)>0$. Because $\theta_1(1-\theta_1)\geq 0$, this implies that $(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha)\theta_1(1-\theta_1)+V_L^2(V_H-\alpha)>0$.

Case (ii): $(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha)<0$. $\theta_1=\frac{1}{2}$ maximizes $\theta_1(1-\theta_1)$, and so maximizes the absolute value of the negative expression: $(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha)$. Substituting $\max[\theta_1(1-\theta_1)]=1/4$, we have

$$(V_L-\alpha)\big(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha\big)\tfrac{1}{4}+V_L^2(V_H-\alpha) = \tfrac{1}{4}V_H^2(V_L-\alpha)+\alpha(\alpha-V_L)^2+\alpha V_L(V_H-V_L),$$

which is verified to always be true because, as per Assumption 1, $V_H>V_L>4\alpha$. Hence, the inequality (45) is true under all circumstances, which establishes the existence of a range of fixed costs $R_2>c>R_a-R_b$ such that M is tempted to offer version H in period 2 when her overall profit would be higher if she commits to not offer H.

(II) When the monopolist sells V_L in both periods: The task is to prove that, simultaneously, (i) $R_a-2c<R_{xy}-c$, and (ii) $R_2>c$; i.e., $R_2>c>R_a-R_{xy}$, or equivalently, $R_{xy}>R_1$ (since $R_a=R_1+R_2$ from Equation (20)).

$$R_{xy}=\frac{9V_L^2}{20(V_L-\alpha)};$$

$$R_1=\frac{1}{2}(-4V_L\theta_1\alpha+4V_L\theta_1V_H-2\alpha^2+2\alpha^2\theta_1-V_H^2\theta_1)\frac{1-\theta_1}{V_H-\alpha},$$

where $\theta_1=((V_H-2\alpha)^2+2V_L(V_H-\alpha))/((V_H-2\alpha)^2+4V_L(V_H-\alpha))$.

To prove:

$$\frac{9V_L^2}{20(V_L-\alpha)} > \frac{1}{2}(-4V_L\theta_1\alpha+4V_L\theta_1V_H-2\alpha^2 +2\alpha^2\theta_1-V_H^2\theta_1)\frac{1-\theta_1}{V_H-\alpha}. \tag{46}$$

Equivalently, to prove:

$$-(V_L-\alpha)(2\alpha^2)\theta_1^2+(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha) \cdot\theta_1(1-\theta_1)+V_HV_L^2-\alpha(V_L-\alpha)^2-\alpha^3>0.$$

Because $-(V_L-\alpha)(2\alpha^2)\theta_1^2<0$, and $\max(\theta_1)=1$, it is sufficient to prove that

$$-(V_L-\alpha)(2\alpha^2)(1)^2+(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha) \cdot\theta_1(1-\theta_1)+V_HV_L^2-\alpha(V_L-\alpha)^2-\alpha^3>0.$$

Simplifying, it is sufficient to prove that $(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha)\theta_1(1-\theta_1)+V_L^2(V_H-\alpha)>0$. Because

$V_H > \alpha$, the second term is always true. With respect to the first term, the following two cases are possible:

Case (i): $(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha)>0$. Because $\theta_1(1-\theta_1)\ge 0$, this implies that $(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha)\theta_1(1-\theta_1)+V_L^2(V_H-\alpha)>0$.

Case (ii): $(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha)<0$. $\theta_1=\frac{1}{2}$ maximizes $\theta_1(1-\theta_1)$, and so maximizes the absolute value of the negative expression: $(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha)$. Substituting $\max[\theta_1(1-\theta_1)]=1/4$, we have

$$\begin{aligned}&(V_L-\alpha)(-4\alpha^2-4V_LV_H+V_H^2+4V_L\alpha)(1/4)+V_L^2(V_H-\alpha)\\&\quad=\tfrac{1}{4}V_H^2(V_L-\alpha)+\alpha(\alpha-V_L)^2+\alpha V_L(V_H-V_L),\end{aligned}$$

which is verified to always be true, because as per Assumption 1, $V_H > V_L > 4\alpha$. Hence, there exists a range of fixed costs $R_2 > c > R_a - R_{xy}$ such that M is tempted to (suboptimally) offer version H in period 2 when her overall profit would be higher if she commits to not offer H.

Lemma 5. If M bundles free NVR with version L for a subset of consumers $(\theta_f, 1)$ in the first period, and produces version H in period two, (i) she never sells version L in period two; (ii) she sells only version H to a fraction of consumers (θ_H, θ_f) and earns a revenue R_H in the second period, where

$$\theta_H=\frac{1}{2}\left(\frac{2V_L-5\alpha+V_H}{4V_L-5\alpha+V_H}-\frac{\alpha}{V_H-\alpha}\right),\qquad \theta_f=\frac{2V_L-5\alpha+V_H}{4V_L-5\alpha+V_H}.$$

(i) From Equation (27), computing partial second derivatives for R_2 with respect to each of the two decision variables,

$$\frac{\partial^2 R_2}{\partial\theta_L^2}=-2V_L+2\alpha<0 \tag{47}$$

$$\frac{\partial^2 R_2}{\partial\theta_H^2}=2(\alpha-V_H+V_L)>0 \tag{48}$$

(because $\alpha > V_H - V_L$ by Assumption 2).

Because $\partial^2R_2/\partial\theta_H^2>0$, any global maximum must be at a corner point for θ_H. In other words, either (a) $\theta_H=\theta_L$, or (b) $\theta_H=\theta_f$.

(a) When $\theta_H=\theta_L$ we have

$$R_{2(\theta_H=\theta_L)}=(\theta_LV_H+\alpha(1-\theta_L))(\theta_f-\theta_L). \tag{49}$$

(b) When $\theta_H=\theta_f$ we have

$$R_{2(\theta_H=\theta_f)}=(\theta_LV_L+\alpha(\theta_f-\theta_L))(\theta_f-\theta_L). \tag{50}$$

It can be seen that $R_{2(\theta_H=\theta_L)}>R_{2(\theta_H=\theta_f)}$, because $R_{2(\theta_H=\theta_L)}-R_{2(\theta_H=\theta_f)}>0$:

$$\begin{aligned}&R_{2(\theta_H=\theta_L)}-R_{2(\theta_H=\theta_f)}\\&\quad=[\theta_L(V_H-V_L)+\alpha(1-\theta_f)](\theta_f-\theta_L)>0,\end{aligned} \tag{51}$$

because by assumption $\theta_L<\theta_f<1$ and $V_H>V_L$. Therefore, M will choose $\theta_H=\theta_L$, i.e., sell version V_H to consumers (θ_L, θ_f) in period 2, and not sell V_L in period 2.

(ii) The goal now is to determine θ_H^*. From Equation (49) above,

$$R_2=R_H=(\theta_LV_H+\alpha(1-\theta_L))(\theta_f-\theta_L)$$

where $\theta_H=\theta_L$. Using θ_H instead of θ_L in the above equation,

$$R_H=(\theta_HV_H+\alpha(1-\theta_H))(\theta_f-\theta_H). \tag{52}$$

Solving the first-order condition, $\partial R_H/\partial\theta_H=0$, we have

$$\theta_H^*=\frac{1}{2}\frac{V_H\theta_f-\alpha\theta_f-\alpha}{V_H-\alpha}. \tag{53}$$

The next goal is to determine θ_f^*, which will help derive θ_H^* in terms of V_H, V_L, α.

Overall revenue $R=R_1+R_H$, where $R_1=P_1(1-\theta_f)$ and R_H is as in Equation (52) above. P_1 satisfies $\theta_fV_L+\alpha(1-\theta_f)+\theta_fV_H+\alpha(1-\theta_H)-P_1\ge\theta_fV_H+\alpha(1-\theta_H)-P_H$, so that

$$P_1=\theta_fV_L+2\alpha-\alpha\theta_f-\alpha\theta_H+\theta_HV_H \tag{54}$$

$$R_1=(\theta_fV_L+2\alpha-\alpha\theta_f-\alpha\theta_H+\theta_HV_H)(1-\theta_f). \tag{55}$$

Substituting for θ_H from Equation (53) into the expressions for R_1 and R_H, and solving the first-order condition: $\partial R/\partial\theta_f=0$, we have

$$\theta_f^*=\frac{2V_L-5\alpha+V_H}{4V_L-5\alpha+V_H}. \tag{56}$$

Because by assumption $V_H>V_L>4\alpha$, we have $0<\theta_f^*<1$. With this value of θ_f, it follows that

$$\theta_H^*=\frac{1}{2}\left(\frac{2V_L-5\alpha+V_H}{4V_L-5\alpha+V_H}-\frac{\alpha}{V_H-\alpha}\right). \tag{57}$$

Lemma 6. Both θ_H and θ_f exist: $0<\theta_H<\theta_f<1$.

(i) $0<\theta_f<1$: From Equation (56), we have $\theta_f=(2V_L-5\alpha+V_H)/(4V_L-5\alpha+V_H)$. By Assumption 1, $V_H>V_L>4\alpha$, therefore we have $0<\theta_f<1$.

(ii) $\theta_H<\theta_f$: Because $\theta_H=\frac{1}{2}(\theta_f-\alpha/(V_H-\alpha))$, therefore $\theta_H<\theta_f$.

(iii) $0<\theta_H$: rewriting Equation (57),

$$\theta_H=\frac{1}{2}\frac{(2V_L-5\alpha+V_H)(V_H-\alpha)-\alpha(4V_L-5\alpha+V_H)}{(4V_L-5\alpha+V_H)(V_H-\alpha)}. \tag{58}$$

The denominator is always positive. The numerator is rewritten as: $(V_H-2\alpha)(V_H-5\alpha)+2V_L(V_H-3\alpha)$. Given assumptions $V_H>V_L>4\alpha$, $V_H-V_L<\alpha$, if the numerator is negative, it implies the $(V_H-5\alpha)$ in the first term is negative. Consider the interval: $4\alpha<V_H<5\alpha$. Expanding the first term,

$$(V_H-2\alpha)(V_H-5\alpha)=-7\alpha V_H+10\alpha^2+V_H^2. \tag{59}$$

Evaluating the first-order condition,

$$\frac{\partial(-7\alpha V_H+10\alpha^2+V_H^2)}{\partial V_H}=-7\alpha+2V_H=0. \tag{60}$$

This implies that $V_H=3.5\alpha$ minimizes the first term. When $V_H=4\alpha$,

$$\frac{\partial(-7\alpha V_H+10\alpha^2+V_H^2)}{\partial V_H}=-7\alpha+8\alpha=\alpha>0. \tag{61}$$

The slope of the curve is positive at $V_H=4\alpha$. Based on results (60) and (61) above, the first term $(V_H-2\alpha)(V_H-5\alpha)$ increases in V_H for all $V_H\in[4\alpha,5\alpha]$. Therefore,

$$\begin{aligned}&\min[(V_H-2\alpha)(V_H-5\alpha)]_{V_H\in[4\alpha,5\alpha]}\\&\quad=[(V_H-2\alpha)(V_H-5\alpha)]_{V_H=4\alpha}=-2\alpha^2.\end{aligned}$$

If $V_H = 4\alpha$, then $V_L = 4\alpha$, by Assumption 1. This implies

$$\min[(V_H - 2\alpha)(V_H - 5\alpha) + 2V_L(V_H - 3\alpha)] \quad (62)$$

$$= (4\alpha - 2\alpha)(4\alpha - 5\alpha) + 8\alpha(4\alpha - 3\alpha) = 6\alpha^2 > 0. \quad (63)$$

Therefore, $0 < \theta_H < 1$ in the range of interest.

PROPOSITION 3. If the monopolist bundles free NVR with version L in period one, there exist some values of fixed cost c when revenue from sale of version H is unprofitable: (a) Free NVR will solve M's commitment problem when the fixed cost is relatively high: c lies between (R_H, c_{MAX}), whether or not M faces the Coasian commitment problem. (b) Free NVR will not solve her commitment problem and will only help collect revenues earlier when the fixed cost is relatively low: c lies between (c_{MIN}, R_H) (or $(c_{MIN(COASE)}, R_H)$, when the monopolist suffers from the Coasian commitment problem).

From Equation (49), $R_H = (\theta_H V_H + \alpha(1 - \theta_H))(\theta_f - \theta_H)$, where

$$\theta_H = \frac{1}{2}\left(\frac{2V_L - 5\alpha + V_H}{4V_L - 5\alpha + V_H} - \frac{\alpha}{V_H - \alpha}\right) \quad \text{and} \quad \theta_f = \frac{2V_L - 5\alpha + V_H}{4V_L - 5\alpha + V_H}.$$

Substituting for θ_H and θ_f in the expression for R_H,

$$R_H = \frac{(V_H(V_H - 5\alpha) + 2V_L(V_H + \alpha))^2}{4(V_H - \alpha)(V_H + 4V_L - 5\alpha)^2}. \quad (64)$$

It can be algebraically verified that $c_{MAX} > R_H > c_{MIN}$ and $c_{MAX} > R_H > c_{MIN(COASE)}$ $\forall (V_H > V_L > 4\alpha, V_H - V_L < \alpha)$, where c_{MAX}, c_{MIN}, and $c_{MIN(COASE)}$ are as per Equations (24), (22), and (23).

When $c \in (R_H, c_{MAX})$, the revenue from selling the upgraded version R_H assumes that the monopolist sells the version L in period 1, followed by version H in period 1. However, if R_H does not cover the fixed cost of upgrade c, and if the consumers' expectation in the first period is that the monopolist will not sell version H in period 2, will the resulting installed base of first-period consumers be such as to tempt the monopolist to offer version H in period 2? We show that this will not happen. First, we show that $R < R_H$ $\forall \theta < \theta_f$. Then, we show that $\theta_x < \theta_f$, which implies that if M intends to sell L in period 2, there are fewer consumers $(1 - \theta_x)$ left in period 1 than there are when M intends to sell H in period 2 $(1 - \theta_f)$. Likewise, we show that $\theta_b < \theta_f$—when M intends to sell L in period 1 and sell nothing in period 2.

We show that $R < R_H$ $\forall \theta < \theta_f$: From Equation (52) we have $R_H = (\theta_H V_H + \alpha(1 - \theta_H))(\theta_f - \theta_H)$. Using result (53), we substitute $\theta_H^* = \frac{1}{2}(V_H\theta_f - \alpha\theta_f - \alpha)/(V_H - \alpha)$, and compute $\partial R_H / \partial \theta_f$:

$$\frac{\partial R_H}{\partial \theta_f} = \frac{1}{2}\theta_f(V_H - \alpha) + \frac{1}{2}\alpha > 0;$$

i.e., as θ_f decreases, R_H decreases: for all $\theta < \theta_f$, $R < R_H$. Therefore, if $R_H < c$, then $R < c$.

We show that $\theta_x < \theta_f$, $\theta_b < \theta_f$: These two inequalities arise because when M does not intend to produce H in period 2, there are two possibilities to consider. (i) If the consumers' expectation in the first period is that the monopolist will sell version L in both periods (i.e., the Coasian commitment problem exists), then the first-period installed base is θ_x (from Lemma 3). (ii) If the expectation is that the monopolist will sell version L in period 1 only, then the first-period installed base is θ_b (from Lemma 3).

In either case, we show that when $c \in (R_H, c_{MAX})$, the ability of Free NVR to solve the monopolist's frequent new-version commitment problem is an equilibrium outcome:

(i) The monopolist will sell version L in period 1 only: $\theta_x < \theta_f$:

From Equation (56), $\theta_f = (2V_L - 5\alpha + V_H)/(4V_L - 5\alpha + V_H)$.

From Equation (41), $\theta_x = \frac{1}{5}(3V_L - 5\alpha)/(V_L - \alpha)$.

It can be seen that $\frac{1}{5}(3V_L - 5\alpha)/(V_L - \alpha) < (2V_L - 5\alpha + V_H)/(4V_L - 5\alpha + V_H)$, because by simplifying the inequality, we get $2V_L(V_H - V_L) > 0$.

(ii) The monopolist will sell version L in both periods: $\theta_b < \theta_f$:

From Equation (33), $\theta_b = \frac{1}{2}(V_L - 2\alpha)/(V_L - \alpha)$.

It can be seen that $\frac{1}{2}(V_L - 2\alpha)/(V_L - \alpha) < (2V_L - 5\alpha + V_H)/(4V_L - 5\alpha + V_H)$, because by simplifying the inequality, we get $V_L(V_H - \alpha) > 0$.

Hence, proved: When $c \in (R_H, c_{MAX})$, bundling free NVR with the version L in period 1 solves the frequent new-version commitment problem.

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