Vaporware

by

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Abstract

It is a widely adopted practice for firms to announce new products well in advance of actual market availability, especially in the computer industry. This practice of pre-announcement often has been derisively referred to as "vaporware" since many of the products either never reach the market or are significantly delayed. We provide a simple model of vaporware and discuss its implications for social welfare and anti-trust policy.

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[S]ome things never change: The tech industry continues to whip up excitement by promising amazing new technologies, only to crush our spirits by delaying, postponing, pushing back or otherwise derailing the arrival of said goods -- sometimes indefinitely.[1]

I. Introduction

It is a widely adopted practice for firms to announce new products well in advance of actual market availability, especially in the computer industry. This practice of pre-announcement often has been derisively referred to as "vaporware" since many of the products either never reach the market or are significantly delayed.[2] As such, the practice has been subject to scrutiny by policymakers for its potential predatory and anti-competitive implications. Specific examples include the IBM case in 1960s and, more recently, the Microsoft case. In the IBM case, for example, IBM announced the development of its System/360 line of computers and related peripherals far in advance of their availability, and the Department of Justice accused IBM of making premature and predatory product announcements regarding the product line.[3]

In relation to the landmark antitrust case of U.S. vs. IBM, Fisher, et al. (1983) provide an early discussion of information transmission, product pre-announcement, and reputation. In defense of such a practice, Fisher, et al. argue:

> In general, there is no reason to inhibit the time when a firm announces or brings products to the marketplace. Customers will be the final arbiters of the product's quality and the firm's reputation. Broken promises and unattractive products can be expected to lead quickly to a loss of credibility and sales. . . . Advance announcement of truthful information about products cannot be anticompetitive. Indeed, such announcement is procompetitive; competition thrives when information is good. . . . If those announcements of its belief were made in good faith, then it was imparting information to consumers and competitors as to what it expected to do. Even if it was later unable to do those things, the imparting of such information can only aid competition. Only deliberate falsehood could possibly be anticompetitive here, and that is highly improbable since a firm that practiced such tactic would acquire a tarnished reputation that would ill-serve it in the future (pp. 289-290).

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[1] Quoted from "Vaporeware 2000: Missing Inaction," *Wired News* by Leander Kahney.
[2] See Bayus et al. (2001) for an entertaining discussion on the origin of the term "vaporware."
[3] For a detailed discussion of the IBM case, see Fisher et al. (1983). See also Levy (1997) for antitrust implications of vaporware.

In this paper, we develop a reputation model of vaporware in which firms can make product pre-announcements. More specifically, we consider a situation where a firm develops a new product while a competitive product already exists. Consumers need to decide whether to purchase the currently available product or to wait until the advent of the new product. For this decision to be relevant, we assume that, due to switching costs, consumers cannot purchase the existing product and later make another purchase when the new product is available (see Klemperer (1995)). However, consumers do not have perfect information about the quality/availability of the new product, which is the firm's private information. We ask whether or not consumers can rely on firm-provided information concerning the quality/availability of the new product. Since the firm always prefers to have the consumers wait for its product, the firm's pre-announcement cannot have any informational content if the game is played only once. Thus, we consider a pre-announcement game played twice to investigate under what circumstances the firm can convey the information in a credible way.

In our paper, different types of firms that have different R&D capabilities have different chances of introducing a high-quality product in the second product cycle. We derive the value of being honest *endogenously* and show that the value of being honest increases in the chance of introducing a high-quality product in the second product cycle. That is, firms with higher R&D capabilities care more about their reputation. We find that there can be an informative equilibrium where the product pre-announcement can convey information about the product's quality. The equilibrium is characterized by a cut-off point where semi-separation of types takes place; only types higher than the cut-off point have the incentive to tell the truth when product quality is low. Thus, in equilibrium we can observe various outcomes—both lying and telling the truth—depending on the firm's type.

We also analyze the welfare effects of product pre-announcement and discuss its anti-trust implications. We show that product pre-announcements always benefit consumers. Even if the firm might make misleading claims about its product quality, consumers can rationally discount the firm's claims, and the firm's announcement can be at least partially revealing, which helps consumers make a better decision.

Farrell and Saloner (1986) provide an early analysis of how product pre-announcements affect consumers' technology adoption decisions. In response to the argument made above by Fisher, et al. (1983), they point out the possibility of anti-competitive product pre-announcements in the presence of *network effects*. In particular, they construct a dynamic model of technology adoption in which the timing of the announcement of a new *incompatible* product can critically determine whether the new product succeeds in replacing the existing technology. Due to the presence of network effects, even if the potential users who decide to wait are indeed well-informed and their welfare is increased as a result of product pre-announcement, their adoption of the new technology may adversely affect both the users in the installed base and later adopters who might have preferred the old technology to the new one. Their paper, however, considers only truthful pre-announcements and the possibility of false announcements and consumers' potentially incorrect inference about the informational content is not analyzed.

Several papers also analyze how product pre-announcements can be used as a strategic tool. For instance, Bayus, et al. (2001) present a model in which product pre-announcement is used as a strategic signal for rival firms. In the paper, intentional vaporware is used as a way to dissuade competitors from developing their own competing new products. Our model, in contrast, analyzes a communication channel between the firm and consumers. Thus, the purpose of product pre-announcement in Bayus, et al. (2001) is entry deterrence, whereas the purpose of our model is to persuade consumers to wait until the arrival of its new product.[4] Also, Bayus, et al. adopt an *ad hoc* assumption that making a false announcement is costly, without any micro-foundation for penalty costs associated with false announcements. In contrast, we develop a model of vaporware in which the reputation cost is *endogenously* derived. Gerlach (2004) is another paper that examines an entrant's incentives to pre-announce new products when such pre-announcements may induce the incumbent to cut prices and preempt the market. He shows that the possibility of a preemptive move by the

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[4] Haan (2003) is another paper that develops a model of vaporware as a means of entry deterrence. In his model, however, separating equilibria do not exist and all firms claim that they have innovation. As a result, pre-announcement has no informational content. In contrast, in our paper, only a subset of firms lie, and, as a result, the pre-announcement is partially informative.

incumbent may prevent the entrant from making announcements. In contrast to our paper, he focuses primarily on verifiable announcements.[5] We show how reputational concerns may prevent firms from making false announcements.

Levy (1997) explores anti-trust implications of vaporware.   As in our model, he considers a situation in which consumers do not know the veracity of the firm's announcement when it is made. However, he does not explicitly model reputation. Dranove and Gandal (2003) provide an empirical analysis of pre-announcement effects in the DVD market. In the standard war between the DVD and DIVX formats, they show that the pre-announcement of DIVX slowed down the adoption of DVD technology, which is consistent with our theory.

Our paper is also related to the theoretical literature on strategic information transmission, which examines how an uninformed party elicits information from an informed party when these two sides can have a 'cheap talk.' (See Crawford and Sobel (1982) and Sobel (1985), for example.)   Sobel (1985) analyzes how reputation is formed in a cheap talk under the assumption that an 'honest' type always tells the truth. One important paper that is closely related to ours is Morris (2001). As in Sobel (1985) and our paper, Morris (2001) analyzes reputational concerns that arise endogenously when a static cheap talk game is repeated. He considers an advice game in which an informed advisor wishes to convey a valuable piece of information to an uninformed policymaker with *identical* preferences. In a twice-repeated cheap talk game, Morris analyzes how reputation concerns affect a cheap talk between informed and uninformed sides.   In particular, he focuses on the possibility that reputational concerns might lead to a situation in which *no* information is conveyed in equilibrium. He calls this "political correctness."[6] Both Morris's and our paper deal with how concerns about future reputation can impact the transmission of information today.   One major difference is that he considers a situation in which the advisor has incentives to tell the truth in a static context, whereas the advisor's incentives to tell the truth and the possibility of valuable information being transmitted are distorted in a dynamic context. In contrast, we

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[5] If false announcements were allowed, all firms would lie in equilibrium.
[6] This paradoxical result takes place when the policymaker thinks that the advisor might be biased in favor of one decision, and the advisor, wanting his/her valuable advice to have an impact on future decisions, does not wish to be thought of as biased.

consider a situation in which the informed party always has incentives to lie and no information can be conveyed in a static context, and we investigate how reputational concerns can mitigate this problem.

The remainder of the paper is organized as follows. In Section II, we develop a model of product pre-announcements. We derive conditions under which a vaporware equilibrium exists and discuss its properties. In equilibrium, more-innovative firms have incentives to maintain reputation and make truthful announcements while less-innovative firms have incentives to make false announcements. Overall, the announcements are partially revealing in equilibrium. In section III, we analyze welfare implications of product pre-announcements. Section IV contains concluding remarks.

II.   A Model of Vaporware

We consider a game that is played by consumers and a firm that develops a sequence of new products. For simplicity, we assume that there are two sequential product cycles in which the firm can introduce a new product. In each product cycle, there exists an alternative product that is competitively supplied. When the firm develops a new product in each product cycle, the quality of the new product can be either high (H) or low (L). The probability that the development research outcome leads to a high-quality product is denoted by $\theta \in [0,1]$, which can be considered the firm's type. The firm type is invariant across product cycles and represents the firm's "innovativeness" or research capability. The realization of quality, however, is independent across product cycles. The firm knows its own type, θ, but consumers know only the distribution of θ. We assume that θ is distributed according to a distribution function F(.).

In each product cycle, there are two periods. In the first period, the only product available is the existing product that is competitively supplied. The firm is in the process of developing a new product that can be introduced in the second period. Through the product development process, the firm knows the quality of the product to be introduced in the next period. To analyze the implications of product pre-announcement, we allow the firm to communicate the quality of the product to consumers prior to its actual introduction to persuade consumers to delay their purchase. However, we do not allow a contract between the firm and consumers that is contingent on the delivered quality of the

new product. In other words, we assume that there is no recourse for consumers if the firm does not deliver its promised quality.[7]

In each product cycle, consumers have unit demand for the product. Each consumer has two choices in the first period: he can either purchase the existing product at the competitive price or wait until the second period for the new product. We assume that once the consumer purchases in the first period, he cannot switch to the new product in the second period. The assumption can be justified if the product is a durable good and making another purchase in the second period does not justify the additional price to pay or if there is a very high switching cost (Klemperer (1995)). When consumers wait, they forego current consumption benefits that can be interpreted as their waiting costs. Consumers are heterogeneous in their current consumption benefits from the existing product, which we denote as w. The foregone consumption benefits/waiting costs (w) are distributed on $[0, \infty)$ according to a cumulative distribution function $G(.)$ with continuous density $G' \geq 0$.

The new product developed by the firm is superior to the existing product regardless of its quality realizations. For each quality realization, we assume that how much *additional* value the new product provides vis-à-vis the existing product is random and differs across consumers. This value is revealed to consumers only in the second period and is unknown to them in the first period.[8] As a result, the additional value of the new product for a consumer is independent of his current benefits from the existing product, and each consumer makes his purchase/wait decision based on expected values, with the high-quality product providing more additional expected value than the low-quality one. The consumers are, thus, heterogeneous only in terms of waiting costs in the first period. This assumption simplifies our analysis since it implies that the waiting decision in the first period does not provide any information about the consumer's relative valuation of the new product and prevents the firm from practicing behavior-based dynamic price discrimination (Fudenberg and Tirole (2000) and Taylor (2003)).

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[7] For instance, when a software company promises features of a new software program in advance, it could be difficult to describe them in precise terms, without any ambiguity, so that the contract could be enforceable in court.

[8] For instance, when new features are promised for new software, it would be difficult to know in advance how much additional value such features would provide.

Let s_H (s_L) be the *expected* value of the indirect utility difference between the high-quality (low-quality) new and old products if consumers delay their purchase decision until the introduction of the new product. That is, the expected consumer surplus from waiting until period two is $w + s_i$, where i = H or L, depending on the quality realization of the new product, while that of buying the current product in period one is $2w$.

We assume that $s_H > s_L > 0$; a consumer gets a higher surplus from the high-quality product than from the low-quality product. This implies that consumers are more willing to wait if the new product is of high quality. When a consumer waits, the firm's expected profits from the high- and low-quality products in period two are denoted by π_H and π_L, respectively, where $\pi_H > \pi_L > 0$. We do not lay out a specific model of competition between the firm that introduces the new product and the competitive suppliers of the existing product and strive to be as general as possible in the model set-up. However, we provide a specific model that fits with the assumptions of the general setting in the Appendix.

II.1. No Announcement Case

To analyze the implications of product pre-announcements, let us consider first the case where such announcements are not feasible or are banned by the government as a benchmark case. In such a case, the consumer's expected value from waiting until the second period in the first product cycle is given by $\overline{w_1}$ = E(θ) s_H+ (1-E(θ))s_L, where E(θ) $= \int_0^1 \theta dF(\theta)$. Thus, the number of consumers who delay their purchase decisions are given by G($\overline{w_1}$).

In the second product cycle, the consumers can update their beliefs about the firm type from the quality of the product in the first cycle. If the firm produced a high-quality product in the first cycle, then the expected value of the firm type is given by:

$$E(\theta|H) = \int_0^1 (\frac{\theta}{\int_0^1 \theta dF(\theta)})\theta dF(\theta) = \frac{E(\theta^2)}{E(\theta)}$$

In contrast, if the firm produced a low-quality product in the first product cycle, the updated beliefs are given by:

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$$E(\theta|L) = \int_0^1 \left(\frac{1-\theta}{\int_0^1 (1-\theta)dF(\theta)}\right)\theta dF(\theta) = \frac{E[\theta(1-\theta)]}{1-E(\theta)}$$

Lemma 1. $E(\theta|L) < E(\theta) < E(\theta|H)$.

Proof. We use Jensen's inequality to prove the claim.

$$E(\theta|H) = \frac{E(\theta^2)}{E(\theta)} \geq \frac{[E(\theta)]^2}{E(\theta)} = E(\theta).$$

$$E(\theta|L) = \frac{E[\theta(1-\theta)]}{1-E(\theta)} = \frac{E(\theta)-E(\theta^2)}{1-E(\theta)} \leq \frac{E(\theta)-[E(\theta)]^2}{1-E(\theta)} = \frac{E(\theta)[1-E(\theta)]}{1-E(\theta)} = E(\theta). \quad Q.E.D.$$

Lemma 1 says that consumers revise their beliefs about the firm's research capability upward after the introduction of a high-quality product and downward after the introduction of a low-quality product. The consumer's expected value from waiting until the second period in the second product cycle therefore depends on the quality of the new product in the previous cycle. If the previous introduction is of quality q, the consumer's expected value from waiting is $\overline{w_2}(q) = E(\theta|q)s_H + (1-E(\theta|q))s_L$, where $q = H, L$ and $\overline{w_2}(H) > \overline{w_1} > \overline{w_2}(L)$. The number of consumers waiting in the second product cycle in turn depends on the history of the game and is given by $G(\overline{w_2}(H))$ and $G(\overline{w_2}(L))$, respectively, with $G(\overline{w_2}(H)) > G(\overline{w_1}) > G(\overline{w_2}(L))$.

II.2. The Announcement Case

Now we allow the possibility that the firm announces in the first period the product quality in each cycle prior to its release in the second period. We are searching for a Perfect Bayesian equilibrium (PBE) in which all players' strategies are sequentially optimal and consumers' beliefs about the firm type are derived by the Bayes' rule whenever possible. We assume that product pre-announcements are 'cheap talk' and do not entail any costs to make. As in any model of cheap talk, we always have a babbling equilibrium in which the cheap talk has no meaning and is rationally ignored by the receiver. We are interested in whether we can have an informative equilibrium in which the firm, by making an announcement, can convey credible information on the quality of

its product to consumers. We analyze how the reputation is formed in equilibrium and how the concern over reputation affects cheap talk.

Figure 1 describes the timing of the game. We denote the discount factor between the two product cycles by δ.[9] For simplicity, we assume that there is no discounting between the two periods in each cycle.[10]

First Product Cycle		Second Product Cycle

Period 1

After observing the quality of the new product, the firm announces its quality.

Buyers wait or buy the current product which is competitively supplied.

Period 2

A new product is introduced, and the true quality is revealed.

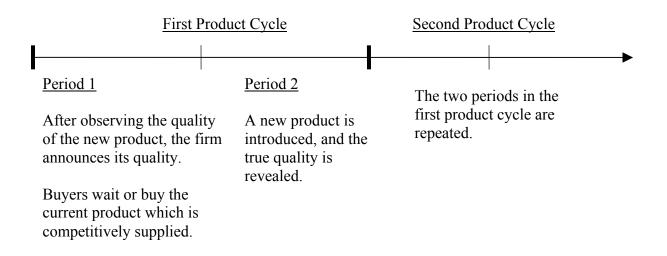The two periods in the first product cycle are repeated.

Figure 1: The Timing of Moves

As usual, we proceed by using backward induction to derive the informative equilibrium.

II.2.1. Second Product Cycle

In the second product cycle that constitutes the last interaction with consumers, the firm does not have any reputational concerns and will simply seek to maximize its current profits. Since all types benefit from inducing more consumers to wait, the firm's announcement in the second product cycle (m_2) has no credibility. Thus, no consumer updates his beliefs μ_2 based on the firm's announcement m_2. Thus, the relevant history in the second product cycle is $h_2 = (m_1, q_1)$, where m_1 and q_1 are the announced quality and

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[9] Even though the two product cycles entail different products, we assume that all parameters are the same across cycles. We can easily modify the model to allow different parameter values with additional notation. We can capture the differences in the importance of the two products by the discount factor δ.
[10] Once again, this assumption is made without any loss of generality, and discounting within the product cycle can be easily accommodated.

the delivered quality of the product, respectively, in the first cycle and
$h_2 \in \{(H,H),(H,L),(L,H),(L,L)\}$.[11]

In each product cycle, consumers' optimal strategy depends on their belief that the new product in the same cycle is of high-quality. Thus, we associate consumers' beliefs with the expected θ based on all information consumers have. This implies that, at the beginning of period 2, there will be history-dependent beliefs (μ_2) conditional on the announced and delivered qualities of the product in the first cycle.

$$\mu_2(h_2) = E(\theta | h_2), \text{ where } h_2 \in \{(H,H),(H,L),(L,H),(L,L)\}$$

Given μ_2, consumers whose waiting cost (w) is lower than $\mu_2 s_H + (1-\mu_2)s_L$ will wait until period two. Let $w_i{}^*$ denote the cutoff point in product cycle i. Note that the threshold value $w_2{}^*$ is history-dependent in the same way as the buyers' beliefs.

$$w_2{}^* = w_2(h_2) = \mu_2(h_2)s_H + [1-\mu_2(h_2)]s_L$$

The number of consumers waiting in the second product cycle is $G[w_2(h_2)]$.

Given the consumers' beliefs μ_2, the expected profit of the firm whose type is θ is given by

$$\Pi_2(\theta) = G[\mu_2 s_H + (1-\mu_2)s_L][\theta \pi_H + (1-\theta)\pi_L].$$

Since the profit is directly proportional to the number of consumers waiting ($G[\mu_2 s_H + (1-\mu_2)s_L]$), and more consumers are willing to wait when the firm has a better reputation for "innovativeness" (that is, a higher μ_2), all types of firms benefit from a better reputation. However, the value of reputation is higher for firms with higher θ, that is, $\frac{\partial^2 \Pi_2(\theta)}{\partial \theta \partial w_2} > 0$. Thus, the Spence-Mirrles single crossing property holds, and this property is an important factor in making the announcement in the first cycle informative.[12]

II.2.2. First Product Cycle

We know that the announcement in the second (last) product cycle cannot contain any meaning since there is no further reputational concern for the firm. In the first

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[11] If the firm does not make an announcement about its product, consumers believe that the product is of low quality.
[12] See Mas-Colell, et al. (1995) for the role of the single crossing property in the incentive literature.

product cycle, however, the firm has to be concerned with its reputation in view of the new product introduction in the second cycle. Let $m_1(q_1 ;\theta)$ denote the message of type θ firm when it has the new product of quality q_1 in the first cycle, where $q_1 = H$ or L.

Since the firm with a higher θ has more incentive to maintain a better reputation, we are looking for an informative equilibrium with the following cut-off point property:

$$\text{For } \theta \geq \theta^* \qquad m_1(q_1;\theta) = q_1$$

$$\text{For } \theta < \theta^* \qquad m_1(q_1;\theta) = H$$

In other words, if the product is of high quality, all types announce it truthfully; if the product is of low quality, then there is a cutoff point θ^* such that types $\theta \geq \theta^*$ announce it truthfully, and types $\theta < \theta^*$ make a false announcement.

Consumers update their belief about the firm's type according to the firm's strategies. Let us denote consumers' beliefs in the first product cycle by $\mu_1(m_1 ; \theta^*)$ when the firm is expected to adopt the cut-off rule of θ^*, where m_1 is the firm's announcement about its quality and $m_1 \in \{H, L\}$. By applying the Bayes rule, we can derive consumers' beliefs in the first and second product cycles as follows:

$$\mu_1(H;\theta^*) = \frac{E(\theta)}{F(\theta^*) + \int_{\theta^*}^{1} \theta dF(\theta)}, \qquad \mu_1(L;\theta^*) = \mu_1(L) = 0$$

We can also derive consumers' beliefs in the second product cycle, $\mu_2(h_2 ;\theta^*) = \mu_2(m_1, q_1 ;\theta^*)$, depending on the announced and delivered qualities in the first product cycle, when the firm was expected to adopt the cut-off rule of θ^* in the first product cycle announcement.

$$\mu_2(H,H;\theta^*) = \mu_2(H,H) = \frac{\int_0^1 \theta^2 dF(\theta)}{E(\theta)} = \frac{E(\theta^2)}{E(\theta)} \quad (\geq E(\theta))$$

$$\mu_2(H, L; \theta^*) = \frac{\int_0^{\theta^*} \theta(1-\theta)dF(\theta)}{\int_0^{\theta^*}(1-\theta)dF(\theta)}, \qquad \mu_2(L, L; \theta^*) = \frac{\int_{\theta^*}^{1} \theta(1-\theta)dF(\theta)}{\int_{\theta^*}^{1}(1-\theta)dF(\theta)}$$

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There is one off-equilibrium path in which the firm announces a low-quality product, but introduces a high-quality product. Since it is an off-equilibrium path, we can put any arbitrary belief on the case. We assume that μ_2 (L, H)$\leq \mu_2$ (H, H) so that it is not optimal for the firm with a high-quality product to make a false announcement.

Let $w_1(m_1; \theta^*)$ denote the critical consumer type who is indifferent between buying and waiting in the first product cycle given that the firm announces $m_1 \in \{H, L\}$. Similarly, let $w_2(h_2; \theta^*)$ denote the second-period history-dependent cutoff point when the firm uses the cut-off point strategy θ^* described above, where h_2 denotes the feasible histories at the start of the second product cycle with $h_2 \in \{(H, H), (H, L), (L, L), (L, H)\}$. Then, the consumers' purchase behavior can be described by the following cut-off points in consumers' waiting cost.

$$w_1(H; \theta^*) = \mu_1\left(H; \theta^*\right) s_H + [1 - \mu_1\left(H; \theta^*\right)] s_L$$

$$= \frac{E(\theta)}{F(\theta^*) + \int\limits_{\theta^*}^{1} \theta dF(\theta)} s_H + [1 - \frac{E(\theta)}{F(\theta^*) + \int\limits_{\theta^*}^{1} \theta dF(\theta)}] s_L \qquad (1)$$

$$w_1(L; \theta^*) = w_1(L) = \mu_1\left(L\right) s_H + [1 - \mu_1\left(L\right)] s_L = s_L. \qquad (2)$$

$$w_2(H, H; \theta^*) = w_2(H, H) = \mu_2\left(H, H\right) s_H + [1 - \mu_2\left(H, H\right)] s_L$$

$$= \frac{E(\theta^2)}{E(\theta)} s_H + [1 - \frac{E(\theta^2)}{E(\theta)}] s_L \qquad (3)$$

$$w_2(L, L; \theta^*) = \mu_2(L, L; \theta^*) s_H + [1 - \mu_2(L, L; \theta^*)] s_L$$

$$= \frac{\int\limits_{\theta^*}^{1} \theta(1-\theta) dF(\theta)}{\int\limits_{\theta^*}^{1} (1-\theta) dF(\theta)} s_H + [1 - \frac{\int\limits_{\theta^*}^{1} \theta(1-\theta) dF(\theta)}{\int\limits_{\theta^*}^{1} (1-\theta) dF(\theta)}] s_L \qquad (4)$$

$$w_2(H, L; \theta^*) = \mu_2(H, L; \theta^*) s_H + [1 - \mu_2(H, L; \theta^*)] s_L$$

$$= \frac{\int_0^{\theta^*} \theta(1-\theta)dF(\theta)}{\int_0^{\theta^*}(1-\theta)dF(\theta)} s_H + [1 - \frac{\int_0^{\theta^*} \theta(1-\theta)dF(\theta)}{\int_0^{\theta^*}(1-\theta)dF(\theta)}]s_L \qquad (5)$$

If a consumer's waiting cost is higher than the relevant cutoff point, consumers buy the currently available product in the first period. Otherwise, the consumer waits until the new product is available. Notice that $w_1(L; \theta^*)$ and $w_2(H, H; \theta^*)$ do not depend on θ^* and $w_2(L, L; \theta^*) > w_2(H, L; \theta^*)$.

So far, we have constructed consumers' optimal choices given the firm's strategy that can be represented by the cut-off point θ^*. We now check whether the firm has any incentive to deviate from the strategy profile under the consumers' optimal choices. To this purpose, let $\Pi(m_1; (\theta, q); \theta^*)$ denote the firm's overall expected profit if the firm announces its quality as m_1 when its type is θ, its actual quality in the first product cycle is q, and consumers believe that the firm is adopting the cutoff rule θ^*. Then, we have

$$\Pi(H; (\theta, H); \theta^*) = G[w_1(H; \theta^*)]\pi_H + \delta G[w_2(H, H)][\theta \pi_H + (1-\theta)\pi_L], \qquad (6)$$

$$\Pi(H; (\theta, L); \theta^*) = G[w_1(H; \theta^*)]\pi_L + \delta G[w_2(H, L; \theta^*)][\theta \pi_H + (1-\theta)\pi_L], \qquad (7)$$

$$\Pi(L; (\theta, L); \theta^*) = G[w_1(L)]\pi_L + \delta G[w_2(L, L; \theta^*)][\theta \pi_H + (1-\theta)\pi_L]. \qquad (8)$$

We can easily find that it is optimal for the firm with a high-quality product to tell it truthfully. The firm with a low-quality product has an incentive to tell the truth (i.e., announce the low quality) if and only if

$$\Delta(\theta, \theta^*) = \Pi(L; (\theta, L); \theta^*) - \Pi(H; (\theta, L); \theta^*)$$
$$= \{G[w_1(L)] - G[w_1(H; \theta^*)]\}\pi_L +$$
$$\delta\{G[w_2(L, L; \theta^*)] - G[w_2(H, L; \theta^*)]\}[\theta \pi_H + (1-\theta)\pi_L] \geq 0 \qquad (9)$$

The first term in the expression above represents potential short-term losses when the firm refrains from cheating in the first cycle, whereas the second term represents the long-term gains from being truthful; as long as the long-term gains outweigh the short-term losses, the firm will have an incentive to tell the truth when it has a low-quality product. We can define an implicit function $\psi(\theta^*)$ that satisfies $\Delta(\psi(\theta^*), \theta^*) = 0$. Notice that $\Delta(\theta, \theta^*)$ is increasing in θ since $\partial\Delta(\theta, \theta^*)/\partial\theta = \delta\{G[w_2(L, L; \theta^*)] - G[w_2(H, L; \theta^*)]\}(\pi_H - \pi_L)>0$; the incentive to tell the truth increases with the type parameter θ. This implies that the cutoff point that satisfies $\psi(\theta^*) = \theta^*$ characterizes an informative equilibrium.

For the equilibrium to be informative, the fixed point θ^* needs to be in the interval of $[0, 1)$, with the lower fixed point θ^* corresponding to a more informative equilibrium in the first product cycle. A sufficient condition for the fixed point θ^* to be less than 1 is $\psi(\theta^*=1) < 1$, or, alternatively, $\Delta(\theta = 1, \theta^*=1) > 0$, which implies that if consumers believe that only the highest type $(\theta =1)$ tells the truth when it has a low-quality product, then there are other types who are willing to tell the truth to disguise themselves as the highest type firm in the first product cycle.

Lemma 2. If $\delta> \frac{\pi_L}{\pi_H} \frac{G(\bar{w}_1)-G(s_L)}{G(s_H)-G(\bar{w}_2(L))}$, then $\psi(\theta^*=1) < 1$.

Proof. We can write the condition as:

$$\Delta(\theta = 1, \theta^*=1) = \Pi(L; (1, L); 1) - \Pi(H; (1, L); 1)$$

$$= \{G[w_1(L)] - G[w_1(H; 1)]\}\pi_L + \delta\{G[w_2(L, L; 1)] - G[w_2(H, L; 1)]\}\pi_H >0$$

We notice that $w_1(L) = s_L$ and $w_2(L, L; 1) = s_H$. Furthermore, by using equations (1)-(5) and the definitions of $\overline{w_1}$ and $\overline{w_2}(L)$, we can derive the following:

$$w_1(H; 1) = \overline{w_1} = E(\theta) s_H + (1-E(\theta))s_L \tag{10}$$

$$w_2(H, L; 1) = \overline{w_2}(L) = \frac{E(\theta) - E(\theta^2)}{1 - E(\theta)} s_H + [1 - \frac{E(\theta) - E(\theta^2)}{1 - E(\theta)}]s_L \tag{11}$$

Equations (10) and (11) essentially say that if only the highest type firm $(\theta =1$ whose mass is zero with a continuous distribution) is expected to make a truthful announcement with everyone else always making an announcement of *H*, consumers ignore the message

of *H* and behave as if there were no announcement. Thus, the condition

$\Delta(\theta = 1, \theta*=1) > 0$ is satisfied if and only if $\delta > \frac{\pi_L}{\pi_H} \frac{G(\bar{w}_1)-G(s_L)}{G(s_H)-G(\bar{w}_2(L))}$.   *Q.E.D.*

The following lemma shows that if consumers believe that all firms tell the truth, then the lowest type firm has an incentive to lie when it has a low quality product in the first product cycle.

Lemma 3. $\psi(\theta*=0) > 0$.

Proof. $\Delta(\theta = 0, \theta*=0) = \Pi(L; (0, L); 0) - \Pi(H; (0, L); 0)$

$= \{G[w_1(L)] - G[w_1(H; 0)]\} \pi_L + \delta\{G[w_2(L, L; 0)] - G[w_2(H, L; 0)] \} \pi_L$.

According to equations (1)-(5), $w_1(L) = s_L$, $w_1(H; 0) = s_H$, $w_2(L, L; 0) = \bar{w}_2 (L) = [(E(\theta)-E(\theta^2))/(1-E(\theta))]s_H + \{1 - [(E(\theta)-E(\theta^2))/(1-E(\theta))]\}s_L$, $w_2(H, L; 0) = s_L$. Since $w_2(L, L; 0) = \bar{w}_2 (L) < s_H$ and $\delta < 1$, $\Delta(\theta = 0, \theta*=0) < 0$, which implies that $\psi(\theta*=0) > 0$.   *Q.E.D.*

Remark

Lemma 3 relies on the assumption that the profits of the firm (π_H and π_L) are the same across product cycles. If the second product cycle market is relatively more important or if there are more product cycles, as in an infinite horizon game, then reputation becomes more important and it is possible that $\psi(\theta*=0) < 0$; there exists an equilibrium in which all firms tell the truth.   For instance, let δ represent the relative market size of the second product market compared to the first one. Then, $\psi(\theta*=0) < 0$ if $\delta > \bar{\delta} = \frac{G(s_H)-G(s_L)}{G(\bar{w}_2(L))-G(s_L)}$ (>1).

The discussion up to this point can be summarized in the following Proposition.

Proposition 1. If $\delta > \dfrac{\pi_L}{\pi_H} \dfrac{G(\bar{w}_1)-G(s_L)}{G(s_H)-G(\bar{w}_2(L))}$, where $\bar{w}_1 = E(\theta)\,s_H + (1-E(\theta))s_L$ and $\bar{w}_2\,(L) =$

$\dfrac{E(\theta)-E(\theta^2)}{1-E(\theta)}\,s_H + [1 - \dfrac{E(\theta)-E(\theta^2)}{1-E(\theta)}]s_L,$ there exists an informative equilibrium with a

cutoff point $\theta^* \in [0, 1)$ that has the following properties:

(a) In the first cycle, the firm whose type is higher than a cut-off point θ^* makes a truthful announcement. That is, it makes a high-quality product announcement only if it has a high-quality product.

(b) In the first cycle, the firm whose type is lower than the cut-off point always announces that its product is of high quality. This implies that a low type firm can practice vaporware in which it makes a promise that it cannot deliver.

(c) Product announcements in the second product cycle do not convey any meaning.

We have developed a reputational model of a cheap talk game with a finite number of product cycles. If we considered an infinite horizon of product cycles, we would have a similar result, with the high types always telling the truth and the low types lying when they have a low-quality product. The mechanism through which the high types tell the truth would be similar to the one in Choi's (1998) model of brand extension. In Choi (1998), as long as all previous products with the same brand name were of high quality, consumers believe that a new product under that brand name will be of high quality as well. Once the brand name is extended to a low-quality product, consumers ignore any signaling value of brand extension. [13]

III. Welfare Analysis

In the previous section, we conducted a positive analysis identifying conditions under which product pre-announcements can convey (partial) information to potential consumers. In this section, we conduct a normative analysis to investigate implications of product pre-announcements for social welfare and antitrust policy. In particular, we

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[13] One major difference between Choi's brand extension model and our model is that the model in Choi (1998) is of moral hazard and there is no uncertainty about the firm type. In contrast, in our model, there is also an adverse selection problem about the firm type with the separation of types taking place over time.

are concerned with how consumers' utilities and the firm's profits change with the possibility of product pre-announcements.[14]

We first claim that allowing pre-announcements helps consumers make better decisions, and its *ex ante* effect on expected consumer welfare is positive.

Proposition 2. Allowing pre-announcement improves expected consumer welfare.
Proof. See the Appendix.

In the Appendix, we prove that consumers are always better off with product pre-announcements, even if the firm is allowed to make misleading claims about its future product. Consumers can rationally discount the firm's claims, and the firm's announcement can be at least partially revealing and, thus, can only help consumers make a better decision.

More specifically, there are two effects that help consumers. In the *first* product cycle, the high-type firms ($\theta \geq \theta*$) reveal their quality truthfully when they have a low-quality product and, thus, enhance their reputation.[15] In contrast, such valuable information will not be available in the absence of product pre-announcements. If the firm announces a high-quality product, consumers will update their beliefs accordingly, taking into account the fact that low-type firms with a low-quality product will lie. Thus, ex ante, rational consumers make better decisions with product pre-announcements in an informative equilibrium.

In the *second* product cycle, there is an additional informational benefit from better *sorting*. To be more precise, we can consider three possible histories in the second product cycle. If the firm introduced a high-quality product in the first cycle, the consumer welfare in the second product cycle would be the same across the two regimes since consumers have the same beliefs about the firm in both cases and adopt the same

cutoff rule ($\overline{w_2}$ (H)) = w_2(H, H) $= \dfrac{E(\theta^2)}{E(\theta)} s_H + [1 - \dfrac{E(\theta^2)}{E(\theta)}]s_L$). However, if the firm

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introduced a low-quality product in the first cycle, consumers can sort the firm into one of the two sets of firm types (high types and low types with the boundary at θ*) depending on whether or not they have lied. As a result, consumers can make ex ante better decisions in the second cycle with product pre-announcements. With these two informational effects taken together, we can conclude that consumers are better off in our model.

Our welfare result on consumers thus formalizes the argument in Fisher, et al. (1983) and Levy (1997). They reason that "[b]roken promises and unattractive products can be expected to lead quickly to a loss of credibility and sales" (Fisher, et al., 1983). As a result, firms will refrain from making false announcements due to concerns about reputation and "there is no reason to inhibit the time when a firm announces or brings products to the market place." In a sense, however, our result is stronger than their claim. In our model, deliberate misrepresentations take place in equilibrium due to the existence of different firm types. Nonetheless, we were able to show that consumers are better off with product pre-announcements as long as consumers are aware of such incentives for misrepresentation on the part of the firm.[16]

The effect of product pre-announcements on the firm's profits is less clear, and we cannot rule out that the firm's ex ante profits may decrease with the possibility of product pre-announcements. We will provide two examples that illustrate the ambiguous effects on the firm's profits; in the first case, allowing pre-announcements increases the firm's expected profit, but in the second case, it reduces the firm's expected profit. Consider an informative equilibrium with θ*=0, that is, all firm types tell truthfully when they have a low-quality product (this would be the case if the reputational concern is sufficiently important). Since all types make a truthful announcement, the expected profit in the second cycle is the same in both regimes.[17] The ex ante expected profit in the first cycle under the informative equilibrium with θ*=0 is

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[16] One can ask the question of why antitrust policy cannot focus only on false claims made by the firm—that is, only truthful product pre-announcements are allowed. In reality, however, it would be difficult to implement such a policy because of the difficulty and ambiguity associated with ascertaining whether the firm actually delivered the promised quality, especially when the new features promised are something non-existent at the time of announcement—a fact that makes direct contracting between the firm and consumers infeasible in the first place.

[17] If θ*=0, then $w_2(L, L; 1) = \overline{w_2}(L)$ and $w_2(H, H) = \overline{w_2}(H)$).

$$\int_0^1 \theta G(s_H)\pi_H + (1-\theta)(G(s_L)\pi_L) \, dF(\theta)$$

The ex ante expected profit in the first cycle without product pre-announcements is

$$\int_0^1 \theta G(\bar{w}_1)\pi_H + (1-\theta)(G(\bar{w}_1)\pi_L) \, dF(\theta), \text{ where } \bar{w}_1 = E(\theta)s_H + (1-E(\theta))s_L.$$

Example 1: If $G(.)$ is a uniform distribution, it can be easily verified that the profit under informative equilibrium is higher than the profit without product pre-announcements.

Example 2: If $G(\bar{w}_1)$ is very close to $G(s_H)$, the profit under informative equilibrium is lower than the profit without product pre-announcements.

Thus, we can conclude that the welfare effect of product pre-announcements on the firm's profits is ambiguous.

IV.   Concluding Remarks

It is common practice, especially in the computer industry, for firms to announce new products well in advance of actual market availability.   This practice, often called "vaporware," has been a topic of intensive discussion both in the business press and the anti-trust arena.   We developed a simple model of such a practice.   In particular, we derived conditions under which such an announcement can impart valuable information to consumers, even if it is cheap talk that does not entail any direct cost of signaling, and investigated its welfare implications.

We conclude by discussing the robustness and potential extensions of the model. Our welfare result for consumers depends crucially on the assumption that there are no externalities associated with consumers' purchase decisions. However, product pre-announcements have been prominent in industries characterized by network effects, such as the computer industry.   In such a case, we cannot rule out the possibility that product pre-announcements may influence which product prevails in the marketplace and lead to socially inefficient technology adoption. This may be true even if those who make purchase/wait decisions are better-informed as a result of product pre-announcements.

The inefficiency arises from the incompatibility between the old and new products that results in "stranding" of consumers who already purchased the old product. Farrell and Saloner (1986) demonstrate such a possibility in a dynamic model of technology adoption.[18] This possibility certainly makes the implementation of anti-trust policy on product pre-announcements difficult and cautions against blanket approval of product pre-announcements. It would be worthwhile to incorporate network effects in our model of product pre-announcements and investigate its welfare implications.

Finally, product pre-announcements are important in fast-evolving and innovative industries where technical progress is rapid and early lock-ins might preclude the emergence of superior technologies. We analyzed the implications of product pre-announcements with the speed of technical progress exogenously given. However, the possibility of product pre-announcements and the government policy concerning them may feed back into the firms' incentives to innovate and their R&D strategies. Considering the central role innovation plays in these industries, investigating the interplay between product pre-announcements and endogenous R&D incentives seems to be an important research agenda.

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[18] Their paper, however, considers only truthful pre-announcements and does not analyze the possibility of false announcements and consumers' inference problem about their informational content.

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Appendix

1. A Specific Model

In the main text, we set up a model without being specific about the nature of competition and the demand structure of consumers. Our model was very general and only assumed that consumers who delay their purchase decision derive a higher expected surplus from the high-quality product than from the low-quality product, that is, $s_H > s_L > 0$. In addition, we assumed that the firm earns higher expected profits from the high-quality product than from the low-quality product, with $\pi_H > \pi_L > 0$. In this appendix, we provide a specific model that satisfies the assumptions in Section II, which can be considered as the micro-foundation of the model.

The new product developed by the firm is superior to the existing product, regardless of its quality realization. For each quality realization, we assume that the amount of *additional* value the new product provides vis-à-vis the existing product is random and differs across consumers. If the new product is of high quality, its additional value is distributed uniformly between $[0, a_H]$, while it is distributed uniformly between $[0, a_L]$ if the product of low quality, where $a_H > a_L$. This value is revealed to consumers only in the second period and is unknown to them in the first period.[19] As a result, with respect to the net valuation of new product, consumers are ex ante homogeneous in period one but are ex post heterogeneous in period two.[20] The measure of consumers is one.

Without any loss of generality, we assume that the production costs for both old and new products are zero. Thus, the existing product is competitively supplied at the price of zero. When the firm sets its price at p_i, consumers whose additional values from

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[19] For instance, when new features are promised for new software, it would be difficult to know in advance how much additional value such features would provide.

[20] The assumption also implies that the firm sets its price for the new product knowing only the distribution of the values, not the actual value for each individual. This assumption, by preventing the possibility that the firm extracts all consumer surplus, gives consumers incentive to wait for the new product.

the new product are higher than p_i will buy the new product. That is, given p_i, the demand

is $\frac{a_i - p_i}{a_i}$ when the quality of the product is i, where $i = H, L$. This implies that the

(inverse) demand curve for the new product is given by $p_i = a_i(1-q)$. A

straightforward calculation reveals that in equilibrium we have

$$p_i = \frac{a_i}{2}$$

$$\pi_i = \left(\frac{a_i}{2}\right)^2$$

$$s_i = \frac{1}{2}\left(\frac{a_i}{2}\right)^2, \text{ where } i = L, H$$

This simple model satisfies all the assumptions in the main text. Consumers make
their purchase/wait decision based on the expected surplus from the new product, with
the high-quality product providing more additional expected value than the low-quality
one.

2. Proof of Proposition 2

We prove that consumer welfare always increases with product pre-
announcement.

Let W^{NA} denote the expected consumer welfare without announcement. We
decompose W^{NA} into expected consumer welfare in the first and second product cycles,
W_1^{NA} and W_2^{NA}. Without product pre-announcements, consumers delay their purchase
in the first product cycle if their waiting costs are less than $\overline{w_1} = E(\theta)s_H + [1-E(\theta)]s_L$.
Consumers' purchase decision in the second product cycle depends on the realization of
new product quality in the first product cycle. When the product quality in the first cycle
quality is q, consumers delay their purchase if their waiting costs are less than $\overline{w_2}(q) =$
$E(\theta|q) s_H + [1-E(\theta|q)]s_L$, where $q = H, L$ and $\overline{w_2}(H) > \overline{w_1} > \overline{w_2}(L)$. Thus, we have

$$W^{NA} = W_1^{NA} + W_2^{NA},$$

where $W_1^{NA} = \int_0^1 \int_0^{\bar{w}_1} [\theta s_H + (1-\theta)s_L + w] \, dG(w) \, dF(\theta) + \int_{\bar{w}_1}^1 2w \, dG(w)$ and

$$W_2^{NA} = \int_0^1 \theta(\int_0^{\bar{w}_2(H)} [\theta s_H + (1-\theta)s_L + w] \, dG(w) + \int_{w_2(H)}^1 2w \, dG(w)) \, dF(\theta)$$

$$+ \int_0^1 (1-\theta)(\int_0^{\bar{w}_2(L)} [\theta s_H + (1-\theta)s_L + w] \, dG(w) + \int_{\bar{w}_2(L)}^1 2w \, dG(w)) \, dF(\theta)$$

Similarly, let W^A denote the expected consumer welfare when the firm is allowed to make an announcement. When the equilibrium is characterized by a cutoff point θ^*, consumers delay their purchase in the first product cycle when their waiting costs are less than $w_1(H;\theta^*)$ and $w_1(L)$ when the firm announces high and low quality products, respectively (see equations (1) and (2) in the main text). The second cycle consumers' decision is characterized by $w_2(H, H)$, $w_2(L, L; \theta^*)$, and $w_2(H, L; \theta^*)$, depending on the announced and delivered quality in the first product cycle (see equations (3)-(5)). Then, we have

$$W^A = W_1^A + W_2^A,$$

where $W_1^A = \int_0^{\theta^*} [\int_0^{w_1(H;\theta^*)} [\theta s_H + (1-\theta)s_L + w] \, dG(w) + \int_{w_1(H;\theta^*)}^1 2w \, dG(w)] \, dF(\theta)$

$$+ \int_{\theta^*}^1 \theta(\int_0^{w_1(H;\theta^*)} (s_H + w) \, dG(w) + \int_{w_1(H;\theta^*)}^1 2w \, dG(w)) \, dF(\theta)$$

$$+ \int_{\theta^*}^1 (1-\theta)(\int_0^{w_1(L)} (s_L + w) \, dG(w) + \int_{w_1(L)}^1 2w \, dG(w)) \, dF(\theta) \text{ and}$$

$$W_2^A = \int_0^1 \theta(\int_0^{w_2(H,H)} [\theta s_H + (1-\theta)s_L + w] \, dG(w) + \int_{w_2(H,H)}^1 2w \, dG(w)) \, dF(\theta)$$

$$+ \int_0^{\theta^*} (1-\theta)(\int_0^{w_2(H,L;\theta^*)} [\theta s_H + (1-\theta)s_L + w] \, dG(w) + \int_{w_2(H,L;\theta^*)}^1 2w \, dG(w)) \, dF(\theta)$$

$$+ \int_{\theta^*}^1 (1-\theta)(\int_0^{w_2(L,L;\theta^*)} [\theta s_H + (1-\theta)s_L + w] \, dG(w) + \int_{w_2(L,L;\theta^*)}^1 2w \, dG(w)) \, dF(\theta)$$

Lemma A1. $W_1^A - W_1^{NA} > 0$

Proof. We first manipulate the expression for W_1^{NA} in the following way:

$$W_1^{NA} = \int_0^1 \int_0^{\bar{w}_1} (\theta s_H + (1-\theta)s + w)\, dG(w)\, dF(\theta) + \int_{\bar{w}_1}^1 2w\, dG(w)$$

$$= \int_0^{\theta^*} \int_0^{\bar{w}_1} (\theta s_H + (1-\theta)s_L + w)\, dG(w)\, dF(\theta)$$

$$+ \int_{\theta^*}^1 \int_0^{\bar{w}_1} \theta(s_H + w)\, dG(w)\, dF(\theta) + \int_{\theta^*}^1 \int_0^{\bar{w}_1} (1-\theta)(s_L + w)\, dG(w)\, dF(\theta)$$

$$+ \int_0^{\theta^*} \int_{\bar{w}_1}^1 2w\, dG(w) + \int_{\theta^*}^1 \int_{\bar{w}_1}^1 \theta 2w + (1-\theta)2w\, dG(w)$$

$$= \int_0^{\theta^*} [\int_0^{\bar{w}_1} (\theta s_H + (1-\theta)s + w)\, dG(w) + \int_{\bar{w}_1}^1 2w\, dG(w)]\, dF(\theta)$$

$$+ \int_{\theta^*}^1 \theta(\int_0^{\bar{w}_1} (s_H + w)\, dG(w) + \int_{\bar{w}_1}^1 2w\, dG(w))\, dF(\theta)$$

$$+ \int_{\theta^*}^1 (1-\theta)(\int_0^{\bar{w}_1} (s_L + w)\, dG(w) + \int_{\bar{w}_1}^1 2w\, dG(w))\, dF(\theta)$$

The difference in consumer welfare in the first product cycle can be written as

$$W_1^A - W_1^{NA} = \int_0^{\theta^*} \int_{\bar{w}_1}^{w_1(H;\theta^*)} (\theta s_H + (1-\theta)s_L - w)\, dG(w)\, dF(\theta) + \int_{\theta^*}^1 \int_{\bar{w}_1}^{w_1(H;\theta^*)} \theta(s_H - w)\, dG(w)\, dF(\theta)$$

$$+ \int_{\theta^*}^1 \int_{w_1(L)}^{w'} (1-\theta)(w - s_L)\, dG(w)\, dF(\theta)$$

$$= \int_{\bar{w}_1}^{w_1(H;\theta^*)} \int_0^{\theta^*} (\theta s_H + (1-\theta)s_L - w)\, dF(\theta)\, dG(w) + \int_{w'}^{w_1(H)} \int_{\theta^*}^1 \theta(s_H - w)\, dF(\theta)\, dG(w)$$

$$+ \int_{w_1(L)}^{\bar{w}_1} \int_{\theta^*}^1 (1-\theta)(w - s_L)\, dF(\theta)\, dG(w)$$

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$$= \int_{\overline{w}_1}^{w_1(H;\theta^*)} [\int_0^{\theta^*} \{\theta s_H + (1-\theta)s_L - w\} \, dF(\theta) + \int_{\theta^*}^1 \theta\{s_H - w\} \, dF(\theta)] dG(w)$$

$$+ \int_{w_1(L)}^{\overline{w}_1} \int_{\theta^*}^1 (1-\theta)\{w - s_L\} \, dF(\theta) dG(w)$$

$$= \int_{\overline{w}_1}^{w_1(H;\theta^*)} [\, s_H(\int_0^1 \theta \, dF(\theta)) + s_L(\int_0^{\theta^*} (1-\theta) dF(\theta)) - w(\int_0^{\theta^*} dF(\theta) + \int_{\theta^*}^1 \theta \, dF(\theta))] dG(w)$$

$$+ \int_{w_1(L)}^{\overline{w}_1} \int_{\theta^*}^1 (1-\theta)(w - s_L) dF(\theta) dG(w)$$

Let us check the sign of the above equation. First, if we divide the first integral term in

the last line $\int_{\overline{w}_1}^{w_1(H;\theta^*)} [\, s_H(\int_0^1 \theta \, dF(\theta)) + s_L(\int_0^{\theta^*} (1-\theta) dF(\theta)) -$

$w(\int_0^{\theta^*} dF(\theta) + \int_{\theta^*}^1 \theta \, dF(\theta))] dG(w)$ by $F(\theta^*) + \int_{\theta^*}^1 \theta \, dF(\theta)$, we have $\int_{\overline{w}_1}^{w_1(H;\theta^*)} [s_H \, \mu_1(H) + s_L(1 -$

$\mu_1(H)) - w] dG(w)$, which is positive for w between $\overline{w}_1$ and $w_1(H;\theta^*)$. Second, $w - s_L$ is

positive for w between $\overline{w}_1$ and $w_1(L)$. Thus, the second term ($\int_{w_1(L)}^{\overline{w}_1} \int_{\theta^*}^1 (1-\theta)\{w -$

$s_L\} \, dF(\theta) dG(w))$ is also positive and $W_1^A - W_1^{NA} > 0$

Lemma A2. $W_2^A - W_2^{NA} > 0$

Proof. The difference in consumer welfare in the second product cycle is given by

$$W_2^A - W_2^{NA} = \int_{w_2(H,L;\theta^*)}^{\overline{w}_2(L)} \int_0^{\theta^*} (1-\theta)(w - \theta s_H - (1-\theta)s_L) \, dF(\theta) dG(w)$$

$$+ \int_{\overline{w}_2(L)}^{w_2(L,L;\theta^*)} [\int_{\theta^*}^1 (1-\theta)\{\theta s_H + (1-\theta)s_L - w\} \, dF(\theta)] dG(w)\}$$

To check the sign of the first integral term, notice that

$$\int_0^{\theta^*} (1\text{-}\theta)(w\text{-}\theta s_H - (1\text{-}\theta)s_L) \, dF(\theta)$$

$$= w(\int_0^{\theta^*} (1\text{-}\theta)dF(\theta)) - \int_0^{\theta^*} (1\text{-}\theta)\theta s_H \, dF(\theta) - \int_0^{\theta^*} (1\text{-}\theta) \, (1\text{-}\theta)s_L \, dF(\theta)$$

If we divide the expression above by $\int_0^{\theta^*} (1\text{-}\theta)dF(\theta))$, we get $w - \mu_2(H, L) \, s_H\text{-}(1\text{-}\mu_2(H, L)) \, s_L$. For w between $\overline{w_2}\,(L)$ and $w_2(H, L; \theta^*)$, $w - \mu_2(H, L) \, s_H\text{-}(1\text{-}\mu_2(H, L)) \, s_L > 0$.

Thus, $\displaystyle\int_{w_2(H,L;\theta^*)}^{\overline{w_2}(L)} \int_0^{\theta^*} (1\text{-}\theta)(w\text{-}\theta s_H - (1\text{-}\theta)s_L) \, dF(\theta)dG(w) > 0$.

    We now check the sign of the second integral term. If we divide the term

$[\int_{\theta^*}^1 (1\text{-}\theta)\{\theta s_H + (1\text{-}\theta)s_L\text{-}w\} \, dF(\theta)]$ by $\int_{\theta^*}^1 (1\text{-}\theta) \, dF(\theta)$, we get $\mu_2(L, L ; \theta^*) \, s_H + (1\text{-}\mu_2$

$(L, L ; \theta^*)) \, s_L\text{-}w$. Since $\mu_2(L, L; \theta^*) \, s_H + [1\text{-}\mu_2(L, L;\theta^*)] \, s_L\text{-}w$ is positive for w between

$\overline{w_2}$ (L) and $w_2(L,L; \theta^*)$, $\displaystyle\int_{\overline{w_2}(L)}^{w_2(L,L;\theta^*)} [\int_{\theta^*}^1 (1\text{-}\theta)\{\theta s_H + (1\text{-}\theta)s_L - w\} \, dF(\theta)]dG(w)\}$ is

positive. Thus, $W_2^A - W_2^{NA} > 0$.

    Combining Lemmas A1 and A2, we can conclude that $W^A - W^{NA} > 0$. *Q.E.D.*