Efficient Upgrading in Network Goods: Is Commitment Always Good?

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Abstract

The frequency of upgrades in technology markets is not socially optimal when the quality improvement is negligible and smaller than the adoption cost of the new product. In monopolies, the literature has identified a sufficient factor for efficient upgrading: the firm's power to commit to whether it will upgrade or not in the future. This is not true when an entry threat applies. In fact, it could even be that commitment is a factor of inefficiency when the market is open to competition. As shown in this paper, the incumbent's commitment adds an additional source of inefficiency while an entry threat could dissolve social optimality.

1 Introduction

Although technological advancement is desirable, it may come at a cost for the society as a whole. Consider for example the software market for personal computers. The frequency at which better versions appear in the market creates an issue of 'technically induced needs'. Even though customers of the older version may be satisfied with the product they own, they are forced to buy the newer version due to forward incompatibility. So, the frequency at which these products are upgraded is inefficient when the learning cost of upgrading is higher than the benefit of the quality improvement. Two questions arise: When is upgrading not socially optimal? What is the reason of this inefficiency?

Ellison-Fudenberg (2001) have tried to answer a similar question in a monopolistic environment. They explore a firm's incentives to provide an upgrade of its durable network good. The authors show that inefficiency could arise due to the monopolist's inability to commit to whether he will choose to upgrade in the next period or not. Commitment empowers the incumbent to preannounce the advent of the new product. He will choose to commit not to upgrade if the cost of adoption for the old users is greater than the gains

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from the quality improvement. If the monopolist lacks the power to commit, he will always upgrade. This forces the users of the old version to either incur the cost of upgrading or suffer from incompatibility while the society may be better-off without the new product. The authors conclude that of the many factors not in their model, the role of actual and potential competition could be the most notable.

This paper evaluates the role of actual and potential competition as factors of inefficiency when the entrant can offer a product that is backward compatible with the incumbent's previously introduced version[3]. When entry deterrence is possible, the incumbent monopolist always upgrades and this fact could be not socially optimal. When entry is guaranteed, the incumbent may commit not to sell the upgrade because otherwise, competition would hurt his total profits. If the entrant can practice price discrimination between the old and new users, there may be inefficient upgrading, independently of whether the incumbent can commit or not. The same potential inefficiency occurs if the entrant cannot exercise price discrimination when the incumbent lacks commitment power. If the incumbent can commit to whether he will choose to upgrade or not in the future, there is also an additional potential inefficiency: the entrant sells the new product only to the new comers, although upgrading by all the customers is optimal. Thus, forbidding the incumbent to commit raises the social welfare. To sum up, potential or actual competition may be a reason of too frequent upgrades and although commitment is socially optimal in monopolies, this is no longer true when the market is open to competition.

These results may shed light on situations where incumbent firms, under entry threat, commit not to upgrade in the future period. The superior product is then introduced by the entrant and purchased by either the whole market or only the new users. The model is tested against real world applications in the software market industry.

2 Related literature

Software products are network goods[4]. They are characterized by externalities; that is, a user's utility is an increasing function of the number of existing buyers of the good. Other features of software products are durability[5] and rapid technological progress.

The literature has long ago highlighted a monopolist's time inconsistency problem when

[3] A famous example of an entrant firm offering backward compatibility with the incumbent monopolist's product comes from the late 80s. In the market for spreadsheet software, Lotus was the dominant player. Microsoft with Excel 3 in 1991 achieved compatibility with the previously introduced version of Lotus 1-2-3. A similar example comes from the early 90s in word processing software with Microsoft Word offering backward compatibility with the WordPerfect previous versions.

[4] For an excellent survey in network goods, see Economides (1996).

[5] See Katz and Shapiro (1999) for a paper where durability and externalities are treated together.

he sells a durable good. He has an incentive to lower the price of the product to capture the lower valuation customers, who have not already bought it when it was initially introduced. These consumers anticipate this behaviour and will indeed withhold their purchase of the good until the reduction in price takes place. The monopolist cannot extract as much profit as he would by precommitting to a flat price. This problem was introduced by Coase (1972). A strand in the literature has developed models focusing on the robustness of the Coase conjecture[6]. Leasing the durable good, distorting the technology or using buyback procedures are strategies that can boost the monopolist's profits[7]. If, nevertheless, he is unable to do so, he may reduce the product durability or make use of planned obsolescence[8].

Another strand in the literature deals with the introduction of new durable goods in an environment where network externalities are present. Most of these papers consider a monopolistic scenario[9]. In a competitive setting, there are papers dealing with endogenous R&D processes by an incumbent and an entrant firm and their aim is to highlight the competitors' incentives to invest into a new technology[10]. Endogenizing the R&D process may provide useful insights with respect to the firms' optimal behaviour. In particular, Hoppe and Lee (2003) analyze the effects of durability on the pricing and innovation behaviour of an incumbent and a potential entrant. To deter entry, the incumbent may charge a lower price compared to the price under no such threat. In their welfare analysis, they identify limit pricing as a source of potential inefficiency. The present work differs as it considers how durability as well as network externalities and costly technology adoption may affect the incumbent's decision to upgrade his product under the threat of entry.

The paper that is closest to the present work is, as already mentioned, Ellison and Fudenberg (2001) and serves as our departure point. This piece of research is structured as follows: Section 3 presents the model. Section 4 analyzes the social optimum and is compared with the market outcome when the incumbent enjoys and lacks the power to commit, respectively. Section 5 gives one real world application of the model and section 6 concludes.

3 The Model

Consider an industry where a software, durable product of quality q_1 is currently supplied by a monopolist. He is considering of whether to upgrade his product or not in the next

[6] See, for example Stokey (1981), Bulow (1982).
[7] See, for example, Fudenberg and Tirole (1998).
[8] See, for example, Grout and Park (2005).
[9] See Fishman and Rob (2000), Waldman (1996), Nahm (2004).
[10] See Cerquera (2006), Hoppe and Lee (2003).

period by selling a good of superior quality q_2. The choice of upgrading does not involve any cost of development as it is assumed that previous investment provides the incumbent the technology to launch the new product. The incumbent knows that there is a serious threat of entry by a firm that can also develop a good of the same quality q_2 after bearing a fixed cost of development F $(F \geq 0)$[11].

In a two period environment, the incumbent sets the price for his products while he is able to offer an upgrade price to the old users[12]. If he has commitment power, he also has an additional simultaneous choice to make: whether to commit to upgrade or not.

The potential entrant chooses to enter at the end of the first period. If entry occurs, the two firms engage into price competition (a la Bertrand) both incurring zero marginal cost of production for all the product versions. I investigate both cases that the entrant can offer an upgrade price to the old users or not.

On the demand side, consumers are assumed identical and arrive in constant flows λ_t $(t = 1, 2)$. Customers' utility is assumed to be linear in income and positively dependent on network effects captured by the parameter α. So, if the buyer joins a network of mass x (including himself), the network benefit is αx. In addition to the monetary cost, consumers also incur a cost of learning the new technology. Each consumer incurs a cost c the first time he starts to use the product followed by an additional upgrade cost c_u (where $c_u < c$) when learning to use the new version. Moreover, they do not incur any switching costs.

Customers who arrive in the market in the first period need to decide whether to buy the good immediately or, depending on their expectations, wait and make their decision in the next period. These expectations are fully aligned in equilibrium; that is, consumers possess perfect foresight.

In the second period and if there is an upgrade in the market, the old customers are not guaranteed to buy it because of the durability of the initial version. These customers' purchasing decision given announced prices resembles a coordination game and can have multiple equilibria. Following the literature, old consumers are assumed to coordinate to the Pareto optimal outcome. In the similar coordination problem related to the new customers' purchasing decisions, the standard assumption is that buyers with the same preferences act as if they were a single player. Thus, after observing the prices, they coordinate to what is best for all of them. All consumers make their purchasing decisions simultaneously. Also note that the same discount factor δ applies to all the agents in the economy.

[11] The case F=0 can be motivated by the fact that in principle, in software markets, the cost of development could be close to zero. It could also be that the potential entrant can costlessly imitate the incumbent's new technology.

[12] this corresponds to the semi-anonymous case in Fudenberg-Tirole (1998).

The model makes the strong assumption that the competitors' superior quality products are compatible. So, a buyer of a high quality good can interact with all the superior product buyers, independently of whether they purchase it from the incumbent or the entrant firm. Backward compatibility makes the upgraded good buyers able to open and save a document that was created with the lower quality product. Thus, the high quality good buyers are part of a network which also consists of the low quality good users. On the other hand, non-forward compatibility prevents the buyers of the initial product to work with documents that are created with the upgraded version.

4 Results

4.1 Social Welfare

I consider the problem faced by a planner who maximises social surplus. He needs to decide whether upgrading or selling the initial version for two periods is socially beneficial.

Think first of the case where the entrant can costlessly develop the high-quality good. Since customers' utility is linear in money, we can derive social welfare by summing over all the agents where I normalize the size of the market in period two by setting $\lambda_1 + \lambda_2 = 1$. If the superior product is introduced, the planner is indifferent of who sells it in the market because of the assumed perfect compatibility between the competitors' new products. If the whole market purchases the upgrade, the total social welfare is:

$$W_U = \lambda_1(q_1 + \delta q_2 + \alpha\lambda_1 + \delta\alpha - c - \delta c_u) + \lambda_2\delta(q_2 + \alpha - c).$$

The first part of the expression above captures the social surplus from the fact that period one customers upgrade in period two after having initially purchased the lower quality good. Note that $\alpha\lambda_1$ is the network benefit the old customers enjoy in period one where the size of the market is λ_1 and $\delta\alpha$ is the period one customers' benefit by joining a network of size 1 in period two. The second part of the expression captures the total discounted social surplus from the new customers' purchase of the superior good. If the upgrade is sold in the market but only the period two customers buy it, the total welfare is:

$$W_I = \lambda_1[(1+\delta)q_1 + (1+\delta)\alpha\lambda_1 - c] + \lambda_2\delta(q_2 + \alpha - c).$$

$(1+\delta)\alpha\lambda_1$ is the total discounted network benefit from the period one customers. Notice that because of forward incompatibility, the old consumers belong to a network of size λ_1

in both periods. Period two customers belong to a network of size $\lambda_1 + \lambda_2 = 1$ because of backward compatibility. Thus, the parameter α in the second part of the expression captures the benefit from being a part of this network.

If the higher quality good is not used, the social welfare is given by the expression:

$$W_N = \lambda_1[(1+\delta)q_1 + \alpha\lambda_1 + \delta\alpha - c] + \lambda_2\delta(q_1 + \alpha - c).$$

Note that in this case, old and new consumers join a network of size 1 in period two.

Comparing the above expressions yields the next proposition that summarizes the socially efficient outcome. Let $\Delta q = q_2 - q_1$ denote the quality improvement.

Proposition 1 *The socially efficient outcome is a) keep the lower quality good in the market for two periods if $a > c_u$ and $\Delta q < \lambda_1 c_u$ or if $\alpha < c_u$ and $\Delta q < \alpha\lambda_1$, b) use the incompatible regime, that is, introduce the upgraded product but only the period two potential customers purchase it if $\Delta q > \alpha\lambda_1$ and $\Delta q + \alpha\lambda_2 < c_u$ and c) upgrade and everyone buys the new product in period two if $\alpha > c_u$ and $\Delta q > \lambda_1 c_u$ or if $\alpha < c_u$ and $\Delta q > c_u - \alpha\lambda_2$.*

Think of the case that the network effects are large compared to the upgrade costs ($\alpha > c_u$). It is then beneficial for the society to maintain the lower quality good if the upgrade cost for the old users exceeds the gain in every customer's second period utility ($\Delta q < \lambda_1 c_u$) and it is socially efficient for the whole market to upgrade if the sign of the inequality is reversed ($\Delta q > \lambda_1 c_u$). When network effects are small ($\alpha < c_u$), the first best is to withhold the superior product when the loss from incompatibility is greater than the utility benefit the new users enjoy from the upgraded version ($\Delta q\lambda_2 < \alpha\lambda_1\lambda_2$). It may also be optimal if the upgrade is introduced and everyone buys it when the quality improvement and the gains from a larger network are greater than the upgrade cost ($\Delta q + \alpha\lambda_2 > c_u$), whereas it is optimal if only the new buyers purchase it when the last inequality is reversed. Figure 1 (in the next page) provides a graphical representation of the socially optimal outcome.

Consider now the scenario where the entrant needs to pay a fixed, strictly positive cost of developing the high quality good. If the upgrade is introduced (and either the whole market or only the new customers buy it), the planner prefers the incumbent to sell it due to the additional investment cost he needs to bear if he used the entrant's technology. If only the initial version is sold in period two, total welfare is the same as when the entrant can costlessly develop the upgrade. Thus, proposition 1 still holds.

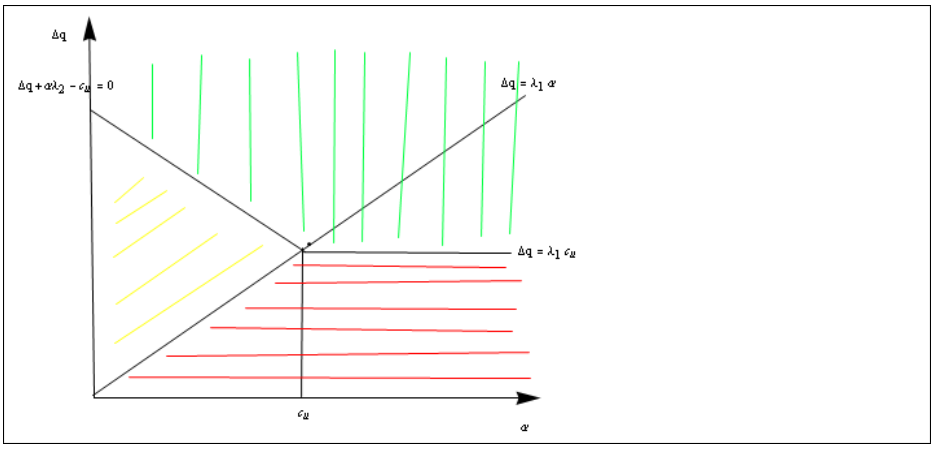

Figure 1: The socially optimal outcome: The red area indicates values in the parameter space where no upgrade is optimal. The yellow area represents parameter values where it is socially optimal if only the new customers upgrade. The green area captures the case where upgrading by the whole market is efficient.

4.2 Market outcome/ Incumbent's commitment

I consider a scenario of potential entry when the incumbent already acquires the technology that allows him to commit to choose to upgrade in the following period. I analyze first the case where the entrant has to bear zero cost to develop the superior product ($F = 0$) while he may have the ability to price discriminate between the old and the new customers or not. Then, I look at the case where the entrant needs to invest a strictly positive development cost ($F > 0$).

4.2.1 Zero development cost for the entrant who can price discriminate

The entrant is considered to be able to costlessly develop the superior good ($F = 0$) and this fact allows her to always enter the market[13]. If the incumbent commits to upgrade, in the second period, Bertrand competition drives all the prices to zero[14]. This is no longer true if he commits to keep the initial product. In this case, the entrant can exploit the quality improvement and charge a strictly positive price either to the whole market or only to the new comers[15]. Since the first period potential customers' expected outside opportunity is higher under the incumbent's commitment to sell the superior version, he could charge them more if he committed to maintain the initial product in the market. Thus, the incumbent could

[13] The same result of certain entry can be alternatively generated if the entrant needed to bear a fixed cost F to develop the product (plus any other costs for advertisement) and she could offer an upgrade with sufficiently smaller adoption cost than the incumbent's superior product.

[14] A complete characterization of the prices set and the market outcome is given in the appendix.

[15] Again, see the appendix for a complete characterization of the market outcome and the prices set.

be better-off if he committed not to upgrade. The next proposition states the incumbent's choice and the equlibrium market outcome for the different parameter values.

Proposition 2 *a) If $\Delta q+\alpha\lambda_2-c_u<0$ or if $\Delta q+\alpha\lambda_2-c_u\geq 0$ and $\alpha\lambda_2<c_u$, the incumbent commits not to upgrade in period two. For the parameter values given first, the entrant sells the higher quality good only to the new potential customers whereas in the latter scenario, he sells it to everyone in the market, b) if $\alpha\lambda_2\geq c_u$, the incumbent commits to sell the high quality good in period two. All the customers upgrade by buying the superior product by either of the competitors.*

Note that under most parameter values, the incumbent commits not to upgrade because if he did, actual competition would lower his total profits. Commitment to keep the initial version allows him to set a higher price for the lower quality software good in period one. He only commits to launch the superior product when the network benefit from upgrading is higher than the cost of learning the superior product ($\alpha\lambda_2\geq c_u$). The proposition above suggests that in equilibrium, the higher quality good is always sold in period two and is purchased either by the whole market or only by the new customers. This fact already highlights the potential inefficiency that may arise in this market as it could be socially beneficial if there is no upgrade in the economy. The next proposition summarizes the potential inefficiency:

Proposition 3 *It is socially optimal if there is no upgrade and nevertheless, a) all the old and new customers buy the superior product if $\Delta q+\alpha\lambda_2-c_u\geq 0$, $\Delta q<\lambda_1 c_u$ (these parameter values imply that $a\geq c_u$). More precisely, the whole market purchases the upgrade from either of the competitors if $\alpha\lambda_2\geq c_u$ and only from the entrant if $\alpha\lambda_2<c_u$, b) only the new potential customers upgrade by purchasing the entrant's product if $\Delta q+\alpha\lambda_2-c_u<0$, $\Delta q<\alpha\lambda_1$(these parameter values imply that $\alpha<c_u$).*

The society would be better-off if the initial version is sold for both periods when the network benefit is relatively large ($\alpha\geq c_u$) and the upgrade cost for the old users exceeds the gain in every customer's second period utility ($\Delta q<\lambda_1 c_u$). Nevertheless, in this case, the superior product is always sold and everyone buys it if the quality improvement and the gains from a larger network are greater than the upgrade costs ($\Delta q+\alpha\lambda_2-c_u\geq 0$). For relatively small network benefit compared to the upgrade cost ($\alpha<c_u$), the first best is to withhold the high quality product from the market if the loss from incompatibility is greater than the utility benefit the new users enjoy from the upgraded version ($\Delta q\lambda_2<\alpha\lambda_1\lambda_2$). However, the entrant sells the superior product and only the new potential customers purchase it when the upgrade costs for the old users are higher than their benefit form upgrading ($\Delta q+\alpha\lambda_2-c_u<$

0). Therefore, in markets where we expect to see the threat of entry, inefficiency may occur as a result of actual competition even when the incumbent can commit to his future actions. Figure 2 represents diagrammatically the potential inefficiency that may arise in the market.

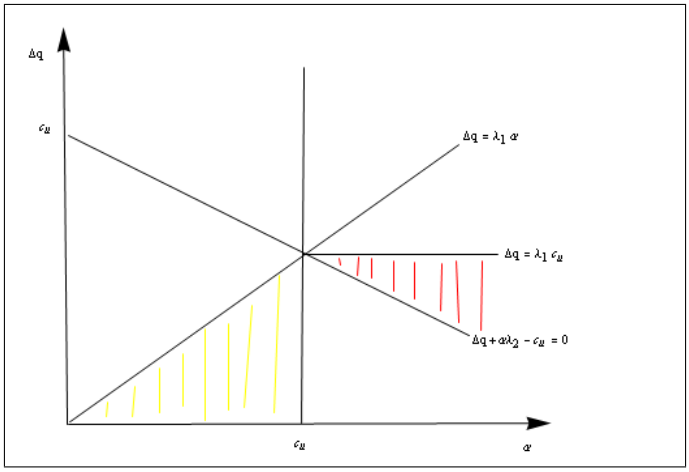

Figure 2: Market outcome and efficiency: The red and yellow shaped areas in the parameter space represent inefficient upgrading by the whole market and the new users, respectively.

4.2.2 Zero development cost for the entrant who cannot price discriminate

If the entrant is unable to offer upgrade prices to the old customers, the analysis if the incumbent commits to upgrade leads to the same prices set by the competitors in periods one and two, respectively[16]. If the incumbent monopolist commits not to upgrade, the entrant may need to decide whether to serve all the market in period two or sell the superior product only to the new comers[17]. The next proposition summarizes the incumbent's choices as well as the market outcome.

Proposition 4 *a) If* $\Delta q+\alpha\lambda_2-c_u<0$ *or if* $\Delta q+\alpha\lambda_2-c_u\geq 0$, $\Delta q\lambda_1+\alpha\lambda_2<c_u$, $\alpha\lambda_2<c_u$, *the equilibrium outcome is that the incumbent commits not to upgrade and the entrant serves only the new comers, b) If* $\Delta q+\alpha\lambda_2-c_u\geq 0$, $\Delta q\lambda_1+\alpha\lambda_2-c_u\geq 0$, $\alpha\lambda_2<c_u$, *the incumbent commits not to upgrade and the entrant serves the whole market. c) If* $\Delta q+\alpha\lambda_2-c_u\geq 0$, $\alpha\lambda_2>c_u$, *the incumbent's profit by commiting to upgrade is equal to his profits if he commits not to upgrade. In such a situation, the incumbent is assumed to commit to bring the higher quality good and the whole market is served by either of the competitors.*

[16] see the appendix for the complete characterization of the equilibrium prices and market outcome.
[17] Again, the appendix contains all the different cases.

The proposition above suggests that in equilibrium and similar to the case that the entrant can exercise price discrimination, the higher quality good is always sold and is purchased either by the whole market or only by the new customers. Note that under most parameter values, the incumbent commits not to sell the higher quality good because if he used the upgrade, actual competition would lower his total profits. The next proposition highlights the potential inefficiency that may arise in the market.

Proposition 5 *It is socially optimal for the lower quality good to be in the market in period two and nevertheless, a) the higher quality product is sold to the whole market if* $\Delta q + \alpha\lambda_2 - c_u \geq 0$, $\Delta q\lambda_1 + \alpha\lambda_2 - c_u \geq 0$, $\Delta q < \lambda_1 c_u$. *In particular, if* $\alpha\lambda_2 < c_u$, *all the customers upgrade to the entrant's product while if* $\alpha\lambda_2 \geq c_u$, *the whole market upgrades to the entrant's superior good, b) the incumbent commits not to upgrade and the entrant sells the higher quality good only to the new customers if* $\Delta q + \alpha\lambda_2 - c_u < 0$, $\Delta q < \alpha\lambda_1$ *or if* $\Delta q + \alpha\lambda_2 - c_u \geq 0$, $\Delta q\lambda_1 + \alpha\lambda_2 < c_u$, $\alpha\lambda_2 < c_u$ *and* $\Delta q < \lambda_1 c_u$. *It is also optimal for everyone to upgrade but the entrant sells it only to the new potential customers if* $\Delta q + \alpha\lambda_2 - c_u \geq 0$, $\Delta q\lambda_1 + \alpha\lambda_2 < c_u$, $\alpha < c_u$.

Thus, there may be an upgrade in the market even though the sociey would be better-off without it for the same parameter values as in the case the entrant can price discriminate. There is also an additional inefficiency: when the quality improvement is relatively large and the network effect as well as the period one market size are relatively small, the first best is everyone to upgrade and nevertheless, the entrant sells the superior good only to the new buyers. Figure 3 represents the potential inefficiency that may arise in the market.

4.2.3 Positive development cost for the entrant

Consider now the case that the potential entrant needs to pay a fixed cost ($F > 0$) to develop the superior good. If the incumbent commits to upgrade, the potential entrant is deterred to enter the market[18]. If the incumbent commits not to upgrade, the analysis is identical with the scenario that the entrant can costlessly come up with the high-quality good under the condition that her development cost is not prohibitively high and this guarantees her entry[19]. The incumbent firm compares the profit gained by its commitment to either withhold the high quality good or sell it in period two and the next result summarizes his choice as well as the market outcome. Note that these results are independent of whether the entrant can offer upgrade discounts or not.

[18] The post-entry game is analyzed in the appendix.

[19] See the appendix for the characterization of the equilibrium prices and profits.

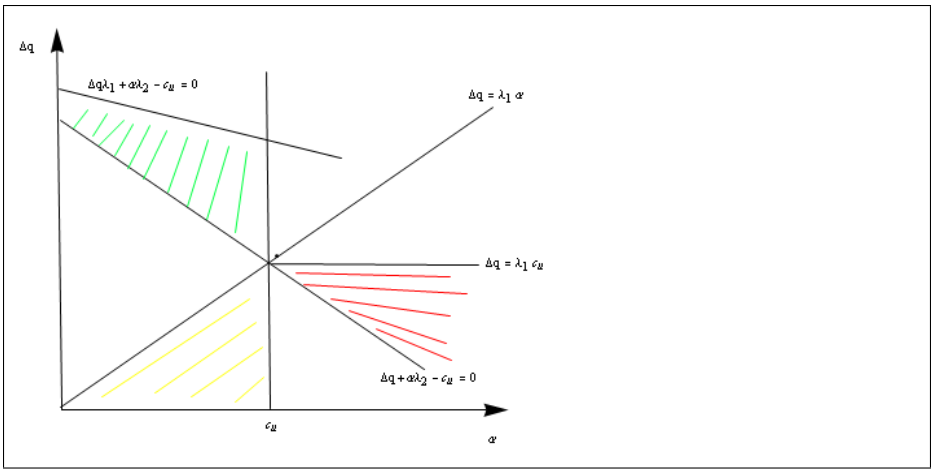

Figure 3: Market outcome and efficiency: The red and yellow shaped areas in the parameter space represent inefficient upgrading. The green area represents the additional inefficiency when the upgrade is purchased only by the new comers while it is socially optimal for everyone to upgrade.

Proposition 6 *The incumbent monopolist always commits to sell the superior product in period two. This fact deters the potential entrant from entering the market. More precisely, if* $\Delta q + \alpha\lambda_2 - c_u \geq 0$, *all the market purchases the upgrade. On the other hand, if* $\Delta q + \alpha\lambda_2 - c_u < 0$, *only the new customers purchase the incumbent's upgrade version.*

The incumbent firm's choice to always commit to upgrade may be socially inefficient as it could be socially optimal if there was no upgrade in the market. This potential inefficiency is highlighted in the next result.

Proposition 7 *It is socially optimal for the low quality good to be sold in the market in both periods and nevertheless, a) the incumbent commits to sell the upgrade and the whole market buys it when* $\Delta q + \alpha\lambda_2 - c_u \geq 0$ *and* $\Delta q < \lambda_1 c_u$, *b) the incumbent commits to sell the superior good and only the new customers purchase it when* $\Delta q + \alpha\lambda_2 - c_u < 0$ *and* $\Delta q < \alpha\lambda_1$.

Note that inefficiency could arise for the same parameter values as in the case where the entrant can costlessly upgrade and price discriminate between the old and the new users. The difference here is that the upgrade is always offered by the incumbent monopolist. Thus, potential competition could lead to inefficient upgrading even if the incumbent has commitment power.

4.3 Market outcome/ Non-commitment for the incumbent

In this subsection, I will discuss the case where the incumbent firm faces the threat of entry and cannot commit to its future actions.

Consider first the case where the potential entrant can costlessly develop the higher quality good and can also offer an upgrade price for the old customers. Due to Bertrand competition, the incumbent's second period profits are zero independently of whether he decides to sell the low or the superior product. In this scenario, he will choose to sell the upgrade in the market because otherwise, the entrant would enjoy positive profits. Therefore, there will be a high quality good in period two sold by both competitors. This may be socially inefficient because, as already explained, it could be optimal for the society if there is no upgrade. In fact, the inefficiency range is the same as in the commitment case analyzed in the previous subsection (proposition 3). If the entrant cannot offer an upgrade price for the old customers, the range of inefficiency is the same except for the case where $\Delta q + \alpha\lambda_2 - c_u \geq 0$, $\Delta q\lambda_1 + \alpha\lambda_2 - c_u < 0$, $\alpha < c_u$. For these parameter values, when the incumbent can commit to his future choice, the market outcome is that the entrant upgrades and only the new customers buy it. When the incumbent lacks commitment power, the new version is purchased by both the old and the new consumers and this fact is socially optimal. Therefore, contrary to the monopolistic environment where social optimality is achieved under the incumbent firm's commitment power, lack of commitment may raise the social welfare when the market is open to competition.

Consider now the situation where the innovation cost for the entrant is positive. The entrant firm would not invest in developing the higher quality good. To see this fact, consider the post entry game. The incumbent would be indifferent between selling the lower or the superior product because (due to Bertrand competition) his profits would be zero in both cases. He would then prefer to upgrade because this would guarantee that the entrant would incur losses. The potential entrant anticipates the incumbent's post entry behaviour and she rationally does not pay the fixed development cost. This fact allows the incumbent to be the sole supplier of the upgrade in the second period. Thus, the range of inefficiency appears to be exactly the same as in the case where the incumbent can commit to his future actions.

To summarize, the inefficiency range when the incumbent firm enjoys or lacks commitment power and the fixed development cost for the entrant is strictly positive or zero, respectively, are highlighted in the following table:

	Commitment for the incumbent	No commitment for the incumbent
Monopoly	Social efficiency	Inefficiency: The monopolist always upgrades even though it could be socially optimal if there is no upgrade in the market
Potential Competition (F>0)	Inefficiency: The same range as in the monopoly case under no commitment	Inefficiency: Same range as in the monopoly non-commitment case
Actual competition/ Upgrade discounts from the entrant	Inefficiency: The same range as in the monopoly case under no commitment	Inefficiency: Same range in the monopoly non-commitment case
Actual competition/ No upgrade discounts from the entrant	Inefficiency: The range of inefficiency is larger than the monopoly non-commitment case. More precisely, the entrant may sell the superior product only to the new customers even if it is socially optimal for everyone to upgrade	Inefficiency: Same range as in the monopoly non-commitment case

5 Applications

The model applies to scenarios where an incumbent monopolist is threatened by a potential entrant and is considering whether to upgrade his product in the subsequent period. It predicts that the superior good is always introduced in the market and this may not be socially beneficial. Such a scenario may occur in technology markets where we observe

frequent new versions sold either by the same firm or a competitor.

The leading example that suits proposition 2a) comes from the spreadsheet market for personal computers. Lotus was holding an almost monopolistic position in that market in IBM machines with its product 1-2-3 version 2.1 and its market share was above 80 percent in 1988. In 1989, Lotus announced its 1-2-3 version 2.2 for IBM computers. Although it had already developed a superior product (1-2-3 version 3), Lotus committed not to upgrade in the Windows platform. At the same time, Microsoft was working on Excel 3 and in 1991 it was available as an application in the Windows platform. Microsoft offered backward compatibility with Lotus 1-2-3 Release 2.2 and upgrade prices for the old Lotus users. Many consumers switched from 1-2-3 to Excel 3 and in 1993, Excel market share exceeded 70 percent. Proposition 3b) suggests that the switch may had been inefficient.

Although the model matches well with the real world example identified above, there are other reasons that may affect an incumbent monopolist's decision of upgrading when he faces an entry threat. For example, it may be the case that he is unsure about the quality improvement introduced by the entrant firm. It could also be that the new platform's success (Windows) was ex-ante questionable. Athough these situations are acknolwledged to be possible, they are not considered in this paper.

6 Conclusion

This paper serves as a small step towards understanding the role of entry threat in the frequency of upgrades in network, durable goods. The message of this work is that better versions of such products may arise too often and this inefficiency may be explained due to potential or actual competition. Going one step further, it is suggested that it may be beneficial for the society if the incumbent is forbidden to commit to whether he will upgrade or not. This fact comes to a sharp contrast with the monopolistic scenario where the first best is achieved under the firm's commitment power.

7 Appendix

7.1 Prices and market outcome if the incumbent commits to upgrade and the entrant can price discriminate (and F=0)

If the incumbent commits to upgrade, in period two, perfect compatibility between the superior products and backward compatibility of the new versions ensure that the new potential customers join a network of size 1 if they buy from either the incumbent or the entrant. Their

net utility if they buy either of the competitors' superior good is $q_2+\alpha-c-p_2^{'}$, $q_2+\alpha-c-p_2$ where $p_2^{'}$, p_2 are the entrant's and the incumbent's price choices, respectively. Old consumers are assumed to coordinate to a 'reluctant rule'; that is, they buy a product independently of what the other period one customers do. So, they will upgrade to the entrant's superior good even if all the other period one customers either stick to the incumbent's initial or upgrade version if:

$$q_2+\alpha-c_u-p_u^{'} \geq \max\left\{q_1+\alpha\lambda_1,\ q_2+\alpha-c_u-p_u\right\},$$

where p_u, $p_u^{'}$ are the competitors' upgrade price choices. Since Bertrand competition drives all prices to zero, the new comers purchase the superior product for free from either of the competitors. Nevertheless, the old customers may or may not upgrade, depending on the parameter values. If $\Delta q+\alpha\lambda_2-c_u<0$, the old customers stick to the incumbent's initial version. If $\Delta q+\alpha\lambda_2-c_u\geq 0$, the whole market upgrades again for free to either the incumbent's or the entrant's high-quality product. Working back in period one, the incumbent sets a price for the initial version to attract the incoming customers. If period one potential customers choose to wait and not buy, they expect (like the incumbent monopolist) a competitor in the following period who will sell a similar superior quality good. Thus, they expect to face a zero price (due to Bertrand competition) if they wait and make their purchase decision in period two. On the contrary, if period one potential customers buy the initial version and expect to upgrade in period two (when $\Delta q+\alpha\lambda_2-c_u\geq 0$[20]), they will do so by paying a price p_1. Nevertheless, this choice further depends on whether their total discounted expected net payoff from buying in period one and upgrading with the rest of the market in period two is at least equal to their discounted expected net payoff from waiting to make their purchase decision in period two. Thus, the incumbent chooses a price p_1 for the lower quality good that satisfies the equality:

$$q_1+\delta q_2+\alpha\lambda_1+\delta\alpha-c-\delta c_u-p_1=\delta(q_2+\alpha-c)$$

[20] In a richer model, although the incumbent commits to upgrade, quality q_2 may not be directly observable in period one. This means that the incumbent monopolist may not be able to commit to the specific characteristics of the superior product but he can assure consumers that the initial product will be indeed upgraded. Consumers form expectations about the high-good quality, q_2^e, which are based on past experience. The initial good of quality q_1 may be itself an upgrade and the quality differential with the previous version is available information to all period one potential customers. This quality improvent can be used as a proxy for the expected magnitude of the upgrade in period two, Δq^e. In period two, the incumbent sells a product such that its actual quality q_2 is equal to the expected quality q_2^e. Although adding uncertainty with respect to the quality differential may be more realistic with respect to real world markets, it woud have no impact on the findings of this paper.

or equivalently, $p_1 = q_1 + \alpha\lambda_1 - c(1-\delta) - \delta c_u$. Similarly, if old customers expect not to upgrade (when $\Delta q + \alpha\lambda_2 - c_u < 0$), they are willing to pay a price p_1 such that their total expected discounted benefit from buying the initial product and not upgrading is greater than or equal to their expected surplus if they postpone their decision for period two. Thus, the equilibrium period one price is set by the incumbent monopolist such that:

$$q_1 + \delta q_1 + \alpha\lambda_1 + \delta\alpha\lambda_1 - c - p_1 = \delta(q_2 + \alpha - c),$$

or $p_1 = q_1 + \delta q_1 + \alpha\lambda_1 - \delta\alpha\lambda_2 - c(1-\delta) - \delta q_2$.

7.2 Prices and market outcome if the incumbent commits not to upgrade and the entrant can price discriminate (and F=0)

Consider now the case that the incumbent commits not to upgrade. The new customers are assumed to act as if they are a single player. Thus, their net utility if they buy the entrant's upgrade product is $q_2 + \alpha - c - p_2^{'}$, where $p_2^{'}$ is her price choice. If they all decide to purchase the incumbent's initial version, their net utility is $q_1 + \alpha\lambda_2 + \alpha\lambda_1 x_1 - c - p_1^{'}$, where x_1 is the old customers' fraction that sticks to the old product and $p_1^{'}$ is his price choice. Thus, the new comers will decide to upgrade to the entrant's good if:

$$q_2 + \alpha - c - p_2^{'} \geq q_1 + \alpha\lambda_2 + \alpha\lambda_1 x_1 - c - p_1^{'}$$

Old customers prefer the entrant's version even if all the other period one consumers stick to the old product if:

$$q_2 + a - c_u - p_u^{'} \geq q_1 + \alpha\lambda_1 + \alpha\lambda_2 x_2,$$

where x_2 is the new consumers' fraction that buys the old good and $p_u^{'}$ is the entrant's price choice. If $\Delta q + \alpha\lambda_2 - c_u < 0$, old customers don't upgrade in period two independently of the entrant's upgrade price. Bertrand competition leads to prices $p_2^{'} = \Delta q$, $p_1^{'} = 0$, $p_u^{'} = 0$ and the new customers purchase the new product. If $\Delta q + \alpha\lambda_2 - c_u \geq 0$, period one comers are willing to upgrade and this depends on the price set by the entrant. Bertrand competition leads to equilibrium prices $p_2^{'} = \Delta q + \alpha\lambda_1$, $p_1^{'} = 0$, $p_u^{'} = \Delta q + \alpha\lambda_2 - c_u$ and all the customers upgrade. Going back to period one, the the incumbent sets a price to attract the period one potential customers. In period one, the incoming potential customers expect a competitor that will sell an upgraded version of the initial product in the following period. Thus, their outside opportunity is to wait and make their purchase in the second period by paying a price Δq (due to Bertrand competition). If they expect that they will upgrade in period

two (when $\Delta q + \alpha\lambda_2 - c_u \geq 0$), they are willing to buy the initial version if their expected total net benefit is higher than their discounted payoff from postponing their decision for the following period. Thus, the period one price set by the incumbent is given by the equality:

$$q_1 + \delta q_2 + \alpha\lambda_1 + \delta\alpha - c - \delta c_u - \delta(\Delta q + \alpha\lambda_2 - c_u) - p_1 = \delta(q_2 + \alpha - c - \Delta q),$$

or equivalently $p_1 = q_1 + \alpha\lambda_1 - c(1-\delta) - \delta\alpha\lambda_2$. If old customers expect not to upgrade in period two (when $\Delta q + \alpha\lambda_2 - c_u < 0$), they are willing to buy the initial product by paying a price p_1 that satisfies the equality:

$$q_1 + \delta q_1 + \alpha\lambda_1 + \delta\alpha\lambda_1 - c - p_1 = \delta(q_2 + \alpha - c - \Delta q)$$

or $p_1 = q_1 + \alpha\lambda_1 - \delta\alpha\lambda_2 - c(1-\delta)$.

7.3 Market outcome when the entrant has zero development cost and is unable to offer an upgrade discount under the incumbent's commitment

If the incumbent commits to upgrade, in period two, perfect compatibility between the superior products and backward compatibility of the new version ensure that the new potential customers join a network of size 1 if they buy from either the incumbent or the entrant. Their net utility if they buy the entrant's or the incumbent's superior good is $q_2 + \alpha - c - p_2^{'}$, $q_2 + \alpha - c - p_2$ where $p_2^{'}$, p_2 are the entrant's and the incumbent's price choices, respectively. The old consumers will buy the entrant's product even if all the other period one customers either stick to the incumbent's initial or upgrade version if:

$$q_2 + \alpha - c_u - p_2^{'} \geq \max\left\{q_1 + \alpha\lambda_1,\ q_2 + \alpha - c_u - p_u\right\},$$

where p_u is the incumbent's price choice for the old consumers who upgrade in period two. Bertrand competition drives all the prices to zero. If $\Delta q + \alpha\lambda_2 - c_u < 0$, the old customers stick to the incumbent's initial version and the new comers purchase the superior good for free by either of the competitors. If $\Delta q + \alpha\lambda_2 - c_u \geq 0$, the whole market upgrades again for free to either the incumbent's or the entrant's high-quality product. In period one, the incumbent sets a price for the initial version to attract the incoming customers, who correctly anticipate, in equilibrium, the second period play. Thus, their outside opportunity in period one is to buy the high quality good in period two by facing a zero price. If the old consumers expect to upgrade in period two ($\Delta q + \alpha\lambda_2 - c_u \geq 0$), the equilibrium price in period one

satisfies the equality:

$$q_1 + \delta q_2 + \alpha\lambda_1 + \delta\alpha - c - \delta c_u - p_1 - \delta p_u = \delta(q_2 + \alpha - c)$$

or equivalently, $p_1 = q_1 + \alpha\lambda_1 - c(1-\delta) - \delta c_u$, where $p_u = p_2^{'} = 0$. If the period one consumers expect not to upgrade (when $\Delta q + \alpha\lambda_2 - c_u < 0$), the equilibrium period one price satisfies the equality:

$$q_1 + \delta q_1 + \alpha\lambda_1 + \delta\alpha\lambda_1 - c - p_1 = \delta(q_2 + \alpha - c),$$

or $p_1 = q_1 + \delta q_1 + \alpha\lambda_1 - \delta\alpha\lambda_2 - c(1-\delta) - \delta q_2$. Consider now the case that the incumbent commits not to upgrade. The new customers choose the entrant's superior good if:

$$q_2 + \alpha - c - p_2^{'} \geq \max\left\{q_1 + \alpha - c - p_1^{'}, 0\right\}$$

where $p_2^{'}$, $p_1^{'}$ are the entrant's and the incumbent's period two price choices for the high and the initial version, respectively. Old consumers prefer the entrant's version and do not stick to the incumbent's initial product if:

$$q_2 + a - c_u - p_2^{'} \geq q_1 + \alpha\lambda_1 + \alpha\lambda_2 x_2$$

or equivalently

$$\Delta q + \alpha\lambda_2 - \alpha\lambda_2 x_2 - c_u - p_2^{'} \geq 0,$$

where x_2 is the new consumers' fraction that buys the old good. If $\Delta q + \alpha\lambda_2 - c_u \geq 0$, $\Delta q > \Delta q + \alpha\lambda_2 - c_u$, $\Delta q + \alpha\lambda_2 - c_u \geq \lambda_2\Delta q$, Bertrand competition leads to $p_2^{'} = \Delta q + \alpha\lambda_2 - c_u$ and $p_1^{'} = 0$ and the equilibrium market outcome is that everyone upgrades. Otherwise, the equilibrium prices are $p_2^{'} = \Delta q$ and $p_1^{'} = 0$ with potentially different equilibrium market outcomes dependent on the parameter values. To be more precise, if $\Delta q + \alpha\lambda_2 - c_u < 0$ or if $\Delta q + \alpha\lambda_2 - c_u \geq 0$, $\Delta q > \Delta q + \alpha\lambda_2 - c_u$, $\Delta q + \alpha\lambda_2 - c_u < \lambda_2\Delta q$, old customers do not upgrade and the new comers purchase the entrant's superior product, whereas if $\Delta q + \alpha\lambda_2 - c_u \geq 0$, $\Delta q < \Delta q + \alpha\lambda_2 - c_u$, everyone upgrades in period two. In the initial stage, the incumbent sets a price p_1 for the lower quality good such that the potential customers buy it and do not wait until period two to make their purchase decision. Old customers' outside opportunity in period one is to purchase the superior entrant's product by paying a price $p_2^{''} = \Delta q$ in period two. If old customers expect to upgrade in period two ($\Delta q + \alpha\lambda_2 - c_u \geq 0$, $\Delta q > \Delta q + \alpha\lambda_2 - c_u$, $\Delta q + \alpha\lambda_2 - c_u \geq \lambda_2\Delta q$), the equilibrium period one price satisfies the equation:

$$q_1 + \delta q_2 + \alpha\lambda_1 + \delta\alpha - c - \delta c_u - p_1 - \delta p_2^{'} = \delta(q_2 + \alpha - c - p_2^{''}), \text{ where } p_2^{'} = \Delta q + \alpha\lambda_2 - c_u,\ p_2^{''} = \Delta q$$

or equivalently $p_1 = q_1 + \alpha\lambda_1 - c(1-\delta) - \delta\alpha\lambda_2$. They are also expected to upgrade if $\Delta q + \alpha\lambda_2 - c_u \geq 0$, $\Delta q < \Delta q + \alpha\lambda_2 - c_u$. In this case, the equilibrium period one price is given by the equality:

$$q_1 + \delta q_2 + \alpha\lambda_1 + \delta\alpha - c - \delta c_u - p_1 - \delta p_2^{'} = \delta(q_2 + \alpha - c - \Delta q), \text{ where } p_2^{'} = \Delta q$$

or $p_1 = q_1 + \alpha\lambda_1 - c(1-\delta) - \delta c_u$. If the old customers expect not to upgrade (if $\Delta q + \alpha\lambda_2 - c_u < 0$ or if $\Delta q + \alpha\lambda_2 - c_u \geq 0$, $\Delta q > \Delta q + \alpha\lambda_2 - c_u$, $\Delta q + \alpha\lambda_2 - c_u < \lambda_2 \Delta q$), the period one equilibrium price satisfies the equation:

$$q_1 + \delta q_1 + \alpha\lambda_1 + \delta\alpha\lambda_1 - c - p_1 = \delta(q_2 + \alpha - c - \Delta q)$$

and thus, $p_1 = q_1 + \alpha\lambda_1 - c(1-\delta) - \delta\alpha\lambda_2$.

7.4 Post entry game and equilibrium market outcome when the entrant needs to bear strictly positive development cost and the incumbent commits to upgrade

Think of the hypothetical post-entry scenario when the entrant needs to bear a fixed positive development cost when the incumbent commits to upgrade. Note that I consider the case where the entrant is able to offer upgrade prices to the old users. Under the assumption of compatibility between the rival firms' products, the new customers' net utility if they buy the high-quality product by either the incumbent or the entrant is $q_2 + \alpha - c - p_2$, $q_2 + \alpha - c - p_2^{'}$, respectively. The old consumers' net payoff from upgrading is independent of the other old or new customers' choices. Thus, they upgrade to the incumbent's superior product even if every other old customer either chooses the entrant's high-quality or the incumbent's initial version when:

$$q_2 + \alpha - c_u - p_u \geq \max\left\{q_2 + \alpha - c_u - p_u^{'},\ q_1 + \alpha\lambda_1\right\}.$$

where p_u, $p_u^{'}$ are the the competitors' price choices. If $\Delta q + \alpha\lambda_2 - c_u < 0$, the old consumers will not buy the upgraded version independently of the rival firms' price choices. Bertrand competition leads to prices, $p_2 = \frac{F}{\lambda_2} - \epsilon$[21], $p_2^{'} = \frac{F}{\lambda_2}$[22]. New customers would purchase the superior good from the incumbent and thus, the potential entrant would incur losses after entry. Thus, she will optimally choose not to invest. Similarly, think of the post-entry game if $\Delta q + \alpha\lambda_2 - c_u \geq 0$, when old customers upgrade. Bertrand competition leads to equilibrium

[21] for ϵ being any small positive number

[22] when, without loss of generality, I assume that the development cost is not prohibitively high: $F < (q_2 + \alpha\lambda_2 - c_u)\min\{\lambda_1, \lambda_2\}$.

prices $p_2 = \frac{F}{\lambda_2} - \epsilon$, $p_2^{'} = \frac{F}{\lambda_2}$, $p_u = \frac{F}{\lambda_1} - \epsilon$, $p_u^{'} = \frac{F}{\lambda_1}$ and the whole market upgrades to the incumbent's high quality product. Thus, the potential entrant would be better-off if she stayed out of the market. In any case, the incumbent remains the sole supplier in period two and this allows him to extract consumers' surplus. Going back to period one, the incumbent needs to attract the potential customers into buying the initial version of the product. Old customers create expectations, which are correct in equilibrium. Thus, their net payoff from waiting to buy the superior good in period two is zero. If they expect to upgrade in period two (when $\Delta q + \alpha\lambda_2 - c_u \geq 0$), the equilibrium period one price is given by the expression:

$$p_1 = q_1 + \alpha\lambda_1 - c + \delta q_2 + \delta\alpha - \delta c_u - \delta p_u,$$

where $p_u = \Delta q + \alpha\lambda_2 - c_u$. If they expect to upgrade (when $\Delta q + \alpha\lambda_2 - c_u < 0$), the equilibrium price p_1 is such that:

$$p_1 = q_1 + \delta q_1 + \alpha\lambda_1 + \delta\alpha\lambda_1 - c.$$

7.5 Post entry game and equilibrium market outcome when the entrant needs to bear strictly positive development cost and the incumbent commits not to upgrade

I analyze the scenario where the entrant can offer upgrdade prices to the users of the old version.

Case 1 $\Delta q + \alpha\lambda_2 - c_u < 0$, $\lambda_2\Delta q - F \geq 0$.

In period two, Bertrand competition leads to the entrant's and the incumbent's equilibrium prices being $p_2^{'} = \Delta q$, $p_1^{'} = 0$, respectively. The market equilibrium outcome is that only the new customers buy the entrant's superior good and the old customers stick to the old product. The incumbent in period one will set a price p_1, such that:

$$q_1 + \alpha\lambda_1 + \delta q_1 + \delta\alpha\lambda_1 - c - p_1 \geq \delta(q_2 + \alpha - c - p_2^{''}),$$

where the left hand side of the inequality is the customers' net utility from purchasing the lower quality good in period one and retaining it in period two. Note that if all consumers wait and purchase the entrant's superior good in period two, the price they would face is $p_2^{''} = \Delta q$. Thus, the equilibrium price in period one satisfies the above inequality as equality and is given by the expression:

$$p_1 = q_1 - (1 - \delta)c + \alpha\lambda_1 - \delta\alpha\lambda_2.$$

The incumbent's and the entrant's equilibrium profits are:

$$\begin{aligned}\Pi_I &= \lambda_1[q_1 - (1-\delta)c + \alpha\lambda_1 - \delta\alpha\lambda_2],\\ \Pi_E &= \lambda_2\Delta q - F,\ \lambda_2\Delta q - F \geq 0,\end{aligned}$$

respectively.

Case 2 $\Delta q + \alpha\lambda_2 - c_u \geq 0$, $\lambda_1(\Delta q + \alpha\lambda_2 - c_u) + \lambda_2\Delta q - F \geq 0$.

In period two, Bertrand competition leads to the prices $p_2^{'} = \Delta q$, $p_u^{'} = \Delta q + \alpha\lambda_2 - c_u$, set by the entrant and $p_1^{'} = 0$ set by the incumbent. The market equilibrium outcome is that everyone upgrades to the entrant's superior good. In period one, the incumbent will set a price p_1, such that:

$$q_1 + \delta q_2 + \alpha\lambda_1 + \delta\alpha - c - \delta c_u - p_1 - \delta p_2^{'} \geq \delta(q_2 + \alpha - c - p_2^{''}),$$

where $p_2^{''} = \Delta q$ is the entrant's price if the old customers wait and purchase the superior product in period two. Thus, the equilibrium prices as well as the competitors' profits are given by the expressions:

$$p_1 = q_1 + \alpha\lambda_1 - c(1-\delta) - \delta\alpha\lambda_2,\ p_2^{'} = \Delta q + \alpha\lambda_2 - c_u,\ p_1^{'} = 0,$$

$$\begin{aligned}\Pi_I &= \lambda_1[q_1 + \alpha\lambda_1 - c(1-\delta) - \delta\alpha\lambda_2],\\ \Pi_E &= \lambda_1(\Delta q + \alpha\lambda_2 - c_u) + \lambda_2\Delta q - F.\end{aligned}$$

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