Incentives to Innovate, Compatibility and Welfare in Durable Goods Markets with Network Effects

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Abstract

This paper investigates the relation between firms' R&D incentives and their attitude toward the compatibility of their potentially innovative future network goods with direct competitors. My work explains puzzling compatibility agreements that market leaders sign with small rivals and challenges the view that compatible standards lead to free-riding in terms of firms' incentives to invest. The paper also explains evidence from a natural experiment in the US where dominant firms decreased their R&D spending despite the higher future value appropriated from being incompatible. Regarding welfare, I find that a policy of mandatory compatibility leads to welfare losses when consumers coordinate on the Pareto optimum.

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1 Introduction

Market R&D spending is imperative for economic growth and development and it is an important governments' target. Thus, incentivizing firms to spend and overcome the problem of appropriability of intellectual property due to the public good nature of knowledge but without neglecting to support competition is of the first order of importance.[1] In this respect, a crucial academic and policy question is how standardization and (in)compatible standards relate to firms' incentives to invest.

This paper is at the heart of this question. I focus on markets that entail physical networks on the demand side -consumers' utility increases with the number of users that use compatible products-, such as the market application software, which is an important multi-billion-dollar industry.[2] In these markets, technological progress is rapid and innovation is carried out either by the initially dominant -in terms of market shares or other traits- or smaller firms. Consumers are key actors whose utility depends on other customers' choice and face a coordination problem related to their purchasing decision. This paper will highlight the crucial role that customers' equilibrium purchasing rule plays in firms' R&D and compatibility choices.

In particular, my work adds to the literature on standards regulation and is close to Cabral and Salant (2014). The authors in that article assume that standardization increases firms' revenues and their main contribution is that incompatible standards are a necessary evil due to decreased firms' R&D incentives under compatibility. By expanding the analysis in markets with direct network externalities and considering, unlike their paper, consumers who affect the equilibrium, I show novel results. More precisely, when consumers coordinate on the Pareto optimum, competition in the product market is fiercer under incompatibility. Thus, the winner of the R&D race can appropriate higher profits under compatible standards. This future benefit from compatibility affects current R&D incentives. In particular, if the

[1]See Belleflamme (2006).
[2]See Gandal (1994) for an article that identifies network externalities in software industries.

dominant firm is likely to be more innovative than its competitor, both firms invest more under compatible standards and are also better off by supporting the compatibility of their future products. These results challenge the view that compatible standards decrease firms' R&D spending. I also explain puzzling agreements that dominant firms sign with smaller competitors regarding the compatibility of their future products through their interrelated R&D and compatibility decisions.[3] In contrast, when market leaders are less likely to come up with an innovative product, I show -similarly to Cabral and Salant- that dominant firms free-ride on their competitors' R&D effort under compatible standards.

When consumers follow their peers in their purchasing decisions, compatible standards no longer benefit the winner of the R&D race like Cabral and Salant (2014) assume. I show that although the innovator can appropriate higher profit under incompatible standards -potentially via the use of a patent-, dominant firms' R&D spending is lower compared to the economy operating under compatibility. This suggests that market leaders decrease their current R&D spending in the anticipation of getting a patent in the future. The result explains evidence from a natural experiment that took place in the software market industry in the US during the 90s. In that period, the patent system both made it cheaper for an innovator to get a patent and decreased the standard above which a patent was granted. These changes should, according to the incentive theory, have a positive effect on established firms' R&D intensity -R&D spending over either number of sales or revenue- due to the higher appropriated profit upon the use of the patent. However, this theoretical prediction failed to match firms' R&D choices in practice. Webbink (2005) showed that Microsoft's -a dominant firm in the productivity suites market during the 90s- propensity to patent was negatively correlated with its R&D relative to revenue.[4] Bessen and Hunt (2007) also found a negative correlation between established firms' R&D intensity and their propensity to get a patent. I show that competitive forces and consumers who follow their peers in their

[3] One example is the 2007 Microsoft-Novell agreement regarding the compatibility of their future products. For more details regarding the agreement, see http://news.microsoft.com/2007/02/12/microsoft-and- novell-announce-collaboration-for-customers/.

[4] See table 1 on page 14.

purchasing decisions lead dominant firms to decrease their R&D spending in the anticipation of getting a patent. Thus, this argument challenges the alleged benefit from the use of patents in boosting firms' R&D incentives, at least prior to innovation.[5]

Moreover, this paper contributes to the debate regarding consumer welfare: Is it welfare-enhancing to have compatible or incompatible standards? I suggest that welfare depends on the equilibrium rule that consumers use in their purchasing decisions. If consumers follow their peers in their purchasing decisions, compatible standards lead to lower prices and higher consumer surplus. In this respect, I agree with proponents of compatibility, such as Economides (2006). In contrast, incompatible standards increase competition and lower prices when consumers coordinate on the Pareto optimum. This argument challenges the welfare-enhancing view of compatibility and adds to the literature that holds a "pensive position" toward compatible standards.[6] Thus, antitrust concerns from dominant firms' refusals to support compatibility, such as the 2008 EU vs Microsoft case, depend on consumers' equilibrium rule related to their coordination problem.[7]

This paper is organized as follows: Section 2 presents the Model. In Section 3, I compare equilibrium outcomes when compatibility is mandatory and when the economy operates under a laissez-faire competition law. Section 4 investigates whether a laissez-faire market or an economy where compatibility is mandatory leads to higher expected innovation rates and is beneficial for consumers. Section 5 concludes.

2 The Model

In the history of the game, a firm has launched a product of quality q_1 and has already built an installed base of consumers of mass λ_1.[8] At t=1, both the dominant firm and a smaller

[5] See, for example, Bessen and Maskin (2009).

[6] See, for example, Chen, Doraszelski, and Harrington (2009), who showed that a laissez-faire market increases welfare in an environment without innovation.

[7] For details regarding this case, see http://europa.eu/rapid/press-release_MEMO-08-19_en.htm.

[8] I follow Ellison and Fudenberg (2000), who also consider product quality as a positive, real number q.

competitor decide how much to invest in R&D. The two research lines are independent, and I assume that R&D spending is quadratic in the probability of successfully improving product quality, which is random. Thus, even if a firm "succeeds" in its R&D effort, the actual future quality follows the distribution functions Φ_i (where i is the dominant firm or the competitor) defined in the interval (q_1,$\bar{q_2}$]. In agreement with software products, the marginal cost of production for all product versions is normalized to zero. Besides the investment decision, at t=1 the two firms also decide their attitude toward the compatibility of their future products should they have commitment power.

A few clarifications regarding compatibility are important. First, I assume that compatibility needs bilateral consent and is a binary decision.[9] I also exclude inter-firm payments for compatibility as they may lead to collusion.[10] Another justification for no licensing and royalties fees is that I look at a static innovation scenario -prior to innovation-, and royalties may be more relevant in a sequential setting.

At date t=2, and upon the realizations of the R&D processes, firms compete a la Bertrand and set their prices to the measure λ_1 of old and to the random measure λ_2 of new consumers. Thus, the model allows for potential market expansion and the following assumption holds regarding new date t=2 consumers:

Assumption 1: The number λ_2 of new customers in the economy follows a Poisson($\overline{\lambda_2}$) distribution with $\overline{\lambda_2} = \theta\lambda_1$, $\theta \geq 0$.

In agreement with realistic markets, I assume that the dominant firm has information regarding its consumers and may exercise price discrimination between the different consumer cohorts.[11]

Identical risk neutral consumers have unit demand and their utility depends partially on network externalities, captured by a parameter α. This means that when compatible

[9]Even if I allow for partial compatibility, the basic trade-offs and results would be intact.
[10]See Malueg and Schwartz (2006) for an article these two assumptions are present.
[11]For example, Microsoft offered discounts to its existing consumers when it sold its Office 2007 productivity suite.

networks arise, all consumers join a network of maximum size independently of their seller. Thus, if a customer purchases a product of quality q_{2i}, her expected utility is:

$$q_{2i} + \alpha\lambda_1 + \alpha E\lambda_2 - p_{2i},\ i = D, R$$

where E denotes the operator with respect to the mathematical expectation of any random variable and the first and second subscripts in the price p_{2i} denote product quality and the seller's identity (D for the dominant and R for the smaller firm), respectively.[12] In contrast, incompatible networks allow consumers to interact only with those that purchase from the same seller. For example, if a customer purchases a product of quality q_{2i}, her expected utility is:

$$q_{2i} + \alpha\lambda_1 x_1 + \alpha E\lambda_2 x_2 - p'_{2i},$$

where x_1, x_2 are the old and new consumers' fractions that also join this seller's network. Thus, consumers' expected utility depends on how other customers behave. While the coordination problem that arises regarding how consumers make their purchasing decisions has multiple equilibria, I consider both the equilibrium condition when customers coordinate on the Pareto optimum and when they follow the other group members in their purchasing decisions.[13]

3 Market Outcome

In this section, I will solve for equilibrium outcomes by using backward induction. In particular, I will calculate the date t=2 prices and consumers' choices in an economy that operates

[12] Although I follow the literature by assuming that consumers value the whole network and not only the agents that they enjoy an immediate interaction, current work relaxes this assumption, by considering the role of pivotal consumers in networks formation.

[13] See Ellison and Fudenberg (2000). Current work looks at how endogenous, behavioral consumers may affect firms' investment and compatibility as well as learning in this environment.

under compatible and incompatible standards, respectively. Going back to date t=1, I will contrast firms' investment decisions in an economy where competitors cannot veto over compatibility and in a market where incompatible networks arise. I will also provide conditions under which firms support or reject compatibility in a laissez-faire market.

Compatible Networks

At date t=2, consumers observe the available products and their prices and join a network of maximum size independently of their seller's identity. Thus, they buy the product of the higher physical quality q_{2i} if their net expected utility (weakly) surpasses their expected utility by purchasing the competitor's q_{2j} :

$$q_{2i} + \alpha\lambda_1 + \alpha E\lambda_2 - p_{2i} \geq q_{2j} + \alpha\lambda_1 + \alpha E\lambda_2 - p_{2j},\ i = D, R$$

and the equilibrium date t=2 prices are:

$$p_{2i} = \Delta q^{''},\ p_{2j} = 0,\ \Delta q^{''} = q_{2i} - q_{2j}.$$

Note that either when there in no successful R&D line or when the dominant firm is the sole inventor, the smaller competitor can provide the market with a product of quality q_1 at t=2. This drives the equilibrium prices either to zero if there is no innovator or to

$$p_{2D} = \Delta q^{'},\ p_{2R} = 0,\ \Delta q^{'} = q_{2D} - q_1,$$

when the dominant firm is the only innovator. In the latter case, consumers purchase the market leader's higher quality product.

Incompatible Networks

Consumers coordinate on the Pareto optimum

At t=2, consumers observe the products and their prices and decide which product to buy. Think of the states when firm i is more innovative than its rival. A consumer that belongs to the random measure λ_2 of new date t=2 consumers purchases firm i's superior product of quality q_{2i} even if all the other new consumers get the competitor's q_{2j} if her expected utility by doing so (weakly) exceeds her expected utility by purchasing q_{2j}:

$$q_{2i} + \alpha\lambda_1 x_1 - p_{2i} \geq q_{2j} + \alpha E\lambda_2 + \alpha\lambda_1(1 - x_1) - p_{2j}.$$

Similarly, a consumer that belongs to the measure λ_1 of old date t=2 consumers purchases the product q_{2i} even if all the other old consumers purchase q_{2j} when:

$$q_{2i} + \alpha E\lambda_2 x_2 - p_{2i} \geq q_{2j} + \alpha E\lambda_2(1 - x_2) + \alpha\lambda_1 - p_{2j}.$$

Thus, if the dominant firm lacks the ability to exercise price discrimination, the equilibrium prices are:

$$p_{2i} = \Delta q^{''} + \alpha E\lambda_2 - \alpha\lambda_1,\ p_{2j} = 0,\ \theta < 1,$$

$$p_{2i} = \Delta q^{''} + \alpha\lambda_1 - \alpha E\lambda_2,\ p_{2j} = 0,\ \theta \geq 1,$$

and all date t=2 consumers purchase the product of higher quality q_{2i}. An important observation is that firms' expected revenue for the states they are more innovative than their competitor is always higher when compatibility is supported. This is because competition is fiercer under incompatible standards and thus, compatibility yields higher payoff for the innovator. In turn, this higher benefit from future compatible standards also affects firms' current R&D incentives.

Similarly to the economy operating under compatibility, Bertrand competition drives the equilibrium date t=2 prices to zero if no firm innovates. If the dominant firm is the only inventor, it may be tempted to stop selling its previous version of quality q_1 to the new date t=2 consumers because of cannibalization effects that would decrease its potential price choice should it decide to sell q_1 at t=2. Nevertheless, the smaller competitor's ability to produce a product of quality q_1 deters the market leader from withdrawing its previous version from the market. It also restores competition, driving to the same equilibrium prices as in the economy under compatible networks.

At t=1, both firms solve their maximization problems, taking into consideration that their competitor is also aiming to maximize its own profit.[14] Similarly to the economy where compatibility is mandated, standard first-order conditions provide us with the competitors' reaction functions.[15] The next proposition compares the competitors' R&D incentives in an economy where they cannot veto over compatibility versus the one where compatibility is blocked either because of the use of a patent or just non-disclosure of technical information. The proposition also provides conditions that explain compatibility agreements signed by dominant and smaller firms and is independent of the dominant firm's ability to exercise price discrimination between the consumer cohorts:

Proposition 1. *Both firms' R&D incentives are boosted under future compatible networks when the dominant firm is likely to be more inventive than its competitor. In this case, both firms sign the compatibility agreement.*

Proof. See the Appendix

□

The proposition offers novel results regarding firms' R&D incentives under compatible and incompatible standards. I suggest that dominant firms' attitude toward investment depends

[14]See the Appendix for the competitors' maximization problems.

[15]See the Appendix.

on firms' relative innovativeness. When market leaders are ex-ante likely to be innovative, both firms invest more under compatible rather than incompatible standards. This happens because innovators' higher appropriated profit under compatibility triggers higher incentives to invest for both competitors. The dominant firm may face a trade-off when it makes its compatibility decision at t=1. Competitors' higher spending under compatible standards increases the endogenous probability of reaching the state where the dominant firm is more innovative than its rival. However, it may also lead to a lower probability of the dominant firm being the sole inventor. When the market leader is ex-ante likely to be more inventive, it signs the compatibility agreement. This occurs as the market leader's benefit through sharing its network of consumers outweighs the likely loss from being the sole innovator. In contrast, if market leaders are less likely to be more inventive than their competitor, their R&D incentives are curbed when standards are compatible and incompatible standards prevail. These results complement Cabral and Salant (2014), who showed that dominant firms free-ride on the competitor's R&D effort under compatible standards. The proposition also rationalizes compatibility agreements that dominant firms sign with smaller competitors, such as the Microsoft-Novell agreement highlighted in the introduction.

Consumers follow their peers

Think of the states where firm i is more creative than its competitor. If consumers follow their peers in their equilibrium decisions, the equilibrium prices in this case are:

$$p_{2i} = \Delta q^{''} + \alpha\lambda_1 + \alpha E\lambda_2,\ p_{2j} = 0,$$

and all consumers purchase the product of superior quality. Thus, when consumers are willing to pay high prices, any innovator is better off by being incompatible, as this increases the profit that the innovator can appropriate.

At t=1, firms choose their R&D spending and aim to maximize their expected profits, taking both the opponent's optimal R&D effort and future outcomes into consideration.[16] Standard first-order conditions give firms' investment as a function of the opponent's R&D effort. The next proposition summarizes the conditions under which dominant firms invest more under compatible rather than incompatible standards and the competitors' attitude toward compatibility.

Proposition 2. *When firms are either equally likely to be innovative or when the smaller competitor is more likely to be more inventive, the dominant firm invests more under future compatible standards and the smaller competitor invests more in the expectation of incompatible standards. In any case, no compatibility agreement is reached at t=1.*

Proof. See the Appendix. □

This proposition suggests that dominant firms invest less although they appropriate higher profits under incompatible standards. It is innovative competitive forces and consumers who follow their peers in their equilibrium coordination rule that explain the puzzling observation of dominant firms' decreased incentives to invest under incompatibility. Thus, this paper offers new insights related to the natural experiment observed in the United States. Firms and in particular, dominant firms decreased their R&D intensity while the intellectual property rights law made it easier for innovators to be granted a patent. I argue that this may occur in markets that entail network externalities in the expectation of being incompatible in future. These results contrast with the existing literature on standards regulation that predicts that incompatibility increases firms' R&D incentives at least prior to innovation (see Cabral and Salant (2014) and Bessen and Maskin (2009)).

[16] See the Appendix for both firms' maximization problem.

4 Value creation/ Consumer Surplus

After investigating firms' investment and compatibility decisions, it is important to understand the effects of the different economic structures on the (expected) value created from innovation and on consumer surplus. The next proposition aims to contribute to the debate on whether compatible rather than incompatible standards lead to higher future degrees of innovation.

Proposition 3. *(a) Incompatible standards decrease the probability of innovation in the market when consumers follow their peers. (b) When consumers coordinate on the Pareto optimum and the market leader is a likely innovator: 1) compatible standards increase the expected value created from moderate future innovation, 2) incompatible standards lead to higher probability of innovation for higher values of the future innovative step.*

Proof. See the Appendix. □

This proposition adds new results in the literature on standards regulation regarding market R&D spending in a scenario prior to innovation. According to Cabral and Salant (2014), incompatible standards are a necessary evil as they lead to firms' higher R&D spending compared to compatible standards. Thus, they argue against early standardization. Proponents of patents also argue that although there are industries that grew without the use of patents, their growth would have been even higher under a stronger intellectual property rights law. I find novel results in markets with direct network externalities on the demand side. Recall that when consumers follow their peers in their purchasing decisions, the dominant firm's R&D spending is higher under future compatibility. In contrast, the smaller competitor invests more in pursuit of being incompatible. I find that under compatible standards, there are more balanced market R&D incentives that increase the market probability of success. This result is new and contrasts with Cabral and Salant (2014). Moreover, if consumers coordinate on the Pareto optimum and the market leader is a likely innovator, compatible standards lead to a higher probability of market innovation for moderate values of the future expected innovative step. Nevertheless, incompatible standards increase the expected value created in the industry for more important future innovative products. These results are also new and are along the lines in Cabral and Salant. Incompatible standards are a necessary evil and early standardization may decrease the market probability of success in industries at their infancy. In contrast, in more mature markets, where innovative steps may be smaller, compatible standards lead to a higher probability of market innovation.

Although the expected rate at which future products are produced is important, it is also crucial to determine when expected consumer surplus is maximized. The next proposition summarizes which economic structure is beneficial for consumers:

Proposition 4. *Ex-post, incompatibility is beneficial for consumers when they coordinate on the Pareto optimum. Compatible standards benefit consumers when they follow their peers in their purchasing decisions.*

Proof. See the Appendix

□

Consumers' equilibrium behavior affects the degree of competition in the market and the welfare effects from (in)compatible standards. More precisely, when consumers follow the other members of their group in their purchasing decisions, competition under compatible networks becomes fiercer. This decreases the equilibrium prices and benefits all consumers. In contrast, when consumers coordinate on the Pareto optimum, incompatible networks lead to more aggressive competition. This fact implies lower prices when firms do not have the power to price discriminate and higher expected consumer surplus for all groups compared to compatible standards. If firms charge different prices to different consumer cohorts, although inevitably only one group benefits from incompatible networks, total expected consumer surplus is maximized when firms block compatibility. Thus, dominant firms' refusals to support compatibility with smaller rivals, such as the EU vs. Microsoft case highlighted in the introduction do not necessarily decrease consumer surplus. Instead, they may lead to a more competitive environment, which benefits consumers rather than being examples of anticompetitive practices and abuse of dominance.

5 Concluding Remarks/ Discussion

This paper offers new insights in how standards relate to firms' incentives to invest in R&D. I find that when consumers follow their peers in their purchasing decisions, market leaders decrease their current R&D spending in the anticipation of being incompatible in future. This result explains why established firms decrease their expenditure under a more strengthened intellectual property law as highlighted in the introduction. Moreover, the market that operates under future compatible networks is more likely to come up with innovative products. This fact suggests that the accepted role of incompatible standards -and patents- to promote innovation -at least in a static innovation scenario- is challenged. When consumers coordinate on the Pareto optimum, firms' increased R&D spending makes them willing to sign a compatibility agreement regarding their future products. Thus, the article explains compatibility agreements, such as the Microsoft-Novell agreement mentioned in the introduction. In contrast, when consumers follow their peers in their purchasing decisions, incompatible networks prevail.

In addition to that, if incompatible networks prevail, either all consumers are better off or total consumer surplus is maximized when consumers coordinate on the Pareto optimum. Thus, a dominant firm's conduct to refuse to be compatible is not necessarily anticompetitive, as the degree of competition is greater under incompatible networks. In contrast, if consumers follow their peers, consumers benefit from compatibility, as incompatible networks lead to a lower degree of competition and higher equilibrium prices.

Future work can look at the role of competition in this setting; what is the effect of more firms that can be potential innovators on investment/innovation and firms' compatibility decisions? Moreover, it would be interesting to investigate how the investment/compatibility decisions would alter in the face of stochastic or endogenously evolving demand.

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6 Appendix

Firms' Optimal R&D effort

Compatible Networks

The dominant firm's maximization problem is:

$\max_{s_D} s_D(1 - s_{R^*})A + s_D s_R^* Prob(q_{2D} \geq q_{2R})B - s_D^2/2$,

where

$$A = E[(\lambda_1 + \lambda_2)\Delta q^{'}],\ B = E[(\lambda_1 + E\lambda_2)\Delta q^{''}/q_{2D} \geq q_{2R}],\ \Delta q^{'} = q_{2D} - q_1$$

and s_R^* is the smaller competitor's optimal R&D effort.

Standard first-order conditions provide us with the dominant firm's reaction function:

$$s_D = [-A + Prob(q_{2D} \geq q_{2R})B]s_R^* + A. \tag{6.1}$$

Similarly, the smaller competitor maximizes its expected profits, taking into consideration that the market leader is doing the same:

$$max_{s_R} s_R(1 - s_D^*)A + s_R s_D^* Prob(q_{2R} \geq q_{2D})B - s_R^2/2.$$

Again, first-order conditions provide us with the smaller competitor's effort as a function of the market leader's optimal choice:

$$s_R = [-A + Prob(q_{2R} \geq q_{2D})B]s_D^* + A. \tag{6.2}$$

After substituting the smaller competitor's effort in the dominant firm's reaction function, one gets:

$$s_D^* = \frac{A + [-A + Prob(q_{2D} \geq q_{2R})B]A}{1 - [-A + Prob(q_{2D} \geq q_{2R})B][-A + Prob(q_{2R} \geq q_{2D})B]}. \tag{6.3}$$

Incompatible Networks

Similarly to the case that networks are compatible, under incompatible networks, the two firms' maximization problems are:

$$max_{s_D^{'}} s_D^{'}(1 - s_R^{'*})A + s_D^{'} s_R^{'*} Prob(q_{2D} \geq q_{2R})B^{'} - s_D^{'2}/2, \tag{6.4}$$

$$max_{s_R^{'}} s_R^{'}(1 - s_D^{*'})A^{'} + s_R^{'} s_D^{'*} Prob(q_{2R} \geq q_{2D})B^{'} - s_R^{'2}/2, \tag{6.5}$$

where the first and the second problem is the dominant firm's and the competitor's maximization problem, respectively.

Standard first-order conditions provide us with the firms' reaction functions:

$$s_D^{'} = [-A + Prob(q_{2D} \geq q_{2R})B^{'}]s_R^{'*} + A, \tag{6.6}$$

$$s_R^{'} = [-A^{'} + Prob(q_{2R} \geq q_{2D})B^{'}]s_D^{'*} + A^{'}, \tag{6.7}$$

where

$$A^{'} = E[(\lambda_1 + \lambda_2)(\Delta q^{'} + \alpha\lambda_2 - \alpha\lambda_1)/q_{2D} \geq q_{2R}],\ \theta \leq 1,$$

$$A^{'} = E[(\lambda_1 + \lambda_2)(\Delta q^{'} + \alpha\lambda_1 - \alpha\lambda_2)/q_{2D} \geq q_{2R}],\ \theta \geq 1,$$

$$B^{'} = E[(\lambda_1 + \lambda_2)(\Delta q^{''} + \alpha\lambda_2 - \alpha\lambda_1)/q_{2D} \geq q_{2R}],\ \theta \leq 1$$

and consumers coordinate on the Pareto optimum, while

$$A' = E[(\lambda_1 + \lambda_2)(\Delta q' + \alpha\lambda_2 + \alpha\lambda_1)/q_{2D} \geq q_{2R}],$$

$$B' = E[(\lambda_1 + \lambda_2)(\Delta q'' + \alpha\lambda_2 + \alpha\lambda_1)/q_{2D} \geq q_{2R}],$$

if customers follow their peers in their purchasing decisions. After substituting s'_R to equation 6.6, one gets the dominant firm's optimal effort under incompatible networks:

$$s'^{*}_D = \frac{A + [-A + Prob(q_{2D} \geq q_{2R})B']A'}{1 - (-A + Prob(q_{2D} \geq q_{2R})B')[-A' + Prob(q_{2R} \geq q_{2D})B']}. \tag{6.8}$$

First note that $B' = B + c$, $A' = A + c$, and c is positive when consumers follow their peers and negative when they coordinate on the Pareto optimum.

The dominant firm invests more under compatible networks if and only if and after some algebraic manipulation:

$$s_D > s'_D \Leftrightarrow$$

$$\Pi = (A - pB)[-Ac + A(1-p) + c] - pc(A+c)(1-A)-$$

$$-Apc[B - pB + c - pc] - [-A + B - pB]A(-pc)(-A + pB)+$$

$$+(1-p)c(A+c)(-A+pB)(-A+B-pB)+$$

$$+[-A+pB]c\{-Ap[-A-c+(1-p)B] + (1-p)c] - A + (1-p)B\} > 0,$$

where p=Prob($q_{2D} \geq q_{2R}$). The function Π is continuous with respect to the probability of the dominant firm being more innovative than the rival should both firms succeed in their R&D effort Prob($q_{2D} \geq q_{2R}$).

The derivative of function Π with respect to the probability p is given by the following (after some algebraic manipulation):

$\Pi' = K + Rp^2 + Lp,$

where:

$$K = -A(c^2 + A) - (A + c)[B + c + cA + cA^2 - 2cAB] + cAB + cB^2 + B^2 c,$$

$$R = c[B^2 - 2B^2 A - A^2 c + cBA - 2cB^2],$$

$$L = (AB + 2A - 3B^2)c^2 + (-B^2 - 5B^2 A + A^2 B - B^3)c - c^3 AB + 2AB.$$

Proof for Proposition 1

When consumers coordinate on the Pareto optimum (c<0), one gets that:

$$R > 0,\ K < 0,\ L > 0,$$

$$lim_{p\to 0} \mathit{\Pi}(p) < 0,$$

$$lim_{p\to 1} \Pi(p) > 0.$$

From the expression of the derivative of Π with respect to p, one can easily infer that Π is positive (and increasing) as long as p$\geq p^*$. The similar problem solved by the small competitor yields that she also invests more under compatible networks. Direct comparison of both firms' profits yields that they both support compatibility as long as the probability that the dominant firm is more innovative than the rival is above a threshold.

Proof for Proposition 2

If consumers follow their peers, one gets:

$$lim_{p\to 0} \mathit{\Pi} > 0,$$

$$lim_{p\to 1} \Pi < 0,$$

$$K > 0,\ R < 0,\ L < 0\, (if\ c < c^*).$$

It is immediate to see that the dominant firm invests more ($\Pi > 0$) under compatible networks when p<p*. Simple algebra provides us with the result that for the values in p that the dominant firm spends more under compatible networks, the small competitor invests more under future incompatible networks. Straightforward algebra proves that firms do not

sign the compatibility agreement.

Proof of Proposition 3

The probability of future innovation in the market that operates under compatible networks is:

$$s_D^*(1 - s_R^*) + s_R^*(1 - s_D^*),$$

and after substituting the probability of the smaller competitor's probability of success as a function of the dominant firm's success, the expression above leads to:

$$s_D^* + A(1 - s_D^*)(1 - 2s_D^*). \tag{6.9}$$

Similarly, the probability of future innovation under incompatibility is:

$$s_D^{*'}(1 - s_R^{*'}) + s_R^{*'}(1 - s_D^{*'})$$

and after substituting the smaller competitor's probability of success as a function of the dominant firm's effort, the above probability becomes:

$$s_D^{*'} + A'(1 - s_D^{*'})(1 - 2s_D^{*'}). \tag{6.10}$$

Thus, the market operating under compatibility is more likely to come up with an innovative product if consumers follow their peers when:

$$s_D^* + A(1 - s_D^*)(1 - 2s_D^*) > s_D^{*'} + A'(1 - s_D^{*'})(1 - 2s_D^{*'}),$$

or equivalently when

$$G = s_D^* - s_D^{*'} + A[2(s_D^* + s_D^{*'}) - 3] - c(1 - s_D^{*'})(1 - 2s_D^{*'}) > 0,$$

after some algebraic manipulation (c$=A' - A > 0$). It is straightforward to see that the function F($\Delta q^{'}$)=$s_D^* - s_D^{*'} + A[2(s_D^* + s_D^{*'}) - 3]$ always takes a positive value.

When consumers coordinate on the Pareto optimum, the probability of future innovation under incompatibility is:

$$s_D^{*'}(1 - s_R^{*'}) + s_R^{*'}(1 - s_D^{*'})$$

and after substituting the smaller competitor's probability of success as a function of the dominant firm's effort, the above probability becomes:

$$s_D^{*'} + A^{'}(1 - s_D^{*'})(1 - 2s_D^{*'}). \qquad (6.11)$$

Thus, the market operating under compatibility is ore likely to come up with an innovative product when:

$$s_D^* + A(1 - s_D^*)(1 - 2s_D^*) > s_D^{*'} + A^{'}(1 - s_D^{*'})(1 - 2s_D^{*'}),$$

or equivalently when

$$G = s_D^* - s_D^{*'} + A[2(s_D^* + s_D^{*'}) - 3] - c(1 - s_D^{*'})(1 - 2s_D^{*'}) > 0.$$

after some algebraic manipulation (c=$A^{'} - A < 0$). It is straightforward to see that the function F($\Delta q^{'}$)=$s_D^* - s_D^{*'} + A[2(s_D^* + s_D^{*'}) - 3]$ always takes a positive value. For medium values of the future expected innovative step, the expression c(1-s_D^*)(1-2s_D^*) is always positive and G takes a positive value. However, if the average innovative step exceeds the cutoff, the expression c(1-$s_D^{*'}$)(1-2$s_D^{*'}$) takes a negative value and for reasonable values, the expression G now becomes negative.

Proof of Proposition 4

If the dominant firm cannot price discriminate and consumers make independent purchasing decisions, their equilibrium expected surplus is:

$$E(CS) = q_{2i} + \alpha\lambda_1 + \alpha E\lambda_2 - [q_{2i} - q_{2j}] = q_{2j} + \alpha\lambda_1 + \alpha E\lambda_2,$$

$$E(CS)' = q_{2i} + \alpha\lambda_1 + \alpha E\lambda_2 - [q_{2i} - q_{2j} + \alpha E\lambda_2 - \alpha\lambda_1] = q_{2j} + 2\alpha\lambda_1,\ \theta < 1,$$

under compatible and incompatible networks, respectively, where firm i is the winner of the R&D race. It is clear that consumers benefit from incompatible networks. Similarly, if the market size is expected to grow at a higher rate, customers' expected surplus under incompatible networks is:

$$E(CS)' = q_{2i} + \alpha\lambda_1 + \alpha E\lambda_2 - [q_{2i} - q_{2j} + \alpha\lambda_1 - \alpha E\lambda_2] = q_{2j} + 2\alpha E\lambda_2,\ \theta \geq 1,$$

which again leads to higher consumers' (expected) surplus under incompatibility.
If the dominant firm is the winner of the R&D and it can price discriminate between the consumer cohorts, customers' expected surplus is the same as above under compatible networks:

$$E(CS) = q_{2i} + \alpha\lambda_1 + \alpha E\lambda_2 - [q_{2i} - q_{2j}] = q_{2j} + \alpha\lambda_1 + \alpha E\lambda_2.$$

Under incompatible networks, the measure λ_1 of old date t=2 consumers' expected surplus is:

$$q_{2i} + \alpha\lambda_1 + \alpha E\lambda_2 - [q_{2i} - q_{2j} + \alpha E\lambda_2 - \alpha\lambda_1] = q_{2j} + 2\alpha\lambda_1.$$

Similarly, the random measure λ_2 of new date t=2 consumers' expected surplus is:

$$q_{2i} + \alpha\lambda_1 + \alpha E\lambda_2 - [q_{2i} - q_{2j} + \alpha\lambda_1 - \alpha E\lambda_2] = q_{2j} + 2\alpha E\lambda_2.$$

Depending on the parameter that corresponds to the expected market size growth, although one of the two groups benefits from incompatible networks, the second group is better off when compatibility prevails. Then, if we use total expected surplus to measure which structure is preferable, incompatible networks lead to higher total expected surplus if:

$$\lambda_1(q_{2j} + 2\alpha\lambda_1) + E\lambda_2(q_{2j} + 2\alpha E\lambda_2) \geq \lambda_1(q_{1j} + \alpha\lambda_1 + \alpha E\lambda_2) + E\lambda_2(q_j + \alpha\lambda_1 + \alpha E\lambda_2) \Leftrightarrow$$

$$\lambda_1(\alpha\lambda_1 - \alpha E\lambda_2) + E\lambda_2(\alpha E\lambda_2 - \alpha\lambda_1) \geq 0 \Leftrightarrow$$

$$\alpha(\lambda_1 - E\lambda_2)^2 \geq 0,$$

which always holds.

If consumers follow their peers, their expected surplus under compatibility is the same as above:

$$E(CS) = q_{2j} + \alpha\lambda_1 + \alpha E\lambda_2.$$

Under incompatible networks, any consumer's expected surplus is:

$$E(CS)' = q_{2i} + \alpha\lambda_1 + \alpha E\lambda_2 - [q_{2i} - q_{2j} + \alpha\lambda_1 + \alpha E\lambda_2] = q_{2j}.$$

Thus, compatible networks are always beneficial for consumers when they follow the other group members in their decisions.