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

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Abstract

This article investigates firms' incentives to invest in R&D and how these choices relate to their current compatibility decisions regarding their future, durable network goods in the presence of forward-looking consumers. Product innovation is sequential with both an initially dominant firm and a smaller competitor as potential innovators. Firms' R&D efforts become strategic complements for the current market leader when compatibility is present and network effects are strong, while they are strategic substitutes for both firms for weak network externalities. A novelty of the article is that it gives an explanation to compatibility agreements that firms with dominant market shares sign with smaller market players: sufficiently innovative future products lead the dominant firm to support future compatibility because the probability that it is the only innovator increases when compatibility is present, allowing this firm to enjoy a higher expected future profit that outweighs its current lost revenue. An interesting theoretical result is that the smaller rival may reject to support compatibility in industries with a relatively smaller number of existing consumers. For less innovative future products, the dominant firm rejects compatibility and there is a cutoff in network externalities below which it invests more when incompatibility is present. Regarding welfare, I find that future incompatible networks increase expected consumer surplus and lead to more balanced market R&D incentives relative to the economy that mandates compatibility when network effects are weak.

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1 Introduction

Why do dominant firms currently decide to support compatibility of their future durable network products with those of rivals?[3] Even if they refuse to support compatibility, does this imply that their R&D incentives are curbed? Could smaller rivals be better-off if they did not sign a compatibility agreement with the current market leader? Which economy offers the socially preferable balance of aggregate R&D incentives: one that operates under mandatory compatibility or under a laissez faire competition law? Are consumers better-off when future compatibility is mandated? These questions are certainly not new but to the best of my knowledge, this is the first article to examine them in an environment where technological progress is modelled in a scenario with sequential innovations of durable network products.

Although economic theory predicts that dominant firms may refuse to support compatibility with smaller rivals, there are cases in technology markets where firms with leading market shares welcome compatibility even from direct competitors. One famous example of a dominant firm's support of compatibility of its future products with those of an innovative rival is the interoperability agreement signed by Microsoft and Novell in 2007 regarding the document format compatibility of their future software products.[4]

In this article, I provide an explanation of dominant firms' current support to future compatibility, as sequential important innovation leads the market leader to voluntarily support compatibility even if it competes directly with its rival in the future. In particular, I consider an initially dominant firm and a competitor that simultaneously choose their R&D investment levels as well as their attitude towards the compatibility of their future durable network products. Thus, I give both firms the ability to come up with non-drastic, substitutable product innovations, resulting from a discrete time R&D stochastic process.

[3] We will use the terms compatibility and interoperability interchangeably throughout the paper.

[4] For more details regarding the agreement, see http://news.microsoft.com/2007/02/12/microsoft-and-novell-announce-collaboration-for-customers/.

When compatibility is present, firms' R&D efforts become strategic complements for the current market leader when network effects are strong, whereas they are strategic substitutes for both firms for weak network externalities. I also find that for important innovative products, the leader invests more when compatibility is present and in fact, he currently chooses to support future compatibility with the rival's products, as his expected gains from the higher probability of being the sole inventor outweigh his loss from the lower current price. An interesting theoretical result is that the rival may not support future compatibility and only signs the interoperability agreement when the current market size is relatively large. For less innovative products, a laissez faire competition law with respect to intellectual property holders leads the dominant firm to reject compatibility and invest more than in an economy mandating compatibility when network effects are weak. Our welfare analysis shows that firms' current disagreements to support future compatibility benefit consumers and lead to more balanced market R&D incentives compared to an economy that mandates compatibility when network effects are weak.

This article is organized as follows: the next subsection discusses the related literature. Section 2 presents the Model. In Section 3, we solve for equilibrium outcomes when compatibility is either mandatory and when the economy operates under a laissez faire competition law. Section 4 provides an answer to the question regarding which economy maximises consumers welfare: an economy that mandates compatibility or the one that adopts a laissez faire approach. Section 5 concludes.

Related Literature

This article relates to the literature regarding firms' attitude towards compatibility. In an economy where network effects exist and product quality is constant, Chen, Doraszelski and Harrington (2009), Malueg and Schwartz (2006), Economides and Flyer (1998), Cremer, Rey and Tirole (2000) investigate whether compatibility is supported by dominant firms where modelling usually consists of a two-stage structure: first firms make compatibility decisions

and then they engage into price or quantity competition. Although compatibility increases the number of potential buyers because of a larger network, the market leader prefers not to support it because otherwise, he would lose the advantage of the larger installed base. When sequential innovation occurs with certainty and products are substitutable, Athanasopoulos (2014) showed that a dominant market player offers interoperability information of his durable products to a smaller innovative rival when he expects a moderately large, future quality improvement from his competitor. Thus, strategic pricing allows the market leader to extract more of the higher expected total surplus when he supports compatibility. An important assumption in this model is that the rival is the only firm that can innovate in the future. This work differs because unlike that article, both competitors are potential future innovators. Moreover, I assume that the investment cost is a function of the probability of success. For sufficiently innovative future products, I also find that the dominant firm voluntarily supports compatibility.

When network effects are not present and innovations are sequential and complementary, Bessen and Maskin (2009) showed that the initial innovator may welcome imitation because it allows both competitors to invest, increasing the exogenous probability of successful innovation and his second period profit, outweighing the loss from the foregone first period revenues. I depart from their work in a number of ways. First, I assume that direct network effects exist and products are durable. Second, there is an alternative process that allows for product innovation even if there is incompatibility in the market. Third, unlike their paper where the probability of successful innovation is a parameter, I adopt a game theoretical approach where firms' R&D cost is a function of the probability of success. I also consider overlapping generations of forward-looking customers and their role in determining equilibrium outcomes. I find that dominant firms welcome compatibility when future products are sufficiently innovative while interestingly, the smaller rival may reject compatibility if the initial market size is relatively small. I also show that the initial market leader rejects compatibility for less important future products.

This work also relates to a threatened incumbent's and a smaller rival's R&D incentives when the economy operates under mandatory compatibility or a laissez faire competition law when network effects exist. The literature has focused mostly on the initial market structure and assesses whether a monopolist with perfectly exclusive Property Rights has higher or lower R&D incentives than his counterpart under perfect or imperfect competition. In this work, I assume an initial monopolist who is threatened to be displaced by a smaller innovative rival. Similarly to Cabral and Salant (2014), who considered a scenario of non cooperative R&D competition and cooperative standards setting but without durable network products and overlapping generations of incoming customers, I also found that dominant firms' R&D incentives are curbed under compatibility when network effects are weak, as they free ride on the rival's R&D effort. Nevertheless, I concluded that when network effects are relatively strong and for less innovative products as well as for important future versions, the dominant firm invests more when it currently supports compatibility.

Regarding welfare, Bessen and Maskin (2009) showed that for important complementary innovations, imitation raises welfare and patents may impede innovation. When network effects are present, Economides (2006) also found that compatibility raises social and consumers' welfare. I find that firms' disagreement to support future compatibility leads to incompatible networks but raises expected consumer surplus and offers more balanced market R&D incentives compared to the economy that operates under mandatory compatibility when network effects are weak.

2 The Model

My objective is to explain how dominant and smaller firms' current compatibility and investment decisions regarding their future, durable network products relate to overlapping generations of forward-looking customers as well as investigate whether an economy that mandates compatibility or a laissez faire market benefits consumers and leads to socially

preferable market R&D incentives. The economy I have in mind is the market for computer software applications.

Supply

In the three-date model, the sequence of events in the supply side is as follows: at date t=0, both an initially dominant firm and a smaller competitor simultaneously decide their investment levels as well as their attitude towards compatibility of their future products. The latter choice is a binary decision that requires both parties consent and following Malueg and Schwartz (2006), compatibility comes free of charge in order to avoid potentially collusive behaviour. The two research lines are independent and no firm has a cost advantage in its R&D process over its opponent. More precisely, we assume that non cooperative R&D spending is quadratic in the probability of successfully improving product quality.

At date t=1, the dominant firm chooses the price for its initial version of quality q_1, where in common with Ellison and Fudenberg (2000), I consider quality as a positive real number. At date t=2, the two firms compete a la Bertrand. If both research lines are successful, firms sell an improved product of quality $q_2 > q_1$. Following Ellison and Fudenberg (2000), forward incompatibility of the product of quality q_1 prevents its users from working with a file that is created with a product of higher quality q_2. If compatibility is supported and because of backward compatibility of new versions, buyers of a product of quality q_2 join a network of maximum size. In contrast, when there is incompatibility, purchasers of a product of quality q_2 join only their seller's network. Note that both firms are risk neutral and their goal is to maximise their expected profits, where in accordance with the software market industry, the marginal cost of production for all product versions is normalized to zero.

Demand

Consumers are identical and arrive in flows of measure λ_t $(t = 1, 2)$. At date t=1, a measure λ_1 of consumers observes the dominant firm's price p_{11} for the product of quality q_1 and

cannot postpone their purchase, as they currently need to use the product. Their utility is linear in income and partially dependent on network effects, captured by the parameter α.[5] Thus, if they buy a product of quality q_1, their total expected discounted utility is $q_1 + \alpha\lambda_1 x_1' - c + \delta E(V) - p_{11}$, where x_1' is the λ_1 customers' fraction that also buys q_1, c is these customers' non monetary cost of learning how to use the product and $\delta E(V)$ is their net future expected discounted payoff. Of course, these customers' total expected benefit depends on how other customers currently behave and on their forecasts regarding the second period play.

At date t=2 and if there is a new product of quality q_2 in the market sold by both firms, a measure λ_1 of old customers observes the rival firms' prices. If a customer that belongs to this group of consumers sticks to the product of quality q_1 and because of its forward incompatibility, her utility is $V = q_1 + \alpha\lambda_1 x_1 + \alpha\lambda_2 x_2$, where x_1, x_2 are the new and old date t=2 customers' fractions that also own the product of quality q_1. If she purchases q_2, she incurs an additional non monetary cost to learn the new product, $c_u < c$. Thus, if compatibility is supported, she joins a network of maximum size and her utility is $V = q_2 + \alpha - c_u - p_{21i}$, after normalizing the second period market size to unity, where the three subscripts in the price charged denote the quality of the product (q_2), the type of consumers (λ_1) and the product maker ($i = 1$ for the leader and $i = 2$ for the smaller rival), respectively. If incompatibility prevails, she joins her seller's network of customers. Thus, if she purchases either the rival's or the dominant firm's product of quality q_2, her utility is $V = q_2 + \alpha\lambda_2\psi_2 + \alpha\lambda_1\psi_1 - c_u - p_{212,}$ $V = q_2 + \alpha\lambda_2(1-\psi_2) + \alpha\lambda_1(1-\psi_1) - c_u - p_{211}$, respectively, where ψ_2, ψ_1 are the new and old date t=2 customers' fractions that prefer the rival's instead of the dominant firm's product of quality q_2. Old customers' purchasing decision, given announced prices, resembles a coordination game and can have multiple equilibria. Following Ellison and Fudenberg (2000), old consumers decide independently of how the other members of their group make their purchasing decisions. A measure λ_2 of new date t=2 consumers

[5] Note that the utility function may not be necessarily linear in income (any monotonic transformation would suffice) but linear utility simplifies the analysis.

also observes the prices. If a consumer from this group purchases the product of quality q_1, her utility is $q_1 + \alpha\lambda_1 x_1 + \alpha\lambda_2 x_2 - p_{12} - c$. If she purchases a product of quality q_2 and there is compatibility in the market, her utility is $q_2 + \alpha - c - p_{21i}$, whereas if she purchases either the rival's or the dominant firm's product q_2 and incompatible networks arise, her utility is $V = q_2 + \alpha\lambda_2\psi_2 + \alpha\lambda_1\psi_1 - c - p_{222,}$ $V = q_2 + \alpha\lambda_2(1-\psi_2) + \alpha\lambda_1(1-\psi_1) - c - p_{221}$, respectively. In the 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. Since price discrimination is possible, both competitors can offer lower prices to old customers. All consumers make their purchasing decisions simultaneously and they purchase a superior product rather than an old version as well as they join a network of superior rather than a smaller size even when their net utility is equivalent. We also assume the same discount factor δ for all the agents in the economy.

Figure 1 at the end of the manuscript summarizes the timing of the agents' moves.

3 Market outcome

In this section, I will solve for equilibrium outcomes; that is, firms' investment and compatibility decisions at date t=0 and their prices as well as customers' choices at dates t=1 and t=2. I will solve the model using backwards induction, starting from firms' pricing decisions at date t=2, going back to calculate the dominant firm's price for its initial version of quality q_1 at t=1 and the competitors' optimal investment and compatibility decisions at t=0. I will start the analysis with an economy that operates under mandatory compatibility.

Mandatory compatibility

Imagine that both firms innovate and think first of the measure λ_2 of new customers, who join a network of maximum size if they purchase the product of quality q_2 independently of

the seller they choose. They observe the prices and their utility by purchasing competitor i's new product is $q_2 + \alpha - c - p_{22i}$. If all these customers purchase the dominant firm's initial version, their utility given its price p_{12} is $q_1 + \alpha\lambda_1 x_1 + \alpha\lambda_2 - c - p_{12}$, where x_1 is the λ_1 customers' fraction that sticks to q_1.

A measure λ_1 of old date t=2 customers also observes the prices. If a customer that belongs to this group buys a product of quality q_2 from competitor i, her utility is $q_2 + \alpha - c_u - p_{21i}$ whereas if she sticks to the product of quality q_1, her utility is $q_1 + \alpha\lambda_1 x_1 + \alpha\lambda_2 x_2$, where x_1, x_2 are the old and new date t=2 customers' fractions that either stick or buy q_1 at date t=2, respectively.[6] If old customers make their purchasing decisions independently of what other old customers do, they will buy either the dominant or the smaller firm's product when:

$$p_{21i} \leq \Delta q + \alpha\lambda_2(1 - x_2) - c_u, \ i = 1, 2,$$

where $\Delta q = q_2 - q_1$. We make the following assumption:

Assumption 1 (A1): $\Delta q - c_u \geq 0$.

This assumption says that old date t=2 customers' benefit from buying any new product exceeds the cost of learning how to use it and allows us to isolate the role of network externalities and the quality improvements in firms' strategies and welfare.

Thus, in such a case, all customers buy or purchase any new version for free due to Bertrand competition.

If the dominant firm is the only innovator, it remains the sole supplier in both periods. Thus, given its prices, if all new date t=2 customers of measure λ_2 buy the new product (q_2), their utility is $q_2 + \alpha - c - p_{221}$, whereas if they all buy its initial version (q_1), their utility is $q_1 + \alpha\lambda_1 x_1 + \alpha\lambda_2 - c - p_{12}$, where x_1 is the old date t=2 customers' fraction that sticks to the initial version. An old customer's utility if she upgrades to the dominant firm's q_2 is $q_2 + a - c_u - p_{211}$ and her utility if she sticks to the old version is $q_1 + \alpha\lambda_1 x_1 + \alpha\lambda_2 x_2$.

[6] These customers are induced to buy the initial product of quality q_1 at $t = 1$ (see the Appendix for the first period analysis).

If old date t=2 customers coordinate on the Pareto optimal outcome, they will buy the new product even if everyone else sticks to q_1 ($x_1 = 1$) if:

$$p_{211} \leq \Delta q + \alpha\lambda_2(1 - x_2) - c_u.$$

Thus, since the dominant firm's date t=2 profit is decreasing in the number of new customers who purchase its initial version of quality q_1, the market leader's optimal choice is to stop selling his initial version and the prices he charges to customers are $p_{221} = q_2 + \alpha - c$, $p_{211} = \Delta q + \alpha\lambda_2 - c_u$.

When the rival firm is the sole inventor, the dominant firm cannot limit production of its product of quality q_1 or refuse to sell it to "would be" rival firm's customers because otherwise, such a choice would be viewed as anti-competitive, leading to weakened competition and higher prices. Thus, competition between the rival's product of quality q_2 and the incumbent's q_1 leads to equilibrium prices, which are $p_{222} = \Delta q + \alpha\lambda_1$, $p_{12} = 0$, $p_{212} = \Delta q + \alpha\lambda_2 - c_u$ and all customers buy the rival firm's product of quality q_2.

When both firms fail to innovate, new date t=2 customers purchase the product of quality q_1 and face a price $p_{12} = q_1 + a - c$.[7]

Dates t=1 and t=0

At date t=1, the dominant firm sets its price for its initial version of quality q_1, wishing to extract consumers' total expected surplus and potential buyers (λ_1) make their purchasing decisions, depending on their expectations regarding the market participants' second period behaviour.

Moving back to date t=0, both firms decide their optimal investment, taking into consideration that the rival is also maximising his/her expected total profits.[8] We will consider the following scenarios:

[7] See the Appendix for the table containing the second period prices in the different scenarios.
[8] See the Appendix for the rival's maximization problems and their optimal investment levels.

Scenario 2 (A2): $\Delta q < \alpha\lambda_1$, $0 < \Delta q - \lambda_1 c_u < 1/2$. This scenario occurs when the quality improvement is small relative to network effects.

Scenario 3 (A3): $\Delta q > \alpha\lambda_1$, $0 < \Delta q - \lambda_1 c_u < 1/2$. In this case, the quality improvement is large relative to the extent of network externalities.

In both scenarios, I assume that the magnitude of the difference between the quality improvement and the cost of adopting the new product is lower than a threshold. The next proposition summarizes the market equilibrium outcome when compatibility is mandatory:

Proposition 1 *If A2 holds, the dominant firm invests more than when A3 holds. Customers at date t=1 purchase the product of quality q_1 and if there is a product of quality q_2 at date t=2, the whole market purhases it.*

Although the competitors' investment decisions are always strategic substitutes for the smaller firm, an interesting result is that when network effects are strong (A2), the competitors' R&D choices become strategic complements for the dominant firm. This is because its expected gain from either both firms succeeding or failing in their R&D processes outweighs its expected income from being the sole inventor. More precisely, a marginal increase in the smaller competitor's R&D spending would increase the dominant firm's investment effort. This happens when its increased date t=1 price to the measure λ_1 customers when both firms either succeed or fail and its date t=2 higher price to new date t=2 consumers when both firms fail surpasses the gain from being the only innovator. If, instead, network effects are relatively weak (A3) and the dominant firm's gains from being the sole inventor outweigh its gain from both firms either succeeding or failing, it seems to free ride on the rival's effort and the competitors' R&D efforts are strategic substitutes.[9] Although the latter result is consistent with the literature regarding dominant firms' R&D incentives in the presence of compatibility, an interesting theoretical prediction of the model is that when network effects are strong, the market leaders' marginal incentives to invest are not curbed.

[9] See figures 2 and 3 at the end of the manuscript for the graphical representation of the different cases.

Laissez faire competition law

Under a laissez faire competition law, both firms initially choose their investment levels as well as whether they will support compatibility in the future period. I will analyze first the scenario where there is incompatibility between the competitors' networks.

Date t=2

Incompatibility between the rivals' products implies that customers only join their seller's network. First suppose that the smaller competitor is the only innovator and think of the measure λ_2 of new date t=2 customers, who observe firms' prices. If they all purchase the rival's product of quality q_2, their utility is $q_2 + \alpha\lambda_2 + \alpha\lambda_1(1 - x_1) - c - p_{222}$, where $1 - x_1$ is the old date t=2 customers' fraction that purchases q_2, whereas if they all buy the dominant firm's product of quality q_1, their utility is $q_1 + \alpha\lambda_2 + \alpha\lambda_1 x_1 - c - p_{12}$. Thus, these customers prefer the rival's product of quality q_2 if:

$$p_{222} - p_{12} \leq \Delta q + \alpha\lambda_1(1 - 2x_1).$$

The measure λ_1 of old date t=2 customers also observes the prices and decides whether to buy the superior product or stick to the initial version of quality q_1. If a customer from this group purchases q_2, her utility is $q_2 + \alpha\lambda_1(1 - x_1) + \alpha\lambda_2(1 - x_2) - c_u - p_{212}$, whereas if she sticks to q_1, her utility is $q_1 + \alpha\lambda_1 x_1 + \alpha\lambda_2 x_2$, where x_1, x_2 are the old and new date t=2 customers' fractions that stick or buy q_1, respectively. Thus, she will buy q_2 even when all the other old customers stick to q_1 if:

$$p_{212} \leq \Delta q + \alpha\lambda_2(1 - 2x_2) - \alpha\lambda_1 - c_u.$$

Depending on the magnitude of the quality improvements relative to network effects, we consider the following two scenarios:

Scenario 4 (A4): $\Delta q + \alpha\lambda_2 - \alpha\lambda_1 - c_u < 0$. In this scenario, old date t=2 customers do not buy the rival's product of quality q_2 as they are better-off by retaining the dominant firm's initial version.

Scenario 5 (A5): $\Delta q + \alpha\lambda_2 - \alpha\lambda_1 - c_u > 0$. In this case, old date t=2 customers are better off by purchasing the rival firm's new product.

If the quality improvement from the rival's new product is relatively small, i.e., if (A4) holds, new customers prefer the product of quality q_2 if:

$$p_{222} - p_{12} \leq \Delta q - \alpha\lambda_1,$$

and thus, the optimal firms' prices are: $p_{222} = \Delta q - \alpha\lambda_1$, $p_{12} = 0$ and new customers purchase the product of quality q_2 when network effects are weak (A3).[10]

If the measure λ_1 of old date t=2 customers buys the rival's product of quality q_2, i.e., if (A5) holds, new customers prefer the rival's product of quality q_2 if:

$$p_{222} - p_{12} \leq \Delta q + \alpha\lambda_1,$$

and the competitors' optimal choices are: $p_{222} = \Delta q + \alpha\lambda_1$, $p_{12} = 0$, $p_{212} = \Delta q + \alpha\lambda_2 - \alpha\lambda_1 - c_u$.[11]

Dates t=1 and t=0

At date t=1, the dominant firm sets the optimal price of its initial version of quality q_1, wishing to extract customers' expected total surplus and potential buyers (λ_1) make purchasing decisions, depending on their expectations regarding the market participants' second period behaviour.

[10] When network effects are strong (A2), old date t=2 consumers would purchase the dominant firm's product of quality q_1 and this triggers the rival firm's deterrence to actually invest at t=0, effectively allowing the dominant firm to be the only investor and potential innovator in the market.

[11] See the Appendix for the date t=2 prices for the other date t=2 cases.

Moving back to date t=0, both competitors choose investment levels to maximise expected profits.[12]

The next proposition summarizes the market equilibrium outcome in an economy that operates under a laissez faire competition law:

Proposition 2 *(a) For relatively less innovative future products (A4), the dominant firm's optimal choice is not to support compatibility. (b) For sufficiently innovative products (A5): (1) both firms welcome compatibility for a relatively large initial market size (λ_1), (2) if the first period market size is relatively small, the rival rejects to support future compatibility.*

Proof. See the Appendix. ■

For less innovative products (A4), incompatibility prevails in the market as the dominant firm prefers not to share its network with the smaller innovative rival. In particular, when network effects are strong (A2), the dominant firm impedes future compatibility and currently remains the only investor, as future market foreclosure deters the rival from investing in the current period. Interestingly, the market leader would have invested more in the economy that mandates compatibility because of the strategic complementarity of the competitors' R&D efforts for the dominant firm.[13] When network effects are weak (A3), the dominant firm rejects to support future compatibility and invests more than the scenario where compatibility is mandatory.[14] Under incompatible future networks, the probability that the current market leader is the sole second period innovator increases and his expected profits are higher. If, instead, products are sufficiently innovative relative to network externalities (A5), the dominant firm both welcomes compatibility and invests more even if the rival is a direct future competitor. This happens as the gains from sharing its network outweigh the potential costs. More precisely, by supporting compatibility, the probability that it is the only inventor increases, allowing this firm to enjoy a larger second period expected

[12] See the Appendix for the competitors' maximization problems and their optimal investment choices as functions of the rival's optimal choice.

[13] See Figure 2.

[14] See Figure 3.

profit, exceeding the first period loss from the lower first period price. The rival faces a trade-off: although compatibility allows her to set a higher future price to the measure λ_1 of old date t=2 consumers, the probability of being the sole second period supplier is lower compared to the economy operating under incompatibility. Thus, when the first period market is relatively large, her optimal choice is to offer compatibility to the market leader (b1). In such a case, she also invests more than in a economy when there is incompatibility. When the number of old customers is smaller (b2), unlike the dominant firm, the rival is better-off by not signing the interoperability agreement.

To analyze market R&D incentives, we focus on scenarios when compatibility agreements are not reached for relatively less innovative future products (A4). When network effects are weak, incompatible networks in a laissez faire economy lead to more balanced competitors' R&D incentives compared to the economy mandating compatibility, when we identified that the dominant firm free rides on the smaller competitor's R&D effort. When network effects are strong, strategic complementarity between the competitors' R&D efforts for the market leader when compatibility is present allows both firms to invest, whereas in a laissez faire market, current disagreements for future compatibility eliminate the smaller rival's incentives to invest.

4 Consumers Welfare Maximisation

In this section I investigate the short-run effects of firms' current inability to reach a compatibility agreement regarding their future products on consumer welfare. The planner seeks to maximize expected consumer surplus via a decision to support compatibility or to allow incompatible networks.

I will focus on the scenario where quality improvements are moderate and network effects are relatively weak (A4 and A3). The reason is that consumers are indifferent between the laissez faire economy and the one that mandates compatibility in any other potential

situation that a laissez faire market leads to incompatible networks. The next proposition provides the economy that maximises expected consumer surplus:

Proposition 3 *Expected Consumer Surplus is higher in a laissez faire market.*

Proof. See the Appendix ■

This proposition highlights the increase in expected consumer surplus when future compatibility is not supported. What really matters are the equilibrium probabilities of reaching the state where the rival firm is the only innovator and the state when both firms' R&D processes are successful. In the former state, new date t=2 customers are better-off when incompatible networks arise due to the reduced prices induced by heightened competition. If, instead, both firms innovate, new date t=2 customers benefit when there is compatibility in the market. Thus, when the probability that the rival is the sole innovator exceeds the probability of reaching the state where both firms' R&D processes are successful, expected consumer surplus is higher when compatibility is not supported.

5 Conclusion

In this article, I provide an explanation of why dominant firms welcome future compatibility with smaller innovative competitors. In particular, I show that sufficiently innovative network products lead the market leader to voluntarily support compatibility even with direct future competitors in an economy with overlapping generations of forward-looking customers. In fact, when compatibility is present, the dominant firm invests more, increasing its probability of success as well as the probability that it is the only inventor in the market. The competitor also demands compatibility only when the initial market size is large.

Moreoever, I show that the dominant firm refuses to support compatibility for less innovative products and its R&D incentives may not be curbed when incompatible networks arise. More precisely, I identify a critical cutoff in network externalities below which the market leader invests more when he currently refuses to support compatibility with his competitor.

My article also contributes to the discussion concerning the desirability of a more interventionist competition law. I find that when network effects are weak, a laissez faire competition law is preferred to an economy that operates under mandatory compatibility. This happens because a laissez faire market either converges to compatibility or when this does not occur, future incompatible networks increase expected consumer surplus and lead to more balanced market R&D.

Regarding extensions of this work, I currently consider firms' long-run compatibility and investment choices in the presence of random quality improvements. Further research may also analyze the competitors' R&D incentives and compatibility decisions in the face of stochastic demand.

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Appendix

A.

Date t=2 prices/ Incompatibility

In the scenario that both competitors' R&D processes are successful, consider first the measure λ_2 of new date t=2 customers. After they observe the competitors' prices, their utility if they all purchase the dominant firm's or the rival's q_2 is $q_2 + \alpha\lambda_2 + \alpha\lambda_1(1-\psi_1) - c - p_{221}$, $q_2 + \alpha\lambda_2 + \alpha\lambda_1\psi_1 - c - p_{222}$, respectively, where $\psi_1, 1-\psi_1$ are the old date t=2 customers' fractions that belong to the rival and the dominant firm's network, respectively. If they all buy the dominant firm's initial version, their utility is $q_1 + \alpha\lambda_2 + \alpha\lambda_1 x_1 - c - p_{12}$. Thus, these customers purchase the dominant firm's superior product if:

$$q_2 + \alpha\lambda_2 + \alpha\lambda_1(1-\psi_1) - c - p_{221} \geq$$

$$\geq \max\{q_2 + \alpha\lambda_2 + \alpha\lambda_1\psi_1 - c - p_{222},\ q_1 + \alpha\lambda_2 + \alpha\lambda_1 x_1 - c - p_{12}\}.$$

If a customer that belongs to the group of old date t=2 customers purchases q_2 from the dominant or the rival firm, her utility is $q_2 + \alpha\lambda_2(1-\psi_2) + \alpha\lambda_1(1-\psi_1) - c_u - p_{211}$, $q_2 + \alpha\lambda_2\psi_2 + \alpha\lambda_1\psi_1 - c_u - p_{212}$, respectively, while if she sticks to the initial version q_1, their utility is $q_1 + \alpha\lambda_2 x_2 + \alpha\lambda_1 x_1$. Thus, she buys the dominant firm's product of quality q_2 even if all the other old customers either stick to the initial version or buy the rival's new version if:

$$q_2 + \alpha\lambda_2(1-\psi_2) - c_u - p_{211} \geq\ q_2 + \alpha\lambda_1 + \alpha\lambda_2\psi_2 - c_u - p_{212}$$

and

$$q_2 + \alpha\lambda_1 + \alpha\lambda_2(1-\psi_2) - c_u - p_{211} \geq q_1 + \alpha\lambda_1 + \alpha\lambda_2 x_2.$$

Note that when A4 holds and old customers coordinate on the Pareto optimum, purchasing the rival's product of quality q_2 is not an option for them as it is strictly dominated by

their alternative of sticking to q_1. The dominant firm's optimal choice is to stop selling the initial version to the measure λ_2 of new second period customers,as this would potentially cannibalize its profits. The equilibrium prices are $p_{221} = \alpha\lambda_1$, $p_{222} = 0$, $p_{211} = \Delta q + \alpha\lambda_2 - c_u$ and all customers buy the dominant firm's superior product. When A5 holds, the whole market buys either the rival's or the dominant firm's new version and Bertrand competition drives all prices to zero.

The scenarios where the dominant firm is the only innovator as well as the case where no firm's R&D process is successful lead to the same market outcome as in the economy that operates under mandatory compatibility.

B.

Calculating firms' investment decisions as a function of the rival's optimal choices

Mandatory compatibility Given the market leader's price (p_{11}), first period customers' total discounted expected utility if they purchase the product q_1 is:

$$
\begin{aligned}
&q_1 + \alpha\lambda_1 - c + \delta s_1(1 - s_2)(q_2 + \alpha - c_u - p_{211}) + \\
&+\delta(1 - s_1)s_2(q_2 + \alpha - c_u - p_{212}) + \delta s_1 s_2(q_2 + a - c_u) + \\
&+\delta(1 - s_1)(1 - s_2)(q_1 + a) - p_{11},
\end{aligned}
$$

where s_1, s_2 are the dominant firm's and the rival's probabilities of successfully innovating, respectively and the subsrcipt e denotes the expectation for the quality improvement and the second period prices. Note that the market leader wishes to extract λ_1 customers' expected total surplus by setting the highest price p_{11} that would induce them to buy q_1 and thus, his

optimal first period choice is:

$$\begin{aligned} p_{11} &= q_1 + \alpha\lambda_1 - c + \delta s_1(1-s_2)(q_2+\alpha-c_u-p_{211}) + \delta(1-s_1)s_2(q_2+\alpha-c_u-p_{212}) + \\ &\quad +\delta s_1 s_2(q_2+a-c_u) + \delta(1-s_1)(1-s_2)(q_1+a). \end{aligned} \tag{1}$$

Moving back to the initial period ($t=0$), the two firms simultaneously choose their investment levels. Thus, the smaller firm's maximization problem is:

$$\max_{s_2\geq 0}\left\{\begin{array}{c} \delta s_2(1-s_1^*)(\lambda_2 p_{222}+\lambda_1 p_{212}) - s_2^2/2 \text{ if } s_2>0 \\ 0,\ \text{otherwise} \end{array}\right\}. \tag{2}$$

The similar maximization problem for the dominant firm is:

$$\max_{s_1\geq 0}\left\{\begin{array}{c} \lambda_1 p_{11} + \delta\lambda_1 s_1(1-s_2^*)p_{211} + \delta\lambda_2 s_1(1-s_2^*)p_{221} + \\ +\delta\lambda_2(1-s_1)(1-s_2^*)p_{121} - s_1^2/2,\ \text{if } s_1>0 \\ \lambda_1 p_{11} + \delta\lambda_2(1-s_2^*)p_{121},\ \text{otherwise} \end{array}\right\}, \tag{3}$$

where p_{11} is given in (1) and s_2^* is the rival's optimal investment choice.

The rival and the dominant firm's investment decisions as a function of the competitor's optimal choice are:

$$s_2 = \delta(1-s_1^*)(\Delta q + 2\alpha\lambda_1\lambda_2 - \lambda_1 c_u), \tag{4}$$

$$s_1 = -s_2^*(\delta\lambda_2\Delta q - \delta\alpha\lambda_1\lambda_2) + \delta(\Delta q - \lambda_1 c_u), \tag{5}$$

respectively.

Incompatibility If A4 and A3 hold, the smaller competitor's optimization problem is:

$$\max_{s_4\geq 0}\left\{\begin{array}{c} \delta(1-s_3^*)s_4\lambda_2 p_{222} - s_4^2/2,\ \text{if } s_4>0 \\ 0,\ \text{otherwise} \end{array}\right\}, \tag{6}$$

where s_4 is her investment choice and s_3^* is the dominant firm's optimal investment decision. The similar maximization problem faced by the market leader is:

$$\max_{s_3 \geq 0} \left\{ \begin{array}{c} \lambda_1 p_{11} + \delta\lambda_1 s_3(1-s_4^*)p_{211} + \delta\lambda_2 s_3(1-s_4^*)p_{221} + \\ +\delta\lambda_2(1-s_3)(1-s_4^*)p_{121} + \delta\lambda_2 s_3 s_4 \alpha\lambda_1 - s_3^2/2, \text{ if } s_3 > 0 \\ \lambda_1 p_{11} + \delta\lambda_2(1-s_4^*)p_{121}, \text{ otherwise} \end{array} \right\} \tag{7}$$

where the price p_{11} extracts the first period customers expected surplus and is given by the expression:

$$\begin{aligned} p_{11} &= q_1 + \alpha\lambda_1 - c + \delta s_3(1-s_4)(q_2 + \alpha - c_u - p_{211}) + \delta s_3 s_4(q_2 + \alpha - c_u - p_{211}) + \\ &\quad +\delta(1-s_3)(1-s_4)(q_1+\alpha) + \delta(1-s_3)s_4(q_1 + \alpha\lambda_1). \end{aligned} \tag{8}$$

When old customers expect to purchase the product of quality q_2 in the second period independently of which firm innovates (A5 holds), the competitors' problems become:

$$\max_{s_4 \geq 0} s_4(1-s_3^*)(\lambda_2 p_{222} + \lambda_1 p_{212}) - s_4^2/2, \tag{6'}$$

$$\begin{aligned} &\max_{s_3 \geq 0} \lambda_1 p_{11} + \delta\lambda_1 s_3(1-s_4^*)p_{211} + \delta\lambda_2 s_3(1-s_4^*)p_{221} + \\ &+\delta\lambda_2(1-s_3)(1-s_4^*)p_{121} - s_3^2/2, \end{aligned} \tag{7'}$$

for the rival and the dominant firm, respectively and the first period price is:

$$\begin{aligned} p_{11} &= q_1 + \alpha\lambda_1 - c + \delta s_3(1-s_4)(q_1 + \alpha\lambda_1) + \delta s_3 s_4(q_2 - c_u) + \\ &\quad +\delta(1-s_3)(1-s_4)(q_1+\alpha) + \delta(1-s_3)s_4(q_1 + 2\alpha\lambda_1). \end{aligned} \tag{9}$$

Note that when both firms' R&D is successful, all customers are expected to buy the product

of quality q_2 from either of the incompatible competitors. Thus, they will be part of a network of size x, with x being any non-negative number. Thus, in the first period, the dominant firm may risk losing these customers if it charges a price greater than p_{11} defined above.

Proof of Proposition 2

a) If A3 and A4 hold, the dominant firm always refuses to support compatibility. To see this fact, let E($\Pi_{no\ compatibility}$)=f(s) and E($\Pi_{compatibility}$)=g(s) denote the dominant firm's expected profit under incompatibility and compatibility, respectively, where f(0)>g(0).

We take the derivative of the two functions with respect to the dominant firm's choice (s): $f_s = -\delta[s_4(\Delta q - \alpha\lambda_1\lambda_2 - \lambda_1 c_u) - (\Delta q - \lambda_1 c_u)] - s$ while $g_s = \delta[\Delta q - \lambda_1 c_u - s_2\lambda_2(\Delta q - \alpha\lambda_1)] - s$, where s_4, s_2 are the rival's optimal choices under incompatibility and compatibility, respectively (see figure 3).

The dominant firm is better-off by not supporting compatibility when:

$$s_2\lambda_2(\Delta q - \alpha\lambda_1) - s_4(\Delta q - \alpha\lambda_1\lambda_2 - \lambda_1 c_u) > 0, \qquad (*)$$

where the smaller competitor's choices lie on the lines:

$s_2 = \delta(1-s)(\Delta q + 2\alpha\lambda_1\lambda_2 - \lambda_1 c_u)$, and $s_4 = \delta(1-s)\lambda_2(\Delta q - \alpha\lambda_1)$.

After substituting s_2 and s_4 in * we get:

$$(1-s)(\Delta q + 2\alpha\lambda_1\lambda_2 - \lambda_1 c_u)\lambda_2(\Delta q - \alpha\lambda_1) - (1-s)\lambda_2(\Delta q - \alpha\lambda_1)(\Delta q - \alpha\lambda_1\lambda_2 - \lambda_1 c_u) > 0$$

which always holds and thus $f_s > g_s\ \forall s$.

After solving for s_1^*, s_3^*, one gets:

$$s_1^* = \frac{\delta(\Delta q - \lambda_1 c_u) - \delta^2(\Delta q + 2\alpha\lambda_1\lambda_2 - \lambda_1 c_u)(\lambda_2\Delta q - \lambda_2\alpha\lambda_1)}{1 - \delta^2(\Delta q + 2\alpha\lambda_1\lambda_2 - \lambda_1 c_u)(\lambda_2\Delta q - \lambda_2\alpha\lambda_1)}$$

and

$$s_3^* = \frac{\delta(\Delta q - \lambda_1 c_u) - \delta^2(\Delta q - \alpha\lambda_1\lambda_2 - \lambda_1 c_u)(\lambda_2\Delta q - \lambda_2\alpha\lambda_1)}{1 - \delta^2(\Delta q - \alpha\lambda_1\lambda_2 - \lambda_1 c_u)(\lambda_2\Delta q - \lambda_2\alpha\lambda_1)}$$

and after substituting to the expressions for s_2^*, s_4^*, we get:

$$s_2^* = \delta[1 - \frac{\delta(\Delta q - \lambda_1 c_u) - \delta^2(\Delta q + 2\alpha\lambda_1\lambda_2 - \lambda_1 c_u)(\lambda_2\Delta q - \lambda_2\alpha\lambda_1)}{1 - \delta^2(\Delta q + 2\alpha\lambda_1\lambda_2 - \lambda_1 c_u)(\lambda_2\Delta q - \lambda_2\alpha\lambda_1)}](\Delta q + 2\alpha\lambda_1\lambda_2 - \lambda_1 c_u)$$

and

$$s_4^* = \delta[1 - \frac{\delta(\Delta q - \lambda_1 c_u) - \delta^2(\Delta q - \alpha\lambda_1\lambda_2 - \lambda_1 c_u)(\lambda_2\Delta q - \lambda_2\alpha\lambda_1)}{1 - \delta^2(\Delta q - \alpha\lambda_1\lambda_2 - \lambda_1 c_u)(\lambda_2\Delta q - \lambda_2\alpha\lambda_1)}]\lambda_2(\Delta q - \alpha\lambda_1).$$

Thus, * becomes after some algebraic manipulation:

$$(\Delta q + 2\alpha\lambda_1\lambda_2 - \lambda_1 c_u)[1 - \delta^2(\Delta q - \alpha\lambda_1\lambda_2 - \lambda_1 c_u)\lambda_2(\Delta q - \alpha\lambda_1)] >$$

$$(\Delta q - \alpha\lambda_1\lambda_2 - \lambda_1 c_u)[1 - \delta^2(\Delta q + 2\alpha\lambda_1\lambda_2 - \lambda_1 c_u)\lambda_2(\Delta q - \alpha\lambda_1)]$$

which simply verifies that $s_3^* > s_1^*$.

Thus, the dominant firm impedes compatibility.

Note that if A4 and A2 hold, the rival's optimal choice is not to invest ($s_4 = 0$) if the dominant firm chooses not to support compatibility. Thus, the market leader impedes compatibility, as this choice allows him to be the sole potential inventor and second period supplier. To verify this, think of the parameter values: $\Delta q = 0.3$, $\alpha = 1$, $\lambda_1 = 0.7$, $\lambda_2 = 0.3$, $c_u = 0.1$, $c = 0.2$, $q_1 = 0.1$, $q_2 = 0.4$, $\delta = 1$. Direct comparison of the dominant firm's expected profit verifies that it does not support compatibility with its competitor.

b1) Think for example the case where: $\Delta q = 0.9$, $\alpha = 1$, $\lambda_1 = 0.8$, $\lambda_2 = 0.2$, $c_u = 0.2$, $c = 0.3$, $q_1 = 0.1$, $q_2 = 1$, $\delta = 1$.

Direct comparison of the two firms' expected profits lead to the conclusion that they both support compatibility.

b2) Think of the parameter values: $\Delta q = 0.4$, $\alpha = 1$, $\lambda_1 = 0.3$, $\lambda_2 = 0.7$, $c_u = 0.2$, $c = 0.3$, $q_1 = 0.1$, $q_2 = 0.5$, $\delta = 1$.

Direct comparison of the firms' expected profits yields that the rival firm refuses to support compatibility with the market leader.

Proof of Proposition 3

We will calculate new date t=2 consumer net expected surplus if compatibility is supported and when incompatible networks arise in the future period. These customers are better-off if compatibility is supported when: $s_3 s_4[q_2 + \alpha - c - (q_2 + \alpha - c - \alpha\lambda_1)] + s_4(1 - s_3)\{[q_2 + \alpha - c - (\Delta q + \alpha\lambda_1)] - [(q_2 + \alpha\lambda_2 - c) - (\Delta q - \alpha\lambda_1)]\} > 0$ or equivalently:

$s_3 s_4 \alpha\lambda_1 - s_4(1 - s_3)\alpha\lambda_1 > 0$. Thus, proposition 3 follows.

Figures and Tables

Tables regarding the second period prices

The next table summarizes the different potential cases as well as the rivals' optimal second period prices charged to the new and the old customers under compatibility:

	Prices to λ_2	Prices to λ_1
Both firms innovate	$p_{22i} = 0$, $\forall i = 1, 2$	$p_{21i} = 0$, $\forall i = 1, 2$
Only the Dominant innovates	$p_{221} = q_2 + \alpha - c$	$p_{211} = \Delta q + \alpha\lambda_2 - c_u$
Only the Rival innovates	$p_{222} = \Delta q + \alpha\lambda_1$	$p_{212} = \Delta q + \alpha\lambda_2 - c_u$
Noone innovates	$p_{121} = q_1 + \alpha - c$	already bought at $t = 1$

Under mandatory incompatibility, the following table summarizes all the potential second period cases as well as the rivals' prices to the different customers' classes under A4 when both firms invest into producing an improved version of quality q_2:

	Prices to λ_2	Prices to λ_1
Both firms innovate	$p_{221} = \alpha\lambda_1$	$p_{211} = \Delta q + \alpha\lambda_2 - c_u$
Only the Dominant innovates	$p_{221} = q_2 + \alpha - c$	$p_{211} = \Delta q + \alpha\lambda_2 - c_u$
Only the Rival innovates	$p_{222} = \Delta q - \alpha\lambda_1$	$p_{212} = 0$
Noone innovates	$p_{121} = q_1 + \alpha - c$	already bought at $t = 1$

while under A5, the table becomes:

	Prices to λ_2	Prices to λ_1
Both firms innovate	$p_{222} = 0$, $p_{221} = 0$	$p_{21i} = 0$, $\forall i = 1, 2$
Only the Dominant innovates	$p_{221} = q_2 + \alpha - c$	$p_{211} = \Delta q + \alpha\lambda_2 - c_u$
Only the Rival innovates	$p_{222} = \Delta q + \alpha\lambda_1$	$p_{212} = \Delta q + \alpha\lambda_2 - \alpha\lambda_1 - c_u$
Noone innovates	$p_{121} = q_1 + \alpha - c$	already bought at $t = 1$

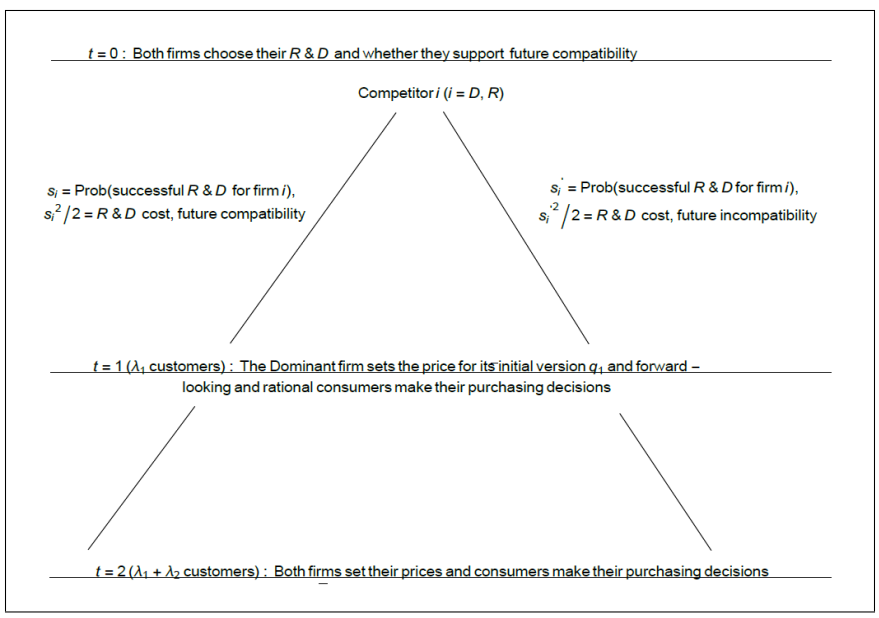

Figure 1: Timing of the agents' moves where D stands for the dominant firm and R for the rival.

The next figures summarize the market equilibrium outcome under a laissez faire Competition Law and under mandatory compatibility:

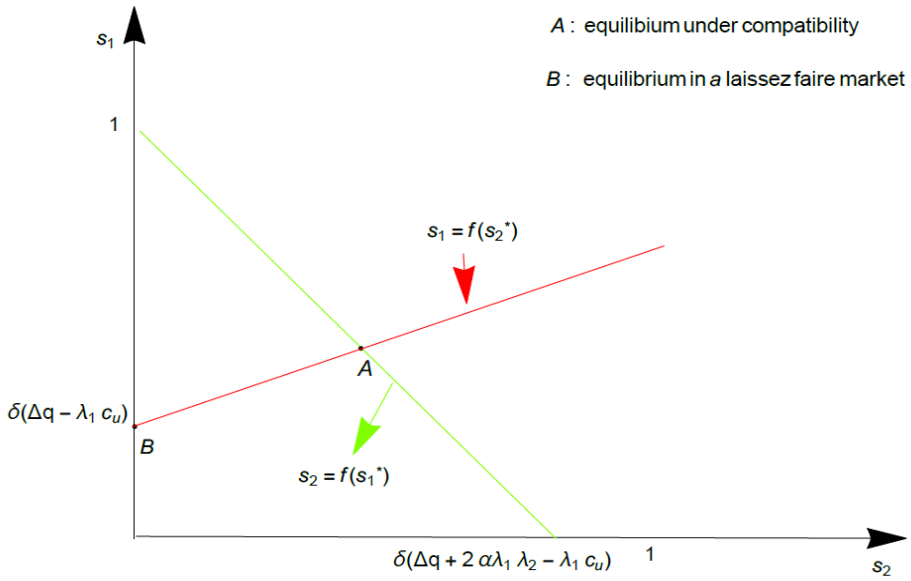

Figure 2: A4 and A2

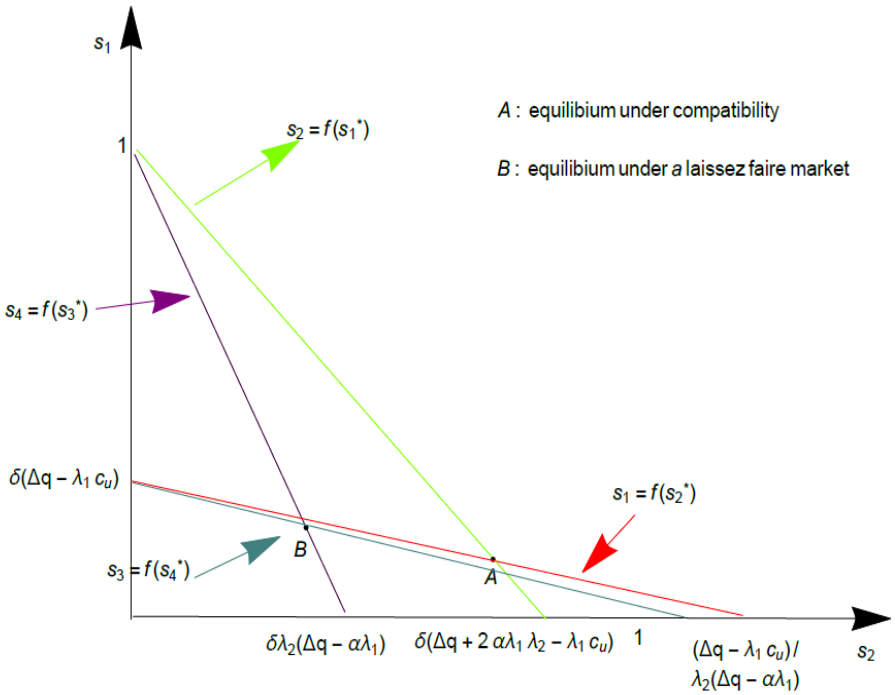

Figure 3: A4 and A3