Cooperative versus Competitive Standard Setting*

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January 30, 2007

ABSTRACT: In markets with network externalities compatibility standards affect not only the pricing decisions of firms but also their incentives to invest into the quality of their goods and/or the standard, their incentives to share technologies and their incentives to enter the market. Firms may cooperate and agree to the development of a common standard, or a *de facto* standard may or may not be established by competition. We show that making products compatible reduces price competition and affects market structure, but has no direct effect on investments. However, if firms can also agree ex ante on technology sharing and fixed and/or linear royalties, investment incentives are strongly affected. Firms will use these instruments to jointly reduce their incentives to invest and to increase the market price. Imposing a zero-royalty rate on this institutional structure makes this problem worse. We also show that firms always prefer an *ex ante* agreement of this kind to *ex post* licensing. We discuss a related example and the anti-trust implications of our results.

Keywords: Standards, standard setting agreements, technology licensing.

JEL Classification Codes: L15, O31, L24, O32, K11.

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* The authors want to thank seminar participants at the University of Munich for valuable comments. Financial support by Deutsche Forschungsgemeinschaft through SFB-TR 15 is gratefully acknowledged.
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I. Introduction

Compatibility standards play an important role in markets with network externalities. Consumers benefit if other people use a product that is compatible with the product they are using either directly because there are more people they can interact with or indirectly because there is a larger market for complementary products and services for a standardized good that is used by many other people as well.

In this paper we compare two basic ways of how standards are established: competitive and cooperative standard setting. If standards compete for customers and if network effects are strong, the market will eventually tip, all consumers will move to the same product which becomes the *de facto* standard that dominates the market. However, if network effects are weak it may also happen that two or more incompatible standards coexist, even though consumers would be better off if all products were based on the same standard. Cooperative standard setting is typically done in standard setting organizations (SSOs) or agreements of similar kind. The most basic form of cooperation is that firms agree to make their products compatible with each other without affecting the quality of their products and without exchanging any intellectual property rights. But often cooperation is considerably more complicated. The standard may not yet exist and firms may have to make large investments to develop it. They may come up with different technologies and have to specify a process that decides which technology to adopt. The technology may be protected by intellectual property rights and rules have to be set up ex ante that govern under what conditions these IP rights will be licensed.

Collaboration on standardisation is sometimes seen with suspicion by anti-trust authorities. After all, competitors cooperate not only to promote the welfare of consumers but also to increase their profits. For example, if they jointly agree on royalties that have to be paid for using a patent that is required for the standard, this agreement could be used to sustain prices above the competitive level. Thus, an important question is whether and how agreements on standardisation should be regulated.

Most of the literature on standard setting and compatibility choice has looked at the effects of standards on product market competition. The main contribution of our paper is to analyse in addition how standard setting affects the incentives of the firms to invest into the quality of their goods and/or the quality of the standard, how it affects the incentives to share technologies, and how it may affect the market structure. Taking these effects into account we will compare the private and social incentives to form a standard for the case where the technologies are substitutes, i.e. only one of the technologies is required for the standard. This is not to say that cases where complementary patents are owned by different firms are not important. But they raise a different set of issues and are not dealt with here. Furthermore, we do not consider possible inefficiencies that may arise due to the dynamic process of standard setting.[1] Again, these problems are important, but they are orthogonal to the main questions to be addressed in this paper. Therefore we abstract from these problems by assuming that the process of standard setting is instantaneous and efficient and that all firms are ex ante symmetric.

We start out with a basic model in which standard setting is very simple. If both firms agree to make their products compatible the common standard is formed. There are no side payments and the standard has no direct effect on the quality of the goods. We analyze how a common standard affects competition on the product market and how it affects the incentives of the firms to invest in the quality of their goods ex ante. We use a simple Hotelling model with horizontal and vertical product differentiation and network effects. We show that the adoption of a common standard relaxes product market competition and increases firms' profits as long as both firms serve the market. However, if the market sustains only one firm, this firm will not agree to make its product compatible with the product of potential entrants. Furthermore, we show that the standard has no direct effect on investment incentives.

[1] If standards compete with each other it may happen that some consumers get stranded if another technology becomes the industry standard. Similarly, it may happen that a dominant firm manages to establish its technology as the industry standard even though this technology is inferior. (see Farrell and Klemperer (2006))

Finally, even though in a first best world a common standard is always efficient, the government may reduce social welfare if it imposes a common standard on the industry. The reason is that the standard may alter the industry structure and thereby adversely affect investment incentives.

Then we consider an extended model in which firms invest in the quality of the standard. The outcome of the investments is stochastic. The parties may agree ex ante that the superior standard will be adopted by the industry ex post, and that the firm with the inferior standard has to pay fixed and/or linear royalties to the firm that provides the standard. Furthermore, the parties may agree on the degree of technology sharing. With no technology sharing, parties only agree to make their products compatible without any spillover effects on quality of technology. If they agree to fully share the technology, the inferior good can provide the same quality level as the superior good by using the superior standard. Intermediate cases are also allowed for. We show that if the uncertainty in the investment process is not too large, the parties will agree on full technology sharing. Furthermore, they will set the fixed royalty equal to 0, but choose a strictly positive linear royalty. The firms face a trade-off. On the one hand the linear royalty increases the perceived marginal cost of each firm and thus raises the output price. If this was the only effect, the parties would use the linear royalty to implement the monopoly price. On the other hand, however, the linear royalty induces firms to invest too much, because firms strive to receive rather than to pay royalties by developing the superior standard. The optimal royalty trades off these two effects. From a social welfare point of view the optimal royalty rate will be set too low and induce too little investment. This implies that the government should not impose a free licensing rule on a standard setting agreement.

Standard setting organisations (SSOs) and agreements of similar kind impose a set of rules on how to adopt a standard *ex ante*, i.e. before the technologies on which the standard is based are developed.[2] Alternatively, the parties could bargain on a standard *ex post*, after the technologies have been developed. This is being done through ex post licensing agreements. We show that in our model, where

[2] Lemley (2002) explains the institutional form of standard setting organisations in great detail.

technologies are substitutes, ex post licensing tends to be anti-competitive. Nevertheless, the involved firms prefer an ex ante agreement to an agreement ex post, because they can thereby govern investment incentives.

There is a large literature on standard setting starting in the 1980s.[3] In a seminal paper, Katz and Shapiro (1985) compare the private and social incentives to achieve compatibility in a Cournot model with network externalities. In their model the private incentives to achieve compatibility are always too low. In a companion paper, Katz and Shapiro (1986) consider a dynamic model with two periods. Without compatibility firms will compete very aggressively in the first period because they need a large market share to attract consumers in the second period. Thus, they may choose compatibility too often in order to reduce the degree of competition in period 1. Farrell and Saloner (1986) show that standardisation may be excessive because it may reduce the variety of products on the market. However, none of these papers considers the incentives to invest in the standard, and they take the number of firm in the market as exogenously given.

Another strand of the literature focuses on the competitive process to establish a standard in the market. Farrell (1996) models this as a "war of attrition" between two parties with their own proposed standards and shows that the better standard will be selected, but that delay is a function of the vested interests of the technology-sponsoring parties. In Farrell and Saloner (1988) two firms have to choose between two incompatible technologies. They can either negotiate on a standard in a SSO or compete in the market place. In their model, SSOs outperform markets with respect to the quality of the standard, but markets reach a decision more quickly. They show that a hybrid model would be best suited to deal with the coexisting issues of maximising quality over a minimal time period. Simcoe (2005) models the conflicts of interest within a standard setting organisation and shows that there may be delay in reaching an agreement even if all parties are symmetrically informed. He uses this model to explain the slowdown of the standards production of

[3] An extensive overview is provided in Farrell and Klemperer (2006).

the Internet Engineering Task Force in the 1990s. Other interesting case studies of the standard setting process are provided in DeLacey et al. (2006).

Finally, our paper is related to Lerner and Tirole (2004, 2006). They analyze the welfare effects of patent pools and SSOs. Although, their models are quite different there is a similarity in the mere fact that SSOs are generically agreements on standard setting *ex ante*, as opposed to patent pools which deal with licensing *ex post*.

The structure of the paper is as follows. Section II sets up the basic model in which the only role of a standard is to make different goods compatible with each other. In Section III we analyse the impact of the standard on price competition and on the incentives of the parties to invest in the quality of their products, and we compare the private and social incentives to form a standard. In Section IV we develop the extended model in which parties invest in the quality of the technology/standard and may share technological improvements. Furthermore, they may agree on royalties. We show how the parties will use these instruments to affect product market competition and the incentives to innovate and we discuss how these instruments should be dealt with by antitrust authorities. We then briefly discuss the applicability of our model to a recent collaboration agreement between Novell and Microsoft. In Section V we compare ex ante standardisation agreements to ex post licensing. Section VI concludes. All proofs are relegated to the Appendix.

II. The Basic Model

In this section we look at standards that are costless to implement and do not have any direct impact on quality. The only role of the standard is to make goods compatible with each other, and any standard achieving this goal is equally good. Firms are symmetric ex ante and can jointly commit to have a common standard or to have products that are not compatible. Investments into the quality of the standard, intellectual property rights, royalties or other side payments are not an issue, but will be dealt with in the next section.

We consider a simple Hotelling model with horizontal and vertical product differentiation and network effects as in Navon et al. (1995). There is a continuum of consumers with mass one, distributed uniformly on $[0,1]$. The two firms, *A* and *B*, are located at the end points of the unit interval. They offer products of quality θ_i and compete in prices p_i, $i \in \{A, B\}$. Each consumer buys at most one unit of the good. A consumer located at point $x \in [0,1]$ who buys from firm i receives utility

$$U(x,i) = \begin{cases} \theta_A - t \cdot x + \alpha \cdot n_A - p_A & if \quad i = A \\ \theta_B - t \cdot (1-x) + \alpha \cdot n_B - p_B & if \quad i = B \end{cases}$$

The goods are vertically differentiated because of the potentially different quality levels θ_A and θ_B that are determined at the first stage of the game. Horizontal product differentiation is captured by a "transportation" cost that is linear in the distance between each consumer's most preferred point *x* and the location of the firm he buys from. The degree of horizontal product differentiation is reflected by the parameter $t > 0$. Furthermore, consumers benefit from direct and/or indirect network externalities that arise if his good is compatible with the goods purchased by other consumers. For simplicity this effect is assumed to be linear in the number of customers n_i using a good that is compatible with good *i*. Note that if goods A and B use different standards and are not compatible, then n_A and n_B are simply the market shares of firms *A* and *B*. However, if the two firms agreed to a common standard so that goods *A* and *B* are compatible, then $n_A = n_B$ is the sum of the market shares of *A* and *B*. We assume that network effects are weak as compared to the degree of horizontal product differentiation, i.e. $0 < \alpha < t$.[4]

[4] If network effects are strong, i.e. $\alpha > t$, there are two asymmetric pure strategy equilibria in each of which only one firm supplies the entire market. In this case a de facto standard always applies.

The time structure of the game is as follows:

- At stage 0 the two firms decide whether or not to agree to a common standard that makes their products compatible with each other. A common standard is formed if and only if both firms agree to it.
- At stage 1 each firm i, $i \in \{A, B\}$, can make an investment θ_i at cost $\frac{K}{2}\theta_i^2$ that improves the quality of its good.
- At stage 2 firms choose their prices p_i, $i \in \{A, B\}$, simultaneously, consumers decide from which firm to buy, and payoffs are realized.

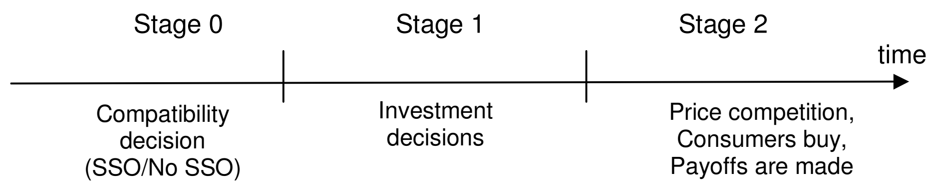

FIGURE 1: Time structure of the model

To avoid uninteresting case distinctions we assume throughout that all consumers $x \in [0,1]$ buy one unit of the good. Note that this assumption implies either that $n_A + n_B = 1$ (if there is no standard) or that $n_A = n_B = 1$ (if a standard has been formed). Finally, we assume that firms produce with constant and identical marginal costs that are normalized to 0.

III. Standards, Competition and Investment

We solve the basic model by backward induction. The arguments are fairly straightforward, so most of the analysis is relegated to the appendix.

III.1. Price Competition with and without a Standard

Assuming that both firms have a positive market share there is one consumer located at $\bar{x}$ who is just indifferent between buying good *A* or *B*. This consumer is given by

$$\bar{x} = \frac{1}{2} + \frac{\theta_A - \theta_B - p_A + p_B}{2 \cdot \hat{t}} \quad \text{with } \hat{t} = \begin{cases} t & \text{if standard} \\ t - \alpha & \text{if no standard} \end{cases}$$

All consumers to the left of $\bar{x}$ buy from firm A, all consumers to the right of $\bar{x}$ buy from firm B. Thus, profit functions are given by

$$\pi_A = p_A \cdot \bar{x}(\theta_A, \theta_B, p_A, p_B) - \frac{K}{2} \bar{\theta}_A^{\,2} \quad \text{and} \quad \pi_B = p_B \cdot (1 - \bar{x}(\theta_A, \theta_B, p_A, p_B)) - \frac{K}{2} \bar{\theta}_B^{\,2},$$

respectively. Firms know the quality levels (θ_A, θ_B) and choose prices simultaneously in order to maximize profits. There is a unique symmetric Nash equilibrium of the pricing subgame with

$$p_A = \frac{\theta_A - \theta_B}{3} + \hat{t} \quad \text{and} \quad p_B = \frac{\theta_B - \theta_A}{3} + \hat{t},$$

marginal consumer $\bar{x} = \frac{1}{2} + \frac{\theta_A - \theta_B}{6\hat{t}}$, and firm profits of

$$\pi_A = \frac{\left(\theta_A - \theta_B + 3\hat{t}\right)^2}{18\hat{t}} - \frac{K}{2}\theta_A^2 \quad \text{and} \quad \pi_B = \frac{\left(\theta_B - \theta_A + 3\hat{t}\right)^2}{18\hat{t}} - \frac{K}{2}\theta_B^2$$

Note that the market sustains two firms if and only if

$$\hat{t} > \left| \frac{\theta_A - \theta_B}{3} \right|$$

If this condition is violated the quality difference between the two firms is so large, that only the firm with the superior product will survive on the market. Note also that this condition implies that profits are strictly increasing in $\hat{t}$.

Proposition 1: *If* $\hat{t} > \left|\frac{\theta_A - \theta_B}{3}\right|$ *both firms serve the market. In this case prices and profits are higher if firms agreed to a common standard (* $\hat{t} = t$ *) than if goods are not compatible (* $\hat{t} = t - \alpha$ *).*

At first glance this proposition may be surprising. One might have suspected that if goods obey a common standard, they are less differentiated than if they are incompatible and that therefore price competition would be more intense with a standard. However, the exact opposite is the case. To see the intuition for this result note if firms have a common standard $(n_A = n_B = 1)$ each consumer gets the full network benefit α no matter which good he buys. Therefore, network externalities do not affect market shares and competition. However, if there is no common standard ($n_A = \bar{x}$, $n_B = 1 - \bar{x}$), consumers are interested in buying a good with a large market share. If firms want to attract customers, they have to offer a large market share which forces them to compete more aggressively.

A slightly different way to see this is to look at the marginal customer $\bar{x}$. He benefits from network externalities in proportion to the market share of firm i, but he also suffers from transportation cost in proportion to the market share of firm i (because he is - by definition - the most distant customer of this firm). Therefore, without a common standard positive network externalities have the same effect as a reduction of the transportation cost t: they make the demand of each firm more price elastic and increase the degree of competition.[5]

Consider now the case where $\hat{t} < \left|\frac{\theta_A - \theta_B}{3}\right|$. In this case only one firm will serve the market. We assume that consumers manage to coordinate to all buy from the firm with the superior quality.[6] Note that this firm is still constrained in its price choice by the potential entry of the other firm. After all, the other firm is prepared to offer the

[5] This is similar to the result of Navon et al. (1995) showing that an increase in the network externality α has the same effect on competition as a reduction of transportation costs. They also draw a distinction between the effects of transportation costs and network externalities in their paper.
[6] The analysis also assumes that there is no battle about who this firm will be as suggested in the literature on wars of attrition.

good at any price greater or equal to 0. Thus, if firm i offers the superior product it will choose the limit price $p_i = |\theta_A - \theta_B| - \hat{t}$ at which no customer is induced to switch to the other firm even if the other firm charges a price of 0. All customers will buy from this firm and the firm's profit is given by

$$\pi_i = |\theta_A - \theta_B| - \hat{t} - \frac{K}{2}\theta_i^2$$

> **Proposition 2:** *If* $\hat{t} < \left|\frac{\theta_A - \theta_B}{3}\right|$ *only the firm with the superior quality serves the market. In this case its price and profit will be higher if firms did not agree to a common standard (* $\hat{t} = t - \alpha$ *) than if goods are compatible (* $\hat{t} = t$ *).*

This is the exact opposite result than in the case where both firms serve the market. The reason is that the firm with the superior product is constrained in its pricing decision by the threat of entry of the other firm. If there is a common standard and products are compatible a consumer can switch to the inferior firm and still enjoy the network externality. Without the standard, this consumer enjoys the network benefits only in proportion to the customer base of the firm he buys from. Thus, if the entrant with the inferior product has no customers, it is much less attractive to buy his product. Therefore, the constraint on the pricing decision of the superior firm is relaxed.

Thus, a common standard relaxes price competition if both firms have positive market share, but it facilitates entry and makes the market more contestable if only one firm serves the market.

III.2. Investments in Quality with and without a Standard

At stage 1 firms choose their quality levels simultaneously. Assuming that both firms are going to serve the market at stage 2, firm A maximizes

$$\pi_A = \frac{\left(\theta_A - \theta_B + 3\hat{t}\right)^2}{18\hat{t}} - \frac{K}{2}\theta_A^2$$

The first order condition gives rise to the reaction functions

$$\theta_A = \frac{3\hat{t} - \theta_B}{9\hat{t}K - 1} \quad \text{and} \quad \theta_B = \frac{3\hat{t} - \theta_A}{9\hat{t}K - 1}$$

The second order condition requires

$$\hat{t} \geq \frac{1}{9K}$$

Note that the second order condition implies that reaction functions are downward sloping. If this condition is satisfied there exists a unique[7] symmetric Nash equilibrium in quality levels with

$$\theta_A = \theta_B = \frac{1}{3K}.$$

In this equilibrium firms charge prices $p_A = p_B = \hat{t}$, each firm serves half of the market, and profits are

$$\pi_A = \pi_B = \frac{\hat{t}}{2} - \frac{1}{18K}$$

The second order condition also implies that these profits are indeed positive. Note that equilibrium quality levels are independent of $\hat{t}$ and thus of the revenues that can be made at stage 2 in order to cover the investment cost.[8] The second order condition makes sure that horizontal product differentiation (and network externalities) allow for sufficiently high revenues on the downstream market to cover the cost of the upfront investment in quality.

Consider now the case where

$$\hat{t} < \frac{1}{9K}$$

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[7] If $\hat{t} > \frac{2}{9K}$ this is the unique Nash equilibrium of the game. If $\frac{1}{9K} < \hat{t} \leq \frac{2}{9K}$ there are two additional asymmetric equilibria in which one firm chooses a quality level of 0 and the other one a quality level of $\frac{3\hat{t}}{9\hat{t}K-1}$. Because of the symmetry of the game, we focus on symmetric equilibria throughout.

[8] Also, total market demand is independent of quality because all consumers buy. The results we obtain would, however, be qualitatively similar if we relaxed this assumption.

In this case each firm's profit function is convex and there are two asymmetric pure strategy equilibria in which only one firm invests into quality and serves the entire market. Suppose w.l.o.g. that this is firm *A*. At stage 2 firm *A* will choose the limit price $p_A = \theta_A - \hat{t}$. Thus, at stage 1 it will choose the quality level θ_A that maximizes

$$\pi_A = \theta_A - \hat{t} - \frac{K}{2}\theta_A^2$$

The optimal investment level of firm *A* is given by $\theta_A = \frac{1}{K}$, while firm B invests $\theta_B = 0$ and stays out of the market. There is also the mirror equilibrium in which firm B invests and firm A stays out. We assume that firms play the correlated equilibrium in which each of the two pure strategy equilibria is played with probability 0.5.[9] In this equilibrium expected profits are

$$\pi_A = \pi_B = \frac{1}{2}\left[\frac{1}{2K} - \hat{t}\right].$$

Proposition 3: *If* $\hat{t} \geq \frac{1}{9K}$ *both firms invest in quality, each chooses* $\theta_A = \theta_B = \frac{1}{3K}$ *and profits are*

$$\pi_A = \pi_B = \frac{\hat{t}}{2} - \frac{1}{18K}.$$

If $\hat{t} < \frac{1}{9K}$ *only one firm invest in quality and chooses* $\theta = \frac{1}{K}$*, while the other firm does not invest. The ex ante probability that firm A (B) invests while firm B (A) abstains is 0.5, so expected profits are*

[9] In a correlated equilibrium firms implicitly agree to use a publicly observable signal to coordinate their behaviour. For example, with equal probability each firm may have a small technological advantage over the other firm. If both firms know about this advantage and know that only one firm can serve the market profitably, it seems natural that the disadvantaged firm withdraws and does not invest.
A symmetric, correlated equilibrium is the most plausible equilibrium in this context. First of all, firms are symmetric, so they should make the same expected profits in equilibrium. Second, while there are also symmetric mixed strategy equilibria, these equilibria are inefficient, because with positive probability both firms invest too much or do not invest at all. In contrast, the correlated equilibrium is efficient in the sense that there exists no other equilibrium in which both firms are better off. Finally, in a mixed strategy equilibrium each firm has an incentive to change its quality level after observing the chosen quality level of its rival. This is not the case in the two pure strategy equilibria that each occur with probability 0.5 in the correlated equilibrium.

$$E(\pi_A) = E(\pi_B) = \frac{1}{4K} - \frac{\hat{t}}{2}$$

In both cases the investment in quality is independent of $\hat{t}$ *and therefore independent of whether the firms agreed to a common standard or not. However, if firms did not agree to a standard (*$\hat{t} = t - \alpha$*) the range of parameters for which only one firm invests is larger than if a standard has been agreed upon (*$\hat{t} = t$*).*

Thus, the only effect of standard setting on investment levels in our basic model is through its effect on market structure. If no standard is agreed upon, it is more likely that only one firm will serve the market, and this firm will have a stronger incentive to invest than the two firms that would serve the market had a standard been formed.

III.3. Standard Setting

Let us now consider the decision at stage 0 whether or not to form a common standard. If each firm could unilaterally make its own product compatible with the product of its rival then it is a dominant strategy for each firm to do so and a standard will always be formed. Here we focus on the more interesting and more realistic case where a common standard is formed if and only if both parties agree to it.[10] Three cases have to be distinguished:

1. If $\frac{1}{9K} + \alpha < t$ there is a unique symmetric equilibrium with both firms serving the market no matter whether a common standard has been adopted or not. In this case, both firms will opt for the common standard. The standard relaxes competition for customers, it raises equilibrium prices from $t - \alpha$ to t and it increases profits of both firms.
2. If $t < \frac{1}{9K}$ there is an asymmetric equilibrium with only one firm serving the market no matter whether firms adopted a common standard. In this case the

[10] This requires that each firm owns some intellectual property right that is necessary to make the two products compatible with each other.

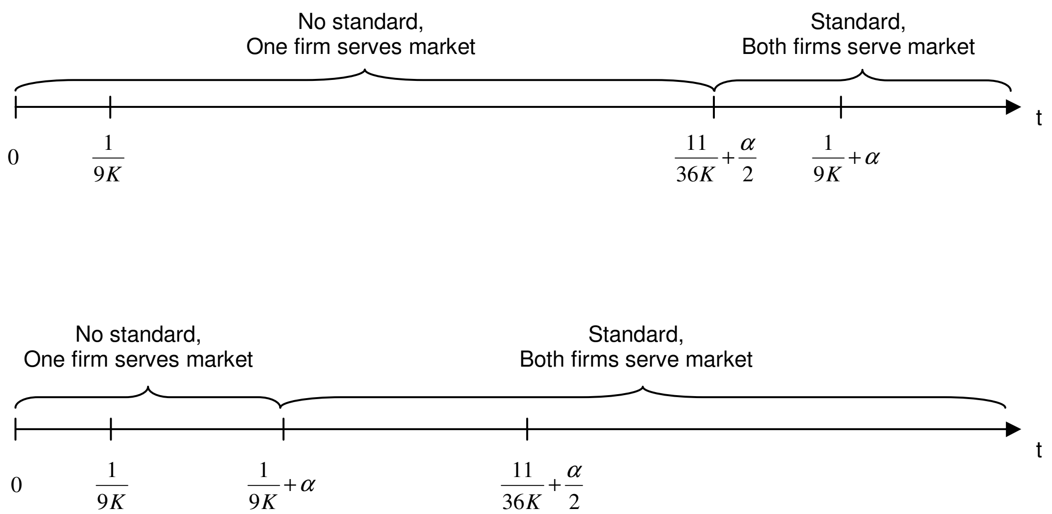
firms will refuse to have a common standard. Adopting a standard would reduce the barriers to entry and make the market more contestable. This would impose a tighter constraint on the limit price that a monopolist can charge.

3. If $\frac{1}{9K} < t < \frac{1}{9K} + \alpha$ there is a symmetric equilibrium if firms adopt a common standard and an asymmetric equilibrium with only one firm serving the market if there is no standard. Comparing profits in both states, the standard will be adopted if

$$\frac{t}{2} - \frac{1}{18K} > \frac{1}{2}\left[\frac{1}{2K} - t + \alpha\right] \quad \Leftrightarrow \quad t > \frac{11}{36K} + \frac{\alpha}{2}$$

Note that $t > \frac{11}{36K} + \frac{\alpha}{2}$ implies $t > \frac{1}{9K}$. Furthermore, $\frac{11}{36K} + \frac{\alpha}{2} < \frac{1}{9K} + \alpha$ if and only if $\alpha > \frac{14}{36K}$. Thus, if network externalities are sufficiently large, there is a range of transportation costs $t \in \left[\frac{11}{36K} + \frac{\alpha}{2}, \frac{1}{9K} + \alpha\right]$ such that the two firms will agree on a common standard and both serve the market, even though they could have implemented a monopoly by not agreeing to a standard.

The three cases are illustrated in Figures 2a and 2b:



FIGURES 2A AND 2B: Adoption of a Standard

Proposition 4: *If* $t > \min\left\{\frac{1}{9K}+\alpha, \frac{11}{36K}+\frac{\alpha}{2}\right\}$ *the two firms will adopt a common standard and both firms will serve the market. If* $t < \min\left\{\frac{1}{9K}+\alpha, \frac{11}{36K}+\frac{\alpha}{2}\right\}$, *the two firms will not adopt a common standard and only one firm will serve the market.*

Proposition 4 allows for some simple comparative static results:

Corollary 1 (Comparative Statics):
(a) The higher the degree of product differentiation measured by the parameter t, *the more likely it is that a standard will be formed.*
(b) The larger the degree of network externalities, α, *the less likely it is that a standard will be formed.*
(c) The larger the marginal cost of quality improvement, K, *the more likely it is that the firms will agree on a standard.*

The intuition for these results is as follows. The more the two goods are horizontally differentiated, the larger are duopoly profits and the smaller is the profit of a monopolist. Thus, it is more likely that a duopoly can be sustained. An increase of α does not affect duopoly profits, but makes a monopoly on this market more profitable. A high α is a high barrier to entry for a firm that did not invest ex ante. Thus, it raises the limit price that a monopolist can charge at date 2. Finally, a high marginal cost of quality improvement K deters firms in a duopoly from investing too much. Recall that in equilibrium both firms invest the same amount, prices are independent of quality, and so firms do not gain from their investments. The investment game is a prisoners' dilemma, and anything that reduces investment levels makes the duopoly more profitable. This is not the case for a monopolist who can charge higher prices for higher quality. Thus, an increase of K makes the duopoly more attractive as compared to the monopoly and thus makes a standard more likely.

III.4. Welfare Evaluation

Are the standardisation choices of firms efficient? We now compare the decisions of the firms to the decisions of a social planner who wants to maximize social welfare, i.e. a weighted sum of consumer surplus and profits of the two firms, weighted with a factor γ, $0 \le \gamma < 1$. The factor γ reflects that the social planner gives more weight to consumers than to producers, for example because the companies may (partially) be owned by foreigners. Note that if $\gamma = 1$, prices are a pure transfer that does not affect social welfare. This is due to the nature of the Hotelling model where each consumer buys exactly one unit of the good. Thus, a price increase does not distort consumption decisions. However, with $\gamma < 1$ we indirectly capture the fact that lower prices tend to improve welfare as long as prices do not fall below marginal cost. The social planner wants to maximize this objective function by choosing prices and quality levels subject to the constraint that firms do not make losses and that each consumer buys his preferred good.

Consider first the case where both firms serve the market. In this case the social planner will always impose the common standard because consumers benefit from the positive network externality of the other good. Thus, the social planner's objective function is given by:

$$W = \int_0^{\bar{x}} (\theta_A - tx - p_A + \alpha)\, dx + \int_{\bar{x}}^{1} (\theta_B - t(1-x) - p_A + \alpha) dx$$
$$+\gamma\left(p_A \bar{x} - \frac{K}{2}\theta_A^2 + p_B\left(1-\bar{x}\right) - \frac{K}{2}\theta_B^2 \right)$$

Given the symmetry of the industry the social planner will order both firms to choose the same investment level. Furthermore, in order to minimize transportation costs he will set $p_A = p_B$ so that each firm serves half of the market. Thus, it suffices to look at the left side of the market and the problem reduces to

$$\max_{p_A,\theta_A} \left\{ \int_0^{1/2} (\theta_A - tx - p_A + \alpha) dx + \gamma\left(\frac{1}{2} p_A - \frac{K}{2}\theta_A^2 \right) \right\}$$

subject to:

$$\frac{1}{2}p_A - \frac{K}{2}\theta_A^2 \geq 0$$

If $\gamma < 1$, the participation constraint of the firm must be binding and the social planner sets

$$p_A = K\theta_A^2$$

Substituting this in the objective function and differentiating with respect to θ_A yields the first order condition which implies

$$\theta_A = \theta_B = \frac{1}{2K} \quad \text{and} \quad p_A = p_B = \frac{1}{4K}$$

Thus, total social welfare is given by

$$W = 2 \cdot \int_0^{1/2} \left(\frac{1}{2K} - tx - \frac{1}{4K} + \alpha \right) dx = \frac{1}{4K} - \frac{1}{4}t + \alpha$$

Consider now the possibility that only one firm, say firm A, serves the entire market. In this case the social planner is indifferent whether or not to form a standard, because all consumers buy from firm A anyway. In this case social welfare is given by:

$$W = \int_0^1 (\theta_A - tx - p_A + \alpha) dx + \gamma \left(p_A - \frac{K}{2}\theta_A^2 \right)$$

Again, if $\gamma < 1$ the social planner will choose p_A as low as possible subject to the constraint that the firm breaks even. Substituting the break-even condition in the welfare function and maximizing with respect to θ_A yields the first order condition

$$\frac{\partial W}{\partial \theta_A} = 1 - K\theta_A = 0$$

which implies

$$\theta_A = \frac{1}{K} \quad \text{and} \quad p_A = \frac{1}{2K}$$

Thus, social welfare is given by

$$W = \int_0^1 \left(\frac{1}{K} - tx - \frac{1}{2K} + \alpha \right) dx + \gamma \left(\frac{1}{2K} - \frac{1}{2K} \right) = \frac{1}{2K} - \frac{1}{2}t + \alpha$$

Comparing social welfare with one firm and two firms, respectively, the social planner prefers to have both firms operating if and only if

$$W^{FB}(2\text{ firms}) = \underbrace{\frac{1}{4K}}_{\substack{\text{investment}\\ \text{surplus}}} - \underbrace{\frac{1}{4}t}_{\substack{\text{transportation}\\ \text{cost}}} + \underbrace{\alpha}_{\substack{\text{network}\\ \text{externality}}} > \underbrace{\frac{1}{2K}}_{\substack{\text{invstement}\\ \text{surplus}}} - \underbrace{\frac{1}{2}t}_{\substack{\text{transportation}\\ \text{cost}}} + \underbrace{\alpha}_{\substack{\text{network}\\ \text{externality}}} = W^{FB}(1\text{ firm}).$$

We summarise the results in proposition 5. Proposition 6 then compares the first best to the actual market outcome.

> **Proposition 5:** *If* $t > \frac{1}{K}$ *the first best efficient outcome is that two firms serve the market, each firm invests* $\theta_A^{FB} = \theta_B^{FB} = \frac{1}{2K}$ *and charges* $p_A^{FB} = p_B^{FB} = \frac{1}{4K}$ *and the two goods use a common standard. If* $t < \frac{1}{K}$*, it is more efficient that only one firm serves the market, invests* $\theta^{FB} = \frac{1}{K}$ *and charges* $p^{FB} = \frac{1}{2K}$*, while the other firm is inactive.*

The advantage of having two firms is the reduction of transportation cost (or the benefit of consumers from having more variety). The cost is the duplication of investments which reduces the investment surplus.

> **Proposition 6:** *There are three potential inefficiencies that may arise in equilibrium:*
>
> 1. *Market prices are higher than in the first best and leave a rent to firms, in particular if only one firm is sustained by the market.*
> 2. *Investments are chosen efficiently if there is only one firm on the market, but inefficiently low if there are two firms.*
> 3. *Standards are chosen efficiently if there are two firms on the market. However, there are parameter constellations under which the market structure is inefficient:*

- *if* $\frac{1}{K} < t < \min\left\{\frac{11}{36K}+\frac{\alpha}{2},\ \frac{1}{9K}+\alpha\right\}$ *the market sustains only one firm that does not obey a common standard, but it would be socially optimal to have two firms using a common standard.*
- *if* $\min\left\{\frac{11}{36K}+\frac{\alpha}{2},\ \frac{1}{9K}+\alpha\right\} < t < \frac{1}{K}$ *the market sustains two firms, but it would be more efficient to have only one firm.*

Suppose that the only policy instrument available to the government is to either impose a standard if firms don't choose one voluntarily or to forbid standards altogether.

At first glance it may seem to be a good idea to make standards mandatory because in the first best the social planner would always impose a common standard. However, in a second best world this is not the case. To see this suppose $t < \min\left\{\frac{1}{9K}+\alpha, \frac{11}{36K}+\frac{\alpha}{2}\right\}$. Without government intervention no common standard will be agreed upon and only one firm will serve the market. If the government imposes a standard, it reduces the barriers to entry. If $t > \frac{1}{9K}$, the monopoly is no longer sustainable and two firms will invest and serve the market. However, this may be inefficient. If $t > \frac{2\left[11\gamma-6-18K\alpha(1-\gamma)\right]}{9K(8\gamma-7)}$ it would have been better to have just one firm even if it charges high prices due to a high barrier to entry.

It may also seem at first glance that the government should never make standards illegal. But, again, this is not true in general. Suppose that $t > \min\left\{\frac{1}{9K}+\alpha, \frac{11}{36K}+\frac{\alpha}{2}\right\}$. Without government intervention the market would sustain a duopoly that would set a common standard. If common standards are made illegal, competition would be more intense and prices would fall from $p_A = p_B = t$ to $p_A = p_B = t-\alpha$. Thus, in equilibrium each consumer would gain α due to the lower price and lose $\frac{\alpha}{2}$ because of the reduced network externality (his good is now compatible with only half of the market). Thus, the net gain of each consumer from this policy measure is $\frac{\alpha}{2}$. On the other hand, the two firms jointly lose α because of the lower price. Therefore, if the weight of the firms in the social welfare is sufficiently small, i.e. if $\gamma < 0.5$, making a standard illegal may actually improve social welfare. In addition, it may trigger a change from a duopoly to a monopoly with an effect on welfare that may go in either direction.

Proposition 7: *In a first best world a common standard is always optimal. Nevertheless, if the government cannot directly control the entry, investment and pricing decisions of firms,*

(a) for some parameter constellations imposing a mandatory standard reduces social welfare

(b) for some parameter constellations forbidding a standard that the industry would like to adopt increases social welfare.

IV. Standard Quality, Royalties and Investment Incentives

So far we looked at standards that are costless to implement and do not differ in quality. Now we consider a situation where the firms' investments not only improve the quality of the good, but may also improve the quality of the standard. Thus, investments may have positive externalities.

We model this as follows. At stage 1 each firm i, $i \in \{A, B\}$, can make an investment $\overline{\theta}_i$ at cost $\frac{K}{2}\overline{\theta}_i^2$ that improves the expected quality of its good and its potential standard. However, final quality is stochastic and given by $\theta_i = \overline{\theta}_i + \widetilde{\varepsilon}_i$ where $\widetilde{\varepsilon}_i \in [-\varepsilon, \varepsilon]$ is uniformly distributed with mean 0, variance ε^2 and covariance $\text{cov}(\varepsilon_A, \varepsilon_B) = 0$. We assume that the noise is "small" in the sense that $\varepsilon < \frac{3}{2}t$.[11] The realized quality levels are commonly observed by both firms at the end of stage 1.

At stage 0 parties may set the rules for the future adoption of a standard. Either both parties agree that the product with the superior quality will be the basis of the standard and that the firm with the inferior quality has to pay fixed and/or variable royalties. Or at least one party objects to a common standard and each product uses its own standard.

IV.1. Price and Quality Competition

Suppose w.l.o.g. that $\theta_A > \theta_B$ and that good A sets the standard. In this case a consumer located at $x \in [0,1]$ who buys good $i \in \{A, B\}$ enjoys utility

$$U(x,i) = \begin{cases} \theta_A - t \cdot x + \alpha \cdot n_A - p_A & \text{if} \quad i = A \\ \theta_B + \lambda(\theta_A - \theta_B) - t \cdot (1-x) + \alpha \cdot n_B - p_B & \text{if} \quad i = B \end{cases}$$

[11] The noise term is required for technical reasons. If investments are deterministic and royalties are positive, then there does not exist a symmetric pure strategy equilibrium in investment decisions in this game. If both firms invested the same amount, each firm would want to invest slightly more in order to make its product the standard and to receive the royalties.

The parameter $\lambda \in [0,1]$ measures the positive spillover effects on the inferior good if it can use the superior standard. If $\lambda = 1$, inferior firm B completely adopts the superior technology of good A and both firm offer the same quality. If $\lambda = 0$ there are no spillovers, the standard merely allows for compatibility and does not affect the quality of the goods, and we are back to the model of the previous section. If $0 < \lambda < 1$ the adoption of the superior standard has some spillover effects, but some quality differences remain. The parameter λ may be affected by the standard setting agreement. The more comprehensive the standard and the more technology is shared by the parties, the higher is λ.

Suppose that both firms serve the market. The consumer who is just indifferent whether to buy product A or B is located at

$$\bar{x} = \frac{1}{2} + \frac{(1-\lambda)(\theta_A - \theta_B) - p_A + p_B}{2t}.$$

The parties may agree on a fixed royalty R and/or linear royalties r that have to be paid by the firm with the inferior product to the firm that sets the standard. Consider stage 2 and suppose that the realizations of quality levels are such that $\theta_A > \theta_B$. In this case, the profit function of firm A is given by

$$\pi_A = p_A \cdot \bar{x}(p_A, p_B) + r \cdot (1 - \bar{x}(p_A, p_B)) + R - \frac{K}{2}\bar{\theta}_A^2$$

On the other hand, if $\theta_A < \theta_B$ A's profit function is

$$\pi_A = p_A \cdot \bar{x}(p_A, p_B) - r \cdot \bar{x}(p_A, p_B) - R - \frac{K}{2}\bar{\theta}_A^2$$

In both cases the first derivative of A's profit function with respect to p_A is the same and yields the first order condition

$$p_A = \frac{t + r + (1-\lambda)(\theta_A - \theta_B) + p_B}{2}$$

This is the same condition as in Section III.1. with $\hat{t}$ replaced by $t + r$ and $\theta_A - \theta_B$ replaced by $(1-\lambda)(\theta_A - \theta_B)$. Thus, there is a unique Nash equilibrium in prices with

$$p_A = \frac{(1-\lambda)(\theta_A - \theta_B)}{3} + t + r \quad \text{and} \quad p_B = \frac{(1-\lambda)(\theta_B - \theta_A)}{3} + t + r$$

Substituting this in the profit function of firm A we get[12]

$$\pi_A = \begin{cases} \frac{\left[(1-\lambda)(\theta_A - \theta_B) + 3t\right]^2}{18t} + r + R - \frac{K}{2}\bar{\theta}_A^2 & if \quad \theta_A > \theta_B \\ \frac{\left[(1-\lambda)(\theta_A - \theta_B) + 3t\right]^2}{18t} - R - \frac{K}{2}\bar{\theta}_A^2 & if \quad \theta_A < \theta_B \end{cases}$$

Consider now investment decisions at stage 1. From an ex ante perspective the expected profit of firm A is given by

$$E(\pi_A) = \int_{\varepsilon_A}\int_{\varepsilon_B} \frac{\left[(1-\lambda)\left(\bar{\theta}_A + \varepsilon_A - \bar{\theta}_B - \varepsilon_B\right) + 3t\right]^2}{18t} \frac{1}{2\varepsilon} d\varepsilon_B \frac{1}{2\varepsilon} d\varepsilon_A$$
$$+ \Pr(\theta_A > \theta_B) \cdot (R + r) - (1 - \Pr(\theta_A > \theta_B)) \cdot R - \frac{K}{2}\bar{\theta}_A^2$$

Note that

$$\Pr(\theta_A > \theta_B) = \Pr\left(\varepsilon_A > \bar{\theta}_B - \bar{\theta}_A + \varepsilon_B\right) = \frac{1}{2} + \frac{\bar{\theta}_A - \bar{\theta}_B}{2\varepsilon}$$

Thus, we get

$$E(\pi_A) = \frac{\left[(1-\lambda)\left(\bar{\theta}_A - \bar{\theta}_B\right) + 3t\right]^2}{18t} + \frac{2(1-\lambda)^2 \varepsilon^2}{18t} + \left(\frac{1}{2} + \frac{\bar{\theta}_A - \bar{\theta}_B}{2\varepsilon}\right)(R + r) - \left(\frac{1}{2} - \frac{\bar{\theta}_A - \bar{\theta}_B}{2\varepsilon}\right)R - \frac{K}{2}\bar{\theta}_A^2$$

Differentiating with respect to $\bar{\theta}_A$ yields the FOC and firm A's best response function

$$\bar{\theta}_A = \frac{9t\frac{2R + r}{2\varepsilon} - (1-\lambda)^2 \bar{\theta}_B + 3(1-\lambda)t}{9Kt - (1-\lambda)^2}$$

Note that the second order condition requires

$$\frac{\partial^2 E(\pi_A)}{\partial \theta_A^2} = \frac{(1-\lambda)^2}{9t} - K < 0 \quad \Leftrightarrow \quad 9Kt - (1-\lambda)^2 > 0$$

[12] In the following we ignore the event $\theta_A = \theta_B$ that occurs with probability 0.

Proposition 8: *Suppose that the two firms agreed to a common standard and to royalties* $r, R \geq 0$ *at stage 0. In the unique symmetric pure strategy equilibrium firms choose investment levels*

$$\overline{\theta}_A = \overline{\theta}_B = \frac{1-\lambda}{3K} + \frac{2R+r}{2K\varepsilon}$$

and expected equilibrium payoffs are

$$E(\pi_A) = E(\pi_B) = \frac{t+r}{2} + \frac{2(1-\lambda)^2 \varepsilon^2}{18t} - \frac{(1-\lambda)^2}{18K} - \frac{(1-\lambda)(2R+r)}{6K\varepsilon} - \frac{(2R+r)^2}{8K\varepsilon^2}$$

If $\lambda = 0$ and $R = r = 0$, investment levels are the same as in the basic model of Section III and expected profits differ from profits in the deterministic model only by a term proportional to ε^2 which reflects the additional vertical product differentiation due to the noise in quality levels. Note also that expected equilibrium profits are increasing in t (because of stronger product differentiation), in K (because of lower investments) and in ε (because of lower investment incentives and less ex post competition).

IV.2. Optimal Royalties and Technology Sharing

What royalties would the parties agree upon ex ante?

Proposition 9: *If the parties agree to a common standard at date 0 they will choose*

$$R = 0 \quad \text{and} \quad r = \max\left\{2K\varepsilon^2 - \frac{2\varepsilon(1-\lambda)}{3}, \quad 0\right\}.$$

The optimal linear royalty r *is increasing in the spillover parameter* λ *and the marginal cost of investment* K. *Furthermore, it goes to 0 as the variance of the noise term* ε^2 *goes to 0.*

To see why the fixed royalty R will be set to zero, note that it has no impact on equilibrium prices but only affects the investment incentives of the two parties. The higher R, the higher is the reward for developing the superior standard and the stronger are the incentives to invest. However, in equilibrium both parties make exactly the same investment. While the investment benefits consumers, it does not benefit the two firms. Both firms would be better off if they could commit not to invest. By setting $R = 0$, they eliminate any incentive to invest coming from the fixed part of royalties.

The linear royalty r, however, may be positive. It trades off two effects. On the one had it is part of the marginal costs of both firms: It is a direct marginal cost for the inferior firm that has to pay the royalty for each of its customers. It is a marginal opportunity cost for the superior firm that loses the royalty income on each customer that it gains. Therefore, the equilibrium price at stage 2 increases one to one with r which raises total profits by r. If this was the only effect, the parties would use r to implement the monopoly price, i.e. to choose r as large as possible in the Hotelling model. However, there is a second effect. The linear royalty induces the parties to invest more which is bad for total profits. Therefore r should not become too large. The optimal linear royalty increases with the spillover parameter λ and the marginal cost of investment K. The larger these parameters, the lower is the incentive to invest in quality which dampens the second effect and makes it optimal to raise r.

Substituting the optimal royalty rates in the expected profit function we get

$$E(\pi_A) = E(\pi_B) = \frac{t}{2} + \frac{K\varepsilon^2}{2} - \frac{(1-\lambda)\varepsilon}{3} + \frac{(1-\lambda)^2\varepsilon^2}{9t}$$

Note that expected profits are a convex function of λ. If firms can choose λ, they will either go for $\lambda = 0$ or $\lambda = 1$, and choose $\lambda = 1$ if and only if $\varepsilon < 3t$. Note that this condition is implied by our assumption that the noise is relatively small, i.e. that $\varepsilon < \frac{3}{2}t$. Note further that expected profits are increasing in transportation cost t and in the variance of the noise term ε^2. Therefore we get:

Proposition 10: *If the parties can choose the spillover parameter* λ*, they will set* $\lambda = 1$ *and* $r = 2K\varepsilon^2$*. There is a unique symmetric equilibrium with* $p_A = p_B = t + 2K\varepsilon^2$, $\bar{\theta}_A = \bar{\theta}_B = \varepsilon$ *and*

$$E(\pi_A) = E(\pi_B) = \frac{t}{2} + \frac{K\varepsilon^2}{2}.$$

IV.3. Private Incentives to Adopt a Common Standard

The question remains whether the two firms want to set up such a standard setting agreement at stage 0 or whether they prefer not to have a standard. Without a standard the analysis is very similar to the analysis of Section III. Two cases have to be distinguished:

1. If $t > \frac{1}{9K} + \alpha$ then there is a unique symmetric equilibrium with $\bar{\theta}_A = \bar{\theta}_B = \frac{1}{3K}$ and $E(\pi_A) = E(\pi_B) = \frac{t-\alpha}{2} + \frac{\varepsilon^2}{9(t-\alpha)^2} - \frac{1}{18K}$.
2. If $t < \frac{1}{9K} + \alpha$ then there is a unique symmetric correlated equilibrium in which each party invests $\frac{1}{K}$ with probability 0.5 while the other firm does not invest. Expected profits are $E(\pi_A) = E(\pi_B) = \frac{1}{4K} - \frac{t-\alpha}{2}$.

Comparing profits with and without a standard we get the following result.

Proposition 11: *Firms agree to form a standard if and only if*

$$t > \max\left\{\frac{2K\varepsilon^2}{9K^2\varepsilon^2 + 9K\alpha + 1} + \alpha,\ \ \frac{1}{9K} + \alpha\right\} \quad \text{or} \quad \frac{1}{4K} - \frac{K\varepsilon^2}{2} + \frac{\alpha}{2} < t < \frac{1}{9K} + \alpha$$

IV.4. Welfare and Policy Implications

If firms cooperate on standardisation ex ante and fully share their technologies, they will invest $\theta_A = \theta_B = \varepsilon$, while if they do not agree on a common standard, either both firms invest $\theta_A = \theta_B = \frac{1}{3K}$ or only one firm invest $\frac{1}{K}$ while the other firm stays out of the market. Thus, if royalties and technology sharing are feasible, standard setting has an important impact on investment behaviour.

From a social welfare point of view, it would always be optimal to have a standard with full technology sharing. Recall that the socially optimal investment levels are either $\theta_A = \theta_B = \frac{1}{2K}$ if both firms serve the market or $\theta = \frac{1}{K}$ if only one firm invests. Thus, the market outcome always fails to be efficient: Either the two firms agree to a common standard with $\lambda = 1$ (which is efficient), but in this case they will not invest efficiently (if $\varepsilon \neq \frac{1}{2K}$). Or they will not form a standard (which is always inefficient) and only one firm will enter the market which will then invest efficiently. Or they will not form a standard, and both invest two little.

Note that if ε is small, standard setting results in underinvestment. The reason is that in our model the two firms are unable to reap any of the benefits of their investments from consumers. Therefore, they have a joint incentive to restrict investments as much as possible, which is socially harmful.[13] If ε is small, a no-investment cartel can be sustained almost perfectly by using the instruments of a common standard, technology sharing and optimal linear royalties. Furthermore, firms use the linear royalty to increase prices in the product market.

In order to restrict the collusive power of these standard setting agreements the government might consider to impose a royalty-free licensing rule, i.e. it might require firms to set $r = R = 0$.

Proposition 12: *If there is an underinvestment problem because the noise in the investment decisions is small* $\left(\varepsilon < \min\left\{\frac{1}{2K}, \sqrt{\frac{t}{2K}}\right\}\right)$, *then imposing a royalty-free licensing rule reduces social welfare.*

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[13] Firms would also underinvest even if there was competition from an outside competitor although this effect would not be as strong.

Proof: If firms set a common standard with $\lambda = 1$ and $r = 2K\varepsilon^2$, social welfare is given by

$$EW = 2\cdot\int_0^{1/2}\left(\varepsilon+\frac{\varepsilon}{3}-t-2K\varepsilon^2+\alpha-tx\right)dx+\gamma 2\left[\frac{t}{2}+\frac{K\varepsilon^2}{2}\right]=\frac{4}{3}\varepsilon-\frac{5-4\gamma}{4}t-(2-\gamma)K\varepsilon^2+\alpha$$

Suppose that the government imposes $r = R = 0$. If it does so, the expected profits of firms that have a common standard reduces to

$$E(\pi_A)=E(\pi_B)=\frac{t}{2}+\frac{2(1-\lambda)^2\varepsilon^2}{18t}-\frac{(1-\lambda)^2}{18K}=\frac{t}{2}+(1-\lambda)^2\left[\frac{2K\varepsilon^2-t}{18Kt}\right]$$

Note that

$$\frac{\partial E(\pi)}{\partial\lambda}>0 \quad\Leftrightarrow\quad \varepsilon^2<\frac{t}{2K}$$

Thus, if $\varepsilon<\sqrt{\frac{t}{2K}}$, the firms will set $\lambda = 1$ which is efficient, but then choose $\bar{\theta}_A = \bar{\theta}_B = 0$, because with $r = 0$ and $\lambda = 1$ there is no private incentive to invest anymore. In this case expected social welfare is given by

$$EW = 2\cdot\int_0^{1/2}\left(E(\max\{\theta_A,\theta_B\}-t+\alpha-tx\right)dx+\gamma\cdot 2\left[\frac{1}{2}t\right]=\frac{\varepsilon}{3}+\alpha-\frac{t}{4}-(1-\gamma)t$$

Thus, the government reduces social welfare with this policy if

$$\varepsilon<\frac{1}{(2-\gamma)K}$$

Note that this is implied by $\varepsilon<\frac{1}{2K}$. Thus, if firms underinvested if left alone, social welfare is reduced by the policy of the government. *Q.E.D.*

On the one hand, if $r = 0$ firms cannot use the royalty rate to inflate prices on the product market. On the other hand, with $r = 0$ there is no incentive to invest and firms will choose $\theta_A = \theta_B = 0$. The proposition shows that the welfare gain due to lower prices is always lower than the welfare loss due to lower investments.

Note, however, that in our model the market size is fixed. If new customers would enter the market if the quality of the goods increased, firms would receive some benefits from their investments and therefore they would not want to eliminate all incentives to invest. However, it would still be the case that they would not be able to capture the entire increase in consumer surplus due to their investments and that their joint incentives to invest would be too low from a social point of view. Therefore, there is always an incentive to use a standard setting agreement ex ante to restrict investment incentives.

IV.5. The Novell/Microsoft collaboration agreement

The recent collaboration agreement between Microsoft and Novell serves as a good example to illustrate some of the theoretical points made in this paper. The agreement of November 2, 2006 came to the amazement of industry insiders and casual observers alike. Microsoft was announcing a fundamental partnership with once arch rival Novell, focused on promoting Linux. Linux is considered to be the fiercest competitor to Microsoft's Windows in the operating systems market. Windows is running on more than 90% of the world's computers whereas Linux, an open-source product mainly supplied by Red Hat and Novell, captures only around 5% but is being increasingly used. Due to high product and code complexity, compatibility decisions lie in the IP owner's hand. Clearly, this deal is not made for the benefit of consumers alone.[14] Microsoft and Novell certainly expect benefits as well. In the past, however, Microsoft has built a reputation for fighting off its rival's and often was successful in doing so.[15] So why collaborate this time?

Before investigating this question we briefly outline some details of the agreement. It consists of a set of business and technical collaboration agreements to build, market and support a series of new solutions to make Novell and Microsoft products work better together.[16] We restrict our attention to the *Technical*

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[14] Novell's webpage might give this expression by titling: "Novell and Microsoft collaborate – customers win". (http://www.novell.com/linux/microsoft on December 1, 2006)
[15] The Netscape Navigator was probably the most prominent example but other examples of aggressive, pre-emptive strategy do exist – sometimes deemed anticompetitive by antitrust suits (Media Player, MS Word, Microsoft vs. Apple, etc.).
[16] A summary is given in the end of the appendix of the paper.

Collaboration Agreement (TCA). As part of the agreement a joint research facility at which Microsoft and Novell technical experts will architect and test new software solutions will be established. Work will focus on three areas:

- Virtualisation: firms will jointly develop a compelling virtualisation offering for Linux and Windows.
- Web services for managing physical and visual servers: make it easier for customers to manage mixed Windows and SUSE Linux Enterprise environments.
- Document format compatibility: the two companies will work together on ways for Open Office and MS Office system users to best share documents and also make available two-way translators.

Our model provides intuition for why the firms may have come to the above agreement. Note that although the market shares are rather asymmetric in the given case, we would expect qualitatively similar results in an asymmetric version of our model.

Firstly, it seems that with the agreement Microsoft has finally accepted that it will not succeed in excluding Linux from the operation systems market. Linux's typical clientele – generally described as technology-affine users and those looking for reliable server systems – was unwilling to incur large "transportation costs" and buy from Microsoft. As a consequence, our model would suggest that parties opt for a common standard. The common standard reduces product market competition and a higher margin relative to a situation without compatibility can be sustained. Note that due to the asymmetries in market shares, Microsoft would be expected to be more reluctant to opt for the common standard; its customers already benefit from large network effects now. Novell is expected to benefit significantly more. Upon announcement shares of Novell have traded up sharply (~ +15%) while shares of Microsoft have slightly decreased. In an asymmetric version of our model one would further expect Novell's market share to increase – an expectation that several industry analysts have raised.

Secondly, let us look at the consumer surplus change resulting from this agreement. Certainly consumers truly gain from the increased compatibility and associated network effects. However, our model also warns that they may suffer from higher future prices. Furthermore, depending on the details of the agreement, technological development may be weakened.

Thirdly, our model makes predictions about firms' equilibrium investments. Of course, actual investment levels are not only kept secret by the firms but also impossible to compare against a counterfactual world where no technology collaboration agreement would have taken place. Nevertheless, our model predicts that under such an agreement firms would choose full technology sharing, a low but positive linear royalty and – in a world without competition from outside – minimal investment levels. These predictions are difficult to assess but present a warning to antitrust authorities. Yet, a joint research facility, as proposed in the agreement, will allow for significant spillovers and is therefore very much in line with predictions of the model. Technical experts working on the standard codes can thereby get a good idea of the competitor's technology, its quality and thereby achieve an improvement of their firm's technology. Some of this technology will, of course, be proprietary and then the royalties that are being paid may allow for a reduction of equilibrium investment of both firms, even though competition from outside (i.e. Red Hat and others) will render this effect quantitatively less pronounced.

Industry experts and bankers were speculating on Microsoft's motive when opting for the agreement. Certainly explanations outside of our model exist and play an important role for the drafting of the technology collaboration agreement.[17] Yet, most of the ideas voiced by industry experts conform to explanations given by our model although many IT experts remain suspicious that it may just be one of Microsoft's strategies to destroy rivals by pretending to cooperate.

[17] For example, fragmenting the opposition that consists of the different Linux suppliers, maybe another explanation. Contradicting this hypothesis is the statement of Microsoft's Steve Ballmer who was quoted saying that Microsoft would want to put that kind of agreement in place with anyone who distributes Linux software.

V. *Ex Ante* versus *Ex Post* Standard Setting

Some standard setting agreements set the rules that govern the standard setting process at a very early stage. Standard setting organisations, for example are typically formed at an early stage, i.e. before all of the technologies that are required for the standard have been developed. At this stage it is often unclear which firm is going to supply the standard and benefit from the royalties that have to be paid. In contrast, firms could agree to licensing agreement at a later stage, when the necessary technologies have been developed already. At that stage the parties may still benefit from adopting a common standard and from sharing their technologies.

This section addresses two questions. First, we ask whether companies prefer *ex ante* standard setting, i.e. before making their investment decisions, or whether they prefer to agree on a standard *ex post*, after investments have been made and the qualities of the different technologies are known. Second, we look at this question from the perspective of anti-trust policy. Should the government interfere with the private decision to form a standard ex ante or ex post in order to improve social welfare by influencing pricing and/or investment incentives?

It is important to note that we restrict attention to the case where the technologies of the two firms are substitutes: either the technology of firm A or the technology of firm B is used for the standard. We do not consider the case where both technologies are required to form the standard (and are thus perfect complements).

V.1. Ex post Bargaining for a Common Standard

Suppose that the firms invested already $\overline{\theta}_A$, $\overline{\theta}_B$ at stage 1 and that both parties observed the realizations of θ_A and θ_B. Now the parties may agree to a common standard and they may decide how many spillovers $\lambda \in [0,1]$ to allow for. If the standard raises joint profits as compared to the situation where each party uses its own technology and products are incompatible, a standard will be formed and the parties will split the surplus 50:50 by agreeing to an appropriate side payment R.

Suppose that $|\theta_A - \theta_B| < 3(t-\alpha)$. If this condition does not hold, only one firm can survive on the market, and this firm will never agree to a common standard. If the condition holds and if no standard is formed, there is a unique pure strategy equilibrium with joint profits net of investment costs

$$\pi^{NS} = \frac{\left(\theta_A - \theta_B\right)^2 + 9(t-\alpha)^2}{9(t-\alpha)}$$

If firms agree to a standard (*ex post*) with spillovers $\lambda \in (0,1)$, joint net profits are given by

$$\pi_A + \pi_B = \frac{(1-\lambda)^2\left(\theta_A - \theta_B\right)^2 + 9t^2}{9t}$$

The first observation is that any ex post agreement will always set $\lambda = 0$, which is inefficient. Investments have been made already and cannot be affected any more. Thus, the only remaining effect of λ is on the degree of product market competition. By setting $\lambda = 0$ parties maximize the degree of vertical product differentiation and thus relax product market competition as much as possible. However, consumers would be better off if the quality of the inferior good was higher and if prices were lower due to more intense competition.

The surplus from this licensing agreement is always strictly positive (if $|\theta_A - \theta_B| < 3(t-\alpha)$, i.e., if both firms will stay on the market) and given by

$$S^{EP} = \frac{\alpha\left[9t(t-\alpha) - \left(\theta_A - \theta_B\right)^2\right]}{9t(t-\alpha)} > 0$$

Suppose that the parties split the surplus 50:50. Then firm A's payoff, given the realizations of θ_A, θ_B, is given by

$$\pi_A^{EP} = \frac{\left[\left(\theta_A - \theta_B\right) + 3t\right]^2}{18t} - \frac{K}{2}\overline{\theta}_A^{\,2}$$

A's expected profit (before the realizations of θ_A, θ_B) is then given by

$$E\left(\pi_A^{EP}\right) = \frac{t}{2} + \frac{\left(\bar{\theta}_A - \bar{\theta}_B\right)^2}{18t} + \frac{\bar{\theta}_A - \bar{\theta}_B}{3} + \frac{\varepsilon^2}{9t} - \frac{K}{2}\bar{\theta}_A^{\ 2}$$

At stage 1 the two firms decide on their investment levels. There is a unique symmetric pure strategy equilibrium with

$$\bar{\theta}_A = \bar{\theta}_B = \frac{1}{3K}.$$

Thus, expected equilibrium profits if firms rely on an ex post agreement are given by

$$E\left(\pi_A^{EP}\right) = E\left(\pi_B^{EP}\right) = \frac{t}{2} - \frac{1}{18K} + \frac{\varepsilon^2}{9t}.$$

Note that this is exactly the same expected payoff as the expected payoff that each party would receive with an ex ante standard setting agreement that sets $\lambda = 0$ and royalties $R = r = 0$.

> **Proposition 13:** *Firms strictly prefer the optimal ex ante standard setting agreement with $\lambda = 1$ and $r = 2K\varepsilon^2$ to ex post bargaining for an optimal standard setting agreement with $\lambda = 0$ and a fixed side-payment.*

The proposition follows from a simple revealed preference argument. The parties could have opted for an ex ante agreement with $\lambda = 0$ and a fixed royalty $R = r = 0$, giving the same investment incentives and the same expected profits as ex post bargaining and standard setting. However, as was shown in Section IV.2., they always prefer $\lambda = 1$ and $r = 2K\varepsilon^2$. Intuitively, this is because ex ante standard setting agreements allow the parties to control their investment decisions which is not possible with ex post bargaining.

Note that we did not allow the parties to write licensing agreements with linear royalties $r > 0$. To see what happens if we allow for $r > 0$ suppose w.l.o.g. that $\theta_A > \theta_B$ and recall that equilibrium prices are given by with

$$p_A = \frac{\theta_A - \theta_B}{3} + t + r \quad \text{and} \quad p_B = \frac{\theta_B - \theta_A}{3} + t + r$$

while profits are

$$\pi_A = \frac{[\theta_A - \theta_B + 3t]^2}{18t} + r - \frac{K}{2}\bar{\theta}_A^2$$

$$\pi_B = \frac{[\theta_A - \theta_B + 3t]^2}{18t} - \frac{K}{2}\bar{\theta}_A^2$$

Thus, a positive linear royalty raises both the prices and profits of firm A by r while the profits of firm B are unaffected. Therefore, firms would have an incentive to choose an infinite linear royalty ex post. More generally, in a model with elastic market demand, firms would use the linear royalty to implement the monopoly price. Obviously, this should be forbidden by anti-trust authorities. Furthermore, firms themselves are harmed from the possibility to charge monopoly prices ex post because this gives excessive incentives to invest ex ante.

V.2. Welfare Comparison

While the previous section has shown that firms always prefer ex ante standard setting agreements to ex bargaining, this is less obvious from a social welfare point of view. On the one hand, ex ante agreements will set $\lambda = 1$ which benefits consumers. On the other hand, however, they will choose r in order to limit their investments. If ε^2 is small and thus the investment levels given by an ex ante agreement are thus small, it may be a welfare improving if the government does not allow ex ante standardisation.

> **Proposition 14:** *If ε^2 is small, ex post bargaining may be preferable from a social welfare point of view because it does not allow the parties to restrict their investments too much.*

VI. Conclusions

In this paper we analyzed the implications of standards, technology sharing and royalties on product market competition and the incentives to invest into the quality of the product and/or the quality of the standard. We have shown that if both firms expect to serve the market, they want to adopt a common standard because it relaxes product market competition. However, if they anticipate that only one firm will survive on the market, a common standard will not be chosen because it reduces the limit price that the successful company can charge. If there is no technology sharing and if there are no royalties, standards have no direct impact on investments, but they may affect the market structure and thereby indirectly affect investment decisions. Even though in a first best world it is always optimal to have a common standard, imposing a common standard on the industry may actually reduce social welfare if it adversely affects market structure.

If we allow for technology sharing and fixed and/or linear royalties, there is a strong impact on investments. Firms will use these instruments to jointly reduce their incentives to invest and to increase the market price. Imposing a zero-royalty rate on standard setting agreements does not mitigate this problem but rather makes it worse.

Finally, we have shown that firms always prefer an ex ante to an ex post standard setting agreement. Even though ex post licensing can also be used to reduce price competition, it is less successful in reducing quality competition. This is the reason why the government may prefer a ex post licensing agreements.

However, it should be kept in mind that our model applies only to the case where different technologies are substitutes. If technologies are complements and if several complementary patents owned by different firms are required for the standard, the analysis would be quite different. In this case, the main purpose of a licensing agreements after technology development is to mitigate the double marginalization problem and to prevent parties from charging royalties that push the market price above the monopoly price (see Lerner and Tirole, 2004, Schmidt 2006). It would be an interesting and important topic of future research to extent the analysis of standard setting agreements and of the firms' investment incentives to this case.

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Appendix

Proof of Proposition 1: Assuming that both firms are active, the condition for the marginal consumer is given by:

$$\theta_A - p_A - t \cdot \bar{x} + \alpha \cdot n_A = \theta_B - p_B - t \cdot (1 - \bar{x}) + \alpha \cdot n_B$$

Therefore it follows that the market share of firm A is given by the indifferent consumer:

$$\bar{x} = \frac{1}{2} + \frac{\theta_A - \theta_B - p_A + p_B}{2 \cdot \hat{t}}$$

Firms profits are thus given by the following expressions:

$$\pi_A = p_A \cdot \bar{x}(\theta_A, \theta_B, p_A, p_B) - \frac{K}{2} \bar{\theta}_A^{\,2} \quad \text{and} \quad \pi_B = p_B \cdot (1 - \bar{x}(\theta_A, \theta_B, p_A, p_B)) - \frac{K}{2} \bar{\theta}_B^{\,2}$$

resulting in the best-response functions of the pricing game:

$$p_A = \frac{\theta_A - \theta_B + p_B + \hat{t}}{2} \quad \text{and} \quad p_B = \frac{\theta_B - \theta_A + p_A + \hat{t}}{2}$$

Note that these best response functions are linear and increasing in the (p_A, p_B)-space[18]. This implies that the symmetric equilibrium must be unique. In a symmetric Nash equilibrium of the pricing subgame firms set:

$$p_A = \frac{\theta_A - \theta_B}{3} + \hat{t} \quad \text{and} \quad p_B = \frac{\theta_B - \theta_A}{3} + \hat{t}$$

The marginal consumer is given by $\bar{x} = \frac{1}{2} + \frac{\theta_A - \theta_B}{6\hat{t}}$. Note that $\bar{x} \notin (0,1)$, i.e. a corner equilibrium with only one firm serving the market is obtained, iff $\hat{t} < \left| \frac{\theta_A - \theta_B}{3} \right|$. Hence, the symmetric equilibrium with both firms active exists iff $\hat{t} > \left| \frac{\theta_A - \theta_B}{3} \right|$ with profits:

$$\pi_A = \frac{\left(\theta_A - \theta_B + 3\hat{t}\right)^2}{18\hat{t}} - \frac{K}{2}\theta_A^2 \quad \text{and} \quad \pi_B = \frac{\left(\theta_B - \theta_A + 3\hat{t}\right)^2}{18\hat{t}} - \frac{K}{2}\theta_B^2$$

Comparative statics with respect to $\hat{t}$ give:

$$\frac{\partial \pi_A}{\partial \hat{t}} = \frac{6\left(\theta_A - \theta_B + 3\hat{t}\right) \cdot 18\hat{t} - 18\left(\theta_A - \theta_B + 3\hat{t}\right)^2}{(18\hat{t})^2} \geq 0$$

[18] Note also that the second order condition for a maximum requires only that $\hat{t} > 0$. This is guaranteed by assumption (compare footnote 4) and this assumption also implies that for $\theta_A = \theta_B$ a symmetric equilibrium with positive prices exists.

iff $3\hat{t} \geq |\theta_A - \theta_B| \;\Leftrightarrow\; \hat{t} \geq \frac{|\theta_A - \theta_B|}{3}$. Thus, if $\hat{t} > \left|\frac{\theta_A - \theta_B}{3}\right|$ profits are strictly increasing in $\hat{t}$ and for $\alpha > 0$ we have that profits are higher if firms agreed to a common standard than if goods are compatible.

Proof of Proposition 2: The first part of the proposition follows from the proof of proposition 1. In a corner equilibrium (prevailing if $\hat{t} < \left|\frac{\theta_A - \theta_B}{3}\right|$) only one firm serves the entire market. Let us assume w.l.o.g. and for means of exposition, that this is firm A.[19] Assume further that firm B sets a price of $p_B = 0$. The optimal price for firm to demand from the furthest away consumer is the limit price which makes this consumer just indifferent between buying from A or B: $p_A = \theta_A - \theta_B - \hat{t}$ if $\theta_A > \theta_B$. Reducing this price clearly cannot be optimal: The firm would lose this price increment on every consumer. Also, increasing the price cannot be optimal: With a marginal price increase of *dp*, the firm gains some revenues through the increased price on its remaining consumers but it loses out more through the resulting demand contraction:

$$dR = x(p) \cdot dp + p \cdot dx$$

$$dR = dp(1 - \frac{\theta_A - \theta_B}{2\hat{t}} + \frac{1}{2}) < 0 \text{ as } \frac{\theta_A - \theta_B}{2\hat{t}} > \frac{3}{2}$$

Hence, there is no incentive to deviate for firm A. It is trivial to see that also firm B has no incentive to deviate: Decreasing the price below zero leads to negative profits. Also, increasing the price into the positive range cannot increase profits. Thus, we have found an equilibrium. Of course, the mirror equilibrium also exists.

Profits in this equilibrium are then given by:

$$\pi_A = \theta_A - \theta_B - \hat{t} - \frac{K}{2}\theta_A^2 \text{ and } \pi_B = 0$$

Thus, $\frac{\partial \pi_A}{\partial \hat{t}} = -1 \leq 0$ and hence price and profits are decreasing in $\hat{t} > 0$. Thus, the firm always prefers no standard ($\hat{t} = t - \alpha$) to a standard ($\hat{t} = t$).

Proof of Proposition 3: Let us consider the symmetric maximisation problem following from proposition 1 and look at the firms' optimal investments. The profit function for $\hat{t} > \left|\frac{\theta_A - \theta_B}{3}\right|$ is:

[19] We also abstract from any total demand effects of price throughout the paper (assuming that all consumers buy). This implies that the highest price firm A can possibly set to satisfy this assumption is the limit price.

$$\pi_A = \frac{\left(\theta_A - \theta_B + 3\hat{t}\right)^2}{18\hat{t}} - \frac{K}{2}\theta_A^2$$

and the second order condition for a maximum requires $\hat{t} \geq \frac{1}{9K}$. The first order condition leads to the following reaction functions:

$$\theta_A = \frac{\theta_B - 3\hat{t}}{1 - 9K\hat{t}} \text{ and } \theta_B = \frac{\theta_A - 3\hat{t}}{1 - 9K\hat{t}}$$

Note that the reaction functions are linear but can be increasing or decreasing depending on the sign of the denominator. The symmetric Nash equilibrium (which may not be unique) of this subgame solves out to:

$$\theta_A = \theta_B = \frac{1}{3K}$$

Profits in this equilibirum are[20]:

$$\pi_A = \pi_B = \frac{\hat{t}}{2} - \frac{1}{18K} \geq 0$$

From the reaction functions, we need to distinguish three cases:

1) *Case 1:* $9K\hat{t} - 1 > 1$

Absolute value of the slope of the reaction functions is smaller than 1. There is a unique symmetric Nash equilibrium which is given by the investment levels:

$$\theta_A = \theta_B = \frac{1}{3K}$$

Note that here the condition $\hat{t} > \left|\frac{\theta_A - \theta_B}{3}\right|$ is clearly satisfied and firms would play symmetrically in the price game as well.

2) *Case 2:* $9K\hat{t} - 1 < 1$

Absolute value of the slope of the reaction functions is larger than 1. The reaction functions give rise to three Nash equilibria, one symmetric equilibrium and two asymmetric equilibiria:

i) $\theta_A = \theta_B = \frac{1}{3K}$ (symmetric equilibrium)

ii) $\theta_A = \frac{3\hat{t}}{9\hat{t}K - 1}$; $\theta_B = 0$ (asymmetric equilibrium)

[20] Note that profits are greater zero because the second order condition requires that $\hat{t} \geq \frac{1}{9K}$ which implies that profits must be positive.

iii) $\theta_A = 0$; $\theta_B = \frac{3\hat{t}}{9\hat{t}K - 1}$ (asymmetric equilibrium)

As we argue in footnote 7 of the main text, the two asymmetric equilibria will be neglected for any further analysis and in case of co-existence of symmetric and asymmetric equilibria, we will focus on the symmetric equilibria only.

3) Case 3: $9K\hat{t} - 1 < 0$*:*

The reaction functions are increasing. Also, case 3 implies that the second order condition of the maximisation problem, $\hat{t} \geq \frac{1}{9K}$, is violated. A symmetric equilibrium can hence not exist. Suppose firm B chooses $\theta_B = 0$. The following cases must be distinguished in the pricing game in stage 2 (following propositions 1 and 2 above):

i) Firm A chooses $\theta_A > \frac{1}{3K}$. In stage 2 there will be an asymmetric equilibrium in which firm A chooses the limit price $p_A = \theta_A - \hat{t}$. Thus, profits at stage 1 are $\pi_A = \theta_A - \hat{t} - \frac{K}{2}\theta_A^2$ and optimal optimal investment is $\theta_A = \frac{1}{K}$ and $\theta_B = 0$.

$$\text{Hence: } \pi_A = \frac{1}{2K} - \hat{t}$$

ii) Firm A chooses $\theta_A < \frac{1}{3K}$. In stage 2 there will be an interior, symmetric equilibrium in which firm A chooses price such that profits are $\pi_A = \frac{(\theta_A + 3\hat{t})^2}{18\hat{t}} - \frac{K}{2}\theta_A^2$. Note that this profit function is convex (because $9K\hat{t} - 1 < 0$). Therefore the firm optimally chooses $\theta_A = 0$ and profits are $\pi_A(\theta_A = 0) = \frac{\hat{t}}{6}$. Firm A always prefers to choose $\theta_A = \frac{1}{K}$ over $\theta_A = 0$ iff $\pi_A(\frac{1}{K}) = \frac{1}{2K} - \hat{t} \geq \frac{\hat{t}}{6} = \pi_A(\frac{1}{K}) \Leftrightarrow \hat{t} \leq \frac{6}{14K}$ which is always true for case 3 (implied by case 3 assumption): $\hat{t} < \frac{1}{9K} < \frac{6}{14K}$. Furthermore note that any mixed strategy equilibrium is excluded from the analysis as explained in footnote 9 of the main text. We assume a symmetric correlated equilibrium in which every firm plays each of the two pure strategy equilibria with probability 0.5.

The last result of the proposition follows trivially from what has been derived above: The investment levels for the equilibrium considered if $\hat{t} > \frac{1}{9K}$ is $\theta_A = \theta_B = \frac{1}{3K}$ and hence independent of $\hat{t}$: $\frac{\partial\theta_A}{\partial\hat{t}} = \frac{\partial\theta_B}{\partial\hat{t}} = 0$. Similarly, for $\hat{t} < \frac{1}{9K}$, the two asymmetric equilibria give rise to investment levels $\theta_A = \frac{1}{K}$ and $\theta_B = 0$ and $\theta_A = 0$ and $\theta_B = \frac{1}{K}$ which are all independent of $\hat{t}$. However, the restrictions on parameters for the equilibria do depend on $\hat{t}$. In particular, if firms did not agree to a standard ($\hat{t} = t - \alpha$) the range of parameters for which only one firm invests, $t \in (0, \frac{1}{9K} + \alpha)$, is larger than if a standard has been agreed upon ($\hat{t} = t$): $t \in (0, \frac{1}{9K})$.

<u>Proof of Proposition 4:</u> Results from the previous propositions are summarised by the cases:

1) If $9K\hat{t} - 1 \geq 0$ (i.e. $\hat{t} \geq \frac{1}{9K}$) there is a unique *symmetric* equilibrium and if $9K\hat{t} - 1 \geq 1$ this equilibrium is unique with prices and profits:

$$p_A = p_B = \hat{t} \text{ and } \pi_A = \pi_B = \frac{\hat{t}}{2} - \frac{1}{18K}$$

2) If $9K\hat{t} - 1 < 0$ (i.e. $\hat{t} < \frac{1}{9K}$) there is are two asymmetric pure strategy equilibria with prices and profits:

$$p_i = \frac{1}{K} - \hat{t} \text{ and } p_{-i} = 0 \text{ and } \pi_i = \frac{1}{2K} - \hat{t} \text{ and } \pi_{-i} = 0$$

Assuming the symmetric correlated equilibrium, expected profits are:

$$E(\pi_A) = E(\pi_B) = \frac{1}{4K} - \frac{\hat{t}}{2}$$

The above results lead to the following case distinctions and give the results of proposition 4:

4. If $\frac{1}{9K} + \alpha < t$ there is a unique symmetric equilibrium with both firms serving the market no matter whether a common standard has been adopted or not. In this case, both firms will opt for the common standard.

5. If $t < \frac{1}{9K}$ there is an asymmetric equilibrium with only one firm serving the market no matter whether firms adopted a common standard. In this case the active firm will veto a common standard.

6. If $\frac{1}{9K} < t < \frac{1}{9K} + \alpha$ there is a symmetric equilibrium if firms adopt a common standard and an asymmetric equilibrium with only one firm serving the market if there is no standard. Comparing profits in both states, the standard will be adopted if

$$\frac{t}{2} - \frac{1}{18K} > \frac{1}{2}\left[\frac{1}{2K} - t + \alpha\right] \quad \Leftrightarrow \quad t > \frac{11}{36K} + \frac{\alpha}{2}$$

Note that $t > \frac{11}{36K} + \frac{\alpha}{2}$ implies $t > \frac{1}{9K}$. Furthermore, $\frac{11}{36K} + \frac{\alpha}{2} < \frac{1}{9K} + \alpha$ if and only if $\alpha > \frac{14}{36K}$. Thus, if network externalities are sufficiently large, there is a range of transportation costs $t \in \left[\frac{11}{36K} + \frac{\alpha}{2}, \frac{1}{9K} + \alpha\right]$ such that the two firms will agree on a common standard and both serve the market, even though they could have implemented a monopoly by not agreeing to a standard.

Proof of Corollary 1: Let t be measured on a line as represented in figure 2a and 2b. The preceding proposition states that a standard is only chosen if:

$$t > \min\left\{\frac{1}{9K} + \alpha, \frac{11}{36K} + \frac{\alpha}{2}\right\}$$

For part (a) of Corollary 1 it thus follows that as t increases this condition is more likely to be satisfied. For part (b), as α increases, the right-hand side of the inequality increases and hence a standard is less likely to be formed: $\frac{\partial}{\partial \alpha}\left(\min\left\{\frac{1}{9K} + \alpha, \frac{11}{36K} + \frac{\alpha}{2}\right\}\right) > 0$. For part (c) of Corollary 1, as K increases, the right-hand side decreases as thus, the inequality is more likely to be satisfied: $\frac{\partial}{\partial K}\left(\min\left\{\frac{1}{9K} + \alpha, \frac{11}{36K} + \frac{\alpha}{2}\right\}\right) < 0$.

Proof of Proposition 5: The standard composite welfare function we use consists of consumer surplus and a discounted producer surplus[21]:

$$W = CS + \gamma \cdot PS \text{ with } \gamma < 1$$

1) Let us first examine the case where the social planner decides to have <u>two active and producing firms</u>:

[21] The reason for discounting producer surplus is standard and arguments follow the intuition given in the regulation and IO literature. Also, this allows prices to have an effect on welfare – rather than just being transfers from consumers to firms.

$$W = \int_0^{\bar{x}} (\theta_A - tx - p_A + \alpha)\,dx + \int_{\bar{x}}^{1} (\theta_B - t(1-x) - p_A + \alpha)dx$$
$$+\gamma\left(p_A \bar{x} - \frac{K}{2}\theta_A^2 + p_B\left(1-\bar{x}\right) - \frac{K}{2}\theta_B^2 \right)$$

Note that the social planner will always want to maximise the positive network externalities by choosing a common standard. The social planner will set prices and investments in order to minimise the overall transport costs (a pure loss to society) and, at the same time, ensure that investments are chosen optimally. To do so the indifferent consumer must sit at $\bar{x} = \frac{1}{2}$. Prices will be set in a symmetric fashion ($p_A = p_B$) and investment levels are also equalised ($\theta_A = \theta_B$). The above conclusions are summarised in the welfare function:

$$W = \theta_A - (1-\gamma)p_A + \alpha - \frac{1}{4}t - \gamma K \theta_A{}^2$$

Maximising this expression with respect to price (p_A) and investment (θ_A) subject to the firms' participation constraints ($\pi_A = \frac{1}{2}p_A - \frac{K}{2}\theta_A^2 \geq 0$) gives the following two conditions:

1) choose p_A as small as possible: $p_A = K\theta_A^2$ to still satisfy the participation of firms
2) choose θ_A such that: $1 - 2K\theta_A = 0$

Thus, the optimal values if two firms are active in the market are:

$$\theta_{\mathrm{A}}^{\mathrm{FB}} = \theta_{\mathrm{B}}^{\mathrm{FB}} = \frac{1}{2K} \text{ and } p_{\mathrm{A}}^{\mathrm{FB}} = p_{\mathrm{B}}^{\mathrm{FB}} = \frac{1}{4K}$$

Welfare with two active firms simplifies to:

$$W = \frac{1}{4K} + \alpha - \frac{1}{4}t$$

2) Let us now suppose the social planner decides to have just <u>one firm producing</u> and supplying the entire market. The welfare function then simplifies to:

$$W = \int_0^1 (\theta - tx - p + \alpha)\,dx + +\gamma\left(p - \frac{K}{2}\theta^2 \right)$$

Again, because $\gamma < 1$, the firm must break-even ($\pi = p - \frac{K}{2}\theta^2 \geq 0$ which is equivalent to $p = K\theta^2$). From the maximisation of social welfare we then get the first order condition and optimal investment as: $1 - K\theta = 0 \Rightarrow \theta = \frac{1}{K}$. Welfare with one active firms solves to:

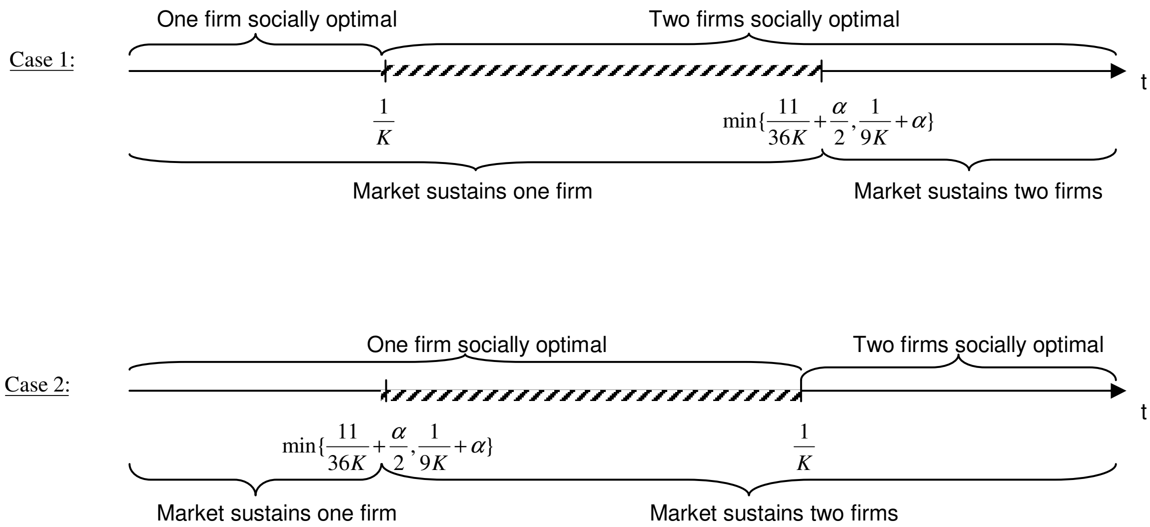
$$W = \frac{1}{2K} + \alpha - \frac{1}{2}t$$

Comparison:

$$W(2firms) > W(1firm)$$
$$\frac{1}{4K} + \alpha - \frac{1}{4}t > \frac{1}{2K} + \alpha - \frac{1}{2}t$$
$$t > \frac{1}{K}$$

Proof of Proposition 6: When the social planner is not coordinating the price, investment and production choice of firms three inefficiencies can arise:

1. Price: If $t < \min\{\frac{1}{K}; \frac{1}{9K} + \alpha\}$ only one firm is sustained in the market and the social planner would also opt for one firm. If the first argument is binding, market price exceeds the socially optimal price if: $p = \frac{1}{K} - \hat{t} > \alpha > \frac{1}{2K} = p^{FB}$, i.e. if $\alpha > \frac{1}{2K}$. If the second argument holds, we find that market price is always greater than the socially optimal price: $p > \frac{1}{K} - \frac{1}{9K} = \frac{8}{9K} > \frac{1}{2K} = p^{FB}$. Thus, the market price may well be above the socially optimal price. Also, as previous propositions have shown, the firms make positive rents.
   Similarly, if $t > \max\{\frac{1}{K}; \frac{1}{9K} + \alpha\}$ two firms are sustained in the market and the social planner would also opt for two firms. If the first argument is binding, market price exceeds the socially optimal price if: $p_A = p_B = \hat{t} > \frac{1}{K}\text{-}\alpha > \frac{1}{4K} = p_A^{FB} = p_B^{FB}$. This will be the case if $\alpha < \frac{3}{4K}$, so if α or K is small enough. However, if the second argument is binding (i.e. α is large), market price is never greater than the socially optimal price: $p_A = p_B = \hat{t} > \frac{1}{9K} > \frac{1}{4K} = p_A^{FB} = p_B^{FB}$. Firms, however, will still make positive rents.
2. From comparing results of propositions 3 and 5, it is evident that investments are chosen efficiently if there is only one firm on the market $\theta^{FB} = \theta_i = \frac{1}{K}$ but there will be underinvestment if there are two firms: $\theta_A = \theta_B = \frac{1}{3K} < \frac{1}{2K} = \theta_A^{FB} = \theta_B^{FB}$.
3. As stated in proposition 5, the social planner would always choose a common standard. In contrast to that, firms may well choose no standard to create higher barriers to entry for potential entrants. This is socially inefficient.
   Also, the market structure is affected in a way which may inefficient from a social point of view. We can summarise the situation in the following figure and can distinguish two cases:



FIGURES 3A AND 3B: Number of firms: Social Planner versus Market

These boundaries are derived from propositions 4 and 5. The market structure is inefficient where market by the striped bars.

Proof of Proposition 7: That a common standard is always socially optimal was established in proposition 5 and 6. Assume now that the government is not able to directly control entry, investment and pricing of the firms. Suppose that the only policy instrument at hand is to either force parties to have a common standard, or to forbid standards. Part a) shows that a mandatory standard may reduce welfare, part b) shows that forbidding a standard can increase welfare:

a) Suppose $t < \min\left\{\frac{11}{36K}+\frac{\alpha}{2},\ \ \frac{1}{9K}+\alpha\right\}$. From proposition 4 we know that only one firm serves the market and no standard will be chosen. Welfare is given by:

$$W = \frac{t}{2}+\gamma\left(\frac{1}{2K}-t+\alpha\right)$$

Suppose, the government imposes a standard:

- If $t < \frac{1}{9K}$, we still have 1 firm, but price falls to the new limit price, $p_A = \theta_A - t = \frac{1}{K} - t$ and welfare becomes $W = \frac{t}{2}+\alpha-\gamma\left(\frac{1}{2K}-t\right)$. Thus, welfare improves because $\alpha > \gamma\alpha$.

- If $t > \frac{1}{9K}$, there will now be two firms on the market: $p_A = p_B = t$ and $\theta_A = \theta_B = \frac{1}{3K}$ and welfare becomes $W = \frac{1}{3K} - \frac{5}{4}t + \alpha + \gamma t - \frac{\gamma}{9K}$. Thus, welfare actually falls if $t < \frac{2[11\gamma - 6 - 18K\alpha(1-\gamma)]}{9K(8\gamma - 7)}$ and $t > \frac{1}{9K}$ both hold.

  To investigate the inequality $\frac{1}{9K} < \frac{2[11\gamma - 6 - 18K\alpha(1-\gamma)]}{9K(8\gamma - 7)}$, assume that:

  - $8\gamma - 7 > 0$: Then $\gamma < \frac{5 + 36K\alpha}{14 + 36K\alpha}$ must hold and as $36K\alpha$ becomes sufficiently large, this is certainly possible and compatible with $8\gamma - 7 > 0$. This shows part).
  - $8\gamma - 7 < 0$: Then $\gamma > \frac{5 + 36K\alpha}{14 + 36K\alpha}$ must hold and as $36K\alpha$ becomes sufficiently small, this is certainly possible and compatible with $8\gamma - 7 < 0$. This substantiates part a) of the proposition.

b) Suppose $t > \min\left\{\frac{11}{36K} + \frac{\alpha}{2},\ \frac{1}{9K} + \alpha\right\}$. From proposition 4 we know that two firms serve the market and a standard will be chosen. Welfare is given by:

$$W = \frac{1}{3K} - \frac{5 - 4\gamma}{4}t + \alpha - \frac{\gamma}{9K}.$$

Suppose, the government forbids the standard:

- If $t > \frac{1}{9K} + \alpha$, we still have 2 firms, but price falls to $p_A = p_B = t - \alpha$ and welfare becomes $W = \frac{1}{3K} - \frac{5 - 4\gamma}{4}t + (\frac{3}{2} - \gamma)\alpha - \frac{\gamma}{9K}$. Thus, welfare improves if $\gamma < \frac{1}{2}$. Thus part b) is shown.

- If $t < \frac{1}{9K} + \alpha$, there will now be only one firm on the market and welfare becomes $W = \frac{t}{2} + \frac{\gamma}{2K} - \gamma t + \alpha\gamma$. Forbidding the standard thus improves welfare if $t > \frac{36K\alpha(1-\gamma) - 11\gamma}{9K(7 - 6\gamma)}$ and $t < \frac{1}{9K} + \alpha$ both hold. This can, however, never be the case.

Proof of Proposition 8: In the extended model, the choice of a common standard affects the network externality and the quality:

$$\overline{\theta}_i = \begin{cases} \theta_i & \text{if } \theta_i \geq \theta_{-i} \\ \theta_i + \lambda(\theta_{-i} - \theta_i) & \text{if } \theta_i < \theta_{-i} \end{cases} \quad \text{where } \lambda \in [0,1] \text{ is a spillover parameter}$$

Assuming w.l.o.g. that firm A has produced the better technology, and firms agree to implement a common standard, the indifferent consumer sits at:

$$\overline{x} = \frac{(1-\lambda)(\theta_A - \theta_B) - p_A + p_B + t}{2t}$$

Hence, profit and the reaction function are given by:

$$\pi_A = p_A\left(\frac{1}{2} + \frac{(1-\lambda)(\theta_A - \theta_B) - p_A + p_B}{2t}\right) + r\left(\frac{1}{2} - \frac{(1-\lambda)(\theta_A - \theta_B) - p_A + p_B}{2t}\right) + R - \frac{K}{2}\overline{\theta}_A^2$$

$$p_A = \frac{t + r + (1-\lambda)(\theta_A - \theta_B) + p_B}{2}$$

Similarly, the problem for the technology-buyer (here firm B):

$$\pi_B = (p_B - r)\left(\frac{1}{2} - \frac{(1-\lambda)(\theta_A - \theta_B) - p_A + p_B}{2t}\right) - R - \frac{K}{2}\overline{\theta}_B^2$$

$$p_B = \frac{t + r + (1-\lambda)(\theta_B - \theta_A) + p_A}{2}$$

The unique symmetric equilibrium (cf. Propositions 1 and 2) is given by:

$$p_A = \frac{(1-\lambda)(\theta_A - \theta_B)}{3} + t + r \quad \text{and} \quad p_B = \frac{(1-\lambda)(\theta_B - \theta_A)}{3} + t + r$$

In this equilibrium, the indifferent consumer is then given by:

$$\overline{x} = \frac{1}{2} + \frac{(1-\lambda)(\theta_A - \theta_B)}{6t}$$

Note that a corner solution would obtain if:

$$t < \left|\frac{(1-\lambda)(\theta_A - \theta_B)}{3}\right|$$

In this case, firm A (with the superior technology) would set the limit price $p_A = (1-\lambda)(\theta_A - \theta_B) - t$ while $p_B = 0$. Profits were $\pi_A = (1-\lambda)(\theta_A - \theta_B) - t - \frac{K}{2}\overline{\theta}_A^2$. We will, however, assume that ε is sufficiently small so that if $\overline{\theta}_A = \overline{\theta}_B$ the condition for an equilibrium in which both firms have a positive market share is never violated. This requires $t > \frac{2(1-\lambda)\varepsilon}{3}$ and if we want this to hold for all $\lambda \in [0,1]$, we have to require: $\varepsilon < \frac{3}{2}t$.

The firms' profit in the symmetric equilibrium then solves out to:

$$\pi_A = \frac{[(1-\lambda)(\theta_A - \theta_B) + 3t]^2}{18t} + r + R - \frac{K}{2}\overline{\theta}_A^2 \text{ and } \pi_B = \frac{[(1-\lambda)(\theta_B - \theta_A) + 3t]^2}{18t} - R - \frac{K}{2}\overline{\theta}_B^2$$

Expected profits are then given by:

$$E(\pi_A) = \int_{\varepsilon_A}\int_{\varepsilon_B} \frac{[(1-\lambda)(\overline{\theta}_A + \varepsilon_A - \overline{\theta}_B - \varepsilon_B) + 3t]^2}{18t} \frac{1}{2\varepsilon} d\varepsilon_B \frac{1}{2\varepsilon} d\varepsilon_A - \frac{K}{2}\overline{\theta}_A^2 + \Pr(\theta_A > \theta_B)(R + r)$$

The probability term evaluates to: $\Pr(\theta_A > \theta_B) = \frac{1}{2} + \frac{(\overline{\theta}_A - \overline{\theta}_B)}{2\varepsilon}$ and we get:

$$E(\pi_A) = \frac{[(1-\lambda)(\overline{\theta}_A - \overline{\theta}_B) + 3t]^2}{18t} + (\frac{1}{2} + \frac{\overline{\theta}_A - \overline{\theta}_B}{2\varepsilon})r + (\frac{\overline{\theta}_A - \overline{\theta}_B}{\varepsilon})R + \frac{2(1-\lambda)^2\varepsilon^2}{18t} - \frac{K}{2}\overline{\theta}_A^2$$

$$E(\pi_B) = \frac{[(1-\lambda)(\overline{\theta}_B - \overline{\theta}_A) + 3t]^2}{18t} + (\frac{1}{2} + \frac{\overline{\theta}_B - \overline{\theta}_A}{2\varepsilon})r + (\frac{\overline{\theta}_B - \overline{\theta}_A}{\varepsilon})R + \frac{2(1-\lambda)^2\varepsilon^2}{18t} - \frac{K}{2}\overline{\theta}_B^2$$

In stage 1 the first order conditions to the above expected profits lead to the reaction functions:

$$\overline{\theta}_A = \frac{-(1-\lambda)^2\overline{\theta}_B + 3(1-\lambda)t + 9t\frac{2R+r}{2\varepsilon}}{9tK - (1-\lambda)^2} \text{ and } \overline{\theta}_B = \frac{-(1-\lambda)^2\overline{\theta}_A + 3(1-\lambda)t + 9t\frac{2R+r}{2\varepsilon}}{9tK - (1-\lambda)^2}$$

Note that the second order condition requires: $9tK - (1-\lambda)^2 > 0$. Investments in the symmetric equilibrium are thus $\overline{\theta}_A = \frac{(1-\lambda)}{3K} + \frac{2R+r}{2K\varepsilon} = \overline{\theta}_B$ and hence profits are:

$$E(\pi_A) = E(\pi_B) = \frac{t+r}{2} + \frac{2(1-\lambda)^2\varepsilon^2}{18t} - \frac{(1-\lambda)^2}{18K} - \frac{(1-\lambda)(2R+r)}{6K\varepsilon} - \frac{(2R+r)^2}{8K\varepsilon^2}$$

<u>Proof of Proposition 9:</u> From proposition 8 we have:

$$E(\pi_A) = E(\pi_B) = \frac{t+r}{2} + \frac{2(1-\lambda)^2\varepsilon^2}{18t} - \frac{(1-\lambda)^2}{18K} - \frac{(1-\lambda)(2R+r)}{6K\varepsilon} - \frac{(2R+r)^2}{8K\varepsilon^2}$$

$$\frac{\partial E(\pi_A)}{\partial R} = -\frac{2(1-\lambda)}{6K\varepsilon} - \frac{4(2R+r)}{6K\varepsilon^2} < 0$$

Thus, firms will always choose to optimally set the fixed royalty element equal to zero.

$$\frac{\partial E(\pi_A)}{\partial r} = \frac{1}{2} - \frac{(1-\lambda)}{6K\varepsilon} - \frac{(2R+r)}{4K\varepsilon^2} = 0$$

$$r = 2K\varepsilon^2 - \frac{2\varepsilon(1-\lambda)}{3} > 0$$

To exclude negative royalties, we have: $r = \max\left\{2K\varepsilon^2 - \frac{2\varepsilon(1-\lambda)}{3},\ 0\right\}$. Note that $\frac{\partial r}{\partial \lambda} \geq 0$, $\frac{\partial r}{\partial K} \geq 0$ and $\lim_{\varepsilon^2 \to 0} r = 0$ which proves the last part of the proposition.

Proof of Proposition 10:

Substitution of the optimal royalty into the expected profits and simplifying gives:

$$E(\pi_A)=E(\pi_B)=\frac{t}{2}+\frac{K\varepsilon^2}{2}-\frac{(1-\lambda)\varepsilon}{3}+\frac{(1-\lambda)^2\varepsilon^2}{9t}$$

Note that expected profits are a convex function of λ:

$$\frac{\partial E(\pi_A)}{\partial\lambda}=\frac{\varepsilon}{3}+\frac{-2(1-\lambda)\varepsilon^2}{9t}$$

$$\frac{\partial^2 E(\pi_A)}{\partial\lambda^2}=\frac{2\varepsilon^2}{9t}>0$$

Firms will either go for $\lambda=0$ or $\lambda=1$, and choose $\lambda=1$ iff $\varepsilon<3t$:

$$E(\pi_A|\lambda=1)>E(\pi_A|\lambda=0)$$
$$\varepsilon<3t$$

Note that because of our assumption that the noise is relatively small, i.e. that $\varepsilon<\frac{3}{2}t$, this condition always holds. Thus, firms will always choose $\lambda=1$. Substitution for the royalty, prices, investments and profits gives $r=2K\varepsilon^2$, $p_A=p_B=t+2K\varepsilon^2$, $\overline{\theta}_A=\overline{\theta}_B=\varepsilon$ and

$$E(\pi_A)=E(\pi_B)=\frac{t}{2}+\frac{K\varepsilon^2}{2}.$$

Comparative statics with respect to several parameters are:

$$\frac{\partial E(\pi_A)}{\partial t}=\frac{1}{2}>0 \text{ and } \frac{\partial E(\pi_A)}{\partial\varepsilon^2}=\frac{K}{2}>0$$

Proof of Proposition 11: From the proposition 10 we have expected profits if firms agree to a common standard.

Common/Cooperative Standard: $\lambda=1$, $r=2K\varepsilon^2$, $n_i=1$, $p_i=t+2K\varepsilon^2$, $\overline{\theta}_A=\overline{\theta}_B=\varepsilon$ and:

$$E(\pi_A)=E(\pi_B)=\frac{t}{2}+\frac{K\varepsilon^2}{2}$$

Competitive Standard: $\lambda=0$, $r=R=0$, $n_A=\overline{x}$, $n_B=1-\overline{x}$ and

1. if $t>\frac{1}{9K}+\alpha$: symmetric equilibrium[22], both firms serve the market with

$$E(\pi_A)=E(\pi_B)=\frac{t-\alpha}{2}+\frac{\varepsilon^2}{9(t-\alpha)}-\frac{1}{18K}$$

[22] Note that $E(\pi_A)=E(\pi_B)>0$ because $2K\varepsilon^2>0$ and $\hat{t}>\frac{1}{9K}$.

2. if $t < \frac{1}{9K} + \alpha$: correlated equilibrium with $E(\pi_A) = E(\pi_B) = \frac{1}{4K} - \frac{t-\alpha}{2}$

Thus, we can distinguish the following cases:

1. if $t > \frac{1}{9K} + \alpha$ firms will mutually vote for a standard if:

   $\frac{t}{2} + \frac{K\varepsilon^2}{2} > \frac{t-\alpha}{2} + \frac{\varepsilon^2}{9(t-\alpha)} - \frac{1}{18K}$, i.e. iff: $\hat{t} > \frac{2K\varepsilon^2}{9K^2\varepsilon^2 + 9K\alpha + 1}$

   Thus, if $t > \max\left\{\frac{2K\varepsilon^2}{9K^2\varepsilon^2 + 9K\alpha + 1} + \alpha,\ \ \frac{1}{9K} + \alpha\right\}$ the parties will form a standard ex-ante.

   This is more likely the larger t, the smaller α, the larger K and the smaller ε^2.

   If, however, $\frac{1}{9K} + \alpha < t < \frac{2K\varepsilon^2}{9K^2\varepsilon^2 + 9K\alpha + 1} + \alpha$, parties will not form a standard and play a symmetric pure strategy equilibrium.

2. if $t < \frac{1}{9K} + \alpha$ firms prefer not to form a standard iff:

   $\frac{1}{4K} - \frac{t-\alpha}{2} > \frac{t}{2} + \frac{K\varepsilon^2}{2}$, i.e. iff: $t < \frac{\alpha}{2} + \frac{1}{4K} - \frac{K\varepsilon^2}{2}$

   Thus, firms will not form a standard and play the correlated equilibrium if $t < \min\left\{\frac{1}{9K} + \alpha,\ \ \frac{1}{4K} - \frac{K\varepsilon^2}{2} + \frac{\alpha}{2}\right\}$. This is more likely if t is small, α is large, K is small and ε^2 is small.

   If, however, $\frac{1}{4K} - \frac{K\varepsilon^2}{2} + \frac{\alpha}{2} < t < \frac{1}{9K} + \alpha$, firms will form a standard and play a symmetric pure strategy equilibrium.

   Thus:

   1) If $t > \max\left\{\frac{2K\varepsilon^2}{9K^2\varepsilon^2 + 9K\alpha + 1} + \alpha,\ \ \frac{1}{9K} + \alpha\right\}$ or if $\frac{1}{4K} - \frac{K\varepsilon^2}{2} + \frac{\alpha}{2} < t < \frac{1}{9K} + \alpha$ parties will form a standard. This proves the proposition.

   2) If $\frac{1}{9K} + \alpha < t < \frac{2K\varepsilon^2}{9K^2\varepsilon^2 + 9K\alpha + 1} + \alpha$ firms will not form a standard. Nevertheless, they will play a symmetric equilibrium and both invest.

   3) If $t < \min\left\{\frac{1}{9K} + \alpha,\ \ \frac{1}{4K} - \frac{K\varepsilon^2}{2} + \frac{\alpha}{2}\right\}$ the firms will not form a standard and only one of them will invest.

Proof of Proposition 12: given in main text.

Proof of Proposition 13: From proposition 10 we have the expected profits under the optimal ex-ante standard setting:

$$E(\pi_A) = \frac{t}{2} + \frac{K\varepsilon^2}{2}$$

Now contrast these to an ex-post technology-exchange under bargaining:

After investments $\overline{\theta}_A$ and $\overline{\theta}_B$ realise (θ_A, θ_B), firms start negotiations on the standard at stage 1.5 and parties split any surplus according to Nash Bargaining (50:50) by a fixed payment, R. The threat point in the bargaining is no standard being set.

Suppose that $|\theta_A - \theta_B| \leq 3(t-\alpha)$, such that under competition a symmetric equilibrium obtains.[23] Then the threat point is:

$$\pi_A = \frac{[\theta_A - \theta_B + 3(t-\alpha)]^2}{18(t-\alpha)} - \frac{K}{2}\overline{\theta}_A^2 \text{ and } \pi_B = \frac{[\theta_B - \theta_A + 3(t-\alpha)]^2}{18(t-\alpha)} - \frac{K}{2}\overline{\theta}_B^2$$

The sum of net profits (without the sunk investment costs) is given by:

$$\pi_A + \pi_B = \frac{(\theta_A - \theta_B)^2 + 9(t-\alpha)^2}{9(t-\alpha)}$$

If the firms were to set a common standard ex-post, then assuming w.l.o.g. that $\theta_A > \theta_B$, profits are:

$$\pi_A = \frac{[\theta_A - \theta_B - \lambda(\theta_A - \theta_B) + 3t]^2}{18t} + R - \frac{K}{2}\overline{\theta}_A^2 \quad \pi_B = \frac{[\theta_B + \lambda(\theta_A - \theta_B) - \theta_A + 3t]^2}{18t} - R - \frac{K}{2}\overline{\theta}_B^2$$

Thus, the sum of net profits is:

$$\pi_A + \pi_B = \frac{(1-\lambda)^2(\theta_A - \theta_B)^2 + 9t^2}{9t}$$

Firms therefore optimally agree on $\lambda = 0$ and the sum of net profits is[24]:

$$\pi_A + \pi_B = t + \frac{(\theta_A - \theta_B)^2}{9t}$$

The surplus from forming a common standard ex-post over forming no standard at all is:

$$S^{EP} = \frac{\alpha[9t(t-\alpha) - (\theta_A - \theta_B)^2]}{9t(t-\alpha)} > 0$$

because $(\theta_A - \theta_B)^2 < 9(t-\alpha)^2 < 9t(t-\alpha)$. Thus, a common standard is beneficial because it reduces price competition.

[23] If only one firm serves the market firms never want to form a common standard. We therefore can w.l.o.g. restrict attention to the case examined here.

[24] Note that this is socially inefficient.

Following the assumption of Nash bargaining, parties split the surplus 50:50 and profits thus are:

$$\pi_A^{EP} = \frac{[\theta_A - \theta_B + 3(t-\alpha)]^2}{18(t-\alpha)} - \frac{K}{2}\bar{\theta}_A^2 + \frac{1}{2}\frac{\alpha[9t(t-\alpha) - (\theta_A - \theta_B)^2]}{9t(t-\alpha)}$$

which simplifies to:

$$\pi_A^{EP} = \frac{[\theta_A - \theta_B + 3t]^2}{18t} - \frac{K}{2}\bar{\theta}_A^2$$

Expected profits of the form from a stage 1 perspective are:

$$E(\pi_A^{EP}) = \int_{\varepsilon_A}\int_{\varepsilon_B} \frac{(\bar{\theta}_A + \varepsilon_A - \bar{\theta}_B - \varepsilon_B)^2 + 6t(\bar{\theta}_A + \varepsilon_A - \bar{\theta}_B - \varepsilon_B) + 9t^2}{18t} \frac{1}{2\varepsilon} d\varepsilon_B \frac{1}{2\varepsilon} d\varepsilon_A - \frac{K}{2}\bar{\theta}_A^2$$

which evaluates to:

$$E(\pi_A^{EP}) = \frac{t}{2} + \frac{(\bar{\theta}_A - \bar{\theta}_B)^2}{3} + \frac{\varepsilon^2}{9t} - \frac{K}{2}\bar{\theta}_A^2 + \frac{(\bar{\theta}_A - \bar{\theta}_B)^2}{18t}$$

Best response functions and incentives to invest in equilibrium are:

$$\bar{\theta}_A = \frac{\bar{\theta}_B - 3t}{1 - 9Kt} \text{ and } \bar{\theta}_B = \frac{\bar{\theta}_A - 3t}{1 - 9Kt}$$

$$\bar{\theta}_A = \frac{1}{3K} = \bar{\theta}_B$$

Expected profits from planning on ex-post licensing are:

$$E(\pi_A^{EP}) = \frac{t}{2} - \frac{1}{18K} + \frac{\varepsilon^2}{9t} = E(\pi_B^{EP})$$

Note that this is exactly the same payoff that each party receives from agreeing to join a common standard at stage 0 and setting $\lambda = 0$ and $r = 0$. We have already seen that this is dominated by an ex-ante standard agreement with $\lambda = 1$ if $\varepsilon < \frac{1}{3K}$. If $\varepsilon > \frac{1}{3K}$ the comparison of profits reveals that the proposition holds here as well:

$$\frac{t}{2} + \frac{K\varepsilon^2}{2} > \frac{t}{2} - \frac{1}{18K} + \frac{\varepsilon^2}{9t}$$

If $9tK > 2$, this is always true. So suppose that $9tK < 2$ but remember that $9tK > 1$ (since $t > \frac{1}{9K}$). Then $\varepsilon^2(2 - 9tK)K < t$ must hold. We have that $\varepsilon < \frac{3}{2}t$ and thus $2 - 9tK < \frac{4}{9tK}$ which is always true since $9tK < 2$. Thus, firms always prefer ex-ante standard setting with $\lambda = 1$ and $r > 0$ to ex-post licensing.[25]

[25] Note that we have assumed ex-post licensing on the basis of fixed royalties only. If we were to allow for linear royalties combined with negative fixed royalties, the monopoly outcome can be implemented!

Proof of Proposition 14: From the proof of proposition 12 we have for the welfare of the optimal ex-ante standard setting agreement that:

$$EW = \frac{4}{3}\varepsilon - \frac{5-4\gamma}{4}t - (2-\gamma)K\varepsilon^2 + \alpha$$

The welfare from an ex-post standard agreement is:

$$EW = \frac{1}{3K} - t + \alpha - \frac{t}{4} + 2\gamma\left[\frac{t}{2} - \frac{1}{18K} + \frac{\varepsilon^2}{9t}\right]$$

Note that as ε^2 goes to zero, the first expression becomes $-\frac{5-4\gamma}{4}t + \alpha$ in the limit whereas the second expression becomes $\frac{1}{3K} - \frac{5-4\gamma}{4} + \alpha - \frac{\gamma}{9K}$ which is always greater as long as $3-\gamma > 0$ which is always true.

The Novell-Microsoft Agreement of November 2, 2006.

The agreement covers distribution, development and legal indemnification. In summary, the following three parts to the agreement can be distinguished:

1) *Business Collaboration Agreement (BCA)*: Microsoft (MSFT) has entered into a reseller arrangement with Novell (NOVL) and committed to purchase and distribute 70K SLES license coupons per year for five years. The license coupons entitle the customer to one year of maintenance and support and will involve dedicated sales resources from MSFT. The companies will also provide joint marketing behind the resale arrangement.
2) *Technical Collaboration Agreement (TCA)*: the two companies will form a joint development effort aligned around virtualisation, management and document format compatibility. We do not expect to see the output from this arrangement overnight, however, it should provide immediate incremental comfort that SUSE can support a Windows environment.
3) *Patent Agreement (PA)*: the cooperative patent resolution provides customers with assurance for patent infringement claims. Essentially, MSFT will not assert patent rights over IP that may be incorporated in the SUSE distribution. The concern of patent infringement suits by MSFT has acted as a barrier to enterprise adoption of Linux and the PA applies only to the SUSE distribution. The PA arrangement specifies that both companies will make upfront payments covering IP protection with a net balancing payment to Novell, due to the volume of Windows versus SUSE shipments. In return, MSFT will receive royalty payments from Novell tied to the company's Open Platform segment.

Source: JPMorgan Analyst Report on Novell on November 8, 2006 by Aaron M Schwartz