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Wey, Christian

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**Compatibility Investments in Duopoly with
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Christian Wey

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Wissenschaftszentrum Berlin für Sozialforschung gGmbH,
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ABSTRACT

Compatibility Investments in Duopoly With Demand Side Spillovers Under Different Degrees of Cooperation

by Christian Wey*

This paper examines the effects of different degrees of cooperation on firms' incentives to undertake interbrand compatibility investments ex post, which benefit the competitor indirectly via an increase of its mass market demand. We find that cooperation in compatibility investments while preserving competition on the product market gives second-best welfare for all positive values of the spillover parameter. For large spillover effects cartelization in compatibility investments and on the product market is welfare improving compared to pure competitive behavior. Hence, the paper gives strong efficiency reasons for forming horizontal organizations such as standardization committees, which help to achieve joint-profit maximization in compatibility investments. Furthermore, we examine the effects of an "open standardization policy" which increases the level of the spillover parameter, and show that an asymmetric outcome might dominate the symmetric solution under a regime, where firms cooperatively determine investment levels and noncooperatively choose production quantities.

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ZUSAMMENFASSUNG

Kompatibilitätsinvestitionen im Duopol in der Gegenwart von nachfrageseitigen Spillover-Effekten und die Rolle von horizontaler Kooperation

Diese Arbeit untersucht die Wirkungen horizontaler Kooperation auf die Anreize der Unternehmen, Kompatibilitätsinvestitionen zu tätigen, die die Wettbewerbsposition des rivalisierenden Unternehmens auf dem Absatzmarkt verbessert. Es wird gezeigt, daß Kooperation auf der Investitionsstufe in Verbindung mit Konkurrenz auf dem Produktmarkt zu zweitbesten Wohlfahrtsergebnissen führt. Dieses Ergebnis gilt für alle zulässigen Werte des Spillover-Parameters. Für den Fall relativ großer Spillover-Effekte kann es sogar dazu kommen, daß eine vollständige Kartellierung der Unternehmen zu einer höheren Wohlfahrt führt als ein vollständig nicht-kooperatives Verhalten der Unternehmen. Damit betont der Beitrag die Effizienzgründe für horizontale Kooperationsformen wie Standardisierungsverbände, deren primärer Zweck die Erlangung von unternehmensübergreifender Kompatibilität ist. Des weiteren werden die Wirkungen einer „Politik offener Standards“ untersucht, die zu einer Erhöhung der Spillover-Effekte führt. Schließlich wird gezeigt, daß eine asymmetrische Lösung die symmetrische Lösung dominieren kann, wenn die Unternehmen ihre Investitionsausgaben kooperativ und ihre Ausbringungsmengen nicht-kooperativ bestimmen.

1 Introduction

Many markets have the property that the higher the degree of compatibility of the product with complementary products, the more valuable it is to an individual consumer. This is a common feature of software markets and networks including e-mail or facsimile machines. The extent to which various products are compatible with one another is one of the most important dimensions of market structure, and market performance.

In this paper we consider those markets in which compatibility among complementary products is achieved *ex post*, i.e., *after* firm-specific standards have been established. To achieve interbrand compatibility *ex post*, firms have to undertake investments to make their newly developed products compatible with other firms' standard technologies. For example, in the computer industry software developing firms as *Microsoft* or *Macintosh* have to decide about the degree of compatibility between their software application programs and the rival's operating system. In this particular case, both firms have established a standard technology -the operating system- and sell in addition complementary application programs. Firm-specific standards are in existence when firms decide about the degree of interbrand compatibility of their complementary products. The purpose of this paper is to examine firms' incentives to invest into interbrand compatibility which gives rise to demand side spillover effects. The paper also investigates the effects of different degrees of cooperation, varying from pure market contact to full cartelization.

We think of examples like computer operating systems and application software, internet browsers and webpage designer tools/online-services, or transportation services and timetable schedules. In each of these cases, firms supply two complementary products: A mass market product and either a complementary niche market product, as in the case of application software and webpage designer tools, or a complementary service, like timetable schedules, as in the case of transportation services. While complementary products of one brand belong to the same

firm-specific compatibility standard, complementary products of different brands are incompatible when firms do not invest into interbrand compatibility. If, however, a firm invests into interbrand compatibility the competitor's mass market demand increases, simply because consumers value compatibility.

To illustrate this point, consider the World Wide Web as a highly stylized example. Firms like *Microsoft* and *Netscape* basically serve two different markets. On the mass market they sell webpage browsers and on their niche markets they sell webpage designer tools or server software to commercial buyers who again produce webpages and online services used by consumers equipped with browsers. Clearly, demand for firm i 's mass market product (like *Netscape's* internet browser) goes up when firm j undertakes investments to make its niche market product (like *Microsoft's* webpage designer tools) more compatible with firm i 's mass market product.

Under these conditions compatibility investments by firm j increase firm i 's mass market demand, and hence, generate positive spillovers which benefit firm i .¹ Furthermore, we assume that each firm is a monopolist on the niche market on which it sells specialized components, like e.g., webpage designer tools.²

As an alternative, and again, highly stylized example of our model consider transportation services, as e.g., the international airline industry. International airlines are organized as hub-and-spoke networks. Consider two airlines, like e.g., *American Airways* (AA) and *British Airways* (BA). AA uses Chicago and BA uses London as its hub, operates to domestic endpoints (like Kansas City (AA) and

¹The issue of compatibility investments is also extremely important in the strongly inter-related computer industry where operating systems represent the mass market products. To guarantee compatibility is critical for the survival of an operating system. For example, Apple had to make large investments to improve the compatibility of its new operating system MacOS 8 with other firms' application software, as has been reported by *Magazin für Computer Technik*, September, 1997, pp. 70-1, where a list of remaining incompatibilities of MacOS 8 is presented.

²This market structure might be the result of locked-in commercial buyers who have undergone specific investments.

Munich (BA)) as well as a transatlantic route to the hub of the other airline. This means, both airlines serve basically two markets: The domestic market, which is called in our paper the niche market, and the transatlantic route, which is in our terms the mass market. Adopting the hub-and-spoke network structure, as analyzed by BRUECKNER & SPILLER [1991] and BRUECKNER [1998], the networks of the two airlines do not overlap, except on the transatlantic route. This means, that airlines are monopolists in domestic city-pair markets other than the transatlantic interhub mass market, on which both firms compete. There are two effects when one airline adjusts its timetable of arrival and departure with the other airline's times of arrival and departure at its domestic hub. *First*, the domestic demand increases because consumers are connected much faster to the other airline when they make oversea travels, and *second*, the other airline benefits indirectly via an increased demand for its transatlantic route.³

In the realm of our model we analyze the tradeoff which each firm faces when it makes investments to make its niche market product more compatible with the rival's mass market product.⁴ On the one hand, each firm internalizes directly the benefits on its niche market, and on the other hand, the positive spillover effect for the rival firm on its mass market makes it behave more aggressively such that, other things equal, mass market profits decrease for the investing firm.

When firms decide about compatibility after mass market standard technologies have already been established this decision is not an either-or decision problem as in the case of *ax ante* standardization but rather a matter of degree.⁵ The

³There are at least two more positive demand side effects from making inter-airline timetable adjustments in the international airline industry: First, there is a positive feedback effect between stronger competition on the transatlantic route and the domestic demand of the investing firm, and *second*, there is another positive spillover effect for the rival on its domestic niche market accruing from the market expansion effect in the home country of the investing firm. However, incorporating these effects into our model would make our point for the need of cooperation even stronger.

⁴With respect to airline services, it is quite obvious that adjusting timetables is costly, and that perfect alignment is almost unfeasible because of congestion constraints on each hub.

⁵A quick look at the computer industry reveals that making a specialized software perfectly

degree of compatibility depends on the amount of investments firms are willing to undertake to design their complementary products or services unilaterally more compatible with the other firm's mass market product.⁶ Therefore, in contrast to the traditional literature on compatibility standardization as represented by FARRELL & SALONER [1985], [1986], KATZ & SHAPIRO [1985], [1986], MATUTES & REGIBEAU [1988] and others, which has focused on the coordination problems of making products either compatible or not compatible with rivals' products *ex ante*, our model looks at the investment incentive problems *ex post* accruing from positive demand side spillovers.⁷ We also discuss how the application of antitrust law and the protection of intellectual property rights affect private incentives to increase interbrand compatibility.

Our paper is also related to the work by KRISTIANSEN & THUM [1996] and FARRELL & KATZ [1998] which examine how compatibility shapes product market competition and firms' incentives to invest into R&D. KRISTIANSEN & THUM [1996] study the patterns of R&D investments in compatible networks where firms sell mass market and niche market products. R&D investments increase the quality of the mass market product, and therefore, benefit both duopolists via their niche markets. Underinvestments results from neglected positive network externalities. Compatible with all operating systems is almost unfeasible. The many different interfaces with older versions, existing ones and those which might be introduced in the future is quite large.

⁶This paper restricts attention to those markets, as we may find them for application software, webpage designer tools or timetable schedules, in which firms can make their niche market products unilaterally compatible *ex post*. If, however, technical information is perfectly protected by patents, then interbrand compatibility can only be achieved by bilateral coordination *ex ante*.

⁷Assuming that consumers value compatibility because of positive network externalities KATZ & SHAPIRO [1985] examine firms' incentives to coordinate sunk investments on a particular compatibility standard *ex ante*. Products remain perfectly incompatible if firms do not coordinate because compatibility is an either-or decision. MATUTES & REGIBEAU [1988], ECONOMIDES [1989], [1991a], [1991b], and EINHORN [1992] use a model of differentiated consumers where a subset of them has a preference for mixing-and-matching products of different brands. However, in those models perfect compatibility is achieved costlessly *ex ante* and is always profitable for firms, which are assumed to behave noncooperatively.

nalities. Overinvestment might occur strategically to induce the competitor to increase mass market products' quality. Since they assume that firms' products are perfectly compatible they do not examine the effects of investments which increase interbrand compatibility. FARRELL & KATZ [1998] analyze the critical role of consumers' expectations concerning each firm's market size and product quality in a model with network externalities, where firms compete in Bertrand fashion. In both models only one supplier of the mass market product prevails in equilibrium while our model examines how duopolistic competition on the mass market affects firms' incentives to invest into compatibility. Finally, both papers do not analyze how antitrust policy towards horizontal cooperation affects product market competition and equilibrium compatibility levels.

Our analysis builds on the pioneering approach adopted by D'ASPREMONT & JACQUEMIN [1988] to analyze firms' R&D investment incentives in a two-stage game. In their model firms choose R&D levels at the first stage and compete on the product market in Cournot fashion at the second stage.⁸ Firms are perfectly symmetric, products are homogeneous, and R&D investment leads to a reduction in unit costs governed by a quadratic cost function. R&D investments are characterized by positive spillover effects measured by the spillover parameter β , with $0 \leq \beta \leq 1$. In the presence of positive spillover effects firm i 's R&D investments do not only reduce firm i 's marginal costs, but also firm j 's marginal costs by the fraction β . Given those conditions d'Aspremont and Jacquemin show that for large spillovers such as $\beta > 0.5$ cooperation in the R&D stage of the game leads to higher investment levels compared to a competitive regime in which each firm chooses its R&D expenditures noncooperatively. On the other hand, for relatively low spillovers cooperation at the R&D stage leads to lower investments

⁸See HENRIQUES [1990] for a critique and D'ASPREMONT & JACQUEMIN [1990] for a reply. Their analysis has been extended and generalized by DE BONDT & VEUGELERS [1991], DE BONDT, SLAETS & CASSIMAN [1992], KAMIEN, MULLER & ZANG [1992], SUZUMURA [1992], VONORTAS [1994], STEURS [1995], BROD & SHIVAKUMAR [1997], LEAHY & NEARY [1997], QIU [1997], and PETIT & TOLWINSKI [1999]. For a review of this literature see DE BONDT [1996].

than competitive R&D. Therefore, the authors conclude that contractual arrangements which induce joint profit maximization at the R&D stage, while keeping firms behaving competitively on the product market, can be efficiency enhancing when R&D spillovers are relatively large.⁹ This efficiency rationale might help explain why antitrust authorities are much less concerned about the anti-competitive effects of cooperative research compared to other forms of horizontal cooperation.¹⁰

Building on the two-stage framework of duopolistic competition as developed by d'Aspremont and Jacquemin our analysis examines the impact of different degrees of cooperation on firms' compatibility investment levels. At the first stage, firms decide on their compatibility investment level either cooperatively or noncooperatively, and at the second stage they determine quantity levels of the mass market product, again, either competitively or collusively. This gives the following three different regimes of interest:¹¹

1. *Compatibility Competition* (\mathcal{NN}): Both firms behave noncooperatively at both stages of the game. At the second stage firm i 's mass market demand is increased to some spillover from the rival's compatibility investments.
2. *Compatibility Committee* (\mathcal{CN}): At the first stage, both firms coordinate their investment activities so as to maximize the sum of overall profits. At the second stage firms compete where each firm's mass market demand is increased to some spillover from the other firm's compatibility investments.

⁹See also KATZ [1986] for an earlier paper which emphasizes the stimulation of incentives towards investments in R&D efforts due to cooperative agreements.

¹⁰An early efficiency rationale of horizontal cooperation has been presented by WILLIAMSON [1968]. See GROSSMAN & SHAPIRO [1986], JORDE & TEECE [1990], BRODLEY [1990] and SHAPIRO & WILLIG [1990] for a critical assessment of the antitrust treatment of horizontal cooperation in research and innovation.

¹¹In the following, the regimes are abbreviated by two calligraphic letters, where the first letter describes firms' first-stage behavior either as noncooperative, what is indicated by \mathcal{N} , or as cooperative, what is indicated by \mathcal{C} . The same method applies for the second letter which stands for firms' behavior at the second stage of the game.

3. *Cartelization (CC)*: Both firms form a cartel and maximize at both stages of the game joint profits.

In reality decisions concerning compatibility often take place within standardization committees.¹² In our model those committees are interpreted as organizations which induce joint profit maximization with respect to firms' compatibility investments. This seems to be appropriate since committees define explicit procedures to coordinate on compatibility standardization. Under the *compatibility committee (CN)* regime we assume that cooperative relations between firms do not lead firms to collude on the output market. In this case relations among firms are a hybrid of cooperation and competition.¹³ Under the *cartelization (CC)* regime it is supposed that standardization committees are a means to collude on the output market, and hence, lead to an overall cartelization of firms.

Yet, despite the intuitive plausibility of demand side spillovers and the need for firms to undertake investments to achieve interbrand compatibility, those investment activities have not been incorporated explicitly into the theoretical literature dealing with research joint ventures and with cooperative standard setting groups.¹⁴ It is also interesting to note that the economic literature on standardization committees is surprisingly small. The only contributions we are aware are FARRELL & SALONER [1988] and GOERKE & HOLLER [1995]. The first paper compares committees and markets as alternative mechanisms to overcome coordination failure when firms choose between incompatible standards ex ante. The

¹²The importance of inter-firm cooperation on the standardization stage in software markets has been emphasized by KATZ & SHAPIRO [1998].

¹³For instance the *W3 consortium* is a standardization committee for achieving interbrand compatibility between web browsers and web designer tools. In this particular case, *Microsoft* and *Netscape* compete on the browser market and coordinate their activities towards interbrand compatibility in the consortium (see *Magazin für Computer Technik*, September, 1997, pp. 80-1, for a description of this case).

¹⁴The literature on research joint ventures (see Footnote 8) does only consider knowledge spillovers between firms. Investment activities which generate positive demand side effects are not examined in this strand of literature.

second paper regards standardization committees as a mechanism of collective decision making which maps *buyers'* preferences into standardization outcomes via voting rules. In contrast to those papers, we interpret a standardization committee not only as a coordination device but also as a device to internalize positive spillovers among firms, which accrue from compatibility investments. Moreover, while those papers target the issue of ex ante standardization our paper investigates firms' incentives to establish compatibility ex post, after standard technologies have come into existence.¹⁵

The main point of our paper is that organizations like standardization committees, or codesharing arrangements in the context of international airline services, do in general help to internalize those spillovers and do lead to second-best welfare levels as long as they do not induce firms to collude on the output market. Surprisingly, for high values of the spillover parameter welfare is even higher under a regime where firms cooperate in both stages compared to pure competitive behavior in both stages. Therefore, our paper might help to explain why horizontal cooperation in standardization committees or international airline alliances are usually not alleged to be anticompetitive, as long as it is limited to standardization issues.¹⁶

The rest of the paper is organized as follows: In Section 2 we present the model, solve for the subgame perfect equilibria for all three regimes, and calculate the

¹⁵Applying our paper to the international airline industry, we may interpret *codesharing* arrangements within an international airline alliance analogously to standardization committees. Those arrangements ticket a trip that involves travelling across the networks of both airlines as if the travel occurred on a single carrier. As reported by BRUECKNER [1998] the main feature of those codesharing arrangements is to achieve schedule coordination and to improve airport gate proximity, so that connections between carriers become more convenient. Hence, if one airline makes timetable adjustments, so that domestic passengers will find it easier to connect to the other airline, an additional domestic passenger creates extra revenues for the domestic firm on the home market and benefits the other firm on its transatlantic route, since a fraction of additional passengers will travel via the other airline's transatlantic route.

¹⁶For instance, KATZ & SHAPIRO [1998] state with respect to the software industry that they "know of no successful antitrust challenges to cooperation to set software standards."

welfare maximizing first-best outcome. In Section 3 we compare our results and summarize the policy conclusions. In Section 4 and 5 we extend our model in two directions. First, we analyze the impact of institutions which increase the spillover effects generated by compatibility investments, and second, we show that an asymmetric solution might dominate the symmetric outcome. Finally, Section 6 concludes.

2 The Model

We posit two firms each producing a mass market product and a complementary niche market product. For each firm we assume that its mass market product and its niche market product is designed according to the same firm-specific interface technology, so that both products are perfectly compatible right from the start. Without any investments into interbrand compatibility firms' products are homogeneous and firms face a linear inverse demand function on the mass market: $p_i(q_i, q_j) = A - Q$, with $i = 1, 2, j \neq i, A > Q \geq 0$, and $Q = q_i + q_j$, where p_i stands for firm i 's mass market product price and q_i denotes firm i 's production quantity.¹⁷ Firms have the same constant marginal costs denoted by c , which are normalized to zero. We assume that entry into the industry is unprofitable and that $A > 0$ holds, so that production is profitable for the incumbents.¹⁸

Let us now in detail describe the nature and the effects of compatibility investments. We focus on investments into interbrand compatibility which make a firm's niche market product more compatible with the other firm's mass market product. In our model those investments undertaken by firm i , which are denoted by $x_i \geq 0$,

¹⁷In accordance with MARTIN [1993] we may interpret A as a measure of market size, derived from the linear inverse demand schedule $p_i(q_i, q_j) = a - bQ$, with $a, b > 0$ and $Q \leq a/b$. The parameter A is then defined by $\frac{a-c}{b}$, and it measures the quantity that would be demanded if price were equal to marginal cost.

¹⁸For the sake of simplicity, we abstract from any cross-market price effects between the niche and the mass markets.

have two effects: *First*, they increase buyers' maximum willingness to pay for firm i 's niche market product, and hence, benefit the investing firm directly via its niche market. In particular, we denote by x_i firm i 's *compatibility investment level* which increases firm i 's niche market net revenues linearly according to vx_i , with $i = 1, 2$, and $v \geq 0$, denoting the constant marginal increase of niche market net revenues. This means, buyers of firm i 's niche market product have a uniform reservation price which increases linearly with firm i 's interbrand compatibility investment level.¹⁹ The monopolistic supplier appropriates the entire consumer surplus and realizes constant marginal net revenues, v , on the niche market from additional investments.²⁰ In order to deal with symmetric firms, we assume that v is the same for both firms.

Second, firm i 's compatibility investment increases firm j 's mass market demand

¹⁹The linear specification of the reduced niche market profits does also apply to an ordinary monopolistic market structure with linear demand. We derive the defining equation for firm i 's net revenue function, vx_i , by calculating the first derivative of firm i 's reduced niche market profit function, $\hat{\Pi}_i(\hat{p}_i, x_i) = \hat{y}_i(\hat{p}_i, x_i)(\hat{p}_i(x_i) - k)$, with respect to x_i , where $\hat{\Pi}_i(\hat{p}_i, x_i)$ denotes firm i 's profits as a function of x_i evaluated at the monopoly price, \hat{p}_i , $\hat{y}_i(\hat{p}_i, x_i)$ stands for firm i 's niche market demand, again, evaluated at the monopoly price, and $k > 0$ denotes the costs per unit of the niche market product. Suppressing the subscript i , we get $\frac{\partial \hat{\pi}}{\partial x} = \frac{\partial \hat{y}}{\partial x}(\hat{p} - k) + \hat{y} \frac{d\hat{p}}{dx}$, where the right-hand side is represented in our model by the expression vx . In the special case of a linear niche market demand function, $y = M + x - hp$, we obtain $\frac{\partial \hat{\pi}}{\partial x} = \frac{1}{2h}(M + x - hk)$, so that v is equal to the constant term $\frac{1}{2h}$, and reduced profits are a linear function of x . However, for non-linear demand functions the impact of compatibility investments on producer surplus is usually not linear.

²⁰In our model specification, we measure the investment variable x_i by the *output* generated by firm i 's compatibility investments. It is not an input variable such as the *amount of research* effort. It should be critically noted that D'ASPREMONT & JACQUEMIN [1988] as well measure the amount of R&D investment by its output, such that an increase in x reduces marginal costs by the same amount. That is, an increase in what d'Aspremont and Jacquemin call investment is strictly speaking the reduction in marginal costs induced by the R&D effort. However, they state that their investment variable measures the "amount of research" a firm undertakes. In contrast to their and our model, KAMIEN, MULLER & ZANG [1992] have defined their investment variable as an input variable. For a comprehensive comparison of both formulations of the R&D spillover effect see AMIR [1998].

because consumers enjoy a broader range of complementary products and services in a more convenient, i.e., in a more compatible way. This effect benefits the rival firm j indirectly via an increase of its mass market demand. Since firm i 's niche market product is complementary to firm j 's mass market product, compatibility investments of firm i by the amount of x_i lead to positive spillovers, such that firm j 's mass market demand is shifted outward by the amount of βx_i , where $\beta \geq 0$ stands for the spillover parameter. In contrast to informational R&D spillovers, compatibility investment spillovers are bounded from above by the increase in consumers' maximum willingness to pay for a marginal increase in compatibility with the other firm's niche market product.

Integrating the spillover effect into each firm's inverse demand schedule gives

$$p_i(q_i, q_j, x_j) = A + \beta x_j - Q, \quad j \neq i, \quad i = 1, 2. \quad (1)$$

This means, compatibility investments by firm i differentiate the firms' products in the sense that they improve the quality of firm j 's mass market product relative to firm i 's mass market product. An improvement in interbrand compatibility undertaken by firm i , therefore, increases consumers' willingness to pay for firm j 's mass market product. Note, when compatibility investments are the same, $x_1 = x_2$, both goods are perfect substitutes and have the same price on the mass market; i.e. $p_i = A + \beta x_j - q_i - q_j$, with $j \neq i$. If, however, compatibility investment levels are not the same, with $x_j > x_i$, then the goods are vertically differentiated. This implies, *every* consumer is willing to pay a quality premium for good i . For the individual inverse demand functions as specified by Equation (1), the quality premium depends only on the difference in investment levels, such that market clearing requires $p_i - p_j = x_j - x_i$.

Note also, that firm i 's individual mass market demand schedule (1) is independent of its own compatibility investments. Those investments by firm i do only create positive spillover effects for the rival's mass market demand.

Moreover, we assume that firm i 's compatibility cost function, K_i , is a convex function of the compatibility investment, x_i , and given by $K_i(x_i) = \frac{\gamma}{2}x_i^2$, with

$i = 1, 2$ and $\gamma > 0$.²¹

Now, let us turn to the description of the two-stage game. In the first stage all firms simultaneously choose their compatibility investment levels and in the second stage all firms determine their output on the mass market. We consider three regimes with varying degrees of cooperation between firms. Under the *compatibility competition* regime (\mathcal{NN}) firms behave noncooperatively in both stages of the game. Under the *compatibility committee* regime (\mathcal{CN}) both firms coordinate their compatibility investments in a standardization committee, but behave noncooperatively in the mass market. Under the *cartelization* regime (\mathcal{CC}) firms cooperate in both stages of the game, so that relations in the standardization committee lead to collusion on the mass market.

In order to compare the outcomes under the different regime, we want to introduce the following assumptions, which are in effect throughout the paper.

Assumption 1 *The marginal profits on the niche market are sufficiently high:*
 $v > \frac{2\beta A}{9}$.

Assumption 1 ensures that each firm's marginal profits on the niche market, i.e., $\frac{\partial(x_i v)}{\partial x_i} = v$, with $i = 1, 2$, give sufficient incentives to undertake compatibility investments when firms behave noncooperatively in both stages of the game (\mathcal{NN} regime). Therefore, given that Assumption 1 holds, both firms spend in all regimes under consideration a strictly positive amount of money on compatibility investments in each symmetric subgame perfect equilibrium.

Assumption 2 *Compatibility costs are sufficiently convex: (i) $\beta < \sqrt{2\gamma} \approx 1.41\sqrt{\gamma}$ and (ii) $\sqrt{2\gamma} \leq \frac{9v}{2A}$.*

²¹Analogously to the concavity restrictions imposed on the R&D production function in the model of KAMIEN, MULLER & ZANG [1992], the strict convexity of K implies $\lim_{x \rightarrow \infty} K' = \infty$, which serves to guarantee existence of equilibria in which compatibility investments are bounded from above.

Assumption 2 (i) ensures that reduced profit functions for all regimes in the first stage of the game are strictly concave in compatibility investments, x_i , along the path of equal investments. This implies, that every subgame at the second stage has a unique symmetric Nash equilibrium.²² According to Assumption 2 (ii) we posit that Assumption 2 (i), and not Assumption 1, is the binding condition for the spillover parameter β .

Let us now define by ω - the set of vectors of parameters, with $\omega = (A, v, \beta, \gamma) \in R_+^4$, which satisfy Assumption 1 and 2; i.e., $\omega = \{\omega \in R_+^4 | \beta < \sqrt{2\gamma} < \frac{9v}{2A}\}$.²³

We now solve the game by backward induction, where we restrict attention to symmetric equilibria.²⁴ In Section 2.1 we calculate the noncooperative and cooperative optimal strategies in the first stage of the game. In Section 2.2 we look at the optimal strategies under all three regimes given the optimal strategies in the second stage of the game. In Section 2.3 we calculate the welfare maximizing outcome.

2.1 Second-Stage Equilibrium

Noncooperative behavior: In the second stage firm i 's profit function, Π_i , conditional on x_1 and x_2 , is

$$\Pi_i = (A + \beta x_j - q_i - q_j)q_i + vx_i - \frac{\gamma}{2}x_i^2, \quad j \neq i, i = 1, 2. \quad (2)$$

The symmetric Nash-Cournot equilibrium can be computed to be²⁵

$$q_i = \frac{A + 2\beta x_j - \beta x_i}{3}, \quad j \neq i, i = 1, 2. \quad (3)$$

²²Analytically Assumption 2 (i) ensures that all second order conditions for \mathcal{NN} , \mathcal{CN} , \mathcal{CC} , and the welfare maximizing regime, which will be introduced below, are fulfilled.

²³With R_+ we denote the set of all positive real numbers including zero.

²⁴In Section 5, following SALANT & SHAFFER [1998], [1999] we also examine asymmetric solutions under the \mathcal{CN} regime.

²⁵The second order condition for a profit maximum is always fulfilled.

Substitution of q_i into the profit function (2) gives the reduced profit function $\Pi_i^{\mathcal{N}}$ (the superscript \mathcal{N} stands for noncooperative behavior in the second stage):

$$\Pi_i^{\mathcal{N}} = \frac{1}{9}(A + 2\beta x_j - \beta x_i)^2 + vx_i - \frac{\gamma}{2}x_i^2, \quad j \neq i, \quad i = 1, 2. \quad (4)$$

Collusive behavior: Now, consider the case where firms use the committee to collude on the mass market. Assuming a symmetric solution, such that $q_1 = q_2 = q$ and $x_1 = x_2 = x$ holds, we get the joint-profit function

$$\Pi = 2(A + \beta x - 2q)q + 2vx - \gamma x^2. \quad (5)$$

Maximization yields for each firm's quantities

$$q = \frac{A + \beta x}{2}, \quad (6)$$

and by substituting (6) into the joint-profit function (5) we get the reduced joint-profit function, $\Pi^{\mathcal{C}}$ (the superscript \mathcal{C} stands for cooperative behavior in the first stage):

$$\Pi^{\mathcal{C}} = \Pi_1^{\mathcal{C}} + \Pi_2^{\mathcal{C}} = \frac{1}{4}(A + \beta x)^2 + 2vx - \gamma x^2, \quad (7)$$

for $x_1 = x_2 = x$ under the symmetric solution $q_1 = q_2 = q$. We now turn to the first stage of the game in which firms decide about their compatibility investment levels.

2.2 First-Stage Equilibrium

Given firms' strategies in the second stage, we examine now the subgame perfect investment decision in the first stage under the three different regimes.

Compatibility Competition (\mathcal{NN}): In this case firms do not coordinate their compatibility decisions. Thus, each firm simultaneously chooses its investment to maximize (4) with respect to x_i . This gives a unique symmetric solution satisfying $(\partial \Pi_i^{\mathcal{N}} / \partial x_i) = 0$, for which we get²⁶

$$x_i^{\mathcal{NN}} = \frac{9v - 2\beta A}{9\gamma + 2\beta^2}, \quad i = 1, 2, \quad (8)$$

²⁶The second order condition requires $\beta^2 - \frac{9}{2}\gamma < 0$ or $\beta < 3\sqrt{\gamma/2} \approx 2.12\sqrt{\gamma}$. The stability condition $|\frac{\partial x_i}{\partial x_j}| < 1$ reduces to the same condition as the second order condition. In contrast

and

$$q_i^{\mathcal{NN}} = \frac{3(\gamma A + \beta v)}{9\gamma + 2\beta^2}, \quad i = 1, 2, \quad (9)$$

where the superscript \mathcal{NN} indicates the *compatibility competition* regime. Note that Assumption 1 ensures that the right-hand side of Equation (8) is strictly positive. We, therefore, exclude the case, that there might prevail perfect interbrand incompatibility in the sense that no firm undertakes any compatibility investments.

Compatibility Committee (CN): Here, as in the case of \mathcal{NN} , firms compete on the mass market in the second stage. However, they coordinate their compatibility investments to maximize the sum of their combined profits. That is, they form a standardization committee while maintaining competition in the product market. We have to maximize the sum of each firm's profits, so that we get for $x_1 = x_2 = x$ the committee's profit function

$$\Pi^{\mathcal{CN}} = \Pi_1^{\mathcal{CN}} + \Pi_2^{\mathcal{CN}} = \frac{2}{9}(A + \beta x)^2 + 2vx - \gamma x^2, \quad (10)$$

where the superscript \mathcal{CN} stands for the *compatibility committee* regime. The symmetric cooperative equilibrium in compatibility investments and in production corresponds to the following unique solution²⁷

$$x^{\mathcal{CN}} = \frac{9v + 2\beta A}{9\gamma - 2\beta^2}, \quad (11)$$

and

$$q^{\mathcal{CN}} = \frac{3(\gamma A + \beta v)}{9\gamma - 2\beta^2}. \quad (12)$$

From Equation (11) we observe that cooperation on the investment stage is sufficient to induce positive investment levels, even if marginal net revenues on the niche market are equal to zero; i.e., $v = 0$.

to the model of D'ASPROMONT & JACQUEMIN [1988], in our model, the stability condition does not restrict the spillover parameter to a positive minimum level as has been detected by HENRIQUES [1990].

²⁷The second order condition requires $\beta < 3\sqrt{\gamma/2} \approx 2.12\sqrt{\gamma}$.

Cartelization (CC): This third case deals with firms maximizing joint profits in both stages of the game. At the first stage, the reduced joint profit function, Π^C , is given by Equation (7), and we obtain the unique solution, satisfying²⁸

$$x^{CC} = \frac{4v + \beta A}{4\gamma - \beta^2}, \quad (13)$$

and

$$q^{CC} = \frac{\gamma A + \beta v}{4\gamma - \beta^2}, \quad (14)$$

where CC represents the *cartelization* regime. Let us now turn to the welfare maximizing investment and output levels before we will compare our results.

2.3 First-Best Welfare

To compare the above results we need to establish an efficient standard. Therefore, let us define first-best social welfare $W^{\mathcal{FB}}(q, x)$ as the sum of the consumer surplus $CS(q, x)$ and the producer surplus (assuming $x_1 = x_2 = x$ and $q_1 = q_2 = q$). Given our specification of an linear inverse demand schedule,²⁹ consumer surplus is $CS(q, x) = 2q^2$, and the social welfare function is given by

$$W^{\mathcal{FB}}(q, x) = 2(A + \beta x - q)q + 2vx - \gamma x^2. \quad (15)$$

We get as the efficient output for each firm³⁰

$$q = \frac{A + \beta x}{2}. \quad (16)$$

Hence, at the first stage, the reduced social welfare function is

$$W^{\mathcal{FB}} = \frac{1}{2}(A + \beta x)^2 + 2vx - \gamma x^2. \quad (17)$$

²⁸The second order condition for the second stage requires $\beta < 2\sqrt{\gamma}$.

²⁹Recall all firms are assumed to extract all the entire consumer surplus in their niche markets.

³⁰The second order condition does always hold.

Table 1: Firms' Equilibrium Quantities, Investments, and Prices

Regime	Quantity	Investment	Price
\mathcal{NN}	$q^{\mathcal{NN}} = \frac{3(\gamma A + \beta v)}{9\gamma + 2\beta^2}$	$x^{\mathcal{NN}} = \frac{9v - 2\beta A}{9\gamma + 2\beta^2}$	$p^{\mathcal{NN}} = \frac{3(\gamma A + \beta v)}{9\gamma + 2\beta^2}$
\mathcal{CN}	$q^{\mathcal{CN}} = \frac{3(\gamma A + \beta v)}{9\gamma - 2\beta^2}$	$x^{\mathcal{CN}} = \frac{9v + 2\beta A}{9\gamma - 2\beta^2}$	$p^{\mathcal{CN}} = \frac{3(\gamma A + \beta v)}{9\gamma - 2\beta^2}$
\mathcal{CC}	$q^{\mathcal{CC}} = \frac{\gamma A + \beta v}{4\gamma - \beta^2}$	$x^{\mathcal{CC}} = \frac{4v + \beta A}{4\gamma - \beta^2}$	$p^{\mathcal{CC}} = \frac{2(\gamma A + \beta v)}{4\gamma - \beta^2}$
\mathcal{FB}	$q^{\mathcal{FB}} = \frac{\gamma A + \beta v}{2\gamma - \beta^2}$	$x^{\mathcal{FB}} = \frac{2v + \beta A}{2\gamma - \beta^2}$	$p^{\mathcal{FB}} = 0$

The efficient level of compatibility investment for each firm satisfying the first order condition for a welfare maximum is³¹

$$x^{\mathcal{FB}} = \frac{2v + \beta A}{2\gamma - \beta^2}, \quad (18)$$

and hence, the welfare maximizing solution on the mass market is

$$q^{\mathcal{FB}} = \frac{\gamma A + \beta v}{2\gamma - \beta^2}, \quad (19)$$

where the superscript \mathcal{FB} indicates the first-best outcome.

3 Comparison of Results

In Table 1 our results concerning quantities, compatibility investments, and prices are summarized, where we suppressed the index i because of symmetry.

We can now formulate the following proposition with respect to firms' investment levels.

Proposition 1 *For $\omega \in -$ the equilibrium compatibility investment levels of each firm, x^l , under the different regimes, $l = \mathcal{FB}, \mathcal{NN}, \mathcal{CN}, \mathcal{CC}$, satisfy the following ordering:*

$$x^{\mathcal{FB}} \geq x^{\mathcal{CC}} \geq x^{\mathcal{CN}} \geq x^{\mathcal{NN}}.$$

³¹The second order condition is given by $\beta < \sqrt{2\gamma} \approx 1.41\sqrt{\gamma}$, which is the binding condition for assuring a unique interior solution for all regimes under consideration.

Furthermore,

$$x^{\mathcal{FB}} > x^{\mathcal{CC}} > x^{\mathcal{CN}} > x^{\mathcal{NN}},$$

if and only if $\beta > 0$ holds (equality holding if and only if $\beta = 0$).

Proof: Follows directly from comparing (8), (11), (13), and (18). For $\beta = 0$ we obtain $x^{\mathcal{FB}} = x^{\mathcal{CC}} = x^{\mathcal{CN}} = x^{\mathcal{NN}} = \frac{v}{\gamma}$. *Q.E.D.*

Proposition 1 states that cooperative investment activity exceeds the competitive investment level in the presence of positive spillovers. Investment levels come closest to the first-best case when firms collude in both stages of the game. Comparison of \mathcal{CN} and \mathcal{NN} reveals an important difference between the economic literature on R&D spillovers and our analysis of positive spillovers from compatibility investments. One major finding of that literature is that cooperative R&D activities in the case of \mathcal{CN} exceed competitive research levels if and only if the extent to which information flows freely among competitors is relatively high. In our model this general finding is independent of the exact parameter value of the spillover parameter.³² Cooperative internalization of the positive externalities on joint profits accruing from each firms' compatibility investments increase investment levels, because they outweigh the disadvantage due to positive spillovers benefiting the competitor on the mass market. Moreover, investment levels increase proportionally with higher degrees of cooperation, so that investments are closest to the first-best level under the cartelization regime (\mathcal{CC}).

The following proposition characterizes the results for the quantities of production.

Proposition 2 *Consider all $\omega \in -$. Then for all $\gamma > 0$ there exists a critical value $\hat{\beta}$, such that the equilibrium quantities of each firm on the mass market, q^l ,*

³²In particular, D'ASPREMONT & JACQUEMIN [1988] report the classification $x^{\mathcal{FB}} > x^{\mathcal{CC}} > x^{\mathcal{CN}} > x^{\mathcal{NN}}$ for large values of $\beta \in (1, 0.5)$, and the classification $x^{\mathcal{FB}} > x^{\mathcal{NN}} > x^{\mathcal{CC}} > x^{\mathcal{CN}}$ for small parameter values of $\beta \in (\underline{\beta}, 0.41]$, where $\underline{\beta} > 0$ is determined by the stability condition $|\partial x_i / \partial x_j| < 1$ for the \mathcal{NN} case (see HENRIQUES [1990]).

under the different regimes, $l = \mathcal{FB}, \mathcal{NN}, \mathcal{CN}, \mathcal{CC}$, satisfy

$$q^{\mathcal{FB}} > q^{\mathcal{CN}} \geq q^{\mathcal{NN}} > q^{\mathcal{CC}}, \text{ for } 0 \leq \beta < \hat{\beta},$$

with $q^{\mathcal{CN}} = q^{\mathcal{NN}}$ if and only if $\beta = 0$, and

$$q^{\mathcal{FB}} > q^{\mathcal{CN}} > q^{\mathcal{CC}} \geq q^{\mathcal{NN}}, \text{ for } \hat{\beta} \leq \beta < \sqrt{2\gamma},$$

with $q^{\mathcal{CC}} = q^{\mathcal{NN}}$ if and only if $\beta = \hat{\beta}$, where $\hat{\beta} \equiv \sqrt{\frac{3}{5}\gamma} \approx 0.78\sqrt{\gamma}$.

Proof: See Appendix. *Q.E.D.*

Proposition 2 states that the closest to the social optimum is what is produced under the committee compatibility (\mathcal{CN}) regime. Moreover, for relatively large spillovers, such that $\beta > \sqrt{\frac{3}{5}\gamma}$ is fulfilled, fully cooperative behavior (\mathcal{CC}) leads to higher production quantities than pure competitive behavior (\mathcal{NN}). This surprising finding reveals an important difference between compatibility and R&D spillovers. In contrast to R&D investments, which primarily reduce the unit costs of the investing firm, investments into interbrand compatibility never generate any direct advantageous effects for the investing firm on the mass market. As a result, full internalization of compatibility investments under the cartelization regime (\mathcal{CC}) might lead to higher production levels on the mass market compared to \mathcal{NN} although monopoly pricing prevails. In this particular case, the market expansion effect generated by compatibility investments outweighs the monopolization effect due to collusive behavior on the mass market. This result is the more likely the higher the value of the spillover parameter.

The following proposition states the welfare results of our model.

Proposition 3 *Consider all $\omega \in -$. Then welfare, W^l , under the different regimes, $l = \mathcal{FB}, \mathcal{NN}, \mathcal{CN}, \mathcal{CC}$, satisfies the following ordering:*

$$W^{\mathcal{FB}} > W^{\mathcal{CN}} > W^{\mathcal{CC}}, \text{ for } \beta \geq 0,$$

and

$$W^{\mathcal{FB}} > W^{\mathcal{CN}} \geq W^{\mathcal{NN}}, \text{ for } \beta \geq 0,$$

where $W^{c\mathcal{N}} = W^{\mathcal{N}\mathcal{N}}$ if and only if $\beta = 0$. Furthermore, for all $\gamma \geq 0$, there exists a critical value β^* , such that

$$W^{\mathcal{N}\mathcal{N}} > W^{cc}, \text{ if and only if } 0 \leq \beta < \beta^*,$$

and

$$W^{\mathcal{N}\mathcal{N}} \leq W^{cc}, \text{ if and only if } \beta^* \leq \beta < \sqrt{2\gamma},$$

where $\beta^* \equiv \frac{1}{92} \sqrt{17434 - 782\sqrt{73}} \sqrt{\gamma} \approx 1.13\sqrt{\gamma}$. Moreover, $W^{\mathcal{N}\mathcal{N}} = W^{cc}$ if and only if $\beta = \beta^*$.

Proof: See Appendix. *Q.E.D.*

From Proposition 3 we see that welfare under \mathcal{CN} is higher than under \mathcal{NN} , whenever the spillover parameter is positive. The intuition for this result is the following: From Proposition 2 we know that $q^{c\mathcal{N}} > q^{\mathcal{N}\mathcal{N}}$ holds for $\beta > 0$, so that consumer surplus must have increased. Firms' profits also must have increased, because otherwise firms would have chosen the noncooperative investment levels under the fully cooperative regime. Therefore, consumer surplus and firms' profits both increase under the \mathcal{CN} regime compared to the \mathcal{NN} regime.

From Proposition 1 and 2 we obtain a sufficient condition for welfare under \mathcal{CC} being higher than under \mathcal{NN} , namely $\hat{\beta} > \sqrt{\frac{3}{5}}\gamma$, so that both quantities of production and compatibility investment levels are higher under \mathcal{CC} . However, Proposition 3 shows that social welfare increases under \mathcal{CC} even for lower values of the spillover parameter, such that $\beta > \beta^*$, with $\hat{\beta} > \beta^*$, has to hold. For relatively small spillovers, such that $0 \leq \beta < \beta^*$ holds, the fully noncooperative solution (\mathcal{NN}) gives higher levels of output, which outweigh the social benefits from relatively higher investments under \mathcal{CC} .

In contrast to R&D investments which reduce the investing firm's unit costs to a larger extent than the other firm's unit costs, spillovers from compatibility investments do *only* benefit the rival firm on the mass market. Therefore, by comparing our results with the literature on cost-reducing R&D spillovers, we

can conclude that spillovers stemming from interbrand compatibility investments give even stronger efficiency reasons for horizontal cooperation.³³ This might help to explain why cooperative interfirm relations within standardization committees or airline alliances with codesharing arrangements, are usually not alleged to be anticompetitive.

Before turning to some extensions of our above analysis, we want to finish the comparison of our results with the following proposition classifying the prices prevailing under each regime.

Proposition 4 *For $\omega \in -$ the equilibrium prices on the mass market, p^l , under the different regimes, $l = \mathcal{FB}, \mathcal{NN}, \mathcal{CN}, \mathcal{CC}$, satisfy the following ordering:*

$$p^{\mathcal{FB}} < p^{\mathcal{NN}} \leq p^{\mathcal{CN}} < p^{\mathcal{CC}},$$

with $p^{\mathcal{CN}} = p^{\mathcal{NN}}$ if and only if $\beta = 0$.

Proof: Follows directly from comparison of equilibrium prices, which are presented in Table 1. *Q.E.D.*

According to Proposition 4 prices increase monotonically with the degree of cooperation. Since compatibility investments increase consumers' willingness to pay for the rival's mass market product, high prices do not necessarily reflect lower consumer surplus. Indeed, as in the \mathcal{CN} case, higher prices are the result of socially beneficial compatibility investments, so that prices above the fully competitive level reflect higher quality of the mass market product.

Finally let us compare our results with the existing literature on parallelly vertically integrated firms, which choose prices of the complementary products and

³³In our welfare analysis we rather underestimated the welfare effects generated by compatibility investments. Assume linear niche market demand and monopolistic pricing, then consumer surplus is a convex function of the supplier's compatibility investments, implying that cooperation might be even more beneficial for society than it is in our model. Given the specification of the demand schedule as stated in Footnote 19, the niche market consumer surplus is in this alternative example equal to $\frac{1}{8h}(M + x - hk)^2$.

product variety when products are either perfectly compatible or perfectly incompatible.³⁴ A common result in those models is that profits are higher in a regime of full compatibility. Compatibility increases demand, and hence, prices, so that profits increase. In contrast to this result, our analysis has shown that firms prefer to choose relatively low compatibility levels in a purely noncooperative environment, because compatibility is costly to achieve and leads to spillover effects which in turn increase the rival's mass product quality.

Before concluding the paper we now examine two extensions of our analysis which deserve more attention. *First*, following KAMIEN, MULLER & ZANG [1992] we investigate firms' incentives to establish RJV-like institutions which lead to higher levels of the spillover parameter or, similarly, the government's incentives to force firms to exchange private information concerning the technical design of interfaces, so that the value of the spillover parameter increases. *Second*, in accordance with SALANT & SHAFFER [1998], [1999] we show that optimal strategies of firms cooperating in investments, while competing on the product market, might lead to asymmetric outcomes.

4 Open Standardization Policy

In accordance with the approach proposed by KAMIEN, MULLER & ZANG [1992] we examine the impact of RJV-like institutions which increase the level of the spillover parameter.³⁵ In contrast to all regimes mentioned above firms pool all their compatibility efforts in an RJV such that all information concerning the technological interface is revealed to each firm, and hence, compatibility in-

³⁴See for example, MATUTES & REGIBEAU [1988], and ECONOMIDES [1989], [1991a].

³⁵More precisely, KAMIEN, MULLER & ZANG [1992] propose that the formation of an RJV increases the spillover parameter to its maximum level, which is one. Our model differs from theirs, since they look at informational R&D spillovers. In our model where β measures the degree to which the other firm's mass market demand increases from compatibility investments, such a rationale for interpreting β does not exist.

vestments become more effective. In the context of standardization committees we may interpret a regime which increases the spillover parameter as an “open standard” committee, which demands that participants reveal all features of the interface technology. Similarly, the government might pursue an open standardization policy by forcing firms to disclose information concerning the compatibility technology.³⁶ The following two lemmas summarize the comparative static results with respect to β for firms’ profits and welfare under the different regimes.

Lemma 1 *For $\omega \in -$, differentiation of the reduced profit functions, Π^l , under the different regimes $l = \mathcal{NN}, \mathcal{CN}, \mathcal{CC}$, with respect to β gives*

$$\frac{\partial \Pi^k}{\partial \beta} > 0, \text{ with } k = \mathcal{CN}, \mathcal{CC}.$$

Under the \mathcal{NN} regime we obtain the following ordering:

(i) *Given $0 \leq \beta < \sqrt{\frac{3}{2}\gamma}$, there exists a critical value $v' = \max\{\frac{2\sqrt{2}\gamma A}{9}, \frac{2\beta A(27\gamma - 2\beta^2)}{27(3\gamma - 2\beta^2)}\}$, such that*

$$\frac{\partial \Pi^{\mathcal{NN}}}{\partial \beta} \geq 0, \text{ if and only if } v \geq v',$$

and

$$\frac{\partial \Pi^{\mathcal{NN}}}{\partial \beta} < 0, \text{ if and only if } v < v'.$$

(ii) *Given $\sqrt{\frac{3}{2}\gamma} \leq \beta < \sqrt{2\gamma}$, we get*

$$\frac{\partial \Pi^{\mathcal{NN}}}{\partial \beta} < 0.$$

Proof: See Appendix. *Q.E.D.*

³⁶One example of an open standardization policy is provided by the recently implemented EC Directive on the Legal Protection of Computer Programs which introduces a limited right of “decompilation” whereby otherwise infringing acts that occur during the course of decompiling a program (i.e., copying files, translating object code back into source code) are permitted where they are necessary to gain information to allow software/hardware interoperability (see also SCHMIDTCHEN & KOBOLDT [1993] and SHURMER & LEA [1995]).

From Lemma 1 we observe that firms unambiguously prefer to reveal all relevant informations concerning the interface technology to their rivals, whenever cooperation on the compatibility investment stage is possible. For the \mathcal{NN} regime firms may want to hide information to make the rival's compatibility investments less effective, whenever the spillover parameter is sufficiently large. Disclosure of interface informations is individually optimal for relatively low levels of the spillover parameter and sufficiently large direct benefits from compatibility investments, v . The intuition for this result can be derived from recognizing that due to free-rider behavior compatibility investments decrease for increasing values of the spillover parameter; i.e., $\frac{\partial x^{\mathcal{NN}}}{\partial \beta} < 0$. However, equilibrium mass product production, $q^{\mathcal{NN}} = \frac{A+\beta x^{\mathcal{NN}}}{3}$, increases if the following condition holds:

$$\begin{aligned} \frac{dq^{\mathcal{NN}}}{d\beta} &= \frac{1}{3} \left(x^{\mathcal{NN}} + \beta \frac{\partial x^{\mathcal{NN}}}{\partial \beta} \right) > 0 \\ \Rightarrow x^{\mathcal{NN}} &> \beta \left| \frac{\partial x^{\mathcal{NN}}}{\partial \beta} \right|. \end{aligned} \quad (20)$$

Each firm's production quantity on the mass market increases with higher values of the spillover parameter, if the contraction in compatibility investments times the spillover parameter is according to Condition 20 not too large. This is the more likely, the lower the initial value of the spillover parameter and the higher the marginal profits on the niche market, v .³⁷ Therefore, if the quantity expansion effect induced by higher levels of the spillover parameter is large enough, firms' profits will increase in the \mathcal{NN} regime when firms agree to reveal relevant interface information.

The following lemma states the corresponding welfare results for each regime.

Lemma 2 *For $\omega \in -$, differentiation of the reduced welfare function, W^l , under the different regimes $l = \mathcal{FB}, \mathcal{NN}, \mathcal{CN}, \mathcal{CC}$, with respect to β gives*

$$\frac{\partial W^k}{\partial \beta} > 0, \quad \text{with } k = \mathcal{FB}, \mathcal{CN}, \mathcal{CC}.$$

³⁷The latter follows from the fact that magnitude of the derivative $\frac{\partial x^{\mathcal{NN}}}{\partial \beta}$ decreases with higher values of v .

Under the \mathcal{NN} regime, there exists a critical value $v'' = \max\{\frac{2\sqrt{2}\gamma A}{9}, \frac{\beta A(45\gamma - 2\beta^2)}{9(9\gamma - 4\beta^2)}\}$ such that

$$\frac{\partial W^{\mathcal{NN}}}{\partial \beta} \geq 0, \text{ if and only if } v \geq v'',$$

and

$$\frac{\partial W^{\mathcal{NN}}}{\partial \beta} < 0, \text{ if and only if } v < v''.$$

Proof: See Appendix. *Q.E.D.*

From Lemma 1 and 2 we can derive Proposition 5 and 6 which summarize the welfare results of an open standardization policy as a result of a private agreement and state intervention.

Proposition 5 *For all $\omega \in -$, any privately enforced increase of the spillover parameter β increases social welfare under all regimes $l = \mathcal{NN}, \mathcal{CN}, \mathcal{CC}$.*

Proof: Follows directly from Lemma 1 and Lemma 2, and recognizing that $v'' < v'$ for $0 \leq \beta < \sqrt{\frac{3}{2}\gamma}$. *Q.E.D.*

Proposition 5 gives clear cut conclusions with respect to private agreements which force firms to disclose relevant informations concerning the interface technology. In all regime those agreements lead to higher welfare levels.

The following proposition states the welfare effects of an open standardization policy pursued by the government via reducing the protection of intellectual property rights.

Proposition 6 *Consider all $\omega \in -$. An increase of the spillover parameter β enforced by the government increases welfare unambiguously in the \mathcal{CN} and the \mathcal{CC} regime. Under the \mathcal{NN} regime, for relatively low levels of the spillover parameter, such that $0 \leq \beta < \sqrt{\frac{2}{3}\gamma}$ holds, an increase of the spillover parameter generated by state intervention increases welfare if and only if $v > v'$ holds; otherwise, higher levels of the spillover parameter induce lower welfare levels.*

Proof: Follows directly from Lemma 1 and Lemma 2, and recognizing for the \mathcal{NN} case that $v'' < v'$ holds for $0 \leq \beta < \sqrt{\frac{3}{2}\gamma}$. *Q.E.D.*

From Proposition 6 we can conclude that an open standardization policy by the government does always unfold socially beneficial effects when firms are allowed to cooperate. The same conclusion may hold for the \mathcal{NN} case, whenever the level of spillovers is relatively low. However, an open standardization policy might reduce welfare when firms operate in a perfectly noncooperative environment and the spillover parameter is relatively large or marginal profits on the niche market are too low, whenever the spillover parameter is relatively low. Under such conditions an increase of the spillover parameter lead firms to reduce compatibility investments and mass market production quantities, so that welfare decreases. Therefore, if cooperation among firms is allowed our analysis confirms the supposition that relatively weak protection of intellectual property rights concerning the compatibility design is socially beneficial (see FARRELL [1989], [1995]).

It should be pointed out that an open standardization policy does not always lead to higher degrees of interbrand compatibility, as measured by the sum of firms' compatibility investments. For the \mathcal{NN} regime higher values of the spillover parameter transform into lower investment levels. This result stands in contrast to the presumption that weaker protection of intellectual property rights directly transforms into higher degrees of compatibility (see FARRELL & KATZ [1998, 44]). Whenever it is costly to achieve compatibility ex ante, as we assume in our analysis, purely noncooperative behavior induces firms to reduce their compatibility efforts for increasing values of the spillover parameter.

5 Standardization as an Asymmetric Solution

Until now, we restricted our analysis to symmetric equilibria in which both firms have the same investment and production levels, and two different interface designs prevailing on the mass market. In this section we drive a sufficient condition,

in which the joint-profit maximizing solution is asymmetric in the \mathcal{CN} regime. The symmetric solution to the hybrid specification of the two-stage game, in which firms choose investment levels *cooperatively* in the first stage and determine production quantities *noncooperatively* in the second stage, has been adopted by almost all the literature that was sparked by the seminal work of D'ASPREMONT & JACQUEMIN [1988].³⁸ The symmetric solution has been recently criticized by SALANT & SHAFFER [1998], [1999].³⁹ They show that joint profit maximization of identical firms on the investment stage may lead to asymmetric outcomes, in which one firm has a larger market share than its rivals. Salant and Shaffer's analysis is based on the general property of any symmetric Cournot equilibrium, namely, that for a given amount of total output aggregate production costs are maximized when identical firms have equal market shares.⁴⁰ Therefore, joint profits can be increased by reallocating investments between firms, such that firms with lower marginal production costs produce more compared to those firms which have higher marginal costs.

Building on this efficiency rationale for market dominance, Salant and Shaffer derive a sufficient condition for an asymmetric outcome to dominate a symmetric outcome, which we now apply to our analysis.⁴¹ According to Salant and Shaffer we have to calculate the reduced joint profits as a function of each firm's individual

³⁸The impact of D'ASPREMONT & JACQUEMIN [1988] can easily be appreciated given the numerous follow-up studies, as cited in Footnote 8, it gave rise to. All those studies confined their analysis to symmetric cooperative R&D investments.

³⁹The only papers beside SALANT & SHAFFER [1998], [1999] we are aware of deviating from this approach are AMIR & WOODERS [1998a], [1998b], which investigate one-sided R&D spillovers.

⁴⁰SALANT & SHAFFER [1998], [1999] analysis builds on BERGSTROM & VARIAN [1985a], [1985b]. In the first paper Bergstrom and Varian shown that for constant marginal costs, aggregate industry output depends in any interior Cournot equilibrium only on the sum of marginal costs and not on the distribution of these costs. In the latter paper the authors proved that an increase of the variance of marginal costs reduces aggregate production costs, so that aggregate production costs are *maximized* when firms have the same marginal costs.

⁴¹This condition is given by Proposition 2 in SALANT & SHAFFER [1999] and has been applied to the d'Aspremont-Jacquemin model in SALANT & SHAFFER [1998].

investment levels under the compatibility committee regime (\mathcal{CN}), which are given by

$$\Pi^{\mathcal{CN}} = \sum_{i=1}^2 \left[\frac{1}{9} (A + 2\beta x_j - \beta x_i)^2 + v x_i - \frac{\gamma}{2} x_i^2 \right], \quad j \neq i. \quad (21)$$

Now, let k be any positive constant and substitute $x_2 = k - x_1$ into Equation (21), what gives

$$\Pi^{\mathcal{CN}} = \frac{1}{9} [(A + 2\beta k - 3\beta x_1)^2 + (A + 3\beta x_1 - \beta k)^2] + vk - \frac{\gamma}{2} [x_1^2 + (k - x_1)^2].$$

To derive a sufficient condition for the existence of an asymmetric outcome yielding higher joint profits than the symmetric outcome, this reduced profit function has to be convex in x_1 . Taking the total derivative twice, one obtains

$$\frac{\partial^2 \Pi^{\mathcal{CN}}}{\partial x_1^2} = 4\beta^2 - 2\gamma > 0. \quad (22)$$

The sufficient condition (22) can be rewritten as $\beta > \sqrt{\frac{1}{2}\gamma}$, which shows that this condition is the more likely to be fulfilled the higher the spillover parameter, β , or the lower the compatibility cost parameter, γ , is. Intuitively, a larger spillover parameter increases the quality gap created by any given reallocation of a fixed aggregate investment, so that the gain from a reduction in joint production costs increases in the second stage. Accordingly, the smaller the slope of the marginal cost of compatibility investment, the smaller will be the increase in aggregate compatibility costs of making investments unequal.⁴²

The following example illustrates that joint profit maximization might lead to a corner solution, in which only one firm serves the mass market, and the other firm specializes in producing its niche market product.⁴³ This means, cooperation

⁴²Comparison of the corresponding sufficient condition for the d'Aspremont-Jacquemin model, as it has been derived by SALANT & SHAFFER [1998], reveals an important difference between their and our model. In the d'Aspremont-Jacquemin model an increase in β tends to *reduce* differences in marginal costs among firms, while in our model such an increase leads to an increase in the difference of consumer's maximum willingness to pay for each firm's products.

⁴³We posit that firm i 's marginal profits on its niche market are zero ($v = 0$), if and only if the rival's mass market production quantity is zero; i.e., $q_j = 0$. Otherwise, firm i would always invest into interbrand compatibility even if the other firm does not supply a mass market product.

among firms on the compatibility investment stage can induce complete standardization, so that only one interface design prevails among the interrelated mass market and niche markets. Under these circumstances one firm monopolizes the mass market and provides the industry compatibility standard to which all firms specializing on their niche markets adhere.

Example (Standardization):⁴⁴ Let $A = 40$, $v = 10$, $\gamma = 1$, and $\beta = 1$. Then compatibility investments (mass market production levels) for the symmetric solution are $x^{\mathcal{CN}} = 24.286$ ($q^{\mathcal{CN}} = 21.43$) and for the asymmetric solution $x_2^A = 60$ ($q_1^A = 50$). Joint profits for the symmetric solution are $\Pi^{\mathcal{CN}} = 920.08$ and for the asymmetric solution $\Pi^A = 1,300$. Welfare for the symmetric solution is $W^{\mathcal{CN}} = 1,732$ and for the asymmetric solution $W^A = 2,550$.

This example shows that the symmetric solution in the \mathcal{CN} regime might be privately and socially dominated by an asymmetric solution in which only one firm serves the mass market and the other firm specializes in the production of its niche market product. As the example indicates, interbrand compatibility is much higher in such an asymmetric outcome than in the symmetric outcome.

6 Conclusion

In this paper we have analyzed firms' incentives to undertake interbrand compatibility investments ex post; i.e., after mass market standard technologies have been established. It has been argued that achieving interbrand compatibility ex post is not an either-or decision problem as in the case of ex ante coordination on a particular industry standard.

Firms have to undertake investments which are governed by a quadratic costs function. We have analyzed the impact of three organizational modes, varying

⁴⁴In the Appendix, we derive the joint profit function and the welfare function, whenever firm 1 monopolizes the mass market and firm 2 specializes in its niche market product, for the \mathcal{CN} regime.

from pure market contact to full cartelization, on firms' incentives to invest into interbrand compatibility which increases the quality of the rival's mass market product via demand side spillovers.

We have compared our results with the first-best regime and have shown that the hybrid regime \mathcal{CN} , with firms cooperating with respect to compatibility investments and competing on the mass market, gives second-best welfare for all feasible values of the spillover parameter. Therefore, our model gives strong efficiency reasons for horizontal cooperation among firms as we may observe it in standardization committees or international alliances which incorporate code-sharing arrangements. However, antitrust authorities should watch those hybrid organizations, since they might be used as a collusive device. While full cartelization leads to second-best compatibility levels it induces monopolistic pricing on the mass market, so that welfare is always lower in the \mathcal{CC} case compared to the hybrid regime \mathcal{CN} .

We also found that depending on the spillover parameter either the compatibility competition (\mathcal{NN}) or the cartelization (\mathcal{CC}) regime is the least desirable one. For relatively low spillover effects the \mathcal{NN} regime generates higher welfare levels than the \mathcal{CC} regime. However, for relatively high levels of the spillover parameter cartelization (\mathcal{CC}) increases investment activity so much that welfare is higher under \mathcal{CC} compared to \mathcal{NN} . This result demonstrates that social payoffs from cooperation towards interbrand compatibility are significantly higher than those which are generated by cooperation in the presence of R&D spillovers. The literature on R&D investments with spillovers has shown that full cartelization (\mathcal{CC}) does never lead to higher welfare levels compared to pure competitive behavior (\mathcal{NN}).

The policy implications are therefore straight forward. In markets that meet our suppositions, cooperation of compatibility investments in standardization committees should be encouraged, while competition on the mass market has to be preserved. In markets with relatively large spillover effects the worst thing the

government could do is to prevent any kind of cooperation among firms. In this case a fully cooperative outcome would be preferable to a fully noncooperative outcome from a social planner point of view.

Moreover, we have analyzed the effects of an open standardization policy, either enforced by the state or by private agreement among firms. An open standardization policy has been interpreted as a legal or private provision compelling firms to reveal relevant intellectual property to firms producing complementary products. Such a policy, which increases the spillover effects from interbrand compatibility investments, has been proved to be socially beneficial, whenever firms are allowed to cooperate. Results concerning the \mathcal{NN} , however, remain ambiguous. In particular, for large levels of spillover parameter any further increase of it leads both to lower investment and production levels. In this case, increasing the spillover parameter induces lower welfare levels.

While many people appear to believe intuitively that compatibility is more conducive to competition and thus public policy should promote or mandate compatibility through an open standardization policy, our model suggests a somewhat different view: An open standardization policy enforced through relatively weak protection of intellectual property rights is unambiguously beneficial for society if firms are allowed to coordinate their investment decisions in cooperative standardization groups. However, when firms are operating in a purely competitive environment, weak protection of intellectual property rights might strengthen the adverse effects of free-rider behavior, leading to even lower compatibility efforts.

As the main result of our paper, therefore, we can conclude that the optimal policy mix in the realm of our model is to allow inter-firm cooperation in standardization committees, while preserving product market competition, and to abandon protection of intellectual property rights concerning the relevant features of the interface technology.

Finally, it has been shown that cooperation at the investment stage might lead to asymmetric outcomes, with only one mass market product, and hence, one com-

patibility standard prevailing. In this case, the other firm specializes in producing its niche market product.

Appendix

Proof of Proposition 2

Cases NN and CN: From (9) and (12) we get $q^{NN} = \frac{3(\gamma A + \beta v)}{9\gamma + 2\beta^2} \leq \frac{3(\gamma A + \beta v)}{9\gamma - 2\beta^2} = q^{CN}$, or $-\beta^2 \leq \beta^2$, with equality holding if $\beta = 0$.

Cases NN and CC: From (9) and (14) we obtain $q^{NN} = \frac{3(\gamma A + \beta v)}{9\gamma + 2\beta^2} > \frac{\gamma A + \beta v}{4\gamma - \beta^2} = q^{CC}$, what reduces to $\beta < \sqrt{\frac{3}{5}\gamma}$. This gives, for all $\omega \in -$, the ordering stated in the proposition.

Cases CN and CC: Comparing (12) with (14) we get $q^{CN} = \frac{3(\gamma A + \beta v)}{9\gamma - 2\beta^2} > \frac{\gamma A + \beta v}{4\gamma - \beta^2} = q^{CC}$, for all $\omega \in -$.

Of course, first-best production quantity, q^{FB} , is the largest because of marginal cost pricing, with $p^{FB} = 0$, and because of first-best compatibility investments, x^{FB} , being higher compared to all other regimes. This proves Proposition 2.

Proof of Proposition 3

Cases CN and NN: Substituting q^{CN} and x^{CN} , and q^{NN} and x^{NN} respectively, into the welfare formula (15) and comparing W^{CN} and W^{NN} we get

$$\frac{288\beta^2(9\gamma - \beta^2)(\gamma A + \beta v)^2}{(-9\gamma + 2\beta^2)^2(9\gamma + 2\beta^2)^2} \geq 0.$$

All three terms in brackets are strictly positive, so that $W^{CN} \geq W^{NN}$ holds for all $\omega \in -$ and equality holding for $\beta = 0$.

Cases CC and NN: Substituting q^{CC} and x^{CC} , and q^{NN} and x^{NN} respectively, into the welfare formula (15) and comparing W^{CC} and W^{NN} we get

$$\frac{(-333\gamma^2 + 379\gamma\beta^2 - 92\beta^4)(\gamma A + \beta v)^2}{(-4\gamma + \beta^2)^2(9\gamma + 2\beta^2)^2} \begin{matrix} \geq \\ \leq \end{matrix} 0.$$

Both terms in the denominator and the second term in the numerator are strictly positive for all $\omega \in -$. Calculating the roots of the first term in the numerator gives four real solutions, with one feasible solution, namely,

$$\beta^* = \frac{1}{92} \sqrt{17434 - 782\sqrt{73}} \sqrt{\gamma} \approx 1.13\sqrt{\gamma}.$$

It is now straight forward to check that $W^{\mathcal{NN}}$ and $W^{\mathcal{CC}}$ have to be ordered as stated in the proposition.

Cases \mathcal{CN} and \mathcal{CC} : Again, we calculate $W^{\mathcal{CN}} = W^{\mathcal{CC}}$ and obtain

$$\frac{(333\gamma^2 - 163\beta^2\gamma + 20\beta^4)(\gamma A + \beta v)^2}{(-9\gamma + 2\beta^2)^2(-4\gamma + \beta^2)^2} > 0.$$

Both terms in the denominator and the second term in the numerator are strictly positive for all $\omega \in -$. Calculating the roots of the first term in the numerator gives two pairs of conjugate complex roots, with no solution along the real axis. It is now easily checked that $W^{\mathcal{CN}} > W^{\mathcal{CC}}$ holds for all $\omega \in -$. This establishes Proposition 3.

Proof of Lemma 1

The first part of the lemma follows directly from differentiation of the reduced profit functions $\Pi^{\mathcal{CN}}$ and $\Pi^{\mathcal{CC}}$ with respect to β . The second part of the lemma, which refers to the \mathcal{NN} regime, follows from substituting (9) and (8) into (2) and differentiating with respect to β . This gives

$$\frac{\partial \Pi^{\mathcal{NN}}}{\partial \beta} = 2 \frac{[27v(3\gamma - 2\beta^2) + 2\beta A(2\beta^2 - 27\gamma)](\gamma A + \beta v)}{(9\gamma + 2\beta^2)^3},$$

so that the sign of the derivative depends on the sign of the term

$$27v(3\gamma - 2\beta^2) + 2\beta A(2\beta^2 - 27\gamma).$$

The second term in brackets is strictly negative for all $\omega \in -$, and the first term in brackets is non-positive for $\beta \geq \sqrt{\frac{3}{2}}$. Hence, the derivative is strictly negative for $\sqrt{\frac{3}{2}} \leq \beta < \sqrt{2\gamma}$. For $0 \leq \beta < \sqrt{\frac{3}{2}}$ we get the following condition, so that the derivative is positive:

$$v > \frac{2\beta A(27\gamma - 2\beta^2)}{27(3\gamma - 2\beta^2)} \equiv \bar{v}.$$

If $v \leq \bar{v}$ the derivative is non-positive. This establishes Lemma 1. Note, that \bar{v} meets Assumption 1, what follows from $\bar{v} = \left(\frac{2\beta A}{9}\right) \left(\frac{27\gamma - 2\beta^2}{9\gamma - 6\beta^2}\right)$, where the second fraction in brackets is strictly greater than one. However, \bar{v} may not comply with Assumption 2, in which case the derivate would always be positive.

Proof of Lemma 2

The first part of the proposition follows directly from inserting the equilibrium values of firms' investment and production levels into the welfare formula (15)

and differentiating with respect to β . Similarly, we obtain for the \mathcal{NN} case

$$\frac{\partial W^{\mathcal{NN}}}{\partial \beta} = 8 \frac{[9v(9\gamma - 4\beta^2) + \beta A(2\beta^2 - 45\gamma)](\gamma A + \beta v)}{(9\gamma + 2\beta^2)^3},$$

so that the sign of the derivative is determined by the sign of the term

$$9v(9\gamma - 4\beta^2) + \beta A(2\beta^2 - 45\gamma).$$

For all $\omega \in -$, both terms in brackets have strictly opposite signs, and we get the following condition for the derivative being positive:

$$v > \frac{\beta A(45\gamma - 2\beta^2)}{9(9\gamma - 4\beta^2)} \equiv \underline{v}.$$

Rewriting \underline{v} according to $\underline{v} = \left(\frac{2\beta A}{9}\right) \left(\frac{45\gamma - 2\beta^2}{18\gamma - 8\beta^2}\right)$, we see that \underline{v} fulfils Assumption 1, because the second term in brackets being strictly greater than one. However, \underline{v} is not within the restricted domain of parameters, -, if $\underline{v} = \left(\frac{2\beta A}{9}\right) \left(\frac{45\gamma - 2\beta^2}{18\gamma - 8\beta^2}\right) > \frac{2\sqrt{2\gamma}A}{9}$ holds. In this particular case any increase of β would increase welfare under the \mathcal{NN} regime. This proves Lemma 2.

Joint Profits and Welfare in the Asymmetric Solution of Example 1

In this example, we focus on a particular asymmetric solution in which $q_1 > 0$, $q_2 = 0$, $x_1 = 0$, and $x_2 > 0$ holds. Whenever firm 1 is the only supplier on the mass market it produces the monopoly quantity $q_1^A = \frac{1}{2}(A + \beta x_2)$. This gives the reduced joint profit function in the first stage: $\Pi(x_2) = (A + \beta x_2 - q_1^A)q_1^A + vx_2 - \frac{\gamma}{2}x_2^2$, which is maximized at $x_2^A = \frac{\beta A + 2v}{2\gamma - \beta^2}$, where the superscript ‘‘A’’ indicates the proposed asymmetric solution in the \mathcal{CN} case. For $q_2 = 0$ being a subgame perfect strategy given that $x_1 = 0$ and x_2^A has been chosen in the first stage, $q_2 = \frac{A - \beta x_2^A}{3} \leq 0$, or $\beta \leq \frac{1}{2A}(\sqrt{v^2 + 4\gamma A^2} - v)$ has to hold. Hence, taking the parameter values of the example, we have to restrict attention to $\beta > 0.88$. Finally, social welfare is given by $W^A = (A + \beta x_2^A - \frac{q_1^A}{2})q_1^A + vx_2^A - \frac{\gamma}{2}(x_2^A)^2$ for the proposed asymmetric solution.

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