

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

By Christian Wey¹

1. Introduction

Many markets have the property that the higher the degree of compatibility of the primary good 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

* Verantwortlicher Herausgeber / editor in charge: U. S.

¹ I wish to thank Paul Heidhues, Manfred Holler, Heidrun Hoppe, Joachim Keller, Willy Spanjers, and two anonymous referees for their helpful comments and suggestions on earlier drafts of this paper. This paper also benefited from presentations at the 1999 Meeting of the Verein für Socialpolitik in Mainz, the Humboldt-University Berlin, the Wissenschaftszentrum Berlin, the 3rd Helsinki Workshop on Standardization and Transportation at VATT, and the 2nd Munich Workshop on Network Economics at CES. Of course, the usual disclaimer applies. Financial support by the Graduiertenförderungstipendium of the state of Saarland in 1998 is gratefully acknowledged. This research was also financially supported by the CEPR research network on The Evolution of Market Structure in Network Industries, funded by the European Commission under the Training and Mobility of Researchers Programme (contract No. ERBFMRXCT 980 203).

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. This 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 in interbrand compatibility. If, however, a firm invests in 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 .²

As an alternative, and again, highly stylized example of our model, consider transportation services in the international airline industry. International airlines are organized as hub-and-spoke networks. Consider two airlines, 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 Munich (BA)) as well as a transatlantic route to the hub of the other airline. This means, both airlines serve basically two mar-

² The issue of compatibility investments is also extremely important in the strongly interrelated computer industry where operating systems represent the mass market products. Guaranteeing 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 reported by *Magazin für Computer Technik*, September, 1997, pp. 70–1, where a list of remaining incompatibilities of MacOS 8 is presented.

kets: 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 and 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 arrival and departure timetable with the other airline's arrival and departure times at its domestic hub. *First*, the domestic demand increases because consumers are connected much faster to the other airline when they make overseas travels, and *second*, the other airline benefits indirectly via an increased demand for its transatlantic route.

In the realm of our model, we examine the tradeoff which each firm faces when it makes investments to make its niche product more compatible with the rival's mass product.³ 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 ex ante standardization but rather a matter of degree.⁴ The 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.⁵ Therefore, in contrast to the traditional literature on compatibility standardization as represented by Farrell and Saloner (1985, 1986), Katz and Shapiro (1985, 1986), Matutes and Regibeau (1988), and others, which has focused on the coordination problems of making products

³ With respect to airline services, it is quite obvious that adjusting timetables is costly, and that perfect alignment is almost impossible because of congestion constraints on each hub.

⁴ A quick look at the computer industry reveals that making a specialized software perfectly 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.

⁵ This 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.

⁶ Assuming that consumers value compatibility because of positive network externalities, Katz and Shapiro (1985) examine firms' incentives to coordinate sunk investments on a particular compatibility standard. Products remain perfectly incompatible if firms do not coordinate because compatibility is an either-or deci-

either compatible or not compatible with rivals' products *ex ante*, our model looks at the investment problems *ex post* accruing from positive demand side spillovers.⁶ In addition, we discuss how the application of antitrust laws and the protection of intellectual property rights affect private incentives to increase interbrand compatibility.

Our paper is also related to the work by Kristiansen and Thum (1996) and Farrell and Katz (1998) who examine how compatibility shapes product market competition and firms' incentives towards R&D investments. Kristiansen and Thum (1996) study the patterns of R&D investments in compatible networks where firms sell mass and niche products. R&D investments increase the quality of the mass product, and therefore, benefit both duopolists via their niche markets. Underinvestment results from neglected positive network externalities. Overinvestment might occur strategically to induce the competitor to increase mass products' quality. Since they assume that firms' products are perfectly compatible they do not examine the effects of partial compatibility. Farrell and 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 in 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 and 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.⁷ 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

sion. Matutes and 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 *ex ante* without costs and is always profitable.

⁷ See Henriques (1990) for a critique and d'Aspremont and Jacquemin (1990) for a reply. Their analysis has been extended and generalized by De Bondt and Veugelers (1991), De Bondt, Slaets and Cassiman (1992), Kamiën, Muller and Zang (1992), Suzumura (1992), Vonortas (1994), Steurs (1995), Brod and Shivakumar (1997), Leahy and Neary (1997), Qiu (1997), and Petit and Tolwinski (1999).

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 with a competitive regime in which each firm chooses its R&D expenditures noncooperatively. For relatively low spillovers cooperation at the R&D stage leads to lower investments 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.⁸ This efficiency rationale might help explain why antitrust authorities are much less concerned about the anticompetitive effects of cooperative research compared to other forms of horizontal cooperation.⁹

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 about their compatibility investment levels, 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:¹⁰

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

In reality decisions concerning compatibility often take place within standardization committees.¹¹ In our model those committees are interpreted as

⁸ See also Katz (1986) for an earlier paper which emphasizes the stimulation of incentives towards investments in R&D efforts due to cooperative agreements.

⁹ An early efficiency rationale of horizontal cooperation has been presented by Williamson (1968). See Grossman and Shapiro (1986), Jorde and Teece (1990), Brodley (1990) and Shapiro and Willig (1990) for a critical assessment of the antitrust treatment of horizontal cooperation in research and innovation.

¹⁰ In the following, the regimes are abbreviated by two calligraphic letters, where the first letter describes firms' first-stage behavior either as noncooperative, which is indicated by N , or as cooperative, which is indicated by C . The same method applies for the second letter which stands for firms' behavior at the second stage of the game.

¹¹ The importance of inter-firm cooperation on the standardization stage in software markets has been emphasized by Katz and Shapiro (1998).

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.¹² 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.¹³ It is also interesting to note that the economic literature on standardization committees is surprisingly small. The only contributions we are aware of are Farrell and Saloner (1988) and Goerke and 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 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.¹⁴

¹² For 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).

¹³ The literature on research joint ventures (see Footnote 7) does only consider knowledge spillovers between firms. Investment activities which generate positive demand side effects are not examined in this strand of literature.

¹⁴ Applying our paper to the international airline industry, we may interpret *code-sharing* 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.

The main point of our paper is that organizations, like standardization committees, 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.¹⁵

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 welfare maximizing first-best outcome. In Section 3 we compare our results and summarize the policy conclusions. In Section 4 we analyze the impact of institutions which increase the spillover effects generated by compatibility investments. Finally, Section 5 concludes.

2. The Model

We posit two firms each producing a mass product and a complementary niche product. For each firm, we assume that its mass product and its niche product are designed according to the same firm-specific interface technology, so that complementary products of the same brand 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:¹⁶ $p_i(q_i, q_j) = A - Q$, 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. 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.¹⁷

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 product more compatible with the other firm's mass

¹⁵ For instance, Katz and Shapiro (1998) state with respect to the software industry that they "know of no successful antitrust challenges to cooperation to set software standards".

¹⁶ As in the d'Aspremont-Jacquemin model, we suppose that the demand function faced by the duopolists is linear but, without loss of generality, we suppose its slope is -1 .

¹⁷ For the sake of simplicity, we abstract from any cross-market price effects between the niche and the mass markets.

product. In our model, those investments undertaken by firm i , which are denoted by $x_i \geq 0$, have two effects: *First*, they increase buyers' maximum willingness to pay for firm i 's niche 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 product have a uniform reservation price which increases linearly with firm i 's interbrand compatibility investment level.¹⁸ The monopolistic supplier appropriates the entire consumer surplus and realizes constant marginal net revenues, v , on the niche market from additional investments.¹⁹ 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 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 product is complementary to firm j 's mass 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

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

This means, compatibility investments by firm i differentiate the firms' products in the sense that they improve the quality of firm j 's mass product

¹⁸ In the Appendix, we show that the linear specification of the reduced niche market profits does also apply to an ordinary monopolistic market structure with linear demand.

¹⁹ In 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 and 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 and 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).

relative to firm i 's mass product. An improvement in interbrand compatibility undertaken by firm i , therefore, increases consumers' willingness to pay for firm j 's mass product. Note, when compatibility investments are the same, $x_i = x_j$, 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 and the spillover parameter β , such that market clearing requires $p_i - p_j = \beta(x_j - x_i)$.

Note also, that firm i 's individual mass market demand schedule (1) is independent of its own compatibility investments. Those investments by firm i only generate 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 $\gamma > 0$.

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 production quantities 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) $\beta < \sqrt{2\gamma}$ and (ii) $\sqrt{2\gamma} \leq \frac{9v}{2A}$.*

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.²⁰ 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 $\omega = (A, v, \beta, \gamma) \in \mathbb{R}_+^4$, which satisfy Assumption 1 and 2; i. e., $\Omega = \left\{ \omega \in \mathbb{R}_+^4 \mid \beta < \sqrt{2\gamma} < \frac{9v}{2A} \right\}$.²¹

We now solve the game by backward induction, where we assume that firms cannot make side payments. This means each firm has to realize its payoffs individually after the second stage of the game, so that “a player’s payoff consists of the second stage production profits less his first-stage R&D expenditure” (Kamien, Muller and Zang, 1992, p. 1294). Because of this assumption we can restrict attention to the symmetric equilibrium under each regime.²²

In Section 2.1 we calculate the noncooperative and cooperative optimal strategies in the second 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

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

²⁰ Analytically Assumption 2 (i) ensures that all second order conditions under \mathcal{NN} , \mathcal{CN} , \mathcal{CC} , and the welfare maximizing regime, which will be introduced below, are fulfilled.

²¹ With \mathbb{R}_+ we denote the set of all positive real numbers including zero.

²² The symmetric solution under the \mathcal{CN} and the \mathcal{CC} regime has been adopted by almost all the literature that was sparked by the seminal work of d’Aspremont and Jacquemin (1988). It has been recently criticized by Salant and Shaffer (1998, 1999) who 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 rival. However, such an asymmetric outcome is only feasible if firms can make side payments, because sales revenue for the firm with the smaller market share are strictly lower in any asymmetric outcome than in the symmetric equilibrium. See also Heidhues and Wey (1999) who show within the d’Aspremont–Jacquemin model that the symmetric solution is pareto-optimal in the \mathcal{CN} regime.

The symmetric Nash-Cournot equilibrium can be computed to be²³

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

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):

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

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

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

Maximization yields for each firm’s quantities

$$(6) \quad q = \frac{A + \beta x}{4} ,$$

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 second stage):

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

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 (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 get²⁴

²³ The second order condition for a profit maximum is always fulfilled.

²⁴ The 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 condi-

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

and

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

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 of perfect interbrand incompatibility.

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

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

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 solution²⁵

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

and

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

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., $v = 0$.

tion. In contrast to the model of d'Aspremont and 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).

²⁵ The 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, satisfying²⁶

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

and

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

where CC represents the *cartelization* regime. Let us now turn to the welfare maximizing investment and output levels before we 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 $W^{FB}(q, x)$ 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,²⁷ consumer surplus is $CS(q, x) = 2q^2$, and the social welfare function is given by

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

We get as the efficient output for each firm²⁸

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

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

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

²⁶ The second order condition for the second stage requires $\beta < 2\sqrt{\gamma}$.

²⁷ Recall all firms are assumed to extract the entire consumer surplus in their niche markets.

²⁸ The second order condition always holds.

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 is²⁹

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

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

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

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 $\omega \in \Omega$ 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:

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

²⁹ The 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,

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

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 $x^{FB} = x^{CC} = x^{CN} = x^{NN} = \frac{v}{\gamma}$. 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 CN and 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 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. 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 (CC).

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

Proposition 2: Consider all $\omega \in \Omega$. 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 , under the different regimes, $l = FB, NN, CN, CC$, satisfy

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

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

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

with $q^{CC} = q^{NN}$ 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 (CN) regime. Moreover, for relatively large spillovers, such that $\beta > \sqrt{\frac{3}{5}}\gamma$ is fulfilled, fully cooperative behavior (CC) leads to higher production quantities than pure competitive behavior (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 (CC) might lead to higher production levels on the mass market compared to 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 more likely the higher the value of the spillover parameter.

The following proposition states the welfare results of our model.

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

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

and

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

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

$$W^{NN} > W^{CC}, \text{ if and only if } 0 \leq \beta < \beta^*,$$

and

$$W^{NN} \leq W^{CC}, \text{ if and only if } \beta^* \leq \beta < \sqrt{2}\gamma,$$

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

Proof: See Appendix. Q. E. D.

From Proposition 3 we see that welfare under CN is higher than under NN , whenever the spillover parameter is positive. The intuition for this result is the following: From Proposition 2 we know that $q^{CN} > q^{NN}$ holds for $\beta > 0$, so that consumer surplus must have increased. Firms' profits also

must have increased, because otherwise firms would have chosen the non-cooperative investment levels within the cooperative standard setting group. Therefore, consumer surplus and firms' profits both increase under the CC regime compared to the NN regime.

From Proposition 1 and 2 we obtain a sufficient condition for welfare under CC being higher than under NN , namely $\hat{\beta} > \sqrt{\frac{3}{5}}\gamma$, so that both quantities of production and compatibility investment levels are higher under CC . However, Proposition 3 shows that social welfare increases under 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 (NN) gives higher levels of output, which outweigh the social benefits from relatively higher investments under 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 *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.³⁰ This might help to explain why cooperative interfirm relations within standardization committees are usually not alleged to be anti-competitive.

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 $\omega \in \Omega$ the equilibrium prices on the mass market, p^l , under the different regimes, $l = FB, NN, CN, CC$, satisfy the following ordering:

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

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

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

³⁰ In our welfare analysis we rather underestimated the welfare effects generated by compatibility investments. If we assume a 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.

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 *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 product variety when products are either perfectly compatible or perfectly incompatible (see, e. g., Matutes and Regibeau 1988, and Economides, 1989, 1991a). 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 investigate firms' incentives to establish 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.

4. Open Standardization Policy

In accordance with the approach proposed by Kamien, Muller and Zang (1992) we examine the impact of RJV-like institutions which increase the level of the spillover parameter. 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 investments 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. One 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, trans-

lating object code back into source code) are permitted where they are necessary to gain information to allow software/hardware interoperability (see Schmidtchen and Koboldt, 1993, and Shurmer and Lea 1995).

The following two lemmas summarize the comparative static results with respect to β for firms' profits and social welfare.

Lemma 1: For $\omega \in \Omega$, 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 $v' = \max \left\{ \frac{2\sqrt{2\gamma}A}{9}, \frac{2\beta A(27\gamma - 2\beta^2)}{27(3\gamma - 2\beta^2)} \right\}$, 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.

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 information 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:

$$(20) \quad \frac{d q^{\mathcal{NN}}}{d \beta} = \frac{1}{3} \left(x^{\mathcal{NN}} + \beta \frac{\partial x^{\mathcal{NN}}}{\partial \beta} \right) > 0$$

$$\Rightarrow x^{\mathcal{NN}} > \beta \left| \frac{\partial x^{\mathcal{NN}}}{\partial \beta} \right|.$$

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 .³¹ 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.

Lemma 2 states the corresponding welfare results for each regime.

Lemma 2: For $\omega \in \Omega$, 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

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

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

³¹ The latter follows from the fact that magnitude of the derivative $\frac{\partial x^{\mathcal{NN}}}{\partial \beta}$ decreases with higher values of v .

Proposition 5: *For all $\omega \in \Omega$, 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 information concerning the interface technology. In all regimes those agreements lead to higher welfare levels. Proposition 6 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 $\omega \in \Omega$. 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 enforced by a government always unfolds 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 leads 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 intel-

lectual property rights directly transforms into higher degrees of compatibility (see Farrell and Katz, 1998, p. 44)

5. 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 in order to achieve interbrand compatibility. We have analyzed the impact of three organizational modes, varying from pure market contact to full cartelization, on firms' incentives to invest in 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 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 airline 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 CC regime compared with the hybrid regime CN .

We also found that depending on the spillover parameter either the compatibility competition (NN) or the cartelization (CC) regime is the least desirable one. For relatively low spillover effects, the NN regime generates higher welfare levels than the CC regime. However, for relatively high levels of the spillover parameter cartelization (CC) increases investment activity so much that welfare is higher under CC compared with 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 (CC) does never lead to higher welfare levels compared with pure competitive behavior (NN).

The policy implications are therefore straight forward. In markets that meet our suppositions, cooperation of compatibility investments in standar-

dization committees should be encouraged, while competition on the mass market has to be preserved. In markets with relatively large spillover effects the worst thing that a 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} regime, 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.

Appendix

Linear downward sloping niche market demand

We show that the linear specification of the reduced niche market profits, vx_i , also applies to an ordinary monopolistic market structure with a linear downward sloping demand function. Assume firm i 's inverse niche market demand is given by $p_i^N = M + x_i - hy_i$, where p_i^N denotes firm i 's niche product price, and y_i stands for quantity. Normalizing marginal costs to zero, firm i 's niche market profits are given by $\Pi_i^N = (M + x_i - hy_i)y_i$. By substituting the monopoly solution back into the profit

function we derive the reduced niche market profits $\hat{\Pi}_i^N = \frac{1}{4h}(M + x_i)^2$. Therefore, firm i 's total profits are

$$\Pi_i = (A + \beta x_j - q_i - q_j)q_i + \frac{M^2}{4h} + \frac{M}{2h}x_i - \frac{2h\gamma' - 1}{4h}x_i^2.$$

We get the same payoff structure as stated in equation (2), if $v \equiv \frac{M}{2h}$ and $\gamma \equiv \frac{2h\gamma' - 1}{2h}$, with $\gamma' > (1/2h)$, holds. Neglecting the constant term $\frac{M^2}{2h}$ does not affect the results derived in the paper qualitatively.

Proof of Proposition 2

Cases NN and CN: From (9) and (14) 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 $\omega \in \Omega$, 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 $\omega \in \Omega$.

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 $\omega \in \Omega$, 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

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

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

$$\beta^* = \frac{1}{2}\sqrt{17434 - 782\sqrt{73}\sqrt{\gamma}} \approx 1.13\sqrt{\gamma}.$$

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

Cases CN and CC : Again, we show that $W^{CN} > W^{CC}$ holds. Comparison of welfare levels gives

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

Both terms in the denominator and the second term in the numerator are strictly positive for all $\omega \in \Omega$. 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 $W^{CN} > W^{CC}$ holds for all $\omega \in \Omega$. This establishes Proposition 3.

Proof of Lemma 1

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

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

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 $\omega \in \Omega$, 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 negative. 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 $\omega \in \Omega$, both terms in brackets have strictly opposite signs, and we get the following condition for the derivative being positive:

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

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

References

- Amir, R.* (1998): Modelling Imperfectly Appropriable R&D Via Spillovers, University of Copenhagen, Centre for Industrial Economics, Discussion Paper 98-07, Copenhagen.
- Brod, A. and Shivakumar, R.* (1997): R&D Cooperation and the Joint Exploitation of R&D, *Canadian Journal of Economics* 30, 673-684.
- Brodley, J. E.* (1990): Antitrust Law and Innovation Cooperation, *Journal of Economic Perspectives* 4, 97-112.
- Brueckner, J. K.* (1998): The Economics of International Codesharing: An Analysis of Airline Alliances, Mimeo., University of Illinois at Urbana-Champaign, Champaign, IL.
- Brueckner, J. K. and Spiller, P. T.* (1991): Competition and Mergers in Airline Networks, *International Journal of Industrial Organization*, 9, 323-342.
- d'Aspremont, C. and Jacquemin, A.* (1988): Cooperative and Noncooperative R&D in Duopoly with Spillovers, *American Economic Review* 78, 1133-1137.
- (1990): Cooperative and Noncooperative R&D in Duopoly with Spillovers: Erratum, *American Economic Review* 80, 641-642.

- De Bondt, R. and Veugelers, R. (1991): Strategic Investments With Spillovers, European Journal of Political Economy 7, 345–366.*
- De Bondt, R.; Slaets, P. and Cassiman, B. (1992): The Degree of Spillovers and the Number of Rivals for Maximum Effective R&D, International Journal of Industrial Organization 10, 35–54.*
- Economides, N. (1989): Desirability of Compatibility in the Absence of Network Externalities, American Economic Review 79, 1165–1181.*
- (1991a): Compatibility and the Creation of Shared Networks, in: M. Guerrin-Calvert and S. Wildman (eds.), *Electronic Services Networks: A Business and Public Policy Challenge*, New York.
 - (1991b): *Compatibility and Market Structure*, Stern School of Business, New York University, New York, Mimeo.
- Einhorn, M. A. (1992): Mix and Match Compatibility with Vertical Product Dimensions, Rand Journal of Economics 23, 535–547.*
- Farrell, J. (1989): Standardization and Intellectual Property, Working Paper No. 89-7, University of California, Berkeley.*
- (1995): Arguments for Weaker Intellectual Property Protection in Network Industries, pp. 368–377 in: B. Kahin and J. Abbate (eds.), *Standards Policy for Information Infrastructure*, Cambridge.
- Farrell, J. and Katz, M. L. (1998): The Effects of Antitrust and Intellectual Property Law on Compatibility and Innovation, Antitrust Bulletin, forthcoming.*
- Farrell, J. and Saloner, G. (1985): Standardization, Compatibility, and Innovation, Rand Journal of Economics 16, 70-83.*
- (1986): Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation, *American Economic Review* 76, 940–955.
 - (1988): Coordination Through Committees and Markets, *Rand Journal of Economics* 19, 235–252.
- Goerke, L. and Holler, M. J. (1995): Voting on Standardization, Public Choice 83, 337–351.*
- Grossman, G. and Shapiro, C. (1986): Research Joint Ventures: An Antitrust Analysis, Journal of Law, Economics, and Organization 2, 315-337.*
- Heidhues, P. and Wey, C. (1999): Unequal Treatment of Identical Agents in Cournot Equilibrium: Comment, Wissenschaftszentrum Berlin, Mimeo.*
- Henriques, I. (1990): Cooperative and Noncooperative R&D in Duopoly with Spillovers: Comment, American Economic Review 80, 638-640.*
- Jorde, T. M. and Teece, D. J. (1990): Innovation and Cooperation: Implications for Competition and Antitrust, Journal of Economic Perspectives 4, 75-96.*
- Kamien, M. I.; Muller, E. and Zang, I. (1992): Research Joint Ventures and R&D Cartels, American Economic Review 82, 1293-1306.*
- Katz, M. L. (1986): An Analysis of Cooperative Research and Development, Rand Journal of Economics 17, 527-543.*
- Katz, M. L. and Shapiro, C. (1985): Network Externalities, Competition, and Compatibility, American Economic Review 75, 424–440.*

- (1986): Technology Adoption in the Presence of Network Externalities, *Journal of Political Economy* 94, 822 – 841.
- (1998): Antitrust in Software Markets, University of California, Berkeley, Mimeo.
- Kristiansen, E. G. and Thum, M.* (1997): R&D Incentives in Compatible Networks, *Journal of Economics* 65, 55 – 78.
- Leahy, D. and Neary, P.* (1997): Public Policy Towards R&D in Oligopolistic Industries, *American Economic Review* 87, 642 – 662.
- Matutes, C. and Regibeau, P.* (1988): Mix and Match: Product Compatibility Without Network Externalities, *Rand Journal of Economics* 19, 221 – 234.
- Petit, M. L. and Tolwinski, B.* (1999): R&D Cooperation or Competition, *European Economic Review* 43, 185–208.
- Qiu, L.D.* (1997): On the Dynamic Efficiency of Bertrand and Cournot Equilibria, *Journal of Economic Theory* 75, 213 – 229.
- Salant, S. W. and Shaffer, G.* (1998): Optimal Asymmetric Strategies in Research Joint Ventures, *International Journal of Industrial Organization* 16, 195 – 208.
- (1999): Unequal Treatment of Identical Agents in Cournot Equilibrium, *American Economic Review* 89, 585 – 604.
- Schmidtchen, D. and Koboldt, C.* (1993): A Peacemaker that Stops Halfway: The Decompilation Rule in the EEC Directive on the Legal Protection of Computer Programs, *International Review of Law and Economics* 13, 413 – 429.
- Shapiro, C. and Willig, R. D.* (1990): On the Antitrust Treatment of Production Joint Ventures, *Journal of Economic Perspectives* 4, 113 – 130.
- Shurmer, M. and Lea, G.* (1995): Telecommunications Standardization and Intellectual Property Rights: A Fundamental Dilemma, pp. 378–402 in: B. Kahin and J. Abbate (eds.), *Standards Policy for Information Infrastructure*, Cambridge.
- Steurs, G.* (1995): Inter-Industry Spillovers: What Difference Do They Make?, *International Journal of Industrial Organization* 13, 249 – 276.
- Suzumura, K.* (1992): Cooperative and Noncooperative R&D in an Oligopoly with Spillovers, *American Economic Review* 82, 1307 – 1320.
- Vonortas, N. S.* (1994): Inter-Firm Cooperation With Imperfectly Appropriable Research, *International Journal of Industrial Organization* 12, 413 – 435.
- Williamson, O. E.* (1968): Economies as an Antitrust Defense: The Welfare Tradeoffs, *American Economic Review* 58, 18 – 35.

Abstract

This paper examines the effects of different degrees of cooperation on firms' incentives to undertake interbrand compatibility investments, 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 feasible values of the spillover parameter. For large spillover effects cartelization in compatibility investments and on the product market is welfare improving compared with pure competitive behavior. Furthermore, we exam-

ine the effects of an “open standardization policy” which increases the level of the spillover parameter.

Zusammenfassung

Diese Arbeit untersucht die Wirkungen horizontaler Kooperation auf die Anreize der Unternehmen, Kompatibilitätsinvestitionen zu tätigen, die die Wettbewerbsposition des rivalisierenden Unternehmens auf dem Massenmarkt verbessert. Es wird gezeigt, daß Kooperation auf der Investitionsstufe in Verbindung mit Konkurrenz auf dem Massenmarkt 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.

JEL-Klassifikation: L13, L41, O31