

Woeckener, Bernd

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**Wirtschaftswissenschaftliche Fakultät
der Eberhard-Karls-Universität Tübingen**

**Network Effects, Compatibility
Decisions,
and Monopolization**

Bernd Woeckener



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Network Effects, Compatibility Decisions, and Monopolization

Bernd Woeckener

*Wirtschaftswissenschaftliche Fakultät, Universität Tübingen,
Mohlstraße 36, D-72074 Tübingen, Germany*

Abstract

This paper analyzes the compatibility decision of a dominant hardware supplier. There are two substitutive variants of the hardware component of a hardware-software system, they are horizontally differentiated, and one of the two has a quality advantage. Among other things, we show under what circumstances the dominant supplier monopolizes his market via maintaining incompatibility with the variant of the competitor. It turns out that, depending on the significance of the network effects, of the horizontal differentiation and of the quality advantage, not only the coexistence of compatible variants but also a monopolization and even the coexistence of incompatible variants can be welfare superior.

Zusammenfassung

Dieses Papier untersucht die Kompatibilitätsentscheidung eines dominanten Hardwareanbieters. Wir nehmen an, daß es zwei substitutive Varianten der Hardwarekomponente eines Hardware-Software-Systems gibt, die horizontal differenziert sind und von denen eine einen Qualitätsvorteil hat. Unter anderem wird gezeigt, unter welchen Umständen der dominante Anbieter seinen Markt mittels der Aufrechterhaltung von Inkompatibilität monopolisiert. Aus der Wohlfahrtsanalyse folgt, daß – je nach der Bedeutung der Netzefekte, dem Ausmaß der horizontalen Differenzierung und der Größe des Qualitätsvorteils – nicht nur die Koexistenz kompatibler Varianten, sondern auch die Marktmonopolisierung mittels aufrechterhaltener Inkompatibilität und sogar die Koexistenz inkompatibler Varianten wohlfahrtsüberlegen sein kann.

Keywords: Compatibility, Monopolization, Network effects, Standardization

JEL classification: D43, L12, L41

1. Introduction

It is everyday experience that a user's surplus from a hardware-software system often depends positively on the total number of users of the same type of system. Obvious examples are personal-computer systems and compact-disk systems (with the disks as 'software'). These 'indirect' or 'market mediated network effects'¹ are due to the fact that software components are typically produced with relatively high fixed costs and (more or less) constant marginal costs. Then, with free market entry, a rising total system demand increases the number of differentiated software-component variants, and with a preference for a variety of software, this results in an increase in each user's surplus. As the significance of the network effects depends on the degree of compatibility between competing system variants, the compatibility decisions of the suppliers of system components are of central importance for market performance and welfare. In particular, the hardware suppliers' decisions on indirect horizontal (in)compatibility with competing hardware variants, i.e. on vertical (in)compatibility with software which is operable under competing hardware variants, are often decisive for the outcome of the system competition.²

The following analysis of the compatibility decision of a dominant hardware supplier takes up this issue. Among other things, it aims at showing how and when he can and will turn a quality advantage into a monopolization of the hardware market by making sure that software which is compatible with his hardware is incompatible with competing hardware, so that consumers of the competing hardware do not benefit from the network effects of his system variant.³ We present a Hotelling model of the competition between two hardware suppliers who can, due to intellectual property rights attached to their interface specifications, unilaterally prevent compatibility. First, the duopolists simultaneously decide on (in)compatibility, and then, they compete in prices. A central feature of our Hotelling model with network effects is that one of the duopolists has a systematic quality advantage, i.e., the Hotelling approach presented is not symmetric. We show that the dominant supplier could monopolize his market whenever network effects are strong compared

¹For this terminology, see Katz/Shapiro (1985), p. 424, and Farrell/Saloner (1985), p. 70. See Holler/Knieps/Niskanen (1997), pp. 383ff, for a classification of network effects.

²For a classification of the various kinds of (in)compatibility, see Wiese (1997), pp. 285ff. In the following, '(in)compatibility' always means 'indirect horizontal (in)compatibility'.

³An example of such a prevention of compatibility can be found in the context of one of several antitrust investigations of the US Department of Justice against Microsoft. There, Digital Research complained that it was being systematically discriminated against (compared with other software developing firms) when Microsoft disclosed details about new specifications of the interface between its (Microsoft's) operating system MS DOS and application programs, and that in this way Microsoft hindered Digital Research's ability to keep its operating system DR DOS compatible with MS DOS. See Baseman/Warren-Boulton/Woroch (1995), pp. 299ff, for details. (In this example, the operating systems are the competing basic 'hardware' variants and the application programs are the 'software' components.)

with the extent of the horizontal differentiation, whereas he has to choose between the coexistence of compatible and of incompatible hardware variants whenever network effects are relatively weak. In the latter case, he always prefers compatibility. However, due to the existence of a quality advantage, this can be welfare inferior to the coexistence of incompatible variants, because under incompatibility more consumers buy the variant with the quality advantage. A monopolization of the hardware market proves to be welfare inferior to compatibility whenever the quality advantage is low compared to the extent of the horizontal differentiation. However, the contrary holds whenever the quality advantage is considerably high. This is due to a price distortion in the case of coexisting system variants.

The first stringent analysis of the private and social incentives for compatibility is Katz/Shapiro (1985). They, however, restrict themselves to discussing the case of homogeneous network-effect goods.⁴ A horizontal differentiation of the basic system component is assumed in Farrell/Saloner (1992), in Desruelle/Gaudet/Richelle (1996) and in Church/Gandal (1996). In the first two articles mentioned, however, the Hotelling approach is symmetric, and thus all of our central results concerning the effects of a vertical quality bias are not derived there. Moreover, while in Farrell/Saloner (1992) compatibility is provided by a converter, i.e. ex post (after production of hardware), in our model, compatibility is realized ex ante (or not at all). In Church/Gandal (1996), incompatibility is exogenously given, i.e., the compatibility decision is not analyzed. They show how a hardware as well as software supplying incumbent can deter entry by offering such a variety of software that his resulting installed base is large enough to make entry unprofitable for an incompatible competitor. That is, in their approach, there is a dominant supplier and this dominant supplier can monopolize the market. His dominance, however, stems from a first-mover advantage, not from a quality advantage, and he monopolizes the market via his installed base, not via deliberately chosen incompatibility. Their dominant supplier, for example, neither has the option of accommodating *compatible* entry, nor can he choose between the coexistence of compatible and of incompatible hardware variants.

The paper is organized as follows: after the basic model has been presented in Section 2, we discuss the price competition of the second stage of the game for given compatibility in Section 3 and for given incompatibility in Section 4. In Section 5, the profit maximizing compatibility decisions are derived and compared with the welfare-theoretical first-best solutions. Here, we also discuss voluntary licensing of the intellectual property rights attached to the interface specifications. In Section 6, policy implications are derived against the background of a reasonable welfare-theoretical standard.

⁴A recent approach along these lines is de Palma/Leruth (1996).

2. The Model

There are two suppliers, D1 and D2, each producing one of two substitutive variants of the hardware component of a hardware-software system, V1 and V2, and selling them at prices p_1 and p_2 , respectively. The hardware variants are horizontally differentiated with V1 at the left-end point and V2 at the right-end point of the unit line. Furthermore, V1 has a systematic quality advantage, i.e., the per se horizontal differentiation has a vertical bias. We assume that this advantage has resulted from an R&D competition in which both suppliers could achieve it with equal probability. Marginal costs of hardware production are constant and equal for both variants.⁵ Without loss of generality, we normalize these costs to zero. For simplicity, the same is assumed to be true with regard to the fixed costs of hardware production. As for the software markets, which are not explicitly modelled, we assume monopolistic competition with free entry and constant and equal marginal costs as well as equal fixed costs in the production of each software variant. Hence, in the case of incompatibility, the software variety of a system variant increases with rising demand for that system variant.⁶ As the specifications of both hardware-software interfaces are protected by intellectual property rights, compatibility only comes about if *both* duopolists prefer it. Moreover, it is assumed that the duopolists can only decide on (in)compatibility *ex ante*, and that, therefore, compatibility causes no extra costs.

Consumers' general willingness to pay for a system variant is uniformly distributed along the unit line, the total number of consumers is normalized to one, and each consumer purchases one (and only one) unit of hardware. Hence, the market is always covered, and the absolute demand for a system variant equals its market share, which in turn equals the variant's network size in the case of incompatibility. It is assumed that each consumer's surplus is a linear function in network size, and that consumers do not differ in their valuation of network effects. Let x and $1 - x$ be the market shares of V1 and V2, respectively, and let $0 \leq i \leq 1$ be the index for a consumer's address on the Hotelling line. Then, in the case of incompatibility, the surplus of a consumer with address i when purchasing V1 or V2 can be formulated as

$$(1) \quad s_{i1} = a_1 - m i + n x - p_1 \quad \text{and}$$

$$(2) \quad s_{i2} = a_2 - m (1 - i) + n (1 - x) - p_2 \quad \text{with } 0 < a_1 - a_2 < m ,$$

⁵Our central results hold as long as the quality advantage is not overcompensated by a cost disadvantage.

⁶See Dixit/Stiglitz (1977), pp. 298ff. Software markets are explicitly modelled in Chou/Shy (1990) and Church/Gandal (1992) (and in the subsequent works of these authors). As we are not interested in the vertical aspects of compatibility per se, we follow Katz/Shapiro (1985) and Farrell/Saloner (1985) in modelling indirect network effects simply by assuming a positive dependence of a user's surplus on the total number of users of compatible system variants.

respectively. Here, n is a measure of network-effect strength, m is a measure of the extent of the horizontal differentiation, and a_j is the basic willingness to pay for system variant V_j ($j = 1, 2$). According to Equations (1) and (2), the variants can differ in network size, in price, and with regard to the systematic (i.e. i - and x -independent) basic willingness to pay. As for the systematic ‘basic advantage’ of V1, $k = a_1 - a_2$, we demand $k < m$, i.e., despite this vertical effect, the differentiation is always horizontal.⁷ In the case of compatibility, both variants have a joint network of size one, i.e., $s_{i1} = a_1 - m i + n - p_1$ and $s_{i2} = a_2 - m(1 - i) + n - p_2$ hold.

We assume that the duopolists simultaneously and credibly commit to (in)compatibility in the first stage of the game and compete in prices in the second stage. In our analysis of the noncooperative market process, we restrict ourselves to the derivation of subgame-perfect Nash equilibria. Hence, in a first step, we compute the Nash equilibria of the price subgame given that compatibility has been established (in Section 3) and given that incompatibility has been maintained (in Section 4). Then (in Section 5) we deduce the profit-maximizing compatibility decisions of the duopolists.

3. Price Competition with Given Compatibility

3.1 Market Equilibria

By equating $a_1 - m i + n - p_1$ with $a_2 - m(1 - i) + n - p_2$, we obtain the address of those consumers who are indifferent between V1 and V2. As total demand is normalized to one and consumers are uniformly distributed along the unit line, this address is identical with the V1 market share. Hence, D1 faces the demand function

$$(3) \quad x = 0.5 + \frac{p_2 - p_1 + k}{2m},$$

and the demand for V2 results as $1 - x = 0.5 + (p_1 - p_2 - k)/(2m)$. Obviously, the effect of a quality advantage is stronger, the less important the horizontal differentiation is. Maximizing profits $G_1 = p_1 x$ and $G_2 = p_2(1 - x)$ with the help of (3) leads, via the first-order conditions, to the best-response functions $p_1 = 0.5(m + k + p_2)$ and $p_2 = 0.5(m - k + p_1)$. Hence, given that compatibility has been established in the first stage of the game, the Nash equilibria of the price competition are

$$(4) \quad p_1^c = m + \frac{k}{3},$$

$$(5) \quad p_2^c = m - \frac{k}{3}$$

⁷For $k > m$, with $p_1 = p_2$ and equal network size, even $i = 1$ -consumers choose V1, i.e., then the differentiation is vertical.

with

$$(6) \quad x^c = 0.5 + \frac{k}{6m}.$$

For individual and total equilibrium profits, we obtain

$$(7) \quad G_1^c = \frac{m}{2} + \frac{k}{3} + \frac{k^2}{18m},$$

$$(8) \quad G_2^c = \frac{m}{2} - \frac{k}{3} + \frac{k^2}{18m},$$

$$(9) \quad G^c = G_1^c + G_2^c = m + \frac{k^2}{9m}.$$

The consumer surplus from V1 and V2 amounts to $S_1 = (a_1 + n - p_1)x - 0.5mx^2$ and $S_2 = (a_2 + n - p_2)(1 - x) - 0.5m(1 - x)^2$, respectively. Using Equations (4), (5) and (6), the consumer surplus in equilibrium results as

$$(10) \quad S^c = \frac{a_1 + a_2}{2} + n - \frac{5m}{4} + \frac{k^2}{36m}.$$

Finally, making use of (9), we obtain total welfare in equilibrium as

$$(11) \quad W^c = \frac{a_1 + a_2}{2} + n - \frac{m}{4} + \frac{5k^2}{36m} \quad \text{with} \quad \frac{a_1 + a_2}{2} = a_1 - \frac{k}{2}.$$

Due to $k < m$, all Nash equilibria are inside the interval $m < p_1^c < 4m/3$ and $2m/3 < p_2^c < m$, i.e. $1/2 < x^c < 2/3$ holds. Furthermore, both prices and profits of both duopolists rise with increasing m . While prices and profits are independent of the network-effect strength n , surplus and welfare increase with rising n (and, of course, decrease with rising m). As for the comparative-static effects of a change in the quality advantage $k = a_1 - a_2$, we restrict ourselves to the analysis of changes in k which result from a symmetric expansion or contraction of the quality interval, i.e., a_1 increases/decreases to the same extent as a_2 decreases/increases. Such changes in k leave the sum $a_1 + a_2$ constant, so that there is *no direct* effect on the levels of surplus and welfare. From Equations (4) to (11), we obtain the following proposition for the price subgame:

Proposition 1. *Given that compatibility has been established in the first stage of the game, both price and market share of the dominant supplier are higher than those of his competitor. Furthermore, a higher quality advantage of the dominant supplier's hardware variant leads to lower profits of his competitor and to higher profits for himself as well as to higher total profits, higher consumer surplus and, hence, higher total welfare.*

The latter results from the indirect effect that, with a higher quality advantage of V1, its market share rises. Such an increase in x always has two opposing effects

on welfare. On the one hand, it increases welfare by $(a_1 - a_2)\partial x$. We call this ‘the vertical welfare effect’. On the other hand, it diminishes welfare due to a higher average distance between a consumer and his ‘ideal good’ (more formally: the sum of the cumulated horizontal alienation terms mi and $m(1-i)$ rises with an increase in the distance between x and 0.5). We call this ‘the horizontal welfare effect’. Within the interval $0.5 < x^c < 2/3$, the positive vertical welfare effect always dominates the negative horizontal welfare effect.

3.2 Welfare Optima

Due to the existence of a quality advantage, the Nash equilibria are characterized by a fundamental price distortion. While the market realizes a price difference of $2k/3$ (see Equations [4] and [5]), a social planner who is confronted with given compatibility would sell both variants at equal prices.⁸ This becomes clear from maximizing total welfare $W = S + G = (a_1 + n)x - 0.5mx^2 + (a_2 + n)(1 - x) - 0.5m(1 - x)^2$ with respect to x and substituting the resulting quantity into (3). Hence, in a *welfare optimum for given compatibility*, we have

$$(12) \quad (p_1 - p_2)^{c,wo} = 0$$

and

$$(13) \quad x^{c,wo} = 0.5 + \frac{k}{2m}.$$

Thus, the highest welfare level feasible for given compatibility is

$$(14) \quad W^{c,wo} = \frac{a_1 + a_2}{2} + n - \frac{m}{4} + \frac{k^2}{4m}.$$

Comparing (6) and (13) makes clear that the higher than optimal market price of V1 leads to a market share of V1 which is by a factor of $k/(3m)$ too low. A social planner who increases x from x^c to $x^{c,wo}$ by selling both variants at equal prices would realize a positive vertical welfare effect $k\partial x$ of $k^2/(3m)$ and a negative horizontal welfare effect of $2k^2/(9m)$. That is, he could increase welfare by $k^2/(9m)$. To enforce welfare-optimal prices in all hardware markets is, however, a quite unrealistic project. Hence, we assume for the following that there are no such direct policy interventions in the price formation (and that the duopolists know that).

⁸As the market is always covered, only relative prices matter.

4. Price Competition with Given Incompatibility

4.1 Market Equilibria

Given that incompatibility has been maintained in the first stage of the game, the address of those consumers who are indifferent between V1 and V2 results from Equations (1) and (2) as $i = 0.5 + [p_2 - p_1 + k + n(2x - 1)]/(2m)$, and using $x = i$ leads to

$$(15) \quad x = 0.5 + \frac{p_2 - p_1 + k}{2(m - n)} .$$

Here, two cases have to be considered: in the first case, the horizontal differentiation dominates the network effects ($m > n$). Then (15) is the demand function for V1. Comparing (15) with the demand function under compatibility, Equation (3), makes clear that the price elasticity in this first case is higher under incompatibility than it is under compatibility. That is, competition is *more* intensive when the system variants are incompatible. This is due to the fact that the existence of network effects has the same effect as a reduction in the horizontal differentiation. In the second case, the network effects dominate the horizontal differentiation ($n > m$). Instead of Equation (15), then an all-or-nothing relationship holds between market shares and the price difference, i.e. $x = 0$ for high $p_1 - p_2$ and $x = 1$ for low $p_1 - p_2$.

4.1.1 The Horizontal Differentiation Dominates the Network Effects

From the first-order conditions of the maximization of $G_1 = p_1x$ and $G_2 = p_2(1 - x)$, we obtain the best-response functions $p_1 = 0.5(m - n + k + p_2)$ and $p_2 = 0.5(m - n - k + p_1)$. The second-order condition is $1/(n - m) < 0$, and, obviously, this is (only) fulfilled for $m > n$. Hence, given that in the first stage of the game *incompatibility* has been maintained, the Nash equilibria of the price subgame in case of a *duopoly* are

$$(16) \quad p_1^{in,d} = m - n + \frac{k}{3} ,$$

$$(17) \quad p_2^{in,d} = m - n - \frac{k}{3} .$$

Again, there is a price difference of $2k/3$. Substituting this price difference into (15) leads to

$$(18) \quad x^{in,d} = 0.5 + \frac{k}{6(m - n)} .$$

Comparing (18) with (6) shows that, despite an identical price difference, the market share of V1 is higher under incompatibility than under compatibility. This reflects

the fact that, in the case of incompatibility, network effects work as a multiplier of the quality advantage. The higher market share of V1 (due to $a_1 > a_2$) here also means a larger network size, and, thus, some consumers who would choose V2 under compatibility opt for V1 under incompatibility. From Equations (16) to (18), we obtain equilibrium profits as

$$(19) \quad G_1^{in,d} = \frac{m-n}{2} + \frac{k}{3} + \frac{k^2}{18(m-n)},$$

$$(20) \quad G_2^{in,d} = \frac{m-n}{2} - \frac{k}{3} + \frac{k^2}{18(m-n)},$$

$$(21) \quad G^{in,d} = G_1^{in,d} + G_2^{in,d} = m - n + \frac{k^2}{9(m-n)}.$$

Now, the consumer surplus from V1 and V2 amounts to $S_1 = (a_1 + nx - p_1)x - 0.5mx^2$ and $S_2 = [a_2 + n(1-x) - p_2](1-x) - 0.5m(1-x)^2$, respectively. Hence, using (16), (17) and (18), consumer surplus and total welfare in equilibrium result as

$$(22) \quad S^{in,d} = \frac{a_1 + a_2}{2} + \frac{3n}{2} - \frac{5m}{4} + \frac{mk^2}{36(m-n)^2},$$

$$(23) \quad W^{in,d} = \frac{a_1 + a_2}{2} + \frac{n}{2} - \frac{m}{4} + \frac{(5m-4n)k^2}{36(m-n)^2}.$$

According to Equation (18), a duopolistic market structure ($x^{in,d} < 1$) requires that $k < 3(m-n)$ holds. This condition can be reformulated as $n/m < 1 - k/(3m)$: for a given ratio k/m , network effects have to be weak in proportion to the extent of the horizontal differentiation. In the following, this is called the case of ‘relatively weak’ network effects.

From Equation (15), it becomes clear that the dominant supplier can deter the entry of his competitor with a price (slightly lower than) $n - m + k$, i.e., whenever $k > m - n$ ($n/m > 1 - k/m$) holds. Then $x = 1$ results even for $p_2 = 0$. The comparison of the corresponding profits $n - m + k$ with the duopolistic profits according to Equation (19) shows that entry deterrence via exclusionary pricing is profitable for $3 < 4k/[3(m-n)] - k^2/[3(m-n)]^2$. This condition, however, is never met for $k < 3(m-n)$, i.e. entry deterrence does not pay off as long as network effects are relatively weak. Hence, for $1 - k/m < n/m < 1 - k/(3m)$, the dominant supplier accommodates entry.

For $k > 3(m-n)$, there is no duopolistic Nash equilibrium for given incompatibility. Since this condition can be reformulated as $n/m > 1 - k/(3m)$, this is called the case of ‘relatively strong’ network effects. Here, for $n < m$, the unique Nash equilibrium of the price subgame with given incompatibility is a D1 monopoly with

$$(24) \quad p_1^{in,m} = G_1^{in,m} = G^{in,m} = n - m + k.$$

In this case, consumer surplus and total welfare in equilibrium amount to

$$(25) \quad S_1^{in,m} = S^{in,m} = a_1 + n - \frac{m}{2} - p_1^{in,m} = \frac{a_1 + a_2}{2} - \frac{k}{2} + \frac{m}{2},$$

$$(26) \quad W^{in,m} = a_1 + n - \frac{m}{2}.$$

This monopolistic outcome is called a ‘de-facto standardization’, because all consumers use the same compatibility standard (interface specification) without there having been a compatibility standardization of the competing variants. Equation (24) makes clear that the existence of network effects is a precondition for this monopolization by a dominant supplier. We can state for the price subgame:

Proposition 2. Given that incompatibility has been maintained in the first stage of the game and that the horizontal differentiation dominates the network effects ($m > n$), relatively weak network effects ($n/m < 1 - k/(3m)$) lead to the coexistence of incompatible variants. Here, the dominant supplier accommodates entry for $1 - k/m < n/m < 1 - k/(3m)$. In contrast, relatively strong network effects ($n/m > 1 - k/(3m)$) result in a de-facto standardization on the dominant supplier’s variant.

Comparing the outcomes of duopolistic competition under incompatibility, Equations (16) to (23), with those under compatibility, Equations (4) to (11), shows that the price, market share, profit, surplus and welfare multipliers of the horizontal differentiation m and of the quality advantage k in both cases have the same signs. In contrast to the latter case, however, in an incompatible duopoly, prices, market shares and profits depend on the strength of the network effects n . Obviously, the following proposition holds for the price subgame:

Proposition 3. Given that incompatibility has been maintained in the first stage of the game and that the network effects are relatively weak ($n/m < 1 - k/(3m)$), stronger network effects lead to a higher market share of the hardware variant of the dominant supplier as well as to lower prices and profits for both duopolists.

The latter is due to the fact that the price elasticity of demand increases with rising network-effect strength, so that, whenever incompatible variants compete *within* the market, the competition is the more intensive, the stronger the network effects are.

In contrast, with competition between incompatible system variants *for* the market, prices increase with rising network-effect strength (see [24]). The exclusionary price of an entry-detering supplier can be higher, the more significant the value of his network is for consumers. From (24) to (26), we obtain for the price subgame:

Proposition 4. Given that incompatibility has been maintained in the first stage of the game and that the network effects are relatively strong but do not dominate the horizontal differentiation ($1 - k/(3m) < n/m < 1$), prices and profits of the

entry-detering dominant supplier are higher, the higher the strength of the network effects n is. Furthermore, they are the higher, the smaller the extent of the horizontal differentiation m is and the higher his quality advantage k is. Consumer surplus does not depend on n and increases with a rise in m as well as with a decline in the quality advantage k .⁹

As for consumer surplus, the negative direct effect of a greater extent of the horizontal differentiation m is overcompensated by its positive indirect effect of an induced reduction in price (see Equation [25] in conjunction with Equation [24]). Furthermore, the positive direct effect of a higher network effect strength n is exactly compensated by its negative indirect effect of an induced rise in price. Unlike in the case of a duopoly, a rise in the quality advantage k now does not have the positive indirect effect of an increase in x , so that there only is its negative indirect effect of an induced rise in price.

4.1.2 The Network Effects Dominate the Horizontal Differentiation

For $n > m$, market shares pursuant to (15) are profit *minimizing*, and a duopolistic equilibrium cannot exist for given incompatibility. Here, a de-facto standardization on the dominant supplier's variant is always a Nash equilibrium, and, then, Equations (24) to (26) hold again. Unlike in the case of $1 - k/(3m) < n/m < 1$, now, a de-facto standardization on V2 could be a Nash equilibrium as well. With a price (slightly lower than) $p_2 = n - m - k$, $x = 0$ holds even for $p_1 = 0$. Hence, for very strong network effects (relative to the horizontal differentiation), $n/m > 1 + k/m$, two Nash equilibria coexist. As the de-facto standardization on the dominant supplier's variant is pareto superior, we assume that this equilibrium is focal, and, therefore, we state for the price subgame:

Proposition 5. Given that incompatibility has been maintained in the first stage of the game and that the network effects are dominant ($n > m$), the dominant supplier always monopolizes the hardware market via exclusionary pricing. The comparative-static results outlined in Proposition 4 hold in this case as well.

The results of Subsections 4.1.1 and 4.1.2 taken together, we have two cases: for relatively weak network effects ($n/m < 1 - k/(3m)$), there is a coexistence of incompatible variants with $x^{in,d} = 0.5 + k/[6(m - n)]$; for relatively strong network effects ($n/m > 1 - k/(3m)$), the dominant supplier monopolizes his market. Figure 1 provides an overview of the kinds of Nash equilibria of the price subgame which result when incompatibility has been maintained in the first stage of the game.

⁹The welfare multipliers of n , m and k have the same signs as in the case of a (compatible or incompatible) duopoly.

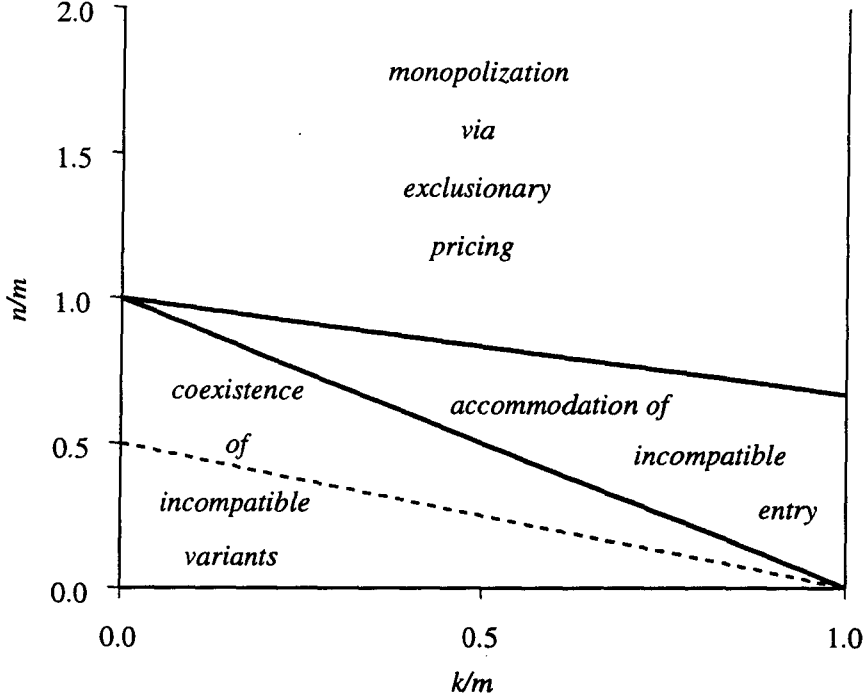


Figure 1: Nash equilibria of the price subgame for given incompatibility (dashed: upper border of welfare-optimal coexistence)

4.2 Welfare Optima

The welfare optima for given incompatibility can be calculated from the maximization of $W = S + G = (a_1 + nx)x - 0.5mx^2 + [a_2 + n(1-x)](1-x) - 0.5m(1-x)^2$ with respect to x . From the first-order condition, we obtain

$$(27) \quad x^{in,d,wo} = 0.5 + \frac{k}{2(m-2n)}.$$

The second-order condition shows that market shares according to (27) lead to welfare maxima for $n/m < 0.5$ and to welfare minima for $n/m > 0.5$. In the latter case, $x = 1$ is always welfare optimal. As becomes clear from (27), this also is true for $n/m < 0.5$ provided that $k > m - 2n$ holds, i.e. for $n/m < 0.5(1 - k/m)$. Hence, there are three cases:

For $n/m < 0.5(1 - k/m)$, the market outcome is a coexistence of incompatible variants, and this is welfare optimal per se. The market share of the variant with the quality advantage, however, is too low (see Equations [27] and [18]). A social planner

who is confronted with given incompatibility would realize the price difference

$$(28) \quad (p_1 - p_2)^{in,d,wo} = -\frac{kn}{m-2n}$$

in order to induce welfare-optimal market shares and achieve the optimal welfare level

$$(29) \quad W^{in,d,wo} = \frac{a_1 + a_2}{2} + \frac{n}{2} - \frac{m}{4} + \frac{k^2}{4(m-2n)}.$$

That is, for given incompatibility, the variant with the quality advantage should even have the lower price. The welfare loss caused by this price distortion amounts to $k^2(2m-n)^2/[36(m-n)^2(m-2n)]$. For $n > 0$, it is higher than the welfare loss in the case of given compatibility. This is due to the fact that in the case of incompatibility the fundamental price distortion of the asymmetric Hotelling approach is aggravated by the network effects. Here, a social planner who increases x from $x^{in,d}$ to $x^{in,d,wo}$ realizes not only a positive vertical welfare effect which overcompensates the accompanying negative horizontal welfare effect, but also additional network effects. As the V1 network is always larger than the network of V2 (due to $a_1 > a_2$), each switch of a consumer from V2 to V1 induces more network effects in V1 than it destroys in V2. In the noncooperative market process, however, this fact is not taken into account, i.e., network effects lead to network externalities.

For $0.5(1 - k/m) < n/m < 1 - k/(3m)$, the market outcome is a coexistence of incompatible variants, whereas the welfare optimum is a de-facto standardization on the variant with the quality advantage (see Figure 1). Here, a monopolization would have the advantage of completely exhausting network effects and vertical welfare effects. This would dominate the disadvantage of a maximum negative horizontal welfare effect. In the noncooperative market process, however, this fact is not taken into account, because the dominant supplier cannot price discriminate and is under threat of entry. Here, a possible policy measure is to grant the status of a mandatory standard to the interface specification of the variant with the quality advantage. But then further interventions would be necessary, because otherwise the dominant supplier would be an unregulated non-contestable monopolist. As we do not see the granting of the status of a mandatory standard as a reasonable policy when incompatibility is given (i.e. without an accompanying compulsory licensing of the intellectual property rights attached to the interface specification), we do not discuss it in the following. A related possible policy measure is to prompt the dominant supplier via subsidies to set an exclusionary price. This, however, requires the determination and enforcement of welfare-optimal prices, a measure which is, obviously, impracticable.

For $n/m > 1 - k/(3m)$, the market realizes a welfare-optimal de-facto standardization on the variant with the quality advantage, and we obtain

$$(30) \quad W^{in,m,wo} = W^{in,m} = a_1 + n - \frac{m}{2}.$$

5. Compatibility Decisions

5.1 Market Equilibria

In this subsection, the Nash equilibria for the first stage of the game are derived on the assumption that neither any kind of side payments nor any policy interventions are feasible (and that both suppliers know this fact).

5.1.1 The Network Effects Are Relatively Weak

Here, for $n/m < 1 - k/m$, the duopolists choose between the coexistence of compatible variants and the coexistence of incompatible variants, while for $1 - k/m < n/m < 1 - k/(3m)$, the dominant supplier has the additional option of monopolizing the market via maintaining incompatibility and setting an exclusionary price. In the last section, however, we have seen that the latter is never profitable. Hence, only the former alternatives are of relevance. From Equations (4) to (6) and (16) to (18), it becomes clear that under a move to compatibility both prices increase and the dominant supplier's market share decreases. Hence, his competitor is always better off with compatibility. Comparing the dominant supplier's profits in the case of compatibility, Equation (7), with those in case of incompatible coexistence, Equation (19), leads to $G^c - G^{in,d} = n + k^2/(9m) - k^2/[9(m-n)]$. For $n/m < 1 - k/(3m)$, this difference is positive. Hence, the duopolists produce compatible hardware variants, and, for $1 - k/m < n/m < 1 - k/(3m)$, the dominant supplier accommodates compatible entry in order to soften competition. Since we assume that the ex-ante move to compatibility causes no extra costs, it does not make any difference whether the interface specification of V1 or of V2 becomes the compatibility standard. Especially in the case of accommodated compatible entry, however, it is obvious that a standardization on the interface of the dominant supplier's variant is focal.¹⁰

Concerning consumer surplus, on the one hand, prices are higher under compatibility, while on the other hand, realized network effects are then higher as well. Furthermore, the existence of network effects leads to a higher price elasticity of demand under incompatibility and, therefore, to $x^{in,d} > x^c$. That means that a move to compatibility induces a negative vertical and a positive horizontal welfare effect. Comparing (10) with (22) shows that the negative effects of a move to compatibility overcompensate the positive effects, i.e. $S^c < S^{in,d}$ holds.

¹⁰Often, compatibility standardization is stipulated by a license contract dealing with the intellectual property rights attached to the dominant supplier's interface specification. In the case of relatively weak network effects, however, such a licensing would always be free of charge, because the dominant supplier cannot credibly threaten to maintain incompatibility. As for terminology, in the following, the term 'licensing' is left to those cases in which a positive licensing fee is agreed upon because the dominant supplier *can* credibly threaten to maintain incompatibility.

As for total welfare, we have to compare the network-effect advantage of compatibility with a higher positive balance of the vertical and horizontal welfare effects in the case of incompatibility. According to (11) and (23), the former dominates the latter whenever $n/2 > [5k^2/(36m)] [(m^2 - 0.8nm)/(m - n)^2] - 5k^2/(36m)$ holds. This results in

$$(31) \quad W^c > W^{in,d} \quad \text{for} \quad \frac{n}{m} < 1 - \frac{5k}{36m} \left(\frac{k}{m} + \sqrt{\left(\frac{k}{m}\right)^2 + 2.88} \right).$$

Evaluating this inequality shows that for most parameter values compatibility is welfare superior. The contrary is true only if n/m is very close to $1 - k/(3m)$ and additionally $k/m > 0.6$ holds, see Figure 3 (in Section 6). Then the dominant supplier accommodates compatible entry, although the accommodation of incompatible entry is welfare superior. For the relevant parameter constellations, $x^{in,d}$ is always higher than 0.9. That is, the network-effect advantage of compatibility is low and, therefore, it can be overcompensated by the disadvantage of a lower balance of vertical and horizontal welfare effects. To sum up, we state:

Proposition 6. Whenever network effects are relatively weak ($n/m < 1 - k/(3m)$), the duopolists make their variants compatible. For $1 - k/m < n/m < 1 - k/(3m)$, this means that the dominant supplier accommodates compatible entry. Except for $1 - [5k/(36m)] [k/m + \sqrt{(k/m)^2 + 2.88}] < n/m < 1 - k/(3m)$, this is welfare superior to the coexistence of incompatible variants. Consumers (as a whole) would always be better off with incompatibility.

5.1.2 The Network Effects Are Relatively Strong

For $n/m > 1 - k/(3m)$, monopolizing the market via maintaining incompatibility and setting an exclusionary price proved to be more profitable for the dominant supplier than accommodating incompatible entry. Such a monopolization, however, is not always profit maximizing when he has the option of accommodating *compatible* entry. This is due to the fact that his exclusionary price can be lower than his price under compatibility. Such a negative price effect of a monopolization can overcompensate the positive quantity effect. From (4) and (24), we obtain

$$(32) \quad p_1^{in,m} < p_1^c \quad \text{for} \quad \frac{n}{m} < 2 - \frac{2k}{3m},$$

and Equations (7) and (24) lead to

$$(33) \quad G_1^{in,m} > G_1^c \quad \text{for} \quad \frac{n}{m} > 1.5 - \frac{2k}{3m} + \frac{k^2}{18m^2}.$$

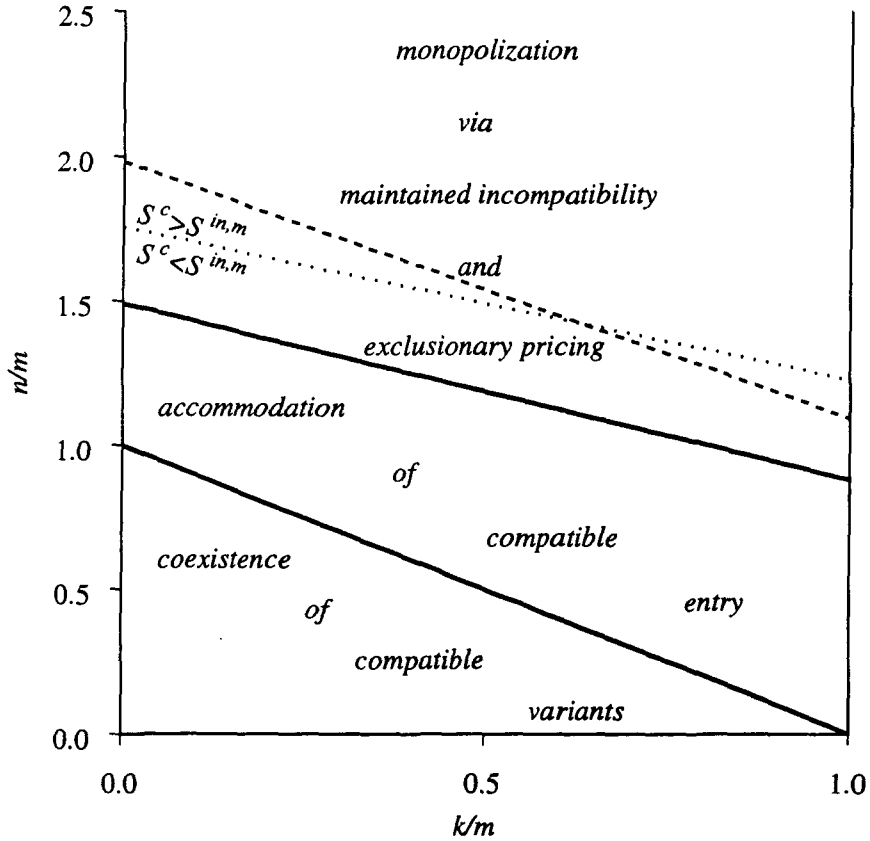


Figure 2: Nash equilibria of the compatibility game
(dashed: upper border of voluntary licensing)

Figure 2 shows for which parameter values the dominant supplier monopolizes the market and under what circumstances it is more profitable for him to soften competition via accommodating compatible entry.

With regard to consumer surplus, a move from a monopoly to compatibility induces a negative vertical welfare effect and a positive horizontal welfare effect. Furthermore, depending on network-effect strength, prices can increase or decrease (see Equation [32]). Comparing consumer surplus in the case of compatibility, Equation (10), with consumer surplus under monopolization, Equation (25), results in

$$(34) \quad S^{in,m} > S^c \quad \text{for} \quad \frac{n}{m} < 1.75 - \frac{k}{2m} - \left(\frac{k}{6m}\right)^2.$$

From Figure 2, it becomes clear that whenever the dominant supplier accommodates

compatible entry, consumers (as a whole) would be better off under monopolization. In the case of monopolization, entry deterrence is in the interest of consumers (as a whole) as long as network effects are strong but not too strong. For most parameter values, however, they are worse off under monopolization.

As for total welfare, we can deduce from (11) and (26) that the positive horizontal welfare effect of an accommodation of compatible entry overcompensates the accompanying negative vertical welfare effect as long as $m/4 > k/2 - 5k^2/(36m)$ holds. This leads to

$$(35) \quad W^c > W^{in,m} \quad \text{for} \quad \frac{k}{m} < 0.6.$$

Hence, for a ‘considerably high’ quality advantage ($k/m > 0.6$), a monopolization of the hardware market by the dominant supplier is welfare superior to compatibility. Thus, we can state:

Proposition 7. In the case of relatively strong network effects ($n/m > 1 - k/(3m)$), the dominant supplier accommodates compatible entry for $1 - k/(3m) < n/m < 1.5 - 2k/(3m) + k^2/(18m^2)$ and otherwise monopolizes his market via maintaining incompatibility and setting exclusionary prices. Such a monopolization is welfare superior to compatibility whenever the quality advantage is considerably high ($k/m > 0.6$); otherwise the contrary holds. A move to compatibility always harms consumers (as a whole), while a monopolization increases consumer surplus for $1.5 - 2k/(3m) + k^2/(18m^2) < n/m < 1.75 - k/(2m) - k^2/(36m^2)$ and diminishes consumer surplus for stronger network effects.

5.2 Welfare Optima

In order to derive the first-best welfare optima for endogenous (in)compatibility, we have to compare welfare optima for given compatibility according to (14) with welfare optima for given incompatibility, i.e. with $W^{in,d,wo}$ according to (29) for $n/m < 0.5(1 - k/m)$ and with $W^{in,m,wo}$ according to (30) otherwise. In the first case, compatibility has the advantage of higher network effects, and this dominates the disadvantage of a lower balance of horizontal and vertical welfare effects as long as $n/2 > 0.25k^2/(m-2n) - 0.25k^2/m$ holds. This is equivalent to $n/m < 0.5 - 0.5k^2/m^2$ and is fulfilled due to $k < m$. In the second case, compatibility has the advantage of a lower negative horizontal welfare effect, and this dominates the disadvantage of a lower positive vertical welfare effect as long as $m/4 > k/2 - 0.25k^2/m$ holds. This is equivalent to $(1 - k/m)^2 > 0$ and, obviously, is fulfilled as well. We can state:

Proposition 8. For endogenous (in)compatibility, compatibility is always the welfare-theoretical first-best optimum. Hence, a monopolization of the hardware market by a dominant supplier via maintaining incompatibility and setting exclusionary prices is a market failure.

This result, however, provides no justification for enforcing compatibility irrespective of the concrete circumstances. This mainly follows from the fact that in the case of coexisting variants price distortions which, to be realistic, cannot be remedied by policy interventions diminish realized welfare (see Subsections 3.2 and 4.2). A second reason for being cautious in deducing policy implications from Proposition 8 is the fact that market participants have developed various forms of cooperation in order to cope with network externalities. A very common form is the voluntary licensing of the intellectual property rights attached to the dominant supplier's interface specification.

5.3 Voluntary Licensing

The costs of negotiating and monitoring the contract left aside, a voluntary licensing (with positive licensing fees) of the intellectual property rights attached to the dominant supplier's interface specification is feasible whenever *joint* profits under compatibility are higher than the dominant supplier's profits in case of monopolization. Comparing Equation (9) with Equation (24) yields

$$(36) \quad G^c > G_1^{in,m} \quad \text{for} \quad \frac{n}{m} < 2 - \frac{k}{m} + \left(\frac{k}{3m} \right)^2.$$

The resulting upper bound of the parameter space for voluntary licensing is depicted in Figure 2. The lower bound for license contracts with positive fees is the upper bound of those parameter constellations which lead to accommodated compatible entry. From (36) in conjunction with (33) and Proposition 7, we can conclude:

Proposition 9. Whenever $1.5 - 2k/(3m) + k^2/(18m^2) < n/m < 2 - k/m + k^2/(9m^2)$ holds, a voluntary licensing of the intellectual property rights attached to the dominant supplier's interface specification is feasible. These license agreements improve welfare for $k/m < 0.6$ and diminish welfare otherwise.

If a considerably high quality advantage exists, consumers (as a whole) would be better off without licensing, whereas for $k/m < 0.6$ parameter constellations exist for which both total profits and consumer surplus are higher under voluntary licensing.

6. Policy Implications

As already mentioned in Subsections 3.2 and 4.2, we see the determination and enforcement of welfare-optimal prices in hardware markets as a project which is too ambitious to be promising.¹¹ Hence, to deduce practicable policy recommendations, we compare welfare in Nash equilibria for given compatibility with welfare in Nash equilibria for given incompatibility, i.e. W^c with $W^{in,d}$ and W^c with $W^{in,m}$, and in each case use the higher welfare as a reasonable welfare-theoretical second-best standard for endogenous (in)compatibility. This boils down to focusing on policy measures which intervene in the compatibility decision but not directly in the price formation.

From Propositions 6 and 7, it becomes clear that, against the background of this second-best welfare standard, not only the coexistence of compatible variants but also the monopolization of the market and even the coexistence of incompatible variants can be welfare optimal. This taken together with Proposition 8 makes clear that the possible welfare inferiority of compatibility is due to the fundamental price distortion caused by the existence of a quality advantage. Figure 3 provides an overview of market equilibria (including voluntary licensing) and second-best welfare optima. Here, we can distinguish between three parameter regimes. For ‘considerably strong’ network effects (relative to the extent of the horizontal differentiation), i.e. for parameter constellations above the upper bound of the voluntary-licensing area, the dominant supplier always monopolizes his market. Taking into account that in the case of compatibility too few consumers opt for the variant with the quality advantage (due to the price distortion), this is welfare optimal as long as the quality advantage is considerably high as well. That means, exclusionary strategies can be welfare improving. For relatively strong, but not considerably strong network effects, the dominant supplier softens competition by accommodating compatible entry or by voluntarily licensing the intellectual property rights for his interface specification. This turns out to be welfare optimal only as long as the quality advantage is not considerably high. Hence, license contracts and related compatibility arrangements should be under the scrutiny of antitrust authorities. Finally, for relatively weak network effects, the suppliers always opt for compatibility, although, for almost strong network effects and a considerably strong quality advantage, a coexistence of incompatible variants is welfare optimal. Thus, concerning the impact of private compatibility decisions on social welfare, we can state with the help of Propositions 6, 7 and 9:

¹¹This includes the subsidization of a dominant supplier in order to prompt him to monopolize the market (in cases where monopolization is welfare superior but not profitable for the dominant supplier), because this requires the determination and enforcement of welfare-optimal prices as well.

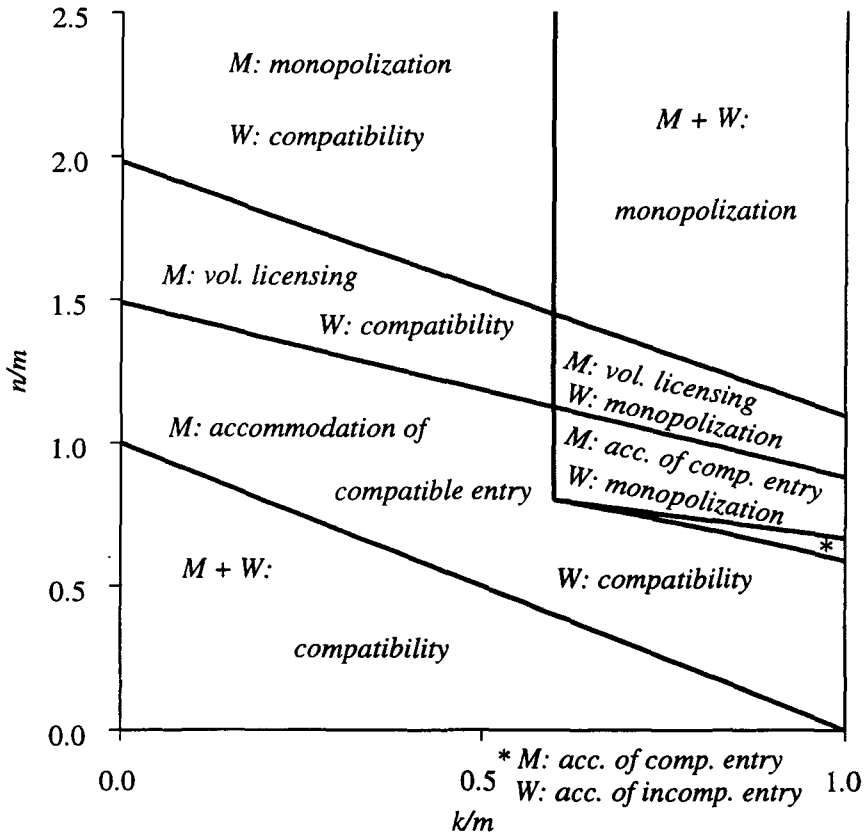


Figure 3: Market equilibria (M) and second-best welfare optima (W) of the compatibility game

Proposition 10. Against the background of a reasonable second-best welfare-theoretical standard, the profit maximizing compatibility decisions differ from the socially optimal decisions in two cases: for considerably strong network effects ($n/m > 2 - k/m + k^2/(9m^2)$) and a quality advantage which is not too high ($k/m < 0.6$), the dominant supplier opts for incompatibility, although compatibility is welfare optimal; for a considerably high quality advantage ($k/m > 0.6$) and almost strong or strong but not considerably strong network effects ($1 - [5k/(36m)][k/m + \sqrt{(k/m)^2 + 2.88}] < n/m < 2 - k/m + k^2/(9m^2)$), the suppliers opt for compatibility, although incompatibility is welfare optimal.

Some market failures, especially welfare inferior monopolization, might be remedied if consumers would contribute to side payments. In theory, a suitable institutional context for negotiating such side-payment agreements are the relevant standards-developing organizations; in Europe, for instance, the relevant commit-

tees of CEN (Comité Européen de Normalisation) and CENELEC (Comité Européen de Normalisation Electrotechnique) as well as the European Telecommunications Standards Institute ETSI. In reality, however, this fails because of the insufficient participation of consumers in these organizations.¹² Hence, the only promising policy measures are interventions in the compatibility decisions of the suppliers. In the case of welfare-inferior monopolization, this means enforcing a compulsory licensing of the intellectual property rights attached to the dominant supplier's interface specifications; in the case of welfare-inferior compatibility, this means the prohibition of compatibility arrangements. In Europe, antitrust authorities can use these measures based on Article 86 EEC Treaty and on Article 85 EEC Treaty, respectively.¹³

7. Conclusions

This paper discusses the compatibility decision of a dominant hardware supplier. Within a Hotelling model with network effects and a vertical quality advantage, it is shown that he could monopolize his market whenever the network effects are relatively strong and for relatively weak network effects whenever his quality advantage is high enough. Otherwise, he has to decide whether compatible or incompatible hardware variants should coexist. It turns out that in the latter case he always prefers compatibility, because then a lower price elasticity of demand leads to higher prices than under incompatibility. This softening of competition is also the reason for the accommodation of compatible entry as well as for the voluntary licensing of the intellectual property rights attached to his interface specifications in the case of relatively strong (but not considerably strong) network effects. Here, accommodation of compatible entry and voluntary licensing are welfare optimal as long as the quality advantage is not considerably high, but welfare inferior to monopolization otherwise. This holds against the background of a reasonable concept of second-best welfare. For considerably strong network effects, it is always profit maximizing to monopolize the hardware market via maintaining incompatibility in conjunction with exclusionary pricing. Here, the compatibility decision of the dominant supplier

¹²For this fundamental deficiency of the European Standardization System, see Woeckener (1997), especially pp. 398ff.

¹³A suit based on Article 86 EEC Treaty can only be successful if it can be proven that compatibility with the hardware of the sued supplier is an 'essential facility', i.e., that the service at issue cannot be supplied without compatibility with the sued supplier's hardware. Furthermore, it must be proven that the accused not only has a dominant position in his market, but also abuses it. Here, the refusal to license is not an abuse of a dominant position per se; see Good (1992), pp. 296f. A prominent example for an antitrust investigation in a case of anti-competitive prevention of vertical compatibility is the dispute between the EC Commission and IBM about the disclosure of the IBM System/370 cpu-periphery interface specification at the beginning of the eighties; see Shurmer/Lea (1995), pp. 388f.

is suboptimal compared with the welfare-theoretical second-best standard whenever the quality advantage is not considerably high as well. We have shown that the possible welfare superiority of market monopolization is due to a price distortion in the case of coexisting hardware variants. In the case of coexistence of incompatible variants, this price distortion is aggravated by the working of the network effects. Nevertheless, it turns out that for some parameter values even the coexistence of incompatible system variants can be welfare superior to compatibility, because under incompatibility more consumers opt for the variant with the quality advantage.

A central conclusion from our welfare analysis is that *per se* rules are not suitable for the problem at hand. In particular, a compulsory licensing of the intellectual property rights *whenever* the hardware market is monopolized proves to be wrong under a reasonable welfare-theoretical standard. Hence, whether compulsory licensing has to be enforced or not, and whether a voluntary licensing of intellectual property rights concerning interface specifications has to be prohibited or not, can only be decided after a careful analysis of the market's structure.

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