DISCUSSION PAPER SERIES

No. 3816

COMPATIBILITY DECISIONS, ENDOGENOUS INSTALLED HOME BASES AND THE THIRD-MARKET COMPETITION

Uwe Walz and Bernd Woeckener

INTERNATIONAL TRADE

Centre for Economic Policy Research

www.cepr.org

Available online at: www.cepr.org/pubs/dps/DP3816.asp

ISSN 0265-8003

COMPATIBILITY DECISIONS, ENDOGENOUS INSTALLED HOME BASES AND THE THIRD-MARKET COMPETITION

Uwe Walz, University of Frankfurt and CEPR
Bernd Woeckener, University of Stuttgart

Discussion Paper No. 3816
March 2003

Centre for Economic Policy Research
90–98 Goswell Rd, London EC1V 7RR, UK
Tel: (44 20) 7878 2900, Fax: (44 20) 7878 2999
Email: cepr@cepr.org, Website: www.cepr.org

CEPR Discussion Paper No. 3816

March 2003

ABSTRACT

Compatibility Decisions, Endogenous Installed Home Bases and the Third-Market Competition

This Paper analyses the compatibility decisions of two regional monopolistic suppliers of a network-effect good who first build up installed bases in their respective home region and then compete in a third market. We show that with weak network effects, installed home bases are always higher under compatibility and suppliers always opt for compatibility. With strong network effects, home markets are covered, and given a sufficiently high home-market size advantage both the favoured supplier and a regional standardization body maintain incompatibility in order (to enable the supplier) to monopolize the third market via limit pricing. As incompatibility always results in a welfare loss, this is a strong case for a global standardization body.

JEL Classification: F12 and L15
Keywords: compatibility decisions, installed home base, international network effects, standardization bodies and third-market competition

Uwe Walz
Department of Economics
University of Frankfurt
Schumannstr. 60
D-60059 Frankfurt
GERMANY
Email: uwe.walz@wiwi.uni-frankfurt.de

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=127377

Bernd Woeckener
Department of Economics
University of Stuttgart
Keplerstr. 17
D-70174 Stuttgart
GERMANY
Email: woeckener@uni-tuebingen.de

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=150040

Submitted 06 February 2003

Compatibility decisions, endogenous installed home bases, and third-market competition

by Bernd Woeckener[a] and Uwe Walz[b]

Abstract. This paper analyzes the compatibility decisions of two regional monopolistic suppliers of a network-effect good who first build up installed bases in their respective home region and then compete in a third market. We show that with weak network effects, installed home bases always are higher under compatibility and suppliers always opt for compatibility. With strong network effects, home markets are covered, and given a sufficiently high home-market size advantage both the favored supplier and a regional standardization body maintain incompatibility in order (to enable the supplier) to monopolize the third market via limit pricing. As incompatibility always results in a welfare loss, this is a strong case for a global standardization body.

JEL classification: F12, L15

Keywords: Compatibility decision; Installed home base; International network effects; Third-market competition; Standardization bodies.

a) Corresponding author: Institut für VWL und Recht der Universität Stuttgart, Abteilung für Mikroökonomik und Räumliche Ökonomik, Keplerstraße 17, D-70174 Stuttgart, Germany, e-mail: woeckener@sofo.uni-stuttgart.de.
b) Fachbereich Wirtschaftswissenschaften, J.W. Goethe-Universitt Frankfurt/Main, Schumannstr. 60, D-60325 Frankfurt/Main, Germany, e-mail: uwe.walz@wiwi.uni-frankfurt.de.

1. INTRODUCTION

The global economy experiences a drastic rise in the importance of network industries. The information and telecommunication industries are only the most visibles ones, but other like the media and consumer electronic branches are obvious examples, too. Despite the obvious and growing importance of these industries there is a surprising neglect of these matters in the economic literature. With only a few exception[1] network industries have been analyzed in closed economy settings or international trade issues have been investigated in the absence of network effects.

A crucial aspect of industries with net work effects is the often decisive importance of installed base effects. When considering global competition of firms in these industries we often observe that firms enter international competition after having established an installed base in their domestic markets. At the beginning, however, firms have to decide upon the compatibility of their products with the ones of the (international) competitors. This usually observed sequence of events is due to the often irreversible character of the compatibility decision as well as to the fact that in the early market phase there typically are binding capacity constraints. Clear examples are mobile phone and television systems[2] in the realm of communications systems (i.e. in the presence of direct network effects) and video systems, video game systems as well as CD and DVD systems in the realm of hardware-software systems (i.e. in the presence of indirect network effects).[3]

In the present paper we take up these issues by analyzing the interplay of compatibility decisions, installed-bases in the domestic market and the third market's structure. We do this by addressing the compatibility decisions of firms being located in different countries and being able to strategically build-up endogenous installed bases in their respective home markets. Beyond investigating the behavior of firms, we ask for the appropriate regulative framework in such a setting.

In particular, we analyze the conduct of two regional monopolistic suppliers of a

[1]See e.g. Matutes/Regibeau (1996), Gandal/Shy (2001), and Barrett/Yang (2001).

[2]For these examples, see Funk and Methe (2001) and Pargal (1996).

[3]In the latter case, due to high fixed costs and low as well as constant marginal costs in software (e.g., CD or DVD) production, a rise in total demand induces a rise in the variety of software, which in turn results in an increase in the surplus of each user. Chou and Shy (1990) and Church and Gandal (1992) were the first models that formalized the emergence of indirect network effects in hardware-software systems.

horizontally differentiated network-effect good who first decide on (in)compatibility, then build up installed bases in their respective home region, and finally compete in a third market. As becomes obvious from the above examples, the suppliers' compatibility decisions are of decisive importance for the third market's structure and for the role of installed home bases in third-market competition. In particular, under incompatibility an installed-base advantage works like a quality advantage and might enable the favored supplier to monopolize the third market. In this case the question arises whether the present mix of several regional standardization bodies with some competence for compatibility standardization and a few global standardization bodies with only very limited competence is sufficient.

In a first step we show that in the early market phase, the regional monopolists become indirect international duopolists. This is due to the existence of international network effects and with rational consumer expectations concerning future network sizes. In this indirect competition in installed home bases, quantities sold in the regional markets become strategic substitutes for given incompatibility and strategic complements for given compatibility. Against this background we can with regard to the significance of the network effects distinguish two fundamental cases. In the presence of weak network effects installed home bases always are higher under compatibility and suppliers always opt for compatibility. This case is typical of some hardware-software systems such as CD and DVD systems. In the presence of strong network effects home markets are covered, and given a high advantage in home-market size, the favored supplier maintains incompatibility in order to monopolize the third-market via limit pricing. This case is typical of communications systems. In addition, we show that a monopolization of the third market never maximizes global welfare.. Moreover, it turns out that a regional standardization body which maximizes total regional welfare makes exactly the same compatibility decisions as the profit-maximizing regional supplier. Hence, regional standardization bodies cannot remedy the market failure of a third-market monopolization. Therefore,in the case of strong network effects a global standardization body with comprehensive competence for compatibility standardization is urgently needed.

The paper at hand builds on Woeckener (1999). There, a Hotelling duopoly with network effects is presented where suppliers first decide on compatibility and then compete in prices. Of course, all of our results concerning the interplay of the decisions on compatibility and on installed bases as well as our welfare analysis considering international standardization policy are new. As for the latter, we take up a line of research suggested in Matutes and Regibeau (1996, pp. 199ff). They explore which standardization policy can serve as a substitute for trade policy. This also is a topic in Gandal and Shy (2001) and in Barrett and Yang (2001). In both papers, there is, in contrast to our approach, no endogenous building up of installed home bases. Thus, these authors are not able to discuss the interplay of compatibility decisions and installed-base decisions when anticipating the subsequent third-market competition. Moreover, the model of Gandal and Shy is symmetric so that in contrast to our approach no region can gain an advantage by maintaining incompatibility. In the model of Barrett and Yang installed bases are exogenously given and belong to an old technology. Moreover, the compatibility standard of the foreign firm is exogenously given, too. Hence, whereas we analyze the strategic interdependence of suppliers who both decide on compatibility and installed bases, Barrett and Yang analyze the conduct of a supplier who adapts himself to given installed bases and a given compatibility decision of his foreign competitor. Finally, in a companion paper (Walz and Woeckener [2002]), we explore the impact of production subsidies in the early market phase on third-market competition and global welfare within the standard setting of international-trade theory.

The paper is organized as follows: after the main assumptions have been presented in Section 2, we discuss third-market competition for given (in)compatibility and given installed home bases in Section 3. Section 4 analyzes the building up of installed home bases for given (in)compatibility and Section 5 presents the profit-maximizing compatibility choices. Finally, in Section 6, we show that regional standardization bodies make exactly the same compatibility decisions as private firms.

2. THE MODEL

In our three-region model there are two suppliers, D1 and D2, who produce substitutive variants of the central hardware component of a hardware-software system or of a communications system V1 and V2. Each of both suppliers has a home region Ri with regional-market size s_i ($i = 1, 2$); here, D1 can have a home-market size advantage ($s_1 \geq s_2$). Moreover, there is a third region Rt (e.g., the world market) with market size $s_t = 1$. The sequence of events is as follows:

(i) In the first stage suppliers irrevocably decide on compatibility. Here, we assume that compatibility of systems requires the consent of both suppliers. This may be due to intellectual property rights attached to interface specifications. Alternatively

it may be the consequence of the fact that specifications of the competitor's variant which are necessary for establishing compatibility are unknown.
(ii) In the second stage suppliers are regional monopolists and build up installed bases x_i $(i = 1, 2)$ in their respective home region. We assume that in the early market phase capacity constraints in production and distribution are binding. This prevents suppliers from exporting and, moreover, means that the indirect competition established by the anticipation of the subsequent third-market competition is in quantities.
(iii) In the third stage – when the product is mature and capacity constraints are of minor importance – suppliers compete in a third market *à* la Hotelling in prices.
We assume constant marginal costs of production c_i $(i = 1, 2)$ in stage two, where supplier D1 might have an initial cost advantage $c_1 \geq c_2$. However, in third-market competition – when the product is mature – $c_{1t} = c_{2t} = c_t$ holds.

As for preferences, we assume that in the third market consumers' general willingnesses to pay are uniformly distributed along the unit line $[0, 1]$ with a density of one (so that $s_t = 1$ holds). The alienation terms are linear in distance to the ideal variant, the alienation coefficient is normalized to one and V1 (V2) is located at the left (right) end of the unit line. Hence, with b_{it} as the basic willingnesses to pay, the general willingnesses to pay read $b_{it} - |i - 1 - h|$ where $0 \leq h \leq 1$ is the address of the respective consumer. We assume that these general willingnesses to pay are sufficiently high to guarantee a covered third market with $x_{1t} + x_{2t} = 1$; furthermore, we assume $b_{1t} = b_{2t} = b_t$. In regions R1 and R2 consumers can only buy the respective home variant; the general willingnesses to pay are uniformly distributed along the the interval $[0, s_1]$ and $[0, s_2]$, respectively, with a density of one. Thus, we have $b_1 - h$ with $0 \leq h \leq s_1$ for consumers in R1 and $b_2 - h$ with $0 \leq h \leq s_2$ for consumers in R2. Here, supplier D1 might have a willingness-to-pay advantage due to a higher level of income in R1 $(b_1 \geq b_2)$.

Considering that part of the willingness to pay which is due to the network effects, we assume that it is linear in network size and that all consumers value network size identically. With n as the network-effect coefficient, we get $n(x_1 + x_2 + 1)$ as the network-effect rent in the case of compatibility and $n(x_i + x_{it})$ as the network-effect rent in the case of incompatibility. Hence, with home-market prices p_i and third-market prices p_{it}, the surplus of a consumer in region Ri with address h when buying the regional variant Vi reads

$$(1) \qquad r_{hi} = b_i - h - p_i + \begin{cases} n(x_1 + x_2 + 1) & \textit{for given compatibility} \\ n(x_i + x_{it}) & \textit{for given incompatibility,} \end{cases}$$

and the surplus of a third-market consumer with address h when buying variant Vi amounts to

$$(2) \quad r_{hit} = b_t - |i - 1 - h| - p_{it} + \begin{cases} n(x_1 + x_2 + 1) & \textit{for given compatibility} \\ n(x_i + x_{it}) & \textit{for given incompatibility.} \end{cases}$$

Note that for network-effect goods often $a_i \equiv b_i - c_i < 0$ holds; however, in order to leave aside critical-mass problems in stage two, we assume $a_i > 0$. Then, our modelling of third-market competition resembles the Hotelling approach of Farrell and Saloner (1992) with the exception that we allow for asymmetries: among other things, in our model there can be a so-called basic advantage of V1 $a_1 > a_2$ due to a cost- and/or due to a willingness-to-pay advantage in stage two which induces an installed-base advantage $x_1 - x_2 > 0$ with regard to stage three.

3. THIRD-MARKET COMPETITION

In this section we derive third-market equilibria for given installed home bases and given (in)compatibility. Under compatibility, the existence of network effects and installed bases does not matter for equilibria because both variants provide a network-effect rent of $n(x_1 + x_2 + 1)$ (and the market is covered anyway). Just as in the standard Hotelling model, equating consumer surplus of V1, r_{h1t}, with consumer surplus of V2, r_{h2t}, solving for the address of the indifferent consumers $\hat{h}$ and using $x_{1t} = \hat{h}$ results in the demand equations $x_{it} = 0.5(1 + p_{jt} - p_{it})$ with $i, j = 1, 2$ and $i \neq j$. Differentiating profits $\Pi_{it} = (p_{it} - c_t)x_{it}$ with respect to prices leads to the well-known result $p_{it}^{co} = 1 + c_t$ and $\Pi_{it}^{co} = x_{it}^{co} = 0.5$.

With given incompatibility, however, network-effect rents (as a rule) are not of the same size; according to Equations (1) and (2) we have $n(x_1 + x_{1t})$ for V1 and $n(x_2 + x_{2t})$ for V2. Now, both the significance of the network effects and differences in installed home bases matter. Moreover, third-market equilibria depend on consumers' expectations about third-market shares x_{it}^e. Here, we confine ourselves to analyzing equilibria with fulfilled (rational) expectations. Then, using $x_{1t} = x_{1t}^e = \hat{h}$, the solution of the indifference condition $r_{h1t} = r_{h2t}$ results in demand equations

$$(3) \qquad x_{it} \;=\; 0.5 + \frac{p_{jt} - p_{it} + n(x_i^{in} - x_j^{in})}{2(1-n)}$$

with $x_1^{in} - x_2^{in} \geq 0$ as a possible installed-base advantage of supplier D1. Differentiating profits with respect to prices leads via the best-response functions $p_{it} = c_t + 0.5[1 - n + n(x_i - x_j) + p_{jt}]$ to Nash equilibria

$$(4) \qquad p_{it}^{in,d} \;=\; c_t + 1 - n + \frac{n(x_i^{in} - x_j^{in})}{3}\,,$$

$$(5) \qquad x_{it}^{in,d} \;=\; 0.5 + \frac{n(x_i^{in} - x_j^{in})}{6(1-n)} \;=\; \frac{1 - n + \frac{n(x_i^{in} - x_j^{in})}{3}}{2(1-n)}\,,$$

$$(6) \qquad \Pi_{it}^{in,d} \;=\; 2(1-n){x_{it}^{in,d}}^2 \;=\; \frac{\left(1 - n + \frac{n(x_i^{in} - x_j^{in})}{3}\right)^2}{2(1-n)}\,,$$

where the second-order condition reads $n < 1$. D2, the supplier with the possible installed-base disadvantage, only has strictly positive prices, quantities, and profits as long as the duopoly condition $1 - n + n(x_2^{in} - x_1^{in})/3 > 0$ holds, i.e. as long as the installed-base advantage of D1 is relatively low:

$$(7) \qquad x_1^{in} - x_2^{in} \;<\; 3\frac{1-n}{n}\,.$$

Note that with an installed-base advantage, supplier D1 has both the higher price and the higher market share (see Eqs. [5] and [6]). Note moreover, that given symmetry $x_1^{in} = x_2^{in}$ prices and profits under incompatibility always are lower than for given compatibility. This is due to the bandwagon effects which are induced by the network effects and lead to tougher price competition. In the following, we call this the price advantage of compatibility.

Whenever the installed-base advantage of D1 is high so that the duopoly condition is not fulfilled the market is monopolized by D1 via limit pricing. The limit price can be derived from the best-response function of D2 and reads

$$(8) \qquad p_{1t}^{in,m} \;=\; c_t - (1-n) + n(x_1^{in} - x_2^{in})\,,$$

i.e., monopoly profits amount to

$$\Pi_{1t}^{in,m} \;=\; p_{1t}^{in,m} \;-\; c_t \;=\; -(1-n) + n(x_1^{in} - x_2^{in})\,. \tag{9}$$

These profits are strictly positive whenever the duopoly condition does not hold. Note how the network effects leverage an installed-base advantage: the stronger the network effects the lower the installed-base advantage necessary to monopolize the third market. To sum up, we state

Lemma 1 Whereas with given compatibility installed home bases do not matter for third-market competition (there always is a compatible duopoly D^{co}), they are of decisive importance under incompatibility. Then, a low installed-base advantage (or none at all) $x_1^{in} - x_2^{in} \leq 3(1-n)/n$ leads to a competition within the market (incompatible duopoly D^{in}) whereas a high installed-base advantage $x_1^{in} - x_2^{in} > 3(1-n)/n$ leads to a competition for the market (monopolization via limit pricing M).

4. BUILDING UP INSTALLED HOME BASES

4.1. Given compatibility: installed bases as strategic complements

Under compatibility and given rational expectations, demand in region Ri positively depends on demand in region Rj. This is due to the fact that consumers in Ri anticipate that they will be in a joint network with consumers in Rj. From Equation (1) with $r_{hi} = 0$ and $x_i = \hat{h}$ we obtain demand equations

$$x_i \;=\; \frac{b_i + n(x_j + 1) - p_i}{1-n}\,. \tag{10}$$

Hence, due to the existence of international network effects and due to rational consumer expectations, regional monopolists become indirect international duopolists. Their home-market profits amount to $\Pi_i = [a_i + n(x_j+1)]x_i - (1-n)x_i^2$, and third-market profits are $\Pi_{it}^{co} = 0.5$ irrespective of x_i (see Section 3). Differentiating profits with respect to quantities, it is straightforward to derive the best-response functions

$$x_i \;=\; \frac{a_i + n}{2(1-n)} + \frac{n}{2(1-n)} x_j\,; \tag{11}$$

the second-order condition reads $n < 1$. Obviously, with given compatibility installed home bases are strategic complements.[4] There are two basic cases:

(i) For $n < 2/3$, i.e. if network effects are not strong and $\partial x_i/\partial x_j < 1$ holds. This means that there are equilibria which are stable under first-order best-response dynamics. This case is typical of some hardware-software systems. The point of intersection of the best-response functions reads

$$(12) \qquad x_i^{co} = \frac{n}{2-3n} + \frac{2(1-n)a_i + na_j}{(2-n)(2-3n)} = \frac{a_i+n}{2-3n} - \frac{n(a_i-a_j)}{(2-n)(2-3n)}\,.$$

Given $a_i \equiv b_i - c_i > 0$, endogenous duopoly equilibria with strictly positive quantities are guaranteed as long as regions are large enough (what is supposed in the following).[5] Note that as a consequence of strategic complementarity, installed bases in region Ri depend positively on willingness to pay b_j and negatively on production costs c_j. If, for instance, a supplier implements a process innovation which lowers his marginal costs, this results in a higher optimal quantity both for him *and* for his competitor. The latter is in contrast to the usual conjunction in quantity competition (where $\partial x_i/\partial c_j < 0$ holds). It is due to the fact that in the presence of network effects and given compatibility a rise in one's own quantity means a larger network for the competitor's variant, too. This is anticipated by the competitor's consumers and, thus, increases their willingness to pay. This, in turn, implies a higher profit-maximizing quantity for him. Substituting quantities according to Equation (12) into demand equations (10) and rearranging terms leads to equilibrium prices $p_i^{co} = c_i + (1-n)x_i^{co}$. Hence, total profits (home-market profits plus third-market profits) in this first case are

$$(13)\, \Pi_{i+it}^{co} = (1-n){x_i^{co}}^2 + 0.5 = (1-n)\left(\frac{a_i+n}{2-3n} - \frac{n(a_i-a_j)}{(2-n)(2-3n)}\right)^2 + 0.5\,.$$

(ii) For strong network effects $2/3 < n < 1$, $\partial x_i/\partial x_j > 1$ holds. Then, the best-response functions have no point of intersection in the positive realm and the bandwagon effects are so strong that home markets are covered: $x_i^{co} = s_i$. This second case is typical of communications systems. Here, suppliers skim off the entire surplus of the last consumer at $h = s_i$ and total profits amount to

$$(14) \qquad \Pi_i^{co} = [a_i + n(s_j+1)]s_i - (1-n)s_i^2 + 0.5\,.$$

[4]Without international network effects regional monopolists would sell $x_i = a_i/[2(1-n)]$.

[5]If regions are not large enough, installed home bases correspond with home-market sizes $x_i^{co} = s_i$ and the results of the second case hold (see below); mixed cases – e.g., $x_1^{co} = s_1$ and x_2^{co} according to Equation (12) – bear no interesting results.

Hence, both these cases considered, we can state

Lemma 2. With given compatibility installed home bases are strategic complements and there are two basic cases:
(i) for $n < 2/3$ a variant's installed home base depends on network-effect strength as well as on both its own basic willingness to pay and production costs and on those of the competing variant.
(ii) for strong network effects $n > 2/3$ a corner solution emerges and installed home bases correspond with home-market sizes.

4.2. Given incompatibility: installed bases as strategic substitutes

Under incompatibility demand in region Ri negatively depends on demand in region Rj because consumers in Ri anticipate that a higher installed base x_j ceteris paribus leads to a lower third-market share of their variant x_{it}, what in turn means a lower network-effect rent $n(x_i + x_{it})$. From Equation (1) with $r_{hi} = 0$, x_{it} according to Equation (5) and $x_i = \hat{h}$ due to rational expectations we find for the demand equations

$$x_i = \frac{b_i + 0.5n - \frac{n^2}{6(1-n)} x_j - p_i}{1 - n - \frac{n^2}{6(1-n)}} . \tag{15}$$

Note that in this indirect duopolistic competition in installed bases (as in third-market competition) the price elasticity of demand is higher under incompatibility due to the bandwagon effects. Solving for prices and multiplying with quantities results in home-market profits

$$\Pi_i = \left(a_i + 0.5n - \frac{n^2}{6(1-n)} x_j \right) x_i - \left(1 - n - \frac{n^2}{6(1-n)} \right) x_i^2 . \tag{16}$$

In contrast to the case of given compatibility, under incompatibility a higher installed home base implies higher third-market profits (see Equation (6)). Therefore, there is a joint maximization of home and third-market profits with regard to installed bases. Moreover, under incompatibility installed-base differences matter for third-market competition (see Lemma 1). Depending on whether the installed-base difference is lower or higher than $3(1-n)/n$ suppliers compete within the third market (duopolistic equilibrium) or for the third market (limit-pricing equilibrium), respectively. Hence, we can distinguish four cases. The first two cases emerge with duopolistic third-market equilibrium with either interior solutions for installed home bases or with covered home markets. Case three and four lead to monopolistic third-market equilibrium with either interior solutions for installed home bases or with covered home markets.

4.2.1. Installed home bases when there is competition within the third market

Given a duopoly equilibrium in the third market, total profits Π_{i+it} are the sum of home profits Π_i according to Equation (16) and third-market profits $\Pi_{it}^{in,d}$ according to Equation (6). The best-response functions are

$$(17) \qquad x_i = \frac{a_i + \frac{5}{6}n}{2\left(1 - n - \frac{2n^2}{9(1-n)}\right)} - \frac{\frac{5n^2}{18(1-n)}}{2\left(1 - n - \frac{2n^2}{9(1-n)}\right)} x_j \,,$$

where the second-order condition reads $1-n-2n^2/[9(1-n)] > 0$, i.e. $n < 0.6796$. Obviously, under incompatibility installed home bases are strategic substitutes. Note that we assume in our derivation that consumers and suppliers expect a duopoly. That is, the results derived in this subsection (only) hold under these duopoly expectations. Note moreover that only for weak network effects $n < 0.6246$, the best-response function of supplier D2 is steeper than that of his competitor D1; this means that for stronger network effects Nash equilibria (when they exist) are unstable. Hence, there are the following two subcases:

(i) With weak network effects ($n < 0.6246$) stable Nash equilibria exist and equilibrium quantities can be derived from Equation (17) as:[6]

$$(18) \quad x_i^{in,d} = \frac{a_i + \frac{5}{6}n}{2(1-n) - \frac{n^2}{6(1-n)}} + \frac{\frac{5n^2}{18(1-n)}(a_i - a_j)}{\left(2(1-n) - \frac{n^2}{6(1-n)}\right)\left(2(1-n) - \frac{13n^2}{18(1-n)}\right)} \,.$$

Thus, the installed-base advantage of supplier D1 in third-market competition amounts to

$$(19) \qquad x_1^{in,d} - x_2^{in,d} = \frac{a_1 - a_2}{2(1-n) - \frac{13n^2}{18(1-n)}} \,.$$

As outlined above, an installed-base advantage is caused by a basic advantage $a_1 - a_2 > 0$ which in turn is due to a willingness-to-pay advantage $b_1 - b_2 > 0$ and/or a marginal-cost advantage $c_2 - c_1 > 0$. Using Equation (7), we get the upper

[6] According to Equation (18), $x_1^{in,d} > 0$ is guaranteed; it is straightforward to prove that this also holds for $x_2^{in,d}$. We again assume that for weak network effects home regions always are large enough to guarantee an interior solution.

regime border for incompatible duopolies D^{in} in third-market competition in terms of V1's basic advantage:

$$(20) \qquad a_1 - a_2 \;=\; \frac{23n}{6} \;-\; 12 \;+\; \frac{6}{n}\,;$$

see the solid line in the left part (left to $n = 0.6246$) of Figure 1. This border between incompatible duopolies and limit-pricing monopolies (only) holds for expectations of a duopoly to emerge.

Substituting equilibrium quantities into profit equations (6) and (16) results after some rearrangements in total equilibrium profits of

$$(21) \quad \Pi^{in,d}_{i+it} = \left(1 - n - \frac{2n^2}{9(1-n)}\right) x_i^{in,d^2} + \frac{n^2}{18(1-n)} x_j^{in,d^2} - \frac{n}{3} x_j^{in,d} + \frac{1-n}{2}\,.$$

(ii) For $n > 0.6246$ there are two subcases with identical result. With $0.6246 < n < 0.6796$ the second-order condition is fulfilled and there exist a point of intersection of the best-response functions. These Nash equilibria, however, are unstable (see above), i.e., they have the meaning of critical masses. Given regional monopolies and rational expectations it seems reasonable to assume that suppliers can overcome this problem. Then, this subcase results in corner solutions $x_i^{in,d} = s_i$. When the second-order condition is not fulfilled, there is no point of intersection in the positive realm. In this case first-order best-response dynamics drives the process to a corner solution $x_i^{in,d} = s_i$, too. Using Equation (7), the regime border between incompatible duopolies and limit-pricing monopolies in third-market competition in terms of the possible home-market size advantage of supplier D1 obviously reads

$$(22) \qquad s_1 - s_2 \;=\; 3\frac{1-n}{n}$$

(see the right part of Figure 1). In this second case with $n > 0.6246$ total profits amount to

$$(23) \;\; \Pi^{in,d}_{i+it} = \left(a_i + \frac{n}{2} - \frac{n^2 s_j}{6(1-n)}\right) s_i - \left(1 - n - \frac{n^2}{6(1-n)}\right) s_i^2 + \frac{\left(1 - n + \frac{n(s_i - s_j)}{3}\right)^2}{2(1-n)}\,.$$

All in all, Figure 1 shows the four parameter regimes for given incompatibility and given duopoly expectations. We can sum up in

Lemma 3a. With given incompatibility,
(i) weak network effects $n < 0.6246$ in conjunction with a low basic advantage of

variant V1 $a_1 - a_2 < 23n/6 - 12 + 6/n$ result in installed home bases according to Equation (19). The corresponding low installed-base advantage of supplier D1 leads to duopolistic third-market equilibria.
(ii) for $n > 0.6246$ installed home bases correspond with home-market sizes. Here, a low home-market size advantage of supplier D1 $s_1 - s_2 < 3(1-n)/n$ results in a low installed-base advantage what in turn leads to a duopolistic third-market equilibrium.

******* Figure 1 about here *******

4.2.2. Installed home bases when there is a monopolization of the third market

When the basic advantage or the home-market size advantage is high, supplier D1 has a high installed-base advantage and might monopolize the third market via limit pricing as discussed in Section 3. In detail, the two monopolistic cases are as follows:
(i) Given weak network effects $n < 0.6246$ and a sufficiently high basic advantage, consumers and suppliers anticipate that D1 monopolizes the third market and that D2 confines himself to selling in his home market (monopoly expectations). Then, installed home bases of supplier D1 amount to

$$x_1^{in,m} = \frac{a_1 + 2n}{2(1-n)} \tag{24}$$

and his equilibrium profits at home are[7]

$$\Pi_1^{in,m} = (1-n)x_1^{in,m\;2} = \frac{a_1^2 + 2a_1 n}{4(1-n)}\,. \tag{25}$$

Analogously, we get for supplier D2

$$x_2^{in,m} = \frac{a_2}{2(1-n)} \tag{26}$$

and

$$\Pi_2^{in,m} = (1-n)x_2^{in,m^2} = \frac{a_2^2}{4(1-n)}\,. \tag{27}$$

[7]From Equation (1) with $x_{1t} = 1$ we get for supplier D1 with respect to his home market $p_1 = b_1 + n - (1-n)x_1$ and thus $\Pi_1 = (a_1 + n)x_1 - (1-n)x_1^2$. Maximizing these home-market profits results in Equation (24). Equilibrium prices in region R1 read $p_1^{in,m} = c_1 + 0.5a_1$.

Hence, given a limit-pricing monopoly (and monopoly expectations) the installed-base advantage of supplier D1 reads

$$x_1^{in,m} - x_2^{in,m} \;=\; \frac{a_1 - a_2 + 2n}{2(1-n)}\,. \tag{28}$$

Substituting this installed-base advantage into Equation (7) gives the borderline between incompatible duopolies and monopolies for monopoly expectations:

$$a_1 - a_2 \;=\; 4n \;-\; 12 \;+\; \frac{6}{n}. \tag{29}$$

This relationship is delineated as the dotted line in the left part of Figure 1. Obviously, this borderline is *to the right of* the borderline for duopoly expectations (see Equation (20)). This implies that in between these borderlines, monopoly expectations result in a duopoly and vice versa. Thus, for $23n/6 - 12 + 6/n < a_1 - a_2 < 4n - 12 + 6/n$ subgame-perfect Nash equilibria with rational (fulfilled) expectations do not exist. The reason behind is that for this parameter constellations the duopolistic installed-base advantage is higher than the monopolistic installed-base advantage.

According to Equation (8), the limit price by which the third market is monopolized amounts to $p_{1t}^{in,m} = -(1-n) + n(a_1 - a_2 + 2n)/[2(1-n)]$ where $\Pi_{1t}^{in,m} = p_{1t}^{in,m}$ holds.[8] With Equation (25) we obtain

$$\Pi_{1+1t}^{in,m} = (1-n)x_1^{in,m^2} - (1-n) - nx_2^{in,m} = \frac{a_1^2 + 2a_1 n}{4(1-n)} - (1-n) + n\frac{a_1 - a_2 + 2n}{2(1-n)}\,. \tag{30}$$

From the first formulation, it becomes clear that a monopolization of the third market implies an installed home base which is higher than one – i.e. higher than third-market size $s_t = 1$.

(ii) Given $n > 0.6246$ and a high home-market size advantage $s_1 - s_2 > 3(1-n)/n$, the induced high installed-base advantage of D1 again results in a monopolization. Total equilibrium profits amount to

$$\Pi_{1+1t}^{in,m} \;=\; (a_1 + n)s_1 - (1-n)s_1^2 - (1-n) + n(s_1 - s_2) \tag{31}$$

for supplier D1 and to

$$\Pi_2^{in,m} \;=\; a_2 s_2 - (1-n)s_2^2 \tag{32}$$

[8]As shown in Section 3, these limit prices and third-market profits always are positive when the duopoly condition is not fulfilled. As home-market profits also are strictly positive, a monopolization – when it occurs – must lead to strictly positive total profits.

for his competitor D2. In a nutshell, the second part of Lemma 3 considering the two monopolistic parameter regimes reads as follows:

Lemma 3b. With given incompatibility
(i) weak network effects $n < 0.6246$ in conjunction with a high basic advantage of variant V1 $a_1 - a_2 > 4n - 12 + 6/n$ result in installed home bases according to Equations (24) and (26). Here, D1 monopolizes the third market via limit pricing, whereas D2 confines himself to selling in his home market quantities according to Equation (26).
(ii) for $n > 0.6246$ installed home bases correspond with home-market sizes. Here, a high home-market size advantage of D1 $s_1 - s_2 > 3(1-n)/n$ results in a high installed-base advantage what in turn leads to a monopolistic limit-pricing equilibrium in the third-market. D2 confines himself to selling in his home market.

5. COMPATIBILITY DECISIONS

When comparing profits for given compatibility with profits for given incompatibility there are three fundamental parameter regimes. First, for weak network effects ($n < 0.6246$) there are interior solutions for installed home bases[9] in the compatibility as well as for incompatibility case. Second, for strong network effects ($n > 2/3$) installed home bases in both cases (compatibility as well as incompatibility) correspond with home-market sizes. Third, with in between installed home bases ($n \in [0.6246, 2/3)$ correspond with home-market sizes in case of incompatibility whereas they have interior solutions in case of compatibility. In the following, we restrict ourselves to analyzing the first and the second parameter regime because the mixed third regime does not lead to additional results. Thus, we have to compare profits for four basic subcases: weak network effects ($n < 0.6246$) in conjunction with low and with high basic advantages ($a_1 - a_2$ lower than $23n/6 - 12 + 6/n$ or higher than $4n - 12 + 6/n$) as well as strong network effects ($n > 2/3$) in conjunction with low and with high home-market size advantages ($s_1 - s_2$ lower or higher than $3(1 - n)/n$). Table 1 provides an overview. Since $x_i = s_i$ with strong network effects in any case, installed base difference do not play a role with respect to the (in)compatibility decision. However, when network effects are weak installed home

[9] Given that home-market sizes are large enough and that n is outside the range $23n/6 - 12 + 6/n < a_1 - a_2 < 4n - 12 + 6/n$

Table 1 The four basic cases

section	regimes	network effects	V1 advantage	Π^{co}_{i+it}	Π^{in}_{i+it}
5.1.1	D^{co} $vs.$ D^{in}	weak	$a_1 - a_2$ low	Eq. (13)	Eq. (21)
5.1.2	D^{co} $vs.$ M	weak	$a_1 - a_2$ high	Eq. (13)	Eqs. (30), (27)
5.2.1	D^{co} $vs.$ D^{in}	strong	$s_1 - s_2$ low	Eq. (14)	Eq. (23)
5.2.2	D^{co} $vs.$ M	strong	$s_1 - s_2$ high	Eq. (14)	Eqs. (31), (32)

bases are not of the same amount for given compatibility and for given incompatibility. Then, as installed home bases are complements under compatibility and substitutes under incompatibility, it would appear that they always are higher under compatibility. And indeed it is straightforward to prove the following important lemma (see Appendix):

Lemma 4. With weak network effects $n < 0.6246$ installed home bases always are higher under compatibility than under incompatibility.

This lemma implies that for $n < 0.6246$ network size under compatibility $x_1^{co} + x_2^{co} + 1$ always is higher than network size for given incompatibility $x_i^{in} + x_{it}$. In other words, compatibility always has a network-size advantage. With strong network effects, this fact is obvious. Considering total profits, this means a higher willingness to pay and thus *ceteris paribus* higher profits under compatibility.

To illustrate the economic intuition behind this note that in total there are only three effects that determine whether profits are higher under compatibility or under incompatibility:
(i) the network-size effect: the network-size advantage of compatibility results in a higher willingness to pay and thus (ceteris paribus) in higher profits under compatibility;
(ii) the price-competition effect: the price advantage of compatibility (due to bandwagon effects under incompatibility) also leads to higher profits under compatibility;
(iii) the installed-base effect: if the installed-base advantage possible under incompatibility is sufficiently high, D1's profits might be higher under incompatibility.

This makes clear the impact of Lemma 4 for the following analysis of the compatibility decisions. From the fact that installed home bases for given compatibility always are higher ($n < 0.6246$) or equal to ($n > 2/3$) installed home bases under incompatibility, we can conclude that
(i) suppliers always unanimously opt for compatibility when there is no basic or home-market size advantage for D1,
(ii) D2 always opts for compatibility.
Therefore, the following analysis centers on the compatibility decision of D1 in the presence of a basic or a home-market size advantage.

5.1. Compatibility decisions with weak network effects ($n < 0.6246$)

Here, an installed-base advantage goes back to a basic advantage and there are two cases:

5.1.1. Given a low basic advantage: compatible vs. incompatible duopoly

Given a low basic advantage $a_1 - a_2 < 23n/6 - 12 + 6/n$ or none at all, the decision on compatibility is a decision on whether to compete within a compatible or within an incompatible duopoly in the third market. As outlined above, when there is no basic advantage, both suppliers vote for compatibility. This is due to the price advantage of compatibility – which under symmetry manifests in third-market profits of 0.5 under compatibility whereas third-market profits amount to $0.5(1-n)$ under incompatibility – as well as to the network-size advantage of compatibility – which guarantees higher home-market profits under compatibility due to a higher willingness to pay. In the presence of a basic advantage of supplier D1, supplier D2 obviously always is better off under compatibility (see above). The decisive question is whether for D1 the installed-base advantage of incompatibility can dominate the two effects favoring compatibility. In the Appendix we show that it cannot; hence, suppliers unanimously establish compatibility.

5.1.2. Given a high basic advantage: compatible duopoly vs. monopoly

Given a high basic advantage $a_1 - a_2 > 4n - 12 + 6/n$, the decision on compatibility is a decision on whether to compete within a compatible duopoly or for the third market. Again, D2 obviously is better off under compatibility. In the Appendix we show that D1 will always agree on compatibility. Hence, with weak network effects D1 never builds up a high installed home base under incompatibility in order to monopolize the third market. Rather, he builds up a high installed home base under compatibility in order to generate a high willingness to pay in his home market.

Thus, we can state:[10]

Proposition 1. With weak network effects $n < 0.6246$ the network-size and price advantages of compatibility always dominate the installed-base advantage of incompatibility (for D1) so that suppliers unanimously opt for compatibility regardless of whether the alternative is an incompatible duopoly or a limit-pricing monopoly in third-market competition.

5.2. Compatibility decisions with strong network effects ($n > 2/3$)

Here, installed home bases always are of the same amount for compatibility and for incompatibility and an installed-base advantage goes back to a home-market size advantage. There are two cases:

5.2.1. Given a low home-market size advantage: compatible vs. incompatible duopoly

Given a low home-market size advantage $s_1 - s_2 < 3(1-n)/n$ or none at all, suppliers have to decide on whether the third market is a compatible or an incompatible duopoly. For $s_1 = s_2$, obviously both suppliers prefer compatibility. When D1 has a home-market size advantage $s_1 > s_2$, D2 always favors compatibility because under incompatibility the induced installed-base effect lowers his profits not only in the third market but – due to rational consumer expectations – also in his home market. As for D1, we again have to weigh up the price-competition effect plus the network-size effect on the one hand with the installed-base effect on the other hand. Again the latter always is dominated by the advantages of compatibility (see Appendix). Hence, given a low home-market size advantage suppliers unanimously

[10]Here and in the following, those parameter constellations for which a subgame-perfect Nash equilibrium with rational expectations does not exist are excluded from the weak-network-effects cases without further notice.

vote for compatibility.

5.2.2. Given a high home-market size advantage: compatible duopoly vs. monopoly

Given a high home-market size advantage $s_1 - s_2 > 3(1-n)/n$, suppliers have to decide on whether to compete within a compatible duopoly or for the third market. In case of incompatibility, supplier D2 is excluded from the third market and makes profits in his home market which are lower than the profits he makes at home under compatibility (where he additionally make third-market profits of 0.5; see Appendix). Thus, D2 always prefers a compatible duopoly. As for supplier D1, we prove in the Appendix that in the case at hand the installed-base advantage of incompatibility dominates the advantages of compatibility for a home-market size advantage higher than $(1.5-n)/n + s_1 s_2$. Note that when s_2 becomes small, the network-size effect becomes small, too. This, in turn, implies that a monopolization must become profitable for sufficiently strong network effects and a sufficiently high home-market size advantage. Figure 2 gives an example; there, we have set D1's home-market size to one (i.e.: $s_1 = s_t = 1$).

Hence, with regard to the two cases with strong network effects we can state:

Proposition 2. With strong network effects ($n > 2/3$) suppliers opt for compatibility whenever the home-market size advantage is low. However, when this advantage is sufficiently high, the installed-base advantage of incompatibility can dominate the network-size and price advantages of compatibility so that the favored supplier (D1) maintains incompatibility in order to monopolize the third market via limit pricing.

******* Figure 2 about here *******

6. STANDARDIZATION BODIES AND WELFARE

A global-welfare maximizing social planner who decides on (in)compatibility and leaves the subsequent decisions to the market would always choose compatibility, because compatibility

(i) always leads to higher cumulated network effects,

(ii) in asymmetric cases ($a_1 \neq a_2$ or $s_1 \neq s_2$) results in lower cumulated alienation

effects,
(iii) for weak network effects $n < 0.6246$ means a higher cumulated basic surplus $a_i x_i$ (remember: $a_i \equiv b_i - c_i$) due to $x_i^{co} > x_i^{in}$.
This is what global standardization bodies such as ISO (among other things with regard to hardware-software systems) and ITU (with regard to communications systems) would do (given they had the power) in order to maximize global welfare. In contrast, regional standardization bodies such as CEN, CENELEC and ETSI in Europe aim at maximizing total regional welfare (regional profits plus regional consumer surplus). For regional standardization bodies we have to compare total regional welfare under compatibility with realized total regional welfare under incompatibility for the four regimes of Table 1. As the regional standardization bodies of region R2 and the third market obviously always favor compatibility, we only discuss the decisions of the regional standardization bodies of region R1. Here, we get for given compatibility

$$W_1^{co} = a_1 x_1^{co} - 0.5 x_1^{co^2} + x_1^{co} n (1 + x_1^{co} + x_2^{co}) + 0.5 \,. \tag{33}$$

The first term represents cumulated basic surplus whereas the second term reflects cumulated alienation effects. The third term stands for cumulated network effects in region R1 while the last term delineates the third-market profits of the regional supplier D1. For given incompatibility, we obtain for the duopoly case

$$W_1^{in,d} = a_1 x_1^{in,d} - 0.5 x_1^{in,d^2} + x_1^{in,d} n (x_1^{in,d} + x_{1t}^{in,d}) + 2(1-n) x_{1t}^{in,d^2} \tag{34}$$

and for the monopoly case

$$W_1^{in,m} = a_1 x_1^{in,m} - 0.5 x_1^{in,m^2} + x_1^{in,m} n (1 + x_1^{in,m}) - (1-n) + n (x_1^{in,m} - x_2^{in,m}). \tag{35}$$

Comparing welfare under compatibility (see Equation (33)) with welfare under incompatibility and a duopoly solution (see Equation (34)) for weak network effects reveals that the regional standardization body makes exactly the same decisions as the regional supplier. The same holds true if we compare for strong network effects welfare under compatibility with welfare under incompatibility and an emerging monopoly (see Equation (35)). The reasons are as follows:

(i) In the case of strong network effects $n > 2/3$ (with $x_i = s_i$) suppliers must not compete for an intramarginal consumer at home and therefore they can skim off the last consumer's total surplus (inclusive the network-effect rent). With regard to total welfare this implies that when maximizing profits, suppliers implicitly take fully account of total welfare. For example, in the case of a high home-market size advantage

$s_1 - s_2 > 3(1-n)/n$ D1 compares the third-market profit advantage of incompatibility with a home-profit advantage of compatibility of ns_1s_2. R1, in turn, compares the former with a cumulated willingness-to-pay advantage of compatibility which also amounts to ns_1s_2. Hence, regional suppliers and regional standardization bodies have identical compatibility incentives. In particular, with a high home-market size advantage and sufficiently strong network effects, the standardization body of region R1 hinders compatibility in order to enable his supplier D1 to monopolize the third market. That is, here market failure and committee failure go together.

(ii) In the case of weak network effects $n < 0.6246$, suppliers have to compete for an intramarginal consumer in home markets and, thus, profit maximization does not include the maximization of consumers' surplus. Hence, the regional standardization body of region R1 has a higher inclination for compatibility than D1. [11] With the help of the above welfare expressions, it is straightforward to prove that the regional standardization body always chooses compatibility. As the sum of cumulated basic surplus and cumulated alienation effects always is higher under compatibility (due to $x_1^{co} > x_1^{in,d}$ and $x_1^{co} > x_1^{in,m}$), it is in both subcases sufficient to show that the network-size advantage of compatibility (willingness-to-pay advantage in home markets) dominates a third-market profit advantage of incompatibility. Moreover, for a low basic advantage, additionally $x_{1t}^{in,d} \leq 1$ holds so that it suffices to prove that $x_1^{co} n x_2^{co}$ is higher than the third-market profit advantage of incompatibility. It is straightforward to show this by simple rearrangements of terms. For a high basic advantage, $x_1^{co} > x_1^{in,m} > 1$ holds so that it suffices to prove that $x_1^{co} + x_2^{co} > 1 + x_1^{in,m}$ is true. Once again this can be shown by some simple rearrangements. Hence, we can state

Proposition 3. While a global standardization body always opts for compatibility, regional standardization bodies make exactly the same compatibility decisions as regional suppliers. In particular, given a high home-market size advantage and sufficiently strong network effects a regional standardization body hinders compatibility in order to enable its supplier to monopolize the third market.

[11] However, as we know from Section 5.1, suppliers nevertheless always vote for compatibility so that there is no market failure.

7. CONCLUSIONS

In this paper we analyzed the compatibility decisions of two regional suppliers of a network-effect good who first build up installed bases in their respective home markets and then compete in a third market. We showed that due to international network effects and rational consumer expectations, installed home bases become strategic substitutes under incompatibility and strategic complements for given compatibility. As a consequence, with weak network effects installed home bases always are higher under compatibility and, therefore, compatibility has a willingness-to-pay advantage. In our analysis of Nash equilibria, we made clear that this effect in conjunction with the price-competition effect always dominates the installed-base effect so that for weak network effects suppliers unanimously opt for compatibility. However, with strong network effects home markets are covered, and given a high advantage in home-market size a supplier might maintain incompatibility in order to monopolize the third-market via limit pricing.

In our welfare analysis we proved that compatibility always is welfare optimal. Hence, when network effects are weak compatibility decisions can be left to the market. However, when network effects are strong – as they usually are in communications systems – the market may fail. Moreover, it turns out that a regional standardization body makes exactly the same compatibility decisions as regional suppliers; i.e., in a global context, regional standardization bodies with competence for compatibility decisions (such as ETSI) never make sense. Rather, in case of considerably strong network effects there is need for a global standardization body with such a competence.

APPENDIX

Proof of Lemma 4

For the symmetric case with $a_1 = a_2$ the validity of Lemma 4 is obvious; then, only the respective first term in the installed-base equations (12) and (18) matters, and simple rearrangements show that for weak network effects ($n < 0.6246$) Lemma 4 holds. In case of a low basic advantage of V1 ($a_1 - a_2 < 23n/6 - 12 + 6/n$), it becomes clear from Equations (12) and (18) that x_2^{co} is higher and $x_2^{in,d}$ lower than under symmetry, whereas for D1's quantity x_1 the opposite holds. Hence, $x_2^{co} > x_2^{in,d}$ holds all the more. Considering x_1, the presumption $x_1^{co} > x_1^{in,d}$ is proven for asymmetric cases when we can show that it holds for the maximum possible basic advantage. Substituting $a_1 - a_2 = 23n/6 - 12 + 6/n$ in Equations (12) and (18) and solving for n makes clear that this really is true. Finally, in case of a high basic advantage ($a_1 - a_2 > 4n - 12 + 6/n$) – i.e., when supplier D1 builds up an installed home base which enables him to monopolize the third market while his competitor D2 confines himself to selling at home – $x_2^{co} > x_2^{in,m}$ holds obviously; see Equations (12) and (26). Moreover, then even the installed home base of supplier D1 is lower than under compatibility; $x_1^{in,m} > x_1^{co}$ would require $a_1 < 4n - 10 + 4/n - 2(1-n)a_2/n$ to hold – see Equations (12) and (24). This, however, cannot be fulfilled in the monopoly regime.

Proof of Proposition 1

(i) Given weak network effects $n < 0.6246$ and a low basic advantage $a_1 - a_2 < 23n/6 - 12 + 6/n$, suppliers compare total profits of $(1-n)x_i^{co^2} + 0.5$ for compatibility with total profits of

$$\left(1 - n - \frac{2n^2}{9(1-n)}\right) x_i^{in,d^2} + \frac{n^2}{18(1-n)} x_j^{in,d^2} - \frac{n}{3} x_j^{in,d} + \frac{1-n}{2}$$

for an incompatible duopoly (see Equations [13] and [21]). For symmetric cases with $a_1 = a_2$ and thus $x_i^{in,d} = x_j^{in,d}$ it is obvious that the former always are higher. Moreover, that in the presence of a basic advantage of D1 supplier D2 always is better off under compatibility is obvious, too. As for D1's profits with $a_1 > a_2$, re-writing the first two terms of the above profit equation for incompatibility as

$$\left(1 - n - \frac{n^2}{6(1-n)}\right) x_1^{in,d^2} - \frac{n^2}{18(1-n)} (x_1^{in,d^2} - x_2^{in,d^2})$$

and comparing with profits under compatibility makes clear that due to $x_1^{co} > x_1^{in}$ his profits always are higher under compatibility.

(ii) Given weak network effects $n < 0.6246$ and a high basic advantage $a_1 - a_2 > 4n - 12 + 6/n$, supplier D1 compares total profits of $(1-n)x_i^{co^2} + 0.5$ (with $i = 1, j = 2$) for compatibility with total profits of $(1-n)x_1^{in,m^2} - (1-n) - nx_2^{in,m}$ for maintaining incompatibility and monopolizing the third-market via limit pricing, whereas supplier D2 compares the former (with $i = 2, j = 1$) with total profits of $(1-n)x_2^{in,m^2}$ from selling only in his home market (see Equations [13], [30], and [27]). From Lemma 4 it is obvious that again profits always are higher under compatibility.

Proof of Proposition 2

(i) Given strong network effects $n > 2/3$ and a low home-market size advantage $s_1 - s_2 < 3(1-n)/n$ or none at all, suppliers compare profits under compatibility of $[a_i + n(s_j + 1)]s_i - (1-n)s_i^2 + 0.5$ with profits under incompatibility of

$$\left(a_i + 0.5n - \frac{n^2}{6(1-n)}s_j\right)s_i - \left(1 - n - \frac{n^2}{6(1-n)}\right)s_i^2 + \frac{\left(1 - n + \frac{n(s_i - s_j)}{3}\right)^2}{2(1-n)}$$

(see Equations [14] and [23]). In the symmetric case with $s_1 = s_2$, the two profit equations clearly reflect the price advantage and network-size advantage of compatibility. For $s_1 > s_2$, supplier D2 obviously always favors compatibility whereas supplier D1 has to weigh up a price-competition effect of $0.5n$ plus a network-size effect of $n(0.5s_1 + s_1 s_2)$ on the one hand with the installed-base effect of incompatibility on the other hand. The latter reads

$$\frac{n^2(s_1 - s_2)}{6(1-n)}s_1 + \frac{n^2(s_1 - s_2)^2}{18(1-n)} + \frac{n(s_1 - s_2)}{3}$$
$$= \frac{n^2}{18(1-n)}\left[(s_1 - s_2)^2 + 2\left(3\frac{1-n}{n} + 1.5s_1\right)(s_1 - s_2)\right].$$

Here, the second and third term of the first formulation reflect the direct part of the installed-base effect that works in third-market competition whereas the first term reflects its indirect part which works in the home market (and which is due to rational consumer expectations). A dominance of the installed-base effect would require

$$s_1 - s_2 > \sqrt{\left(3\frac{1-n}{n} + 1.5s_1\right)^2 + 18\frac{1-n}{n}(0.5 + 0.5s_1 + s_1 s_2)} - \left(3\frac{1-n}{n} + 1.5s_1\right).$$

This condition, however, can never be fulfilled because for $n > 2/3$ the square root of $9(1-n)/n$ always is higher than $3(1-n)/n$. Hence, profits always are higher under compatibility.

(ii) Given strong network effects $n > 2/3$ and a high home-market size advantage $s_1 - s_2 > 3(1-n)/n$, supplier D1 compares total profits of $[a_i + n(s_j + 1)]s_i - (1-n)s_i^2 + 0.5$ (with $i = 1, j = 2$) for compatibility with total profits of $(a_1 + n)s_1 - (1-n)s_1^2 - (1-n) + n(s_1 - s_2)$ for maintaining incompatibility and monopolizing the third-market via limit pricing, whereas supplier D2 compares the former (with $i = 2, j = 1$) with total profits of $a_2 s_2 - (1-n)s_2^2$ from selling only in his home market (see Equations [14], [31], and [32]). The result for D2 is obvious. Considering D1's home-market profits, there is a network-size effect of ns_1s_2 in favor of compatibility; on the other hand, maintaining incompatibility and monopolizing the third market via limit pricing can lead to higher third-market profits: $-1.5 + n + n(s_1 - s_2) > 0$ holds for $s_1 - s_2 > (1.5-n)/n$, where $(1.5-n)/n$ is less than $3(1-n)/n$ for $n > 0.75$. Hence, a monopolization pays off for $-1.5+n+n(s_1-s_2) > ns_1s_2$, i.e. for a home-market size advantage higher than $(1.5-n)/n + s_1s_2$.

REFERENCES

Barrett, C.B. and Y.-N. Yang (2001), 'Rational Incompatibility with International Product Standards', *Journal of International Economics* 54, 171-191.

Chou, C.-F. and O. Shy (1990), 'Network Effects without Network Externalities', *International Journal of Industrial Organization* 8, 259-270.

Church, J. and N. Gandal (1992), 'Network Effects, Software Provision, and Standardization', *Journal of Industrial Economics* 40, 85-103.

Farrell, J. and G. Saloner (1992), 'Converters, Compatibility, and the Control of Interfaces', *Journal of Industrial Economics* 40, 9-35.

Funk, J.L. and D.T. Methe (2001), 'Market- and Committee-based Mechanisms in the Creation and Diffusion of Global Industry Standards: the Case of Mobile Communication', *Research Policy* 30, 589-610.

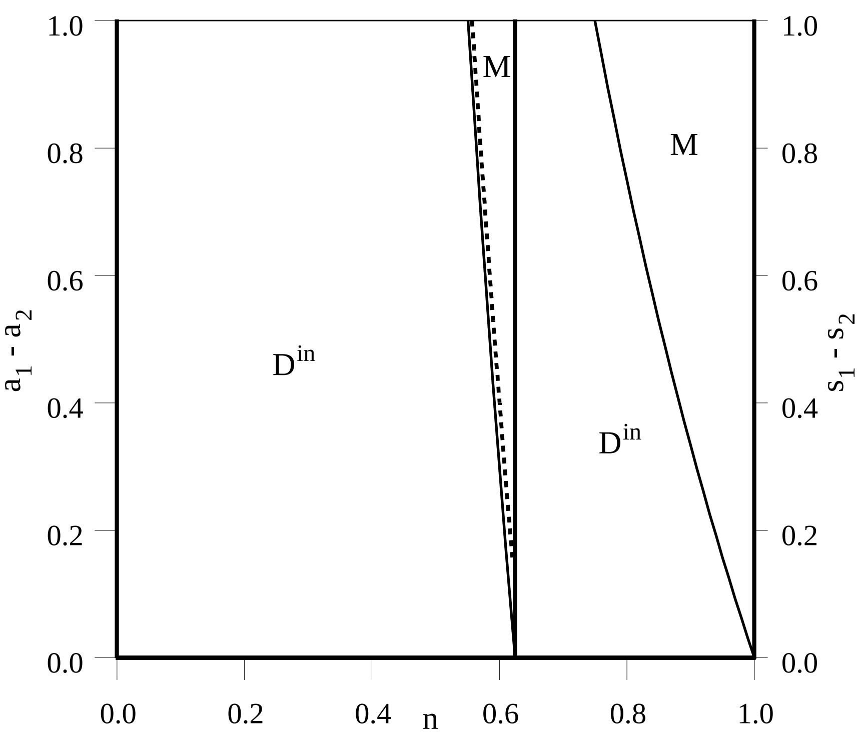
Gandal, N. and O. Shy (2001), 'Standardization Policy and International Trade', *Journal of International Economics* 53, 363-383.

Matutes, C. and P. Regibeau (1996), 'A Selective Review of the Economics of Standardization: Entry Deterrence, Technological Progress and International Competition', *European Journal of Political Economy* 12, 183-209.

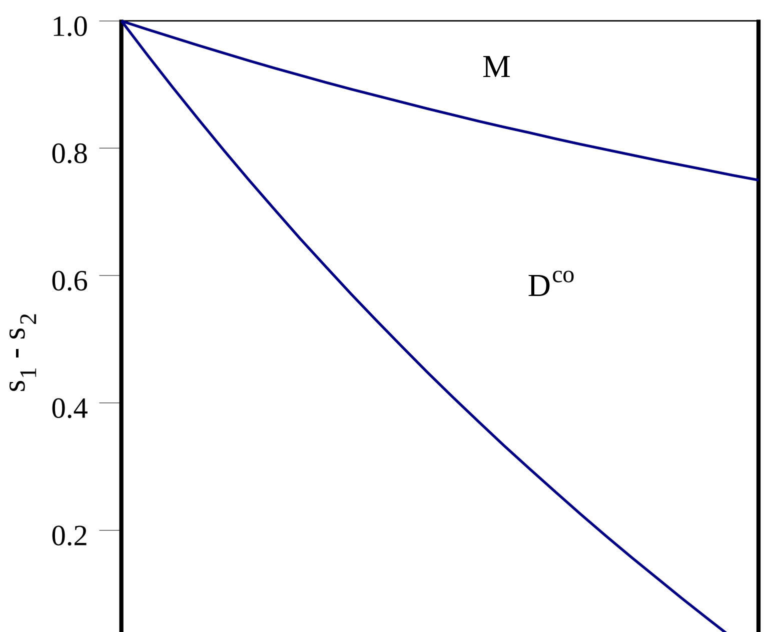
Pargal, S. (1996), 'Do Incompatible Network Standards Lead to Domestic Benefits? The Case of Color Television', *Information Economics and Policy* 8, 205-227.

Walz, U. and B. Woeckener (2002), 'Compatibility Standards and Strategic Trade Policy', Mimeo.

Woeckener, B. (1999), 'Network Effects, Compatibility Decisions, and Monopolization', *Zeitschrift für Wirtschafts- und Sozialwissenschaften (ZWS)* 119, 23-44.



1.0
0.8
0.6
0.4
0.2
0.0
a1 - a2
s1 - s2
M
M
D^in
D^in
0.0
0.2
0.4
n
0.6
0.8
1.0



1.0
0.8
0.6
0.4
0.2
0.0
$s_1 - s_2$
M
D^{co}
0.75
0.80
0.85
n
0.90
0.95
1.00