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Manfred Stadler, Céline Tobler Trexler, Maximiliane Unsorg

Faculty of Economics and Social Sciences
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The Perpetual Trouble with Network Products

Why IT Firms Choose Partial Compatibility

Manfred Stadler[*], Céline Tobler Trexler[†], Maximiliane Unsorg[‡]

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Abstract

Compatibility of network products is an important issue in markets for communication technology as well as hard- and software products. Empirical findings suggest that firms competing in these markets typically choose intermediate degrees of product compatibility. We present a strategic two-stage game of two firms deciding strategically or commonly on the degree of product compatibility in the first stage and on prices in the second stage. Indeed, partial compatibility constitutes a subgame perfect Nash equilibrium when coordination costs of standardization are high and the installed bases are low.

Keywords: Compatibility, Network Products, Network Effects
JEL classification: C72, L13, L15

[*]University of Tübingen, Department of Economics, Nauklerstr. 47, D-72074 Tübingen, Germany. e-mail: manfred.stadler@uni-tuebingen.de

[†]University of Tübingen, Department of Economics, Nauklerstr. 47, D-72074 Tübingen, Germany. e-mail: celine.tobler-trexler@uni-tuebingen.de

[‡]University of Tübingen, Department of Economics, Nauklerstr. 47, D-72074 Tübingen, Germany. e-mail: maximiliane.unsorg@uni-tuebingen.de

1 Introduction

Markets for goods and services exerting network effects are growing in number as well as in size. Consumer demand for communication technology, hard- and software is increasing continuously. Telephones, mobile phones, the internet, music and video players, banking and airline services, and also the hard- and software of computers are improved gradually, especially when new suppliers enter the market.

Network products have certain features making them interdependent on each other. For example, consider the connection of newly updated software with apps on mobile phones or the operating ability of new computers with older technology, enabled via suitable adapters.

The special characteristics of these markets are compatibility, consumption externalities and consumer switching costs, see Shy (2001) for an overview. Recently, and not only since the COVID19 pandemic, markets for computer hard- and software again have received increased attention. Ever since the introduction of digital IT systems, the compatibility of hard- and software causes problems and inconveniences. Usually, systems or products are not completely incompatible. There exists a range of different adapters to make hardware connections compatible or, furthermore, files of different systems and formats can be converted by translation programs to be usable again. Obviously, firms choose partial compatibility of their network products.

Network effects, describing an externality on consumers' utility or firms' profits caused by the compatibility of technology, can either be positive or negative (Shy, 2010). In markets where a special kind of snobbishness for the exclusivity exists, negative network effects can be found.

However, more common is the existence of positive network effects, meaning that consumers prefer goods or services being at least partially compatible. Positive network effects increase consumer utility and firm profits. Switching costs arise when consumers switch from one brand to another being not perfectly compatible with the former one. For example, switching from a mobile operating system to another, i.e. from Android to iOS, compatibility issues arise not only because of applications or file formats, but also because peripheral devices like earphones mostly are incompatible. Especially, customers using an Apple device achieve a higher utility and a better consumer experience when they use Apple products only due to the high incompatibility of Apple hard- and software with rival products.

In the theory of industrial organization, the degree of compatibility is not treated as exogenously given, but instead as a strategic decision of rival firms. Competition is modeled as a two-stage game where firms decide on the degree of compatibility of their products in the first stage and engage in price competition in the second stage, see e.g. Matutes and Regibeau (1988), Economides (1989), Pfähler and Wiese (2006) or Kim and Choi (2015). However, none of these models derives an explicit solution for partial compatibility of network products.

This paper derives an explicit solution, arising under certain situations, for the observed partial compatibility decisions of firms, enabling us to analyze comparative statics and to determine decisive factors leading to partial compatibility. We show that, depending on the costs of coordinating technical standards, a symmetric equilibrium with partial compatibility can exist. If the coordination costs are high and the installed bases are low, firms will not choose complete compatibility of their products, triggering the often observed perpetual trouble for the users.

Additionally, the model also allows to account for common standardization decisions. We can show that if firms decide to coordinate their compatibility choices, partial compatibility still can arise, also depending on the costs of coordinating standardization. However, whether firms decide for a higher degree of compatibility in the cases of strategic or common decisions depends on the size of the installed bases and on whether costs arising from participating in a standards developing organization are high.

The rest of the paper is organized as follows: Section 2 provides a brief review of the existing literature. Section 3 presents a symmetric model of strategic compatibility choice, explaining the empirical evidence of partial compatibility. Section 4 studies the case of a common compatibility decision. Section 5 concludes.

2 Relation to the Literature

This section provides a brief insight in the existing literature and research regarding compatibility of products or services, network effects and externalities. In a series of papers, Katz and Shapiro (1985, 1986a,b) have analyzed several key factors and mechanisms regarding compatibility. First, they showed in a static environment that firms' incentives are lower than social ones to offer complete compatibility (Katz and Shapiro, 1985). Furthermore, they derived that, under certain circumstances, compatibility can be undersupplied by the market (Katz and Shapiro, 1986a). In their follow-up paper, Katz and Shapiro (1986b) have analyzed the incentives for compatibility in a dynamic framework. In contrast to the static setup, they find that firms are characterized by excessive compatibility incentives when compatibility serves to reduce competition.

Church and Gandal (2004) distinguish between direct and indirect (virtual) networks via referring to horizontal and vertical product compatibility. The former type of network is achieved via some common standard across different products purchased by consumers in the network such as for example telecommunication. Indirect networks in contrast describe the compatibility between some kind of hard- and software, where one unit of hardware often is compatible with many different units of software - or at least partially. While many illustrative examples can be found in consumer electronics, also credit card types and stores accepting them can be considered as networks with vertical compatibility, i.e. whether certain credit card providers are accepted in all or only in few stores.

The majority of these products is characterized by positive network effects, i.e. the bigger the network size, the better for consumers. Though, not only direct network effects are decisive but also indirect effects can increase consumers' utility. Those effects can arise from the fact that the bigger the number of consumers using a certain type of hardware, the higher the incentive to provide compatible hardware. Clearly, this also shows why the size of the installed base matters. Those firms or products with a large base are less likely to aim for compatibility.

David and Steinmueller (1994) find that even if compatibility standards are in the interest of consumers and producers, they do not only generate winners, but also losers. Based on the example of telecommunication, they showed that the process of standardization can either stimulate or retard (private) investment in R&D, depending on whether investment is undertaken in universal standards or in variety-increasing standardization processes.

Gallagher (2011) has analyzed the battle for standards in the case of Sony's Blue-Ray vs. Toshiba's HD-DVD. Standards are used to decrease transaction and switching costs and to create a network of compatible users. The study shows that in this battle the indirect network effects are a key factor and that compatibility of network products is an appropriate strategy of firms.

Gandal (2002) claims that compatibility decisions and network effects are highly prevalent especially in technological markets. Further, he argues that with increasing importance of markets characterized by network effects, the need to analyze these effects gains more importance as well.

The effects of initial usage share, manipulation of compatibility and network effects are summarized by Heinrich (2017). On behalf of a replicator model, the author investigates the impact of initial conditions and compatibility. Beyond the commonly known finding that initial usage is crucially important for successful implementation of standards, the author shows that compatibility of standards can have a significant effect that may be able to outweigh a low initial usage share.

As already mentioned, Pfähler and Wiese (2006) do not derive an explicit solution, however, they show that in the case of symmetric firms, a corner solution with perfect compatibility constitutes an equilibrium, thereby, providing the basis for the following analysis. To solve for an explicit solution, we provide a theoretical model explaining the empirical evidence of partial compatibility and shedding light on the decisive factors leading to these strategic decisions.

3 Strategic Compatibility Decisions

We consider a two-stage game, where two firms $i = 1, 2$ decide independently on the compatibility of their network products in the first stage and engage in price competition in the second stage. Consumers of mass 1 are characterized by heterogeneous preferences that are uniformly distributed along a linear Hotelling line defined on the unit interval $x \in [0, 1]$. When not being able to purchase their most preferred product, consumers suffer from a quadratic loss of utility.

Each consumer buys exactly one unit of the product, thereby realizing positive network externalities. As a consequence, their utility increases in the mass of consumers adopting the respective product. Furthermore, we assume that the firms have chosen maximum horizontal differentiation, i.e. they have positioned their products at the extremes of the Hotelling line. Without loss of generality, we define the product of firm 1 being located to the left of firm 2, implying $x_1 = 0$ and $x_2 = 1$.

The influence of the mass of consumers using the rival's product depends on the degree of product compatibility $k_i \in [0, 1]$. The limit case of $k_i = 0$ describes complete incompatibility, whereas, the opposite limit case $k_i = 1$ denotes perfect compatibility of the products.

The network of firm i consists of its installed base b_i, defined as the amount of products sold to users in the past, and the quantity q_i, denoting the sales in the considered period. We assume symmetric initial conditions for both firms, i.e. $b_1 = b_2 = b \geq 0$, in order to derive an explicit equilibrium solution, characterized by a two-sided partial compatibility. Then, the network size of firm i is defined as

$$g_i = b + q_i + k_i(b + q_j) \ , \quad i, j = 1, 2 \ , \ i \neq j.$$

The surplus of every consumer buying product i adds up to

$$CS_i = u_0 + \beta g_i - p_i - \alpha(x - x_i)^2 \ ,$$

where u_0 denotes the basic utility and p_i the price charged by firm i. The parameters α and β indicate consumers' preferences for the two-dimensional product characteristics heterogeneity and compatibility. Accordingly, $\alpha \geq 0$ is a measure of horizontal product differentiation and $\beta \in [0, \alpha/3]$ is a measure of the strength of network effects.

The consumer being indifferent between buying product 1 (from firm 1) or product 2 (from firm 2) is located on the Hotelling line at

$$x^0 = \left[\alpha + (p_j - p_i) + \beta[b(k_i - k_j) + (1 - k_j)q_i - (1 - k_i)q_j]\right]/(2\alpha) \ ,$$

implying the firm-specific demand functions $D_1 = x^0$ and $D_2 = 1 - x^0$.

Supposing rational and self-fulfilling expectations, as it is adequate in a subgame perfect Nash equilibrium, it, consequently, has to hold that $q_i = D_i, i = 1, 2$. Solving the two-equation system gives the firms' (expected) demand functions

$$D_i(p_1, p_2, k_1, k_2) = \frac{1}{2} + \frac{p_j - p_i + \beta(1 + 2b)(k_i - k_j)/2}{2\alpha - \beta(2 - k_i - k_j)} \ .$$

Firms have to incur constant marginal production costs c as well as coordination costs that are a prerequisite for their decision on the degree of product compatibility. Following Kim (2002), we assume the quadratic cost function $(\gamma/2)k_i^2$, where $\gamma > 0$ denotes a coordination cost parameter. This gives the firms' profit functions

$$\pi^i(p_1, p_2, k_1, k_2) = (p_i - c)\left[\frac{1}{2} + \frac{p_j - p_i + \beta(1 + 2b)(k_i - k_j)/2}{2\alpha - \beta(2 - k_i - k_j)}\right] - \frac{\gamma k_i^2}{2} \ . \quad (1)$$

In the second stage of the game, firms maximize their profits with respect to the prices. From the first-order conditions we derive the equilibrium prices

$$p_i = c + \alpha - \beta\left(3 - 2k_i - k_j - b(k_i - k_j)\right)/3 \ . \quad (2)$$

For $\beta = 0$ we derive the standard price-setting result of the Hotelling model, see e.g. Tirole (1988). An increase of the parameter β reflects a higher importance of network effects. Obviously, in the symmetric equilibrium with $k_1 = k_2$, incompatibility of products leads to fiercer price competition between the firms.

By substituting the price equations (2) into the profit equations (1), we obtain the firms' reduced-form profit functions

$$\pi^i(k_1, k_2) = \frac{\left[3\alpha - \beta(3 - 2k_i - k_j - b(k_i - k_j))\right]^2}{9[2\alpha - \beta(2 - k_i - k_j)]} - \frac{\gamma k_i^2}{2} \ . \quad (3)$$

Figure 1: Firm profits as depending on their compatibility decisions ($\alpha = 2, \beta = 1, \gamma = 1, b = 0$)

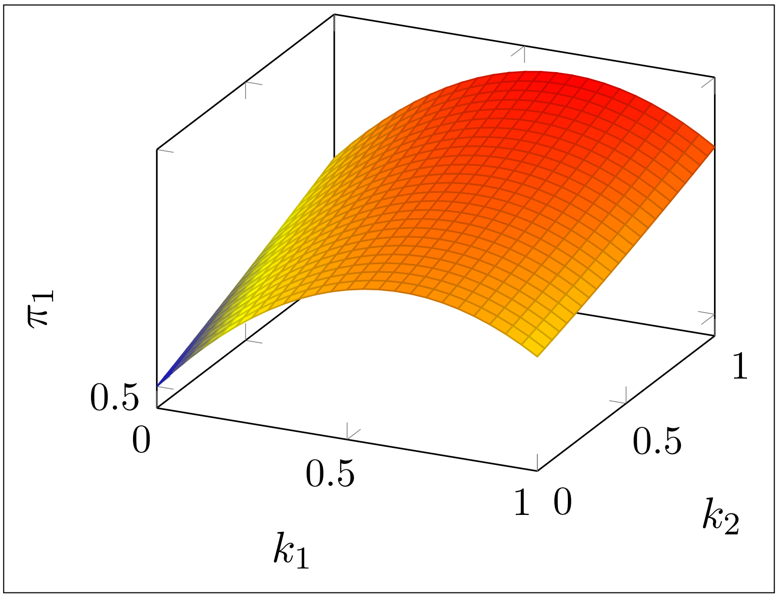


Figure 1 illustrates the dependence of firm profits on their independent compatibility decisions. The influence of the rival's compatibility decision on the profits is ambiguous and depends on the preferences for heterogeneity and compatibility as well as on the size of the installed bases.

In the first stage of the game, firms simultaneously decide on the degree of compatibility of their products in anticipation of the impact on price competition. Differentiation of the reduced-form profit functions (3) with respect to the strategic variables k_i and then imposing symmetry leads to

$$\left.\frac{d\pi^i}{dk_i}\right|_{k_1=k_2=k^*} = \frac{(5+4b)\beta}{12} - \gamma k^*.$$

Obviously, we have to distinguish two parameter ranges. For low parameter values $\gamma \in [0, (5+4b)\beta/12]$, the symmetric equilibrium is the corner solution $k^* = 1$, implying perfect compatibility of both products. This is the well-known outcome of the game when coordination costs are neglected, see e.g. Pfähler and Wiese (2006). However, in the case of sufficiently high parameter values $\gamma > (5+4b)\beta/12$, the first-order conditions $d\pi^i/dk_i = 0$, $i = 1, 2$, lead to an interior optimum indicating only partial compatibility as solution. This result is all the more relevant, the smaller the installed bases b are.

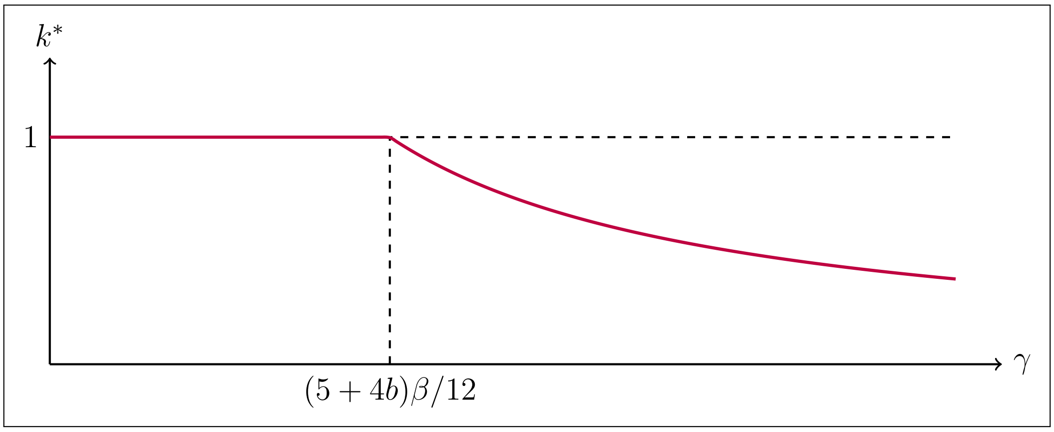
In emerging markets and in those markets where frequent innovations induce a continuing process of creative destruction, typically the installed base is low and the coordination cost is high. These are exactly the conditions under which our model predicts partial compatibility. Indeed our model provides a convincing explanation for the perpetual compatibility trouble with IT products.

The overall subgame perfect Nash equilibrium solution of our model is characterized by the firms' compatibility decisions

$$k^* = \min\{(5+4b)\beta/(12\gamma), 1\}\ .$$

As is shown in Figure 2, the solution covers all degrees of compatibility, depending on the coordination cost parameter γ.

Figure 2: Firms' strategic choice on the degree of compatibility

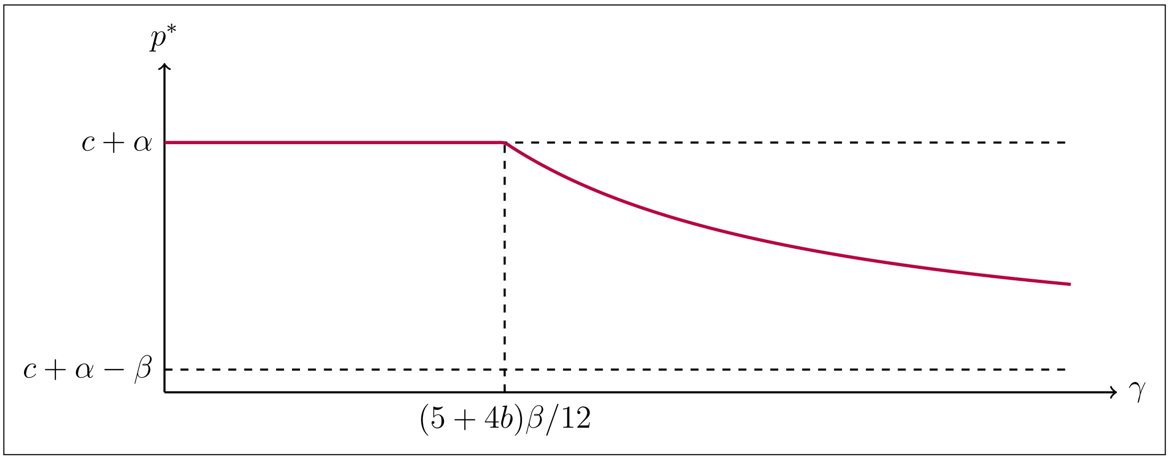


In the second stage of the game, firms observe the compatibility decisions of each other and charge the equilibrium prices

$$p^* = \begin{cases} c+\alpha & \text{if } (5+4b)\beta/(12\gamma) \geq 1 \\ c+\alpha-\beta\big[1-(5+4b)\beta/(12\gamma)\big] & \text{if } (5+4b)\beta/(12\gamma) < 1\,. \end{cases}$$

Figure 3 depicts the dependence of the equilibrium prices on the cost parameter γ. For low parameter values, when firms choose perfect compatibility, prices consist of the sum of unit cost and a mark-up determined by the product-differentiation parameter α. Clearly, this solution corresponds to the basic Hotelling model where no compatibility decisions are considered. With increasing parameter values, prices decline and converge to their minimum value $c+\alpha-\beta$.

Figure 3: Equilibrium prices in the case of strategic compatibility choices

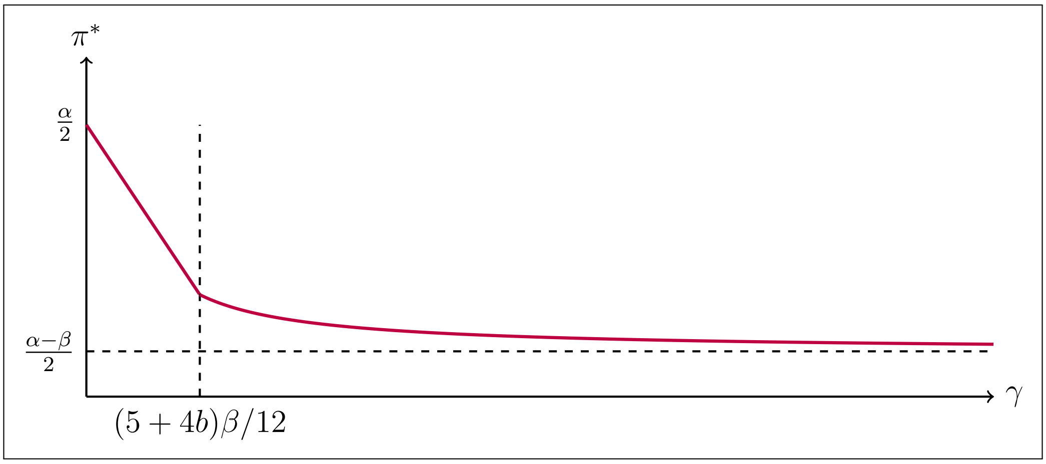


Finally, the firm profits amount to

$$\pi^* = \begin{cases} \frac{1}{2}(\alpha - \gamma) & \text{if } (5+4b)\beta/(12\gamma) \geq 1 \\ \frac{1}{2}\left[\alpha - \beta + \frac{(5+4b)(7-4b)\beta^2}{144\gamma}\right] & \text{if } (5+4b)\beta/(12\gamma) < 1\,. \end{cases}$$

Figure 4 depicts the profits in dependence of the cost parameter γ. When compatibility costs are negligible, the profits are $\pi^* = \alpha/2$ and again correspond to those resulting in the Hotelling model. However, with increasing parameter values, profits decline and finally converge to their minimum value $(\alpha - \beta)/2$.

Figure 4: Equilibrium profits in the case of strategic compatibility choices



When the installed bases b are modest and the impact β of network effects on consumers' utility is of minor importance, the critical value $(5+4b)\beta/(12\gamma)$ is low, implying a wider range for partial compatibility and lower prices and profits.

The model presented so far, is able to explain different degrees of compatibility emerging in markets with different costs of coordination. The model can account for partial compatibility in those cases where coordination costs are (sufficiently) high.

4 Common Standardization Decisions

In this section we shed some light on common standardization decisions. Firms often have the possibility to define common compatibility standards via so called market-specific "standards developing organizations" (SDOs). The term SDO usually refers to national organizations. However, there are also independent international standards organizations, that are organized as non-profit institutions and financed by their members' (and possibly benefactors') contributions.

These members are usually firms being affected by the common standards. For example, in the field of web-based telecommunication, the "World Wide Web Consortium" (w3c) has set many common standards on internet protocols. The internet protocol suite encloses many essential technologies, such as the markup languages HTML and XML or the style sheet language CSS. A further milestone of internet technology, the programming language JavaScript, also results from standardization processes of major IT firms (e.g. Yahoo, Microsoft, Google, etc.) under the umbrella organization "Ecma International" (European Computer Manufacturers Association).

Our approach can easily capture common standardization decisions of firms. Instead of independently deciding on firm-specific degrees of compatibility k_i, $i = 1, 2$, firms choose a common degree of compatibility k in the first stage of the game. We allow for a proportional standardization cost function $(\zeta\gamma/2)k^2$, where $\zeta > 0$ represents for example a membership fee to finance the SDO.

The price decisions (2) in the second stage of the game remain unchanged. The firms' reduced-form profit functions (3), however, simplify to

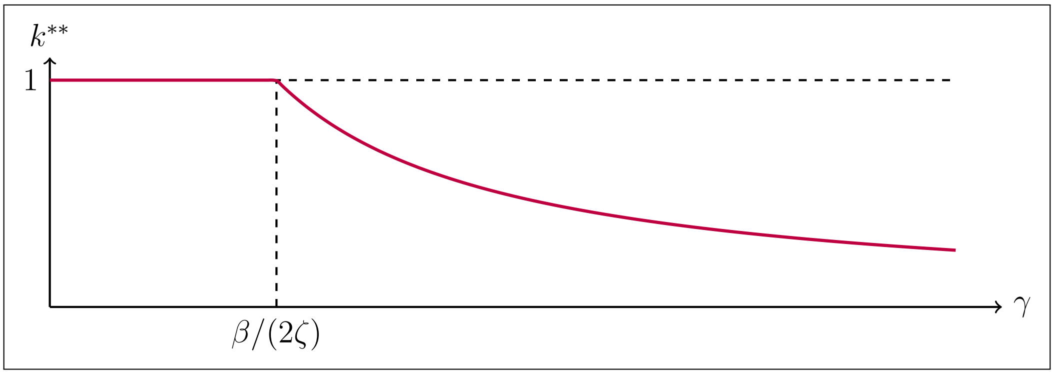
$$\pi^i(k) = \frac{\alpha - \beta(1-k) - \zeta\gamma k^2}{2} , \quad i = 1, 2 .$$

Maximization with respect to the common compatibility parameter k leads to the optimal degree of standardization

$$k^{**} = \min\{\beta/(2\zeta\gamma), 1\} .$$

In the case of a common standardization level, the installed bases b do not exert any influence on the compatibility decision k^{**}. As shown in Figure 5, the solution of the model again is able to account for all degrees of compatibility.

Figure 5: Firms' common choice on the degree of compatibility



A comparison of strategic and common compatibility decisions shows that even for identical coordination cost functions, i.e. $\zeta = 1$, the relation of the parameters depends on the installed bases b,

$$k^* \gtrless k^{**} \quad \text{for} \quad \zeta \gtrless \frac{6}{5+4b} \; .$$

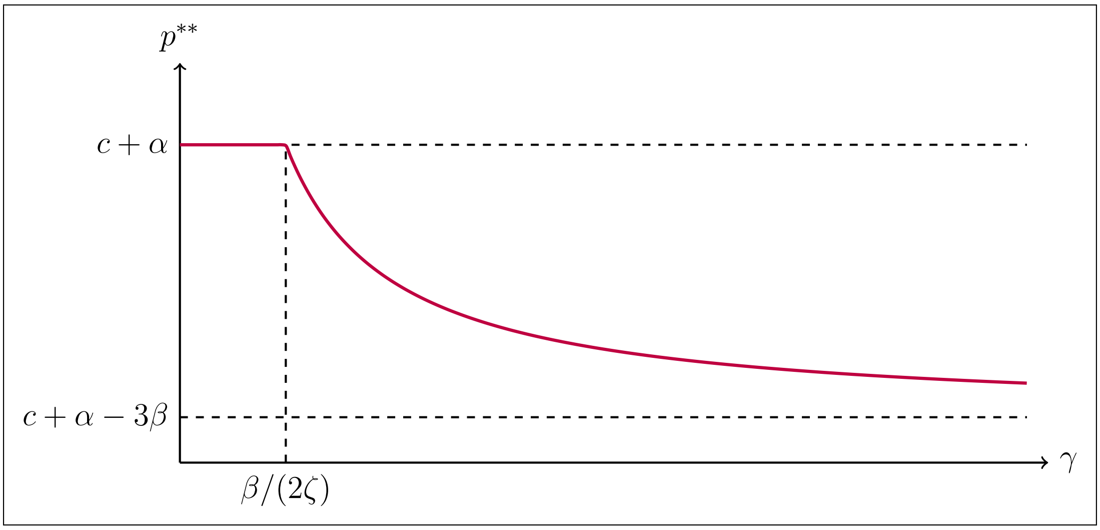
If the installed bases are negligible, firms decide for a lower degree of compatibility in case of independent decisions in comparison to common decisions, i.e. $k^* < k^{**}$. However, when the (membership fee) cost parameter ζ of the SDO is high, the result switches and the firms' common compatibility decision results in a lower degree of standardization.

The common compatibility decisions k^{**} lead to the equilibrium prices

$$p^{**} = \begin{cases} c + \alpha & \text{if } \beta/(2\zeta\gamma) \geq 1 \\ c + \alpha - 3\beta\big[1 - \beta/(2\zeta\gamma)\big] & \text{if } \beta/(2\zeta\gamma) < 1 \; . \end{cases}$$

Figure 6 depicts the dependence of equilibrium prices on the cost parameter γ. Again, for the range of low parameter values, where firms choose perfect compatibility, prices consist of the sum of unit cost and the mark-up depending on the product-differentiation parameter α. For increasing costs, prices decline and finally converge to their minimum $c + \alpha - 3\beta$, which is lower than the one under strategic decisions.

Figure 6: Equilibrium prices in the case of common compatibility choices



Finally, firm profits are derived as

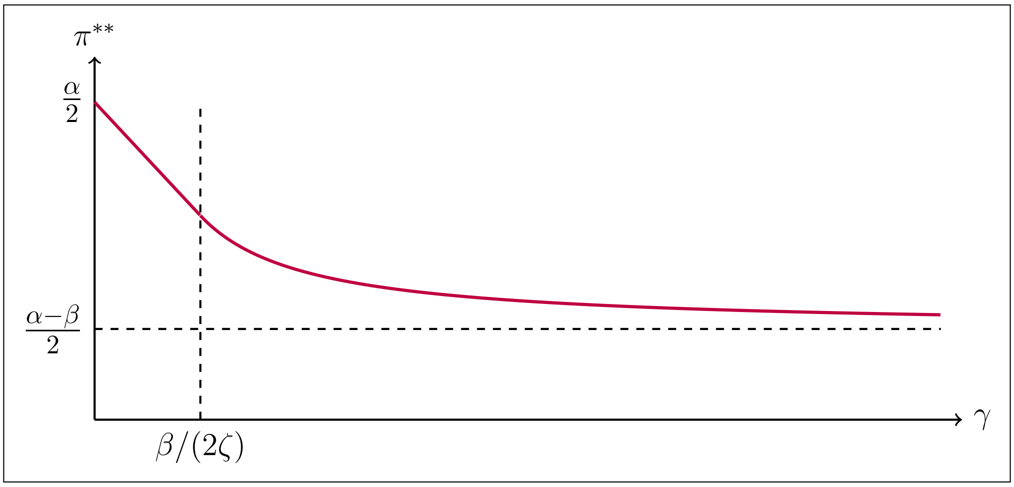
$$\pi^{**} = \begin{cases} \frac{\alpha-\zeta\gamma}{2} & \text{if } \beta/(2\zeta\gamma) \geq 1 \\ \frac{\alpha-\beta}{2} + \frac{\beta^2}{8\zeta\gamma} & \text{if } \beta/(2\zeta\gamma) < 1\,. \end{cases}$$

Profits increase in the product-differentiation parameter α and decrease in the cost parameter $\zeta\gamma$, whereby the influence of the initial coordination cost parameter γ is identical to the effect of the factor scaling them, ζ, in case firms define a common compatibility standard.

The strength of network effects, β, affects the equilibrium profits only if coordination costs are relatively high ($\beta \leq 2\zeta\gamma$), which occurs exactly in the situation when partial compatibility is optimal. In such an equilibrium with partial compatibility, firm profits decline in the strength of network effects.

Figure 7 describes the development of profits with increasing costs of coordination, which reflects a similar pattern as under strategic compatibility decisions.

Figure 7: Equilibrium profits in the case of common compatibility choices



5 Conclusion

Why do rival IT firms choose partial compatibility of network products? Applied game theory in industrial organization studies this question in the context of strategic competition. The simplest framework for such analyses is a two-stage duopoly game in a heterogeneous market where rivals decide on the degree of compatibility of their network products in the first stage and charge prices in the second stage.

For asymmetric market structures, resulting e.g. from differences in the installed bases of the products, no simple explicit solution exists. For symmetric market structures, earlier models imply the corner solution of full compatibility. Therefore, these models are not appropriate to explain the empirical evidence of partial compatibility in IT markets.

This paper shows that the consideration of coordination costs leads indeed to an explicit solution with partial compatibility. The optimal degree of compatibility is increasing in the products' installed bases. However, in emerging markets and in markets where frequent innovations induce a continuing process of creative destruction, the installed bases are rather low. Under such circumstances, our model predicts partial compatibility of network products as it can be observed in many markets.

Furthermore, we show that partial compatibility can also be explained when compatibility decisions are not strategic but common. This environment is relevant e.g. in markets with standards developing organizations (SDOs). Therefore, our approach provides a convincing explanation for the perpetual compatibility trouble with IT products we experience every day.

A further question arising from this study might be how compatibility decisions influence endogenous choices of product positioning in a multi-dimensional product space with preference conglomeration around the center, see e.g. Stadler (2019). It might also be worthwhile to extend the approach with respect to a price-elastic total demand or uncertainty about the fashion trend. Such interesting topics are left for future research.

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