2006

# Strategies to Boost Standard Diffusion in Communication Networks Insights from Network Effect Theory

Roman Beck
*Johann Wolfgang Goethe University*, beck@itu.dk

Daniel Beimborn
*Johann Wolfgang Goethe University*, beimborn@wiwi.uni-frankfurt.de

Jochen Franke
*Johann Wolfgang Goethe University*, jfranke@wiwi.uni-frankfurt.de

Tim Weitzel
*Bamberg University*, weitzel@is-bamberg.de

Follow this and additional works at: http://aisel.aisnet.org/digit2006

# Strategies to Boost Standard Diffusion in Communication Networks Insights from Network Effect Theory

Roman Beck, Daniel Beimborn, Jochen Franke

Institute of Information Systems
Johann Wolfgang Goethe University
Mertonstrasse 17, 60054 Frankfurt/Main,
Germany
Phone: +49 69 798 23318  Fax: +49 69 79828585
{rbeck | beimborn | jfranke }@wiwi.uni-frankfurt.de

Tim Weitzel

Chair of Information Systems and Services
Bamberg University
Feldkirchenstr. 21, 96045 Bamberg,
Germany

weitzel@is-bamberg.de

## Abstract

*IT standards are subject to network effects which establish challenges concerning a successful diffusion of standards. A renowned example is a mobile service provider trying to establish a network of customers while potential user often wait until the network is sufficiently large in terms of other users (direct network effect) or content available (indirect effect). Despite the potential benefits to adopters and providers, there is still much uncertainty on the differential impact of direct and indirect network effects on the diffusion of standards and their impact on successful diffusion strategies to establish a user base. Our research questions thus are:*

> *(a) …what are the adoption drivers of IT standards and*

> *(b) …how can providers influence these drivers to develop an installed base?*

*Based on network effect theory, we propose a formal model that simultaneously considers the different effects of direct and indirect network effects on the diffusion of communication standards. Using computer-based simulation we can show that IT providers could exploit the alternating impact of direct and indirect network effects at different diffusion stages to successfully establish an installed base. This has fundamental implications for the provider's pricing and market strategy.*

## Keywords

*Communication standards, simulation, diffusion, innovation, network effect theory*

# 1 Introduction

Communication standards and technologies exhibit potential benefits such as ubiquitous Internet and e-mail access for each adopter. Yet, successful diffusion of these standards depends on the potential adopters' expectations about adoption decisions of others and thereby the eventual market success, i.e. the path of diffusion of a new standard in the future. Thus, technology vendors have to find a way of attracting initial users to a standard that promises to be useful only if others are using it as well. While the single adopter has—in general—not the means to solve this coordination problem, the provider of a standard might be able to answer the question of how to establish an installed base of users. Or to put it more simply "Which dominoes should be tipped to overcome the startup problem?" (Weitzel et al. 2006), i.e. to generate sufficient network effects to initiate a bandwagon effect. While not all start-up problems appear to remain unsolved, network effect theory has not been too successful explaining either failure or success. Accordingly, the main research questions addressed in this paper are

(a) …what are the adoption drivers of communication standards and

(b) …how can providers influence these drivers to develop an installed base?

Drawing from the literature on network effects and diffusion of innovations (section 2), in section 3 a conceptual model of communication standards and service diffusion is developed and used for simulation studies in section 4. There, the findings are incorporated into a simulation model mirroring the diffusion of a new standard, while at the same time focusing on the interplay between direct and indirect network effects as main utility drivers.

The proposed model allows for an explicit differentiation between direct and indirect network effects as utility drivers (from adopting a new communication standard) and can support service providers in terms of their decision concerning the pricing and bundling of their services.

# 2 Theoretical foundation: standards and network effects

The theory of positive network effects describes a positive relation between the number of users of a network good and its utility (Katz and Shapiro 1985) that is called *network effect*. In this context, the term "network" is often used to describe the network of users of certain technologies or communication standards (Besen and Farrell 1994). As network effects are externalities (Weitzel et al. 2000), interpersonal coordination problems occur that can result in unfavorable or unintended diffusion results (e.g., too small or too large adopter networks) (Hildebrand 1976).

Network effects describe "the change in the benefit, or surplus, that an agent derives from a good when the number of other agents consuming the same kind of good changes" (Liebowitz and Margolis 1995; Thum 1995). Katz and Shapiro (1985) first differentiated between *direct network* effects in terms of the direct "physical effects" of being able to exchange information (also called horizontal compatibility) and *indirect network effects*, arising from interdependencies in the consumption of complementary goods (also called vertical compatibility as using one standard (like printer or DVD) requires others (like a computer or DVD player) (Chou and Shy 1990; Church and Gandal 1992; Teece 1987). Telephones or fax machines are good examples of direct network effects: the more people use the technology the more people I can reach with it and thus the more valuable the technology becomes to me. Indirect networks effects, in contrast, require some complementarities; examples include computer operating systems and available application software, or video cassette recorder systems and the format of the tapes. This relation is sometimes called the "hardware-software-paradigm" (Katz and Shapiro 1985, 424). Other sources of indirect network effects can be the availability of after sales services (support: automobile makes that are often sold will probably have a higher availability of different services than rare models (Katz and Shapiro 1985, 425; Katz and Shapiro 1986, 823), learning effects, uncertainties about future technology availability, or the existence of a market for used goods.

Since network effect goods, unlike stand-alone goods, draw their main value from joint use with other adopters, the diffusion of such goods often fails to meet expectations. Theoretically speaking, the existence of a positive externality (i.e. network effect) implies networks that are too small. The reason is that the private benefits of adoption are smaller than the social benefits: individual adopters only consider their own utility when deciding on joining a network (e.g. adopting the communication standard) but do not consider that joining would make the network more valuable to all other users at the same time. From the perspective of an individual standards adopter, the associated reluctance to adopt a standard can be explained in terms of incomplete information about the communication standard at the time of the adoption decision, heterogeneous preferences among potential adopters, or uncertainties about the adoption decision of the other market participants. As a consequence it is a dominant strategy for the individual to wait for others to adopt first instead of choosing a standard too early, since early adopters face the risk of finding themselves stranded in a standard that might turn out to be unsuccessful later (Choi 1994). This *start-up problem* (Economides and Himmelberg 1995a; Farrell and Saloner 1986; Katz and Shapiro 1985) can prevent any adoption at all of a network effect good, even if it is preferred by everyone. In network effect theory, this fundamental phenomenon is called a *penguin effect*[1]. A resulting challenge for network effect theory is thus to explain

(a) …how to solve the start-up problem and

(b) …what is the role of direct and indirect network effects

during the diffusion of network effect goods. Existing adoption and diffusion models mostly do not consider direct and indirect network effects and their interplay in a very same model. However, especially their dynamic interplay seems to be pivotal in order to explain the diffusion of network effect goods such as mobile data communication standards successfully.

---

[1] "Penguins who must enter the water to find food often delay doing so because they fear the presence of predators. Each would prefer the others to test the water first" (Farrell and Saloner 1986).

# 3 Research model

## 3.1 Model requirements and network effect theory extension

While traditional network effect theory contributes greatly to the understanding of standards and compatibility issues (Cowan 1992; Economides 1998; Farrell and Saloner 1985; Farrell and Saloner 1992), externalities and positive feedback effects (Arthur 1990; Arthur 1996; Beck 2006; David 1994), critical mass phenomena (Economides and Himmelberg 1995a; Economides and Himmelberg 1995b), bandwagon (Leibenstein 1950; Rohlfs 1974; Rohlfs 2003) or lock-in effects (Cowan 1990; Greenstein 1993) associated with the evolution of networks, much research is still needed. This is especially true when trying to understand many observable real world phenomena, especially when trying to develop solutions to the aforementioned start-up and network establishing problems (Liebowitz and Margolis 1994). In particular, the specific interaction of potential standard adopters within their personal socio-economical environment is often neglected. This means that most research approaches assume identical network effects for all network participants, regardless of their type, interaction and network topology and "network embeddedness" (Weitzel et al. 2006). As a result, important phenomena of modern network effect markets, such as the coexistence of different products despite strong network effects or the fact that strong players in communication networks force other participants to use a certain solution, cannot be sufficiently explained by the existing approaches (Liebowitz and Margolis 1994; Weitzel et al. 2000).

Earlier research dealing with the start-up problem assumes some kind of early adopter or diffusion initiator benefiting most from a good or standard even with no or only few further adopters (Beck 2006). However, this concept is not applicable in the case of communication standards in the absence of any stand-alone benefit. Information systems-related approaches analyze the start-up and diffusion of communication standards with network effects by using social science concepts such as social coherence or closeness. Relational closeness between agents in a social system is analyzed by using neural networks

simulating a population of agents (Plouraboue et al. 1998) or stochastic simulations (Wendt and Westarp 2000) analyzing the patterns of diffusion for standards.

A thorough review of the literature shows that the distinction between direct and indirect effects is commonplace in the introductions to most articles on network effects. Nevertheless, despite theoretical and empirical indications that their economic implications are quite different, the distinction is not carried through to the models and analyses (Weitzel et al. 2000). Therefore, it appears promising to apply network effect theory to concrete cases as in the telecommunications application domain and at the same time extend the traditional view of network effects by differentiating between direct and indirect effects as diffusion drivers of communication standards in a single diffusion model. We thus need a model that incorporates

(a) …the dynamic interplay between direct *and* indirect network effects,

(b) … individual standardization costs and benefits (*user view*),

(c) …network topology.

Accordingly, in the next sections basic findings from network effect theory are extended and incorporated into a simulation model to analyze the importance and magnitude of the aforementioned factors in terms of the diffusion of communication standards.

## 3.2 Model development

The model developed in this section considers the features and aspects of the different standards responsible for the two sources of network effects as described in the previous sections.

We assume a network of $n$ independent agents already using a certain communication standard $A$. Each agent $i$ has to decide in each period to continue to use $A$ or to shift to a new (technologically superior) standard $B$. Based on their bounded and dynamically adapted information set constituted—among other

things—from past technology adoption decisions made by their direct neighbors, agents can decide to adopt $B$ in one period and drop it in the next.

The agents use $A$ resp. $B$ to directly communicate with their $nb_i$ neighbors in the network[2]. Further, both offer complementary services whose value to the user does not depend on the communication standard's diffusion in the personal network. Let us assume agents deciding on adopting mobile technology standards or more precisely i-mode which offers i-mail for direct communication (technologically superior to SMS) and content services. While the user's benefit from i-mail depends on the diffusion of i-mode in her social network (direct network effects), the utility from content services is based on an overall sufficient diffusion (indirect network effects). Content providers (or more general: providers of complementary services) have to be globally attracted by a large user base before offering content and services via i-mode.

The decision calculus of each agent is to evaluate the periodical benefit surplus using standard $B$ instead of $A$. This benefit surplus accrues from the additional capabilities and features offered by $B$, given that the local network (i.e. neighbors) also adopts it (direct network effects) resp. that the global network (indirect network effects) adopts it. The benefit is reduced by stand-alone costs (e.g. basic fees) for adopting the new communication standard $B$. See (Beck et al. 2003) for a very early version of the model and a derivation of the simulation model parameters from cell phone contracts of German provider firms.

**Direct network effects**: Using $B$, agent $i$ gains a higher benefit from the new standard by communicating with any $B$ capable neighbor $j$ in comparison with using $A$ (e.g. using MMS instead of SMS). The

---

[2] To visualize the communication relation, agents and their relations can be described as nodes and edges in a graph. To create a close network topology, the participating agents are randomly located in a unit square. Afterwards, agent $i$ activates a vectored communication to her nearest neighbors $nb_i$ in Euclidian distance. Such a graphic illustration represents the social network of agents and does not determine the geographical location (Weitzel et al. 2006).

valued additional direct benefit $u_{ij}^D$ is calculated as the difference of utility from using $B$ $u_{ij}^{D,B}$ and $A$

$u_{ij}^{D,A}$:   $u_{ij}^D = u_{ij}^{D,B} - u_{ij}^{D,A}$ .

Analogous to the benefit, the additional direct costs $c_{ij}^D$ can be described as the additional costs of the

communication relations between $i$ and its neighbor $j$: $c_{ij}^D = c_{ij}^{D,B} - c_{ij}^{D,A}$ .

The resulting additional net benefit coefficient $nu_{ij}^D$ is:

$$nu_{ij}^D = u_{ij}^D - c_{ij}^D = u_{ij}^{D,B} - c_{ij}^{D,B} - \left( u_{ij}^{D,A} - c_{ij}^{D,A} \right) \qquad \text{(subject to: } nu_{ij}^D \geq 0) \qquad (1)$$

**Indirect network effects**: The model assumes a monotonously increasing relation between the diffu-

sion of a new technology in an existing network and the complementary services and content offered.

Since no installed base of users of $B$ is available at the very beginning, third-party providers are not

necessarily willing to bear the risk of investing in complementary services content. However, without

complementary offerings, potential users often will not decide to adopt (e.g., if no i-mode content is

available), and a typical chicken and egg problem occurs. With close interdependencies between pro-

viders of complementary services and users (and among users), the network related benefit of $B$ will

occur only after a certain number of users have adopted (critical mass). After this vicious circle is even-

tually broken, the steadily increasing number of adopters and use of complementary services will moti-

vate further providers to augment their supply, which again leads to further network effect benefits. As

the network grows, the ratio of achievable direct and indirect network benefits increases and varies

with positive feedback to each other. A self-perpetuating *network effect helix* occurs (Beck et al. 2003).

If we assume the new standard $B$ to be backward compatible, the indirect network benefit is always $\geq 0$

for adopters of $B$. The resulting indirect network effect benefits per period accompanied by the use of

the communication standard are therefore a function of the number of all standard adopters $b_t^q$ of any

same standard $q$:

For adopters of $A$: $U_{i,t}^{N,A} = U_{i,t}^{N,A}(b_t^A)$ with costs $C_{i,t}^{N,A} = C_{i,t}^{N,A}(b_t^A)$  (2)

For adopters of $B$: $U_{i,t}^{N,B} = U_i^{N,B}(b_t^B)$ with costs $C_{i,t}^{N,B} = C_{i,t}^{N,B}(b_t^B)$  (3)

In the following, these functions are explicated by linear proportional functions[3].

$U_{i,t}^{N,A} = u_i^{N,A} \cdot b_t^A$ and $C_{i,t}^{N,A} = c_i^{N,A} \cdot b_t^A$  (4.1)

$U_{i,t}^{N,B} = u_i^{N,B} \cdot b_t^B$ and $C_{i,t}^{N,B} = c_i^{N,B} \cdot b_t^B$  (4.2)

subject to: $u_i^{N,A}; c_i^{N,A}; u_i^{N,B}; c_i^{N,B} \geq 0$  (4.3)

Using equations (4), the following indirect network effect net benefit coefficients can be derived:

$nu_i^{N,A} = u_i^{N,A} - c_i^{N,A}$ and $nu_i^{N,B} = u_i^{N,B} - c_i^{N,B}$  (5)

In case of indirect network effects, the term "net benefit" refers to the total benefit of complementary services of $B$ while in the case of direct network effects, benefits are defined as the difference of the net benefit coefficient $nu_{ij}^D$ (see equation 1) between $A$ and $B$.

The overall individual net benefit deriving from indirect network effects is defined as $U_{i,t}^{INE}$:

$$U_{i,t}^{INE} = \begin{cases} nu_i^{N,B} \cdot b_t^B - nu_i^{N,A} \cdot b_t^A & \text{if } U_{i,t}^{INE} > 0 \\ 0 & \text{if } U_{i,t}^{INE} \leq 0 \end{cases}$$  (6)

Because we assume backward compatibility of the new communication standard $B$ to $A$, the value of indirect network effects is defined to be greater than 0. Table A1 in the appendix summarizes all used parameters.

---

[3] Although a sigmoid form of the function curve seems to better reflect the potential diffusion path, analogous to a slow diffusion start at the beginning, followed by rapid growth and finally a saturation-like slower adoption, a linear function was chosen, since this reveals the dynamics between direct and indirect network effects we are focusing on in a better way. Furthermore, using a sigmoid function would require a more complex parameterization making the traceability of the subsequent simulation studies more difficult.

**Decision Calculus:** The overall benefit from adopting $B$ is defined in equation 7:

$$U_{i,t}^{B} = -K + \sum_{j \in NB_i} \left( nu_{ij}^{D} \cdot x_j \right) + U_{i,t}^{INE} \tag{7.1}$$

subject to:

$x_j \in \{0;1\}$ (binary indicator for the adoption of $B$ by agent $j$) (7.2)

$n = b_t^{B} + b_t^{A}$ (number of all network members) (7.3)

The adoption decision is based on uncertain and imperfect information about the adoption decision of other users, so adopter $i$ has to estimate the adoption decisions of neighbor $j$. In the decentralized standardization model (Weitzel et al. 2006), the probability $p_{ij}$ (eq. 8) describes agent $i$'s estimations that agent $j$ will adopt a new standard.

$$p_{ij} = \frac{c_{ji} \cdot nb_j - K_j}{c_{ji} \cdot nb_j} \tag{8}$$

Every communication edge $ij$ between agent $i$ and her neighbor $j$ (with costs to be saved $c_{ij}$ and $nb_i$ the numbers of neighbors) contributes to the amortization of the adoption costs $K$ of the adopting agent $i$. The decentralized standardization model assumes that the initial standard adoption costs $K$ and the variable communication costs $c_{ji}$ are the only costs known to agent $i$ regarding $j's$ adoption situation. Therefore agent $i$ can assume that the edge $ji$ is representative of all of $j's$ edges. Combining all assumed data, agent $i$ can then develop the following estimator $p_{ij}$ for the probability of technology adoption on the part of agent $j$, where $c_{ji}$ is equivalent to $nu_{ij}^{D}$. In addition to the decentralized standardization model, in our model the heuristic estimation has additionally to consider the indirect network effect benefit resulting from the neighbor's technology adoption decision. Therefore, the numerator in this model is extended to the expected indirect network effect net benefit of neighbor $j$ ( $E\left[U_{jt}^{INE}\right]$ ).

$$p_{ijt} = \frac{nu_{ji}^{D} \cdot nb_j - K_j + E\left[U_{jt}^{INE}\right]}{nu_{ji}^{D} \cdot nb_j} \tag{9}$$

If neighbor $j$ uses $B$ in the previous period, $p_{ijt}$ is set to 1. Agent $i$ believes that it is implausible that neighbor $j$ will switch the current chosen new standard in the next period back to $A$. Similar to the decentralized standardization model we assume that agent $i$ has sufficient information about the direct net benefit components of her neighbors $j$ regarding the communication linkage to $i$. Furthermore, the model assumes that $i$ knows $j$'s benefits from potential indirect network effects or is at least able to form sufficient estimations about them[4].

Unlike direct network effects, the impact of indirect network effects depends on the total number of adopters. To forecast the adoption rate, concepts taken from diffusion theory such as relational and structural interaction patterns (neighborhood concept) to explain the diffusion of innovations have been incorporated in this model. This model is based on a restrictive estimation for adopters of standard $B$ ($b_t^B$) orientated on the installed base of $B$ users in the previous period:

$$E\left[b_t^B\right] = b_{t-1}^B + 1 \tag{10}$$

The expected benefit of indirect network effects in period $t$ is:

$$E\left[U_{i,t}^{INE}\right] = \left(\left(u_i^{N,B} - c_i^{N,B}\right) \cdot b_{t-1}^B - \left(u_i^{N,A} - c_i^{N,A}\right) \cdot \left(n - b_{t-1}^B\right)\right) \tag{11}$$

The decision calculus of a risk neutral agent $i$ in period $t$ depends on the estimated total benefit $E\left[U_{i,t}^B\right]$. If the benefit is $> 0$, then agent $i$ will adopt communication standard $B$. Each agent can decide once per period $t$. The adoption calculus is:

$$E\left[U_{i,t}^B\right] = -K_j + \sum_{j \in NB_i} \left(nu_{ij}^D \cdot p_{ijt}\right) + E\left[U_{i,t}^{INE}\right] \tag{12}$$

---

[4] The quality of estimating the partners' net benefits from indirect network effects does only affect the estimation of the perceived adoption probability $p_{ijt}$ regarding $j$'s adoption of the new standard. The less this probability reflects the actual intention of neighbor $j$ to adopt the new standard the more wrong decisions from the individuals' perspectives will lead to either more or less adoption activities, depending on whether the agents form optimistic or pessimistic assumptions about their partners' benefit components from adopting standard B. For the impact of alternative neighborhood concepts see (Weitzel et al. 2003).

**Provider strategies:** Communication standard providers can determine different parameters, which drive or inhibit the diffusion of the standard. As one possible strategy, providers often drive indirect network effects by implementing a virtual base to attract adopters even without an established installed base of users. One approach to achieve such a virtual base is to subsidize providers of complementary content and services in early periods of market penetration (e.g., if a telecom provider starts to offer i-mode to its customers). Due to the close relation between provision of content and services on the one hand and the number of users on the other hand, eligible adopters will use the virtual base as an estimator for prospective indirect network effects. A dominant provider strategy is therefore the signaling of the hopefully increasing indirect network effect benefits that will accrue in the future as a result of implementing a virtual base *VB* previous to the market launch. Implementing a *virtual base* can be defined as the provider's strategy to provoke (e.g. using monetary incentives) the same effect which would be caused by an actual installed base of actors not having appeared, yet. *VB*=100 means that the technology provider subsidizes content providers by a virtual base, corresponding to a real existing adopter network of 100 users of standard *B*, i.e., the amount of the subsidy corresponds to the revenue which the content provider would get from 100 users. Having such a subsidized number of content providers in place, a potential adopter can take *VB* into her adoption decision. As an example, Table 1 provides a set of strategies for a telecom provider offering i-mode as new communication standard.

| | Benefit drivers | | |
| --- | --- | --- | --- |
| | **Stand-alone** | **Direct network effects** | **Indirect network effects** |
| **Technology** | Integrating any stand-alone functionality in the i-mode browser (or in the device by product bundling) | Increasing marginal utility of switching to i-mode, e.g., increasing message capacity for images or movies | Increasing marginal utility of switching to i-mode, e.g., providing unique browsing functionalities |
| **Pricing** | Decreasing basic fee | Decreasing costs for inter-customer communication | Decreasing prices for using content and services |
| **Subsidizing** | | Subsidizing messages (e.g., offering a number of free messages per month) | Subsidizing content and service providers to establish a virtual base (*VB*) |

**Table 1. Example: Strategy set for mobile service providers to attract potential adopters**

# 4 Simulation analysis

In the following, the previously developed formal model is applied in simulation studies. The model has been implemented in Java 1.5. The following parameterization has been chosen:

| Demographics | $n = 100$ actors | $nb_i = 5 \quad \forall i$ (each actor has 5 communication partners) |
|---|---|---|
| Direct network effects $nu_{ij}^d$ | Normally distributed | Mean varies between $\mu\!\left(nu_{ij}^d\right) = [.5; \ 2.0]$ <br> variation coefficient = 0.2 |
| Indirect network effects $nu_i^N$ | Normally distributed | Means vary between <br> $\mu\!\left(nu_i^{N,B}\right) = [.004; .35]$; $\mu\!\left(nu_i^{N,A}\right) = [.003; .35]$ <br> variation coefficient = 0.2 |
| Stand-alone costs | $K = 5$ | |

**Table 2. Parameter setting for simulation studies[5]**

During the simulation runs, the parameter values are varied in incremental steps of .1 ($nu^D$) and .02 ($nu^N$) allowing for a (ceteris paribus) sensitivity analysis. The virtual base *VB* was varied from 0 to 200 between the different simulation runs and existed only in the first period (i.e. providers of complementary services were only subsidized in the first period). Each simulation run represents one communication network. Having generated the network topology, the agents' behavior is simulated over multiple periods until a stationary state is reached (i.e. no more adoption activities).

The results presented in this section are structured as follows: in a first step, we analyze what circumstances (combinations of different levels of net benefits from direct and indirect network effects) lead to an adoption of standard B or not. In the latter case, we analyze whether a virtual base can "heal" this start-up problem from the technology provider's perspective. The second part will focus on a single simulation run to analyze and to visualize the impact of the network effect helix. The last section investigates the duration of the adoption process and the *VB*'s influence on it.

---

[5] The initial parameters for the model represent the status quo of the German mobile service market and have been have been empirically gathered from contracts offered by providers to individual adopters. See (Beck et al. 2003) for details including contract duration, base and variable fees. For the sensitivity analyses, parameter ranges have been chosen to capture the impact of all relevant model parameters.

## The effect of direct and indirect network effects

The first simulation results presented in figure 1 depict the number of adopters of standard $B$ at stationary state (stable equilibrium in the period after the last adoption activities). During the simulation, the expectations concerning the normally distributed direct and indirect additional benefits $nu_{ij}^D$, $nu_i^{N,A}$, $nu_i^{N,B}$ have been varied (with $nu_i^{N,B} > nu_i^{N,A}$ and $\Delta nu_i^N = nu_{i-mode,i}^N - nu_{WAP,i}^N$). Further, the simulations were conducted for different levels of $VB$.
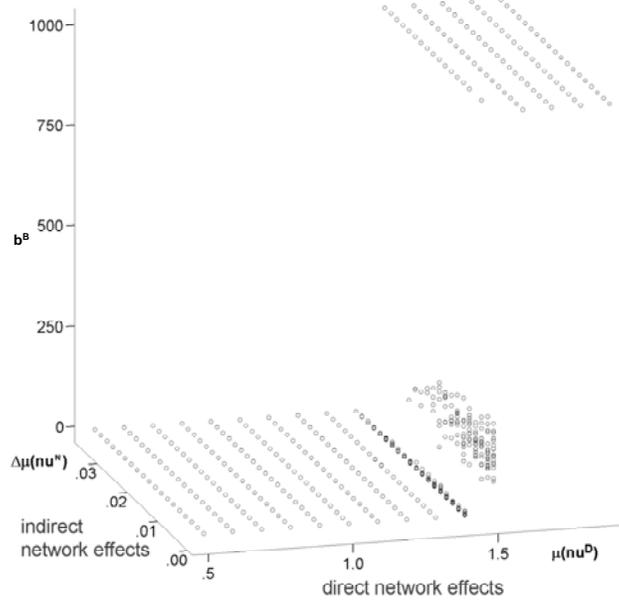


**Figure 1. Numbers of adopters of B in the stationary state, depending on the net benefit parameters (with $VB = 0$)**

In figure 1, each data spot represents the result of a single simulation run. In a basic simulation with no virtual base ($VB=0$), two main sections and a small interfacial area can be identified. In the lower section, nobody adopts $B$ (lower left area of figure 1). The results are only marginally impacted by indirect network effects. On the other hand, if the direct network effect parameter $E[nu_{ij}^D]$ is greater than 1.6, the network will be completely equipped with $B$ as depicted in the figure in the upper right area. The most interesting region is the interfacial area around $E[nu_{ij}^D] = 1.5$. Here, the typical dilemma known from standardization research appears, i.e. the start-up problem (penguin effect (Farrell and Saloner 1986)) or tippy networks (Shapiro and Varian 1998). In this area, the frequency of mixed solutions (i.e.

an only partial market penetration by *B* where only some agents adopt it) is highest. These mixed solutions have a maximum of 226 adopters of *B* in the stationary state; more adopters will lead to tipping of the whole user base to standard *B*.

The influence of $\Delta nu_i^N$ (indirect network effects) in this region determines the tippiness of the network (Arthur 1989; Besen and Farrell 1994; Shapiro and Varian 1998), which means that an increase of $\Delta nu_i^N$ does not increase the number of *B* adopters ($b^B$) in mixed networks but rather enforces the shift towards a *B* monopoly. Due to the low variance of marginal benefits (representing mostly homogenous interests of network participants), only a few mixed networks occur. For a sensitivity analysis, the variation coefficient was raised from .2 to .4, covering a larger heterogeneity of the individual utility parameters. As a result, the percentage of oligopoly solutions ("mixed networks", see (Beck et al. 2003) increases by factor 1.12, i.e. the simulation results react quite insensitively to modifying the variance.
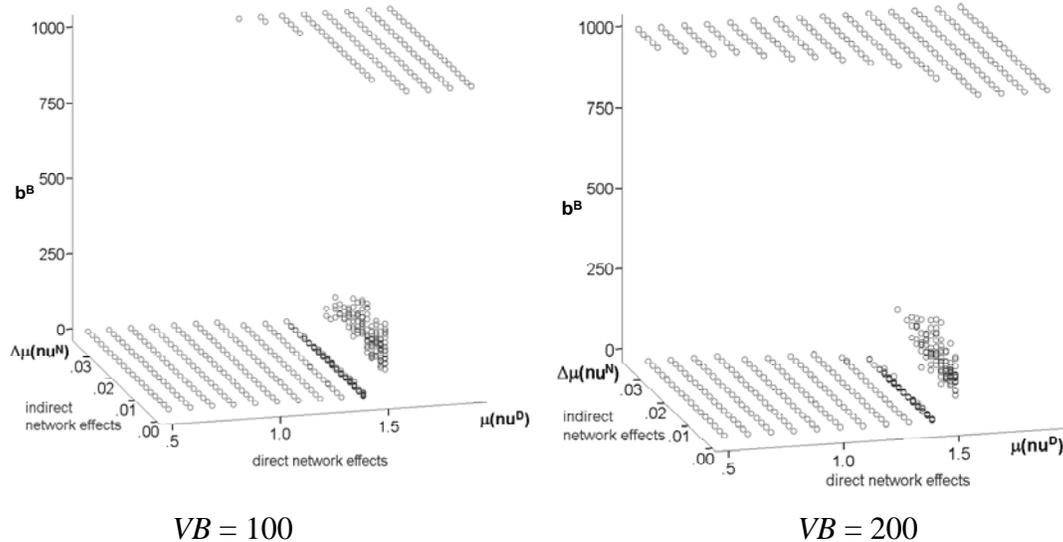


$$VB = 100 \qquad\qquad VB = 200$$

**Figure 2. Numbers of adopters of *B* in the stationary state, depending on the net benefit parameters, for different sizes of virtual bases *VB***

If the provider of standard *B* supports a virtual base (*VB*=100 and *VB*=200), further diffusion activities are triggered, as displayed in figure 2. With the implementation of a virtual base of *VB* = 200, the network switches completely to *B*, even if the benefit from direct network effects is only marginal

( $E\left[nu_{ij}^{D}\right] \rightarrow 0.0$ ) while the indirect network effects are sizable. In contrast to a rollout of *B* without an installed *VB,* where exclusively direct network effects are responsible for the market penetration, a pivotal element for a successful diffusion of *B* with *VB* are the indirect network effect benefits of *A* ( $nu_{i}^{N,A}$ ) as shown in figure 3 with $nu_{i}^{N,A}$ , $nu_{i}^{N,B}$ , and $nu_{ij}^{D}$ as decision variables of potential adopters of *B*. In figure 3, the scatter plots provide all parameter constellations of $nu_{i}^{N,A}$ , $nu_{i}^{N,B}$ , and $nu_{ij}^{D}$ which lead to a complete diffusion of *B* under a certain parameterization for different *VB*.
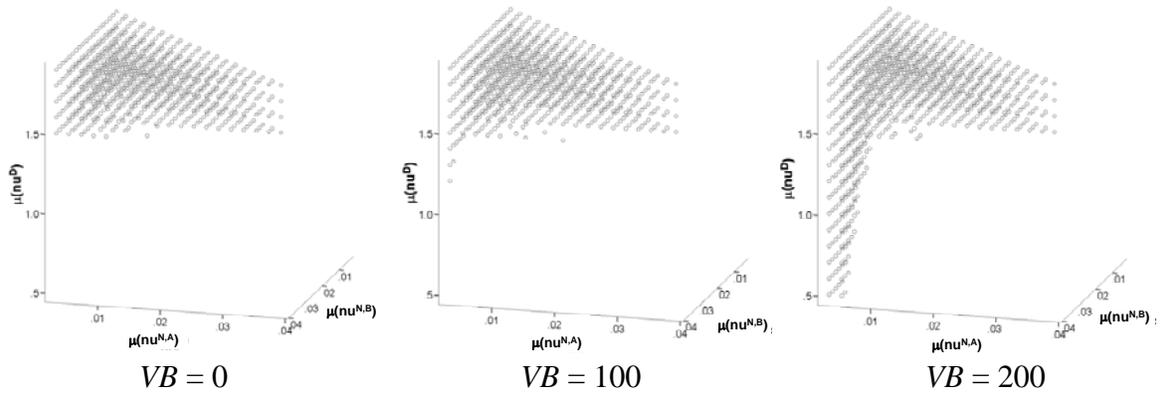


$VB = 0$        $VB = 100$        $VB = 200$

**Figure 3. Parameter constellations, leading to a network-wide adoption of standard B**

Consequently, the interfacial areas in figure 2 for $\Delta nu_{i}^{N} = [0.02, 0.03]$ are caused by different levels of $nu_{i}^{N,A}$ : the higher the indirect network effects benefit deriving from the usage of standard *A*, the less likely it is that users of *A* will adopt *B*, although their benefit would also increase with *B*.
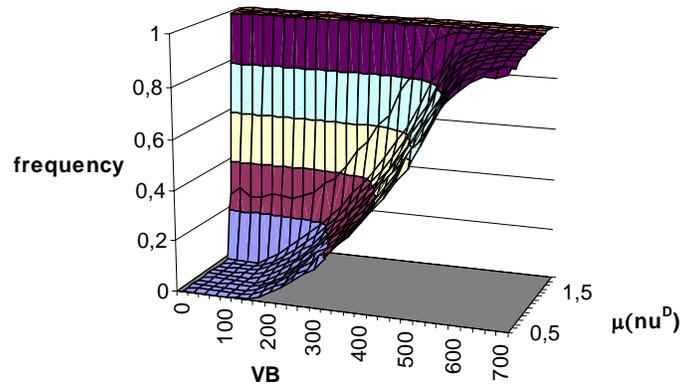


**Figure 4. Relative frequency of B-networks for different VB and direct network effects**

By combining the direct (bidirectional data communication) and indirect (services and content, provided upfront as *VB*) network effect benefits in one diagram (figure 4), a technology provider can chose

which setscrews have to be adjusted to reach a certain level of diffusion of the new standard *B*. Each frequency level can be seen as the combinations of $nu_{ij}^D$ and *VB* (isoquants) which may substitute each other on the same isoquant (as range for technology providers to choose their strategy, aiming at a certain market penetration) to switch a network consisting of solely *A*-users into a *B*-network.

The analysis allows a clear insight into the interdependent impact of the different setscrews on the market penetration by *B*. Without subsidizing any providers of complementary services, the direct effects are the only available force that can launch the diffusion process, while indirect network effects help to ensure market penetration. By using the subsidizing strategy (*VB*>0) the technology provider will increase the importance of indirect network effects which can partly substitute the impact of direct network effects. The substitution rate between the impact of direct and indirect network effects in the stationary state is moderated by the level of the initial virtual base.

**User view of adoption process and network effect helix**

In the following, we will focus on particular simulation runs to investigate the role and interplay of direct and indirect effects on an agents' adoption behavior from a potential user's view over time.
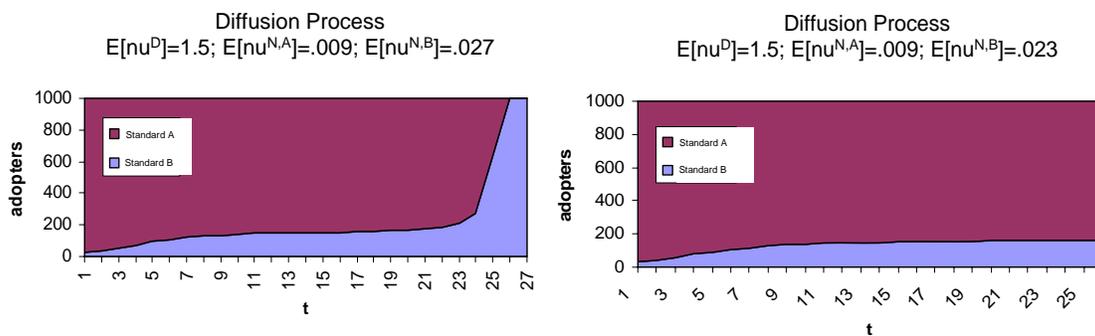


**Figure 5. Diffusion process of B vs. A (VB = 0 in both cases)**

Figure 5 provides two exemplary diffusion paths over time, which lead to different results but are based on an almost identical parameterization. In the left scenario, the network switches completely to *B*, while in the right scenario (where only $\Delta nu_i^N$ is marginally lower), an oligopolistic equilibrium appears, although the diffusion process is almost identical for the first 20 periods. The differences are produced

by some resulting marginal deviations in the local adoption behavior. They match with (Arthur 1989) who states micro-behavior leading to unpredictable system behavior in the presence of network effects.

The diagrams in figure 6 illustrate the expected average user benefit (neglecting setup costs), based on direct and indirect network effects ($E[U_i^{INE}]$), visualizing the network effect helix character. The left diagram depicts a scenario with *VB*=0, while in the right scenario the diffusion process is driven by a virtual base of 100. In the first case, the diffusion process is only driven by the expected direct network benefits, which are not strong enough to establish standard *B* network-wide, but only among 16 adopters. In the second case, the virtual base is responsible for immediately accessible indirect network effects, high enough to trigger a network-wide diffusion process. In the second period, the estimated indirect network effects are decreasing because some agents assume that content providers will leave the market after the ending of the subsidies in the second period. This contradictory effect can be over-compensated by increasing direct effects, which again push the indirect network effects $E[U_i^{INE}]$ in the following periods. Nevertheless, the stationary state is reached after five periods. As argued earlier in this paper, different network effects may have different impacts (in strength and direction) on diffusion behavior, which should be reconsidered and structurally analyzed by technology providers when developing pricing strategies.
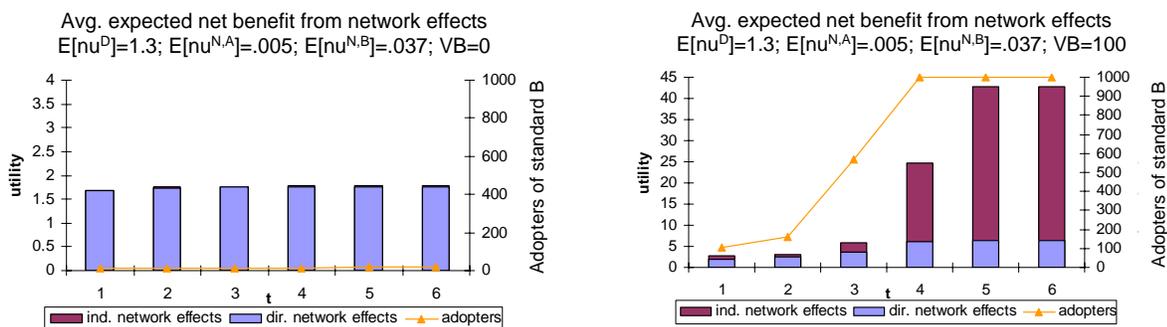


**Figure 6. Diffusion process and progression of net benefit, based on direct and indirect network effects for an exemplary parameterization with *VB* = 0 (left) and *VB* = 100 (right)**

**Summary of the Results**

The results of the simulation analyses are summarized in Figure 1. In the head row, we distinguish between the two scenarios of a minor virtual base and a high virtual base ($VB \geq 200$ in the simulations). The different rows present the results in different phases of the diffusion process. If no virtual base is apparent, the impacts of direct and indirect network effects can be handled separately. While direct network effects provide a huge impact on both the "strength" and the speed of the diffusion process, indirect network effects do not play a role, even in later phases of the diffusion process, and they do not accelerate the diffusion process. Slightly increasing the virtual base accelerates the diffusion.

| Impact on driving the diffusion process | Virtual base | | |
|---|---|---|---|
| | No or low virtual base | | High virtual base |

**Early diffusion phase** (Diffusion phase)

No or low virtual base — Direct network effects

| Indirect network effects | | Low | High |
|---|---|---|---|
| | Low | No effect | High effect |
| | High | No effect | High effect |

High virtual base — Direct network effects

| Indirect network effects | | Low | High |
|---|---|---|---|
| | Low | Low effect | High effect |
| | High | Rather high effect | High effect |

**Late diffusion phase** (Diffusion phase)

No or low virtual base — Direct network effects

| Indirect network effects | | Low | High |
|---|---|---|---|
| | Low | Low effect | High effect |
| | High | Low effect | High effect |

High virtual base — Direct network effects

| Indirect network effects | | Low | High |
|---|---|---|---|
| | Low | Low effect | High effect |
| | High | Rather high effect | High effect |

**Figure 7. Diffusion scenarios for different communication standards**

The situation changes if a high virtual base is implemented, e.g. by subsidizing providers of complementary services. Of course, the impact of direct network effects remains constantly high, but the impact of indirect network effects not only becomes stronger but it also becomes dependent on the level of direct network effects. The higher the direct network effects the higher is the impact of indirect network effects, which due to the virtual base are significantly higher than in a scenario without a virtual base. As a further effect, implementing a virtual base moderately accelerates the diffusion process, but not as strong as direct network effects do.

# 5 Discussion and Conclusions

When introducing a new communication standard, the significant influence of direct network effects (communication) is often neglected in early diffusion stages and the dynamic interplay with indirect effects (complementary services) is not analyzed systematically. We recommend that management has to leverage both effects in the appropriate phases in network effect markets. Based on the model introduced in this paper, the simulations show that for fostering standard diffusion and thereby, among others, overcoming the notorious startup problem, the provider should also consider the changing ratio and magnitude of direct and indirect network effects. In addition to the conventional wisdom of applying low price strategies for successful market rollouts equivalent to low communication prices in the beginning until an installed base of users is established, providers have to orchestrate the next wave of network growth by focusing on complementary services resp. indirect network effects. Thus, nurturing direct network effects at the very beginning is important but not necessarily sufficient, thus management has to focus on indirect network effects. We call this fundamental network phenomenon—where direct and indirect network effects amplify the number of adopters and stabilize the ongoing diffusion process—the *network effect helix*. By applying the model, technology providers can analyze various diffusion scenarios in order to identify interesting and promising market and price strategies for their planned services.

In many markets, provider strategies have often focused on strategically promoting complementary services as the main diffusion driver while ignoring the importance of direct network effects (e.g. in mobile communication). In fact, as the simulation results have revealed, establishing a subsidized base of providers of complementary services—even without any existing adopter of the new standard—is important for a successful market rollout. But, the virtual base as strategic instrument loses its strategic importance after the market introduction. At that point, the users' estimates of future direct and indirect network effect benefits predominate. While indirect network effects certainly are of great importance

for the ongoing diffusion process, the possibility of direct bidirectional communication (direct network effect) is initially at least as important as a subsidized base of providers of complementary services.

For example, in the case of the i-mode launch in Germany, the telecom provider subsidized 70 i-mode service and content providers. Due to an unsatisfying adoption rate of i-mode in the early phase, the provider reduced the price for i-mail (as source of direct network effects) significantly. Afterwards, the initially slow diffusion process accelerated in 2004 quadrupling the number of i-mode subscribers in Germany from 191,000 to 855,000. Apparently, the changed market strategy has been highly effective in penetrating the mobile market.

In a next step, we will validate the model and result with empirical data from different real diffusion scenarios, as the already referred i-mode diffusion (against WAP) in Germany, or the advent of UMTS technology and services. Especially the i-mode diffusion, together with the rollout strategies, which were chosen by the telecom provider in the past, seems to—to a certain degree—yield a first validation of our results.

In future research, the model will be extended by further important factors such as market heterogeneity, users' risk preferences, different degrees of compatibility, or different types of diffusion functions.

The main contribution of this research is thus to provide strategic decision support or building blocks for a better and more systematic understanding of the dynamics of value drivers in networks. The model, and simulations based on it, can support the development and evaluation of a variety of communication networks and thereby contribute to establishing a networked infrastructure in different domains.

# References

Arthur, B.W.: Competing Technologies, Increasing Returns, and Lock-In by Historical Events. In: The Economic Journal (99:394) 1989, pp. 116-131.

Arthur, B.W.: Positive Feedbacks in the Economy. In: Scientific American (262:2) 1990, pp. 92-99.

Arthur, B.W.: Increasing Returns and the New World of Business. In: Harvard Business Review (74:4) 1996, pp. 100-109.

Beck, R.: The Network(ed) Economy: The Nature, Adoption and Diffusion of Communication Standards. DUV, Wiesbaden, 2006.

Beck, R., Beimborn, D., and Weitzel, T.: The German Mobile Standards Battle. In: Proceedings of the 36th Hawaii International Conference on System Sciences (HICSS-36); Big Island, Hawaii, USA.

Besen, S.M., and Farrell, J.: Choosing How to Compete: Strategies and Tactics in Standardization. In: The Journal of Economic Perspectives (8:2) 1994, pp. 117-131.

Choi, J.P.: Irreversible Choice of Uncertain Technologies with Network Externalities. In: The RAND Journal of Economics (25:3) 1994, pp. 382-401.

Chou, C.-f., and Shy, O.: Network Effects Without Network Externalities. In: International Journal of Industrial Organization (8:2) 1990, pp. 259-270.

Church, J., and Gandal, N.: Network Effects, Software Provision, and Standardization. In: Journal of Industrial Economics (40:1) 1992, pp. 85-103.

Cowan, R.: Nuclear Power Reactors: A Study in Technological Lock-in. In: The Journal of Economic History (50:3) 1990, pp. 541-567.

Cowan, R.: High Technology and the Economics of Standardization. In: New Technology at the Outset. Social Forces in the Shaping of Technological Innovations, U. Hoffmann and M. Dierkes (eds.), Campus Verlag, 1992, pp. 279-300.

David, P.A.: Positive Feedbacks and Research Productivity in Science: Reopening another Black Box. In: Economics of Technology, O. Grandstrand (ed.), Elsevier, Amsterdam, 1994.

Economides, N.: Compatibility and Market Structure for Network Goods. In: Discussion Paper EC-98-02) 1998.

Economides, N., and Himmelberg, C.: Critical Mass and Network Evolution in Telecommunications. In: Toward a Competitive Telecommunications Industry: Selected Papers from the 1994 Telecommunications Policy Research Conference, G. Brock (ed.), Lawrence Erlbaum Association, 1995a.

Economides, N., and Himmelberg, C.: Critical Mass and Network Size with Application to the US FAX Market. In: Discussion Paper no. EC-95-11) 1995b.

Farrell, J., and Saloner, G.: Standardization, Compatibility and Innovation. In: The RAND Journal of Economics (16:1) 1985, pp. 70-83.

Farrell, J., and Saloner, G.: Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation. In: The American Economic Review (76:5) 1986, pp. 940-955.

Farrell, J., and Saloner, G.: Converters, Compatibility, and the Control of Interfaces. In: Journal of Industrial Economics (40:1) 1992, pp. 9-35.

Greenstein, S.M.: Did Installed Base Give an Incumbent any (Measurable) Advantages in Federal Computer Procurement? In: The RAND Journal of Economics (24:1) 1993, pp. 19-39.

Hildebrand, W.: Introduction to equilibrium analysis: variations on themes by Edgeworth and Walras. Elsevier Science, Amsterdam, 1976.

Katz, M.L., and Shapiro, C.: Network Externalities, Competition and Compatibility. In: The American Economic Review (75:3) 1985, pp. 424-440.

Katz, M. L., and Shapiro, C.: Technology adoption in the presence of network externalities. In: Journal of Political Economy (94:4) 1986, pp. 822-841.

Leibenstein, H.: Bandwagon, Snob, and Veblen Effects in the Theory of Consumers' Demand. In: The Quarterly Journal of Economics (64:2) 1950, pp. 183-207.

Liebowitz, S.J., and Margolis, S.E.: Network Externality: An Uncommon Tragedy. In: The Journal of Economic Perspectives (8:2) 1994, pp. 131-150.

Liebowitz, S.J., and Margolis, S.E.: Are Network Externalities A New Source of Market Failure? In: Research in Law and Economics (17) 1995, pp. 1-22.

Plouraboue, F., Steyer, A., and Zimmermann, J.-B.: Learning Induced Criticality in Consumers´ Adoption Pattern: A Neural Network Approach. In: Economics of Innovation and New Technology (6:1) 1998, pp. 73-90.

Rohlfs, J.: A Theory of Interdependent Demand for a Communications Service. In: The Bell Journal of Economics and Management Science (5:1) 1974, pp. 16-37.

Rohlfs, J.: Bandwagon Effects in High-Technology Industries. The MIT Press, Cambridge, 2003.

Shapiro, C., and Varian, H.R.: Information Rules: A Strategic Guide to the Network Economy. Harvard Business School Press, Boston, 1998.

Teece, D.J.: Capturing value from technological innovation: Integration, strategic partnering, and licensing decisions. In: Technology and Global Industry: Companies and Nations in the World Economy, B.R. Guile and H. Brooks (eds.), National Academy Press, Washington, DC, 1987.

Thum, M.: Netzwerkeffekte, Standardisierung und staatlicher Regulierungsbedarf. J.C.B. Mohr (Paul Siebeck), Tübingen, Germany, 1995.

Weitzel, T., Beimborn, D., and Koenig, W.: A Unified Economic Model of Standard Diffusion: The Impact of Standardization Cost, Network Effects, and Network Topology. In: Management Information Systems Quarterly (30, Special Issue on Standard Making) 2006, pp. 489-514)

Weitzel, T., Wendt, O., and Westarp, F.v.: Reconsidering Network Effect Theory. Proceedings of the 8th European Conference on Information Systems (ECIS 2000), Vienna, Austria, 2000, pp. 484-491.

Weitzel, T., Wendt, O., Westarp, F.v., and König, W.: Network Effects and Diffusion Theory – Extending Economic Network Analysis. In: International Journal of IT Standards & Standardization Research (JITSR) (1:2) 2003, pp. 1-21.

Wendt, O., and Westarp, F.v.: Determinants of Diffusion in Network Effect Markets. IRMA International Conference, Anchorage, USA, 2000.

# Appendix

| | communication standard $A$ | communication standard $B$ |
|---|---|---|
| Number of communication standard users (installed base) in period $t$ | $b_t^A$ | $b_t^B$ |
| Fixed (additional) fee for using $B$ (per agent and period) (stand-alone costs) | | $K$ |
| Additional utility from direct network effects after adopting $B$ (per link and period) | | $u_{ij}^D = u_{ij}^{D,B} - u_{ij}^{D,A}$ |
| Additional costs from direct network effects after adopting $B$ (per link and period) | | $c_{ij}^D = c_{ij}^{D,B} - c_{ij}^{D,A}$ |
| Direct network effect net benefit resulting from adopting $B$ (per link and period) | | $nu_{ij}^D = u_{ij}^D - c_{ij}^D =$ $u_{ij}^{D,B} - c_{ij}^{D,B} - \left( u_{ij}^{D,A} - c_{ij}^{D,A} \right)$ |
| Indirect network effect benefit per actor and period based on the number of adopters (installed base) | $U_{i,t}^{N,A} = U_{i,t}^{N,A}\left(b_t^A\right)$ | $U_{i,t}^{N,B} = U_i^{N,B}\left(b_t^B\right)$ |
| Indirect network effect costs per actor and period based on the number of adopters (installed base) | $C_{i,t}^{N,A} = C_{i,t}^{N,A}\left(b_t^A\right)$ | $C_{i,t}^{N,B} = C_{i,t}^{N,B}\left(b_t^B\right)$ |
| Indirect network effect net benefit coefficient per period based on the number of adopters (installed base) | $nu_i^{N,A} = u_i^{N,A} - c_i^{N,A}$ | $nu_i^{N,B} = u_i^{N,B} - c_i^{N,B}$ |

| General Parameters | |
|---|---|
| $n$ = number of actors | $nb_i$ = number of communication partners of actor $i$ |
| $VB$ = size of the virtual base | $sub_i$ = substitution rate of actor $i$ |

**Table A1: Model parameters**