Reconsidering Network Effect Theory

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Abstract- **According to *Network Effect* literature network externalities lead to *market failure* due to Pareto-inferior coordination results. We show that the assumptions and simplifications implicitly used for modeling standardization processes fail to explain the real-world variety of diffusion courses in today's dynamic IT markets and derive requirements for a more general model of network effects. We argue that *Agent-based Computational Economics* provides a solid basis for meeting these requirements by integrating evolutionary models from *Game Theory* and *Institutional Economics*.**

I. Introduction: The Status Quo

It is common in many markets that the buying decision of one consumer influences the decisions of others. Interdependencies such as the *bandwagon*, s*nob*, and *Veblen effect* are broadly discussed in economic literature (e.g. Leibenstein 1950, Ceci/Kain 1982). Besides these general effects applying to all the consumer decisions, some markets are determined by strong positive network effects, the so called demand-sided economies of scale, deriving from the need of product compatibility. This means that the willingness to adopt a product innovation correlates positively with the number of existing adopters. Popular examples are the information technology and telecommunication markets. The network effects in these markets mainly originate from two different areas, the need for compatibility to exchange information or data and the need for complementary products and services. Parallel with the growth of the telecommunication and information technology markets in recent years, a new area of research emerged aiming at explaining the phenomena of strong positive network effects in markets and their implications on market coordination and efficiency. We will refer to this research field as the *theory of positive network effects*.

The primary goal of most traditional approaches is an analysis of particular properties of modern information and communication technologies, i.e. increasing returns to marginal adopters, or network effects (e.g. Farrell/Saloner 1985, Katz/Shapiro 1985, Besen/Farrell 1994). Thus, the particularity of network effects lies in the fact that they are considered to be characteristic of IT products and standards that are therefore different in character from more traditional commodities and subject to different problems not as smoothly solvable by markets (Katz/Shapiro 1985, Farrell/Saloner 1985, Arthur 1996). Various perspectives can be distinguished in the literature (Kleinemeyer 1998, Yang 1997). Looking at empirical approaches authors mainly try to prove the existence of network effects and estimate their values by using regression analysis to estimate the hedonic price function of network effect goods (Hartmann/Teece 1990, Gandal 1994, Economides/Himmelberg 1995, Moch 1995, Gröhn 1999). Theoretical approaches mostly use equilibrium analysis to explain phenomena such as the start-up problem (Rohlfs 1974, Oren/Smith 1981, Katz/Shapiro 1985, 1994, Wiese 1990, Besen/Farell 1994, Economides/Himmelberg 1995), market failure (Farrell/Saloner 1985, 1986, Katz/Shapiro 1986, 1992, 1994, Gröhn 1999), instability (also called "tippiness") of network effect markets (Arthur 1989, 1996, Besen/Farell 1994, Farrell/Saloner 1985, Katz/Shapiro 1994, Shapiro/Varian 1998), and path dependency (David 1985, Arthur 1989, Besen/Farell 1994, Katz/Shapiro 1994, Liebowitz/Margolis 1995b).

These models focus on individual buying decisions, marketing strategies of competing vendors, supply and demand equilibria, and welfare implications. Common results are the following:

- In many cases, the existence of network effects leads to Pareto-inferior results in markets.
- Demand-sided positive network effects inhibit multiple equilibria and the market will finally lock-in to a monopoly situation with one standard winning total market share.
- Instability is a typical characteristic describing the fact that multiple, incompatible technologies can only seldom coexist and that the switch to a single, leading standard can come suddenly.
- The start-up problem prevents adoption even of superior products; excess inertia can occur as no actor is willing to bear the overproportional risk of being the first adopter of a standard.
- On the other hand, excess momentum can occur, e.g. if a sponsoring firm uses low prices in early periods of diffusion to attract a critical mass of adopters.
- In the case of sponsored technologies there is a possibility to internalize the otherwise more or less lost network gains by strategic intertemporal pricing. There are private incentives to providing networks that can overcome inertia problems; still they do not guarantee social optimality per se.
- The question arises if the laissez-faire of decentralized markets should be replaced by centralized state control to ensure favorable diffusion of technologies subject to network effects.

While the traditional models greatly contributed to the understanding of a wide variety of particular (macroeconomic) problems associated with the diffusion of standards, they fail to explain the phenomenological variety of diffusion courses in today’s dynamic information and communication technology markets. The examination of network effects is done in a rather general way, which does not cover the heterogeneous properties of the markets with products such as digital television, cellular phones, office software, Internet browsers, or EDI-solutions. Furthermore, the specific interaction of potential adopters within their personal socio-economical environment, and potential decentral coordination of network efficiency are neglected. As a result, important phenomena of modern network effect markets such as the coexistence of different products despite strong network effects, the appearance of small but stable clusters of users of a certain solution despite the fact that the competition dominates the rest of the market, or the fact that strong players in communication networks force other participants to use a certain solution can not sufficiently be explained by the existing approaches.

In the remainder of this article, we will first systematically reveal deficiencies in the models of positive network effects by analyzing common assumptions and conclusions (section 2), before extending this criticism to the more general premises of the neo-classical framework (section 3). Based on our findings we will identify areas of improvement proposing a new approach to model markets with strong positive network effects. The article ends with first results of simulations based on our framework as a sound basis for further research.

II. COMMON DRAWBACKS IN TRADITIONAL NETWORK EFFECT MODELS

In contrast to focussing on macroeconomic public policy implications, our goal is to use and extend already elaborated theoretical findings to support individual decision processes associated with the diffusion of standards. We propose the hypothesis that assumptions and simplifications implicitly and uncritically used for modeling standardization problems inevitably lead to the described results such as market failure under network effects and that the analysis of the diffusion of standards needs to be extended in order to descriptively capture real world phenomena and be actionable.

A Direct vs. indirect network effects

Although the distinction between direct and indirect network effects (introduced by Katz/Shapiro 1985) is almost commonplace in the introduction of articles about standards there is very little consideration of these differences in the models. But indirect network externalities have different economic implications (Katz/Shapiro 1994). Empirical research shows that direct and indirect network effects are evaluated differently by potential buyers and also depend on the category of the network effect product (Westarp et al. 1999). Still, the distinction is not carried out in the models, adding to the vagueness of their results.

B Network effects versus network externalities

Liebowitz/Margolis (1994, 1995a) argue that not all network effects are externalities, in fact. Generally speaking, in accordance with traditional literature on economics or externalities in particular, a network externality exists if market participants fail to somehow internalize the impact of a new network actor on others; with positive network externalities the private value from another actor is smaller than the social value, leading to networks smaller than efficient. Although an individual standards adopting actor is not likely to internalize his effect (from joining the network) on others, in owned ("sponsored")[1] networks there is no essential obstacle to a network owner internalizing these effects. Thus, the existence of network effects does not necessarily imply market failure, especially in the case of competing sponsored technologies. Liebowitz/Margolis (1995a) show under what conditions the profit maximizing network size is also socially optimal. Katz/Shapiro (1986, 825) show problems of sponsored technologies when competing with unsponsored technologies and second-mover advantages, i.e. advantage of one sponsored technology that will be superior in the future over another. Still, the proposed ubiquity of failing markets remains doubtful. Generally speaking, it appears to be difficult to find examples of inferior standards having prevailed over superior ones, partly because of uncertainty of not pursued paths and their results inherent to a not deterministic world and the imperfect foresight of individuals (ex ante vs. ex post efficiency)[2], and possibly because – in a world with potential Schumpeterean entrepreneurs - there is no such situation. The reason could be e.g. exhaustible networks effects and heterogeneous preferences and therefore parallel or equally desirable networks or the fact that most standards are somehow supported by actors with patents, copyrights or other forms of property rights. A similar argument can be made focussing on satisficing instead of maximizing actors. Supposed the QWERTY keyboard really is superior (see Liebowitz/Margolis 1990 for a critical discussion) the question remains who benefits from being able to type 100 words a minute when typing skills restrict one to a fraction of this.[3] This argument somewhat resembles what Liebowitz/Margolis call first-degree path dependence: There is a sensitivity to early historic events but no implied inefficiency. And if, therefore, different standards are equally beneficial after all, “efficiency models cannot be expected to predict which of several equally efficient possibilities will be chosen” (Liebowitz/Margolis 1995b).

The point made here is not the irrelevance of externalities but rather to raise the question if standards really are that different in terms of economic implications from ‘traditional’ goods[4] and to identify areas of improvement on modeling diffusion processes of standards.

C The bigger the better

The proposition of indefinitely increasing positive network effects as described in the literature (e.g. Chou/Shy 1990, Katz/Shapiro 1986, Farrell/Saloner 1992) implies natural monopolies. If optimal networks under network externalities are the size of the whole population (monopolies), all networks are too small. If network effects were exhaustible multiple networks could coexist. Even though IT might be less subject to physical limitations going together with the law of diminishing returns, there might be organizational or managerial problems restraining optimal network size (Radner 1992). Thus, the question raised by the existence of traditionally described network effects is not optimal network size but optimal network since inferior standards could battle out better ones. While Arthur (1989) proposes an example consisting of one technology that has greater value in earlier but smaller in later diffusion stages leading - under increasing returns - to (ex post) regrettable market outcomes Liebowitz/Margolis (1995a) argue that "synchronization effects" are more likely uniform as there is no difference in the value of one more user of videorecorder technology to others in either a VHS or Beta network.

D Homogeneous network effects

Another limiting assumption is that of similar and actor-independent valuation of networks and growth of network effects. Heterogeneity of preferences can have substantial impact on the evaluation of different competing networks as well as on the value assigned to new actors. For example, a close colleague of an engineer will add more value to the engineer's network than a sociologist from China. Another example is VHS with compared to Beta possibly inferior picture quality but longer recording times (Poole 1997, Liebowitz/Margolis 1990). Heterogeneous preferences increase

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[1] A quite commonly adopted terminology distinguishes between market-mediated diffusion processes of compatibility standards (leading to de facto standards) and de jure standards resulting from either political (“committee”) or administrative procedures. De facto standards can either be sponsored (with certain actors holding property rights and the capability to restrain the use of the standard) or unsponsored (no actors with proprietary interests). David/Greenstein (1990), S. 4.

[2] This corresponds to what Liebowitz/Margolis call second-degree path dependence: Sensitive dependence on early events may lead “to outcomes that are regrettable and costly to change. They are not, however, inefficient in any meaningful sense, given the assumend limitations on knowledge” (Liebowitz/Margolis 1995b).

[3] “...the QWERTY keyboard appears to be fast enough for almost all uses of it. If you are just driving around town you do not need a 500 horsepower V8” (Poole 1997)

[4] If this is the case - with network effects constituting particular instances of market failure – then and only then technology policies different from traditional industrial policies should be considered.

the chance of efficient coexistence of networks and overcome natural monopoly tendencies. Good examples of asymmetric partner contingent valuations of network effects can be found between intra-group communications standards e.g. used in corporate intranets between specialized professionals and the inter-group communication standards within and outside that same company. Thus, installed base effects cannot be generalized without regard to who is part of the personal network and who else uses compatible technologies outside the usual interaction scope of the respective individual.

E Costs of network size

If optimal networks under network externalities are monopolies, all networks are too small. This hypothesis only holds under constant or falling (average) costs of adding new members to a network. The costs of network size are ignored in almost all models. Thus network effects are not sufficient for natural monopoly and one single standard is not a compulsory social optimum. Instead, there can be optimal network sizes below the entire population and different standards can coexist.

F Confusion of Centralized and Decentralized Decision Making

Different instances of standardization problems are subject to different institutional backgrounds. For example, in corporate intranets, there are - at least in principle - different possibilities of approaching strategic situations of interdependent actors. Thus, we propose a distinction between centrally and decentrally coordinated networks (Westarp et al. 2000). In contrast to the distinction between sponsored and unsponsored technologies, the institution of centralized control within a hierarchy could coordinate dependencies due to network effects even of non-proprietary standards. Additionally, autonomous actors could change their institutional background by founding and submitting to a central authority and therefore transform the problem of market failure to a traditional agency problem, for example; this is basically how the emergence of enterprises is explained in organization theory.

Additionally, Poole (1997) describes institutional impacts of corporate cultures and the associated path dependent properties on innovation diffusion using the failure of the steam locomotive industry in the first half of the 20th century as an example.

G Normative Implications

Closely related to the problem of designing advantageous coordination designs is the need for normative results. Whether or not public intervention is necessary in network effect markets is a common controversy in the literature. Recommendations vary from centralized standard setting or restriction of market power by the government on the one hand side to total laissez-faire without intervention on the other. Since network effects don't stop at national borders, the question arises whether public intervention might be out dated. New emerging phenomena like the Internet show the power of decentralized coordination while the basic implications of network effects remain the same. Despite this, approaches to improve decentralized coordination of standardization - especially in the context of particular groups of individuals, e.g. within enterprises - can not be found in the traditional models. Finding advantageous coordination designs, efficient intermediaries and network specific cost and incentive structures may lead the way to answer questions as of the optimal network size, the trade-off between architectural (open) standards as XML and - based upon these - (proprietary) complementary technologies.

Thus, most traditional approaches towards diffusion processes of standards fail to properly consider costs and character of network effects and lack consideration of actor contingent knowledge and of institutional personal neighborhood structures.

III. General Drawbacks of the neo-classical paradigm

Although individual utility maximization, as unanimously agreed upon throughout the neoclassical paradigm, should not be disputed here, the "Homo oeconomicus" comes with further premises, the economic literature on network effects quoted above implicitly assumes to hold. What these premises are and which one of them may default within an interdisciplinary context, will be discussed in the sequel.

However, if (and only if) all of these premises hold, then the validity of the following two so-called "fundamental theorems of welfare economics" (Hildenbrand 1976) can be proven:

- A competitive total *equilibrium* always represents a *Pareto optimal allocation* of the total bundle of economic goods (a so-called Pareto optimum).
- For *each* realizable Pareto optimum a (positive) *price vector* exists, for which this Pareto optimum represents a competitive equilibrium.

The goal of an economy thus is to reach a Pareto-optimal allocation[5] of goods. The ability of the market mechanism to accomplish this task (more or less strongly) depends on the following implicit assumptions:

- Absence of *Externalities*:

  In earlier definitions, an externality was considered to be present whenever the utility function $U_i(.)$ of some economic agent *i* includes real variables whose values are chosen by another economic agent *j* without particular attention to the welfare effect on *i*'s utility. As shown by Coase, the market mechanism may overcome some of these problems by adding "property rights" as tradable goods to the economy. Therefore, nowadays an externality is said to be present whenever there is insufficient *incentive* for a potential market to be created for some good and the non-existence of this market leads to a *non-Pareto-optimal equilibrium*. So far, the absence of externalities is the only premise, network effect literature – as discussed above – is trying to relax.

- Complete rationality of the Homo oeconomicus:

  Network effect literature often relies on the neo-classical assumption that all agents do not only know their own action space and utility function but likewise have a complete and realistic model of all the other agents' current allocation, action spaces and utility functions as well! In a pure neo-classical "exchange economy" this assumption may be relaxed and even when we only bargain with our direct neighbors the decentralized exchange still leads to a unique and Pareto-optimal equilibrium, but unfortunately only if there are no network externalities or indivisibilities (see below). But for "realworld" individuals, parametric and strategic (or strategic and statistical (Williamson 1985)) uncertainty (Hayek 1937) imposes constitutional bounds (Hayek 1994, 171) to the knowledge, their decisions can be

[5] An allocation x is considered to be Pareto-optimal if and only if no other allocation y exists, which is weakly preferred over x by all individuals and strongly preferred by at least one individual.

based upon. Additionally, heterogeneous institutional and structural environments influence the decisions of individual socio-economic actors.

Therefore, research in the area of *New Institutional Economics* (Hodgson 1993) rejects this concept of complete rationality in favor of a "learning" individual and search-theoretical models of evolutionary systems. Equilibrium analysis models are replaced by models of the evolution process of the examined multi-agent system, in which the optimal action of actor i at time t is modeled as function of his individual knowledge at this point in time.

- Exclusion principle:

Prices only lead to Pareto-optimal collective action in a multi-agent system if the exclusion principle applies to the goods to be exchanged i.e. unique possession and ownership exists, permitting consumption only to a single individual. When common use or free duplication of products is possible (as being the case for information products like software), the equilibrium price is zero (if there were no copyrights artificially restricting this duplication as an incentive to the producer).

- Consumption paradigm :

Utility is drawn exclusively from consumption, i.e. the *destruction* of resources. The temporary possession of a good (like e.g. a piece of art or a game software), which is sold to some other individual after some periods, cannot be evaluated in the utility function. When extending the model to a multi-period economy, this inclusion gets possible but immediately destroys the validity of price coordination. Especially for information products the neo-classical notion of "consumption" (together with the exclusion principle mentioned above) poses a major obstacle to market coordination.

However, if not the consumption but the use of the resource comes to the center of attention, *property rights* lose their additional potential of generating utility compared to *usufruct rights*. "Network Economics" of the Information Age has to migrate from a *consumer*-oriented to a *user*-oriented discipline, in which the efficient solution of scheduling problems (*which resources* is used *when* in *which process*?) will turn out to be a critical success factor for an efficient creation of social welfare.

- Separation of consumers and producers

The classification of the economic actors into *consumers* and *producers* turns out to be problematic in a world replacing the classical notion of "work" more and more by freelance activities, thus "mixing" both concepts. In a "prosumer economics" we must not neglect the fact that human work does "flow out of the power plug socket" like energy but humans represent discrete *renewable resource*, whose entire economic and "recovery process" must efficiently be synchronized with other individuals of the network.

- Divisibility of resources

One of the most extensive restrictions certainly is the neo-classical assumption of arbitrary divisibility of all goods, i.e. each apple must be permitted to be cut into n pieces, sold separately. What may be acceptable for the apple, is impossible for screws or information. Interestingly enough, in defense of equilibrium theory it is argued, that the "rounding error" from unjustified acceptance of the divisibility assumption "washes out" for large quantities. While this may be true with screws, the argument breaks down at least for all goods, for which the optimal quantity of an individual's use is close to one (e.g. automobiles, houses and all *information* goods).

- Concave Utility Functions / no complementarities

The preference orders of the consumers over the bundles of goods must be representable by (strictly) concave, continuous utility functions. How far this assumption misses reality becomes clear if we realize that this does not allow for modeling complementary goods although complementarities can be found in all areas from recipes (if one ingredient is not available in sufficient quantity, the cake cannot be baked) and service industries (if I'd like to spend a three weeks vacation on an island, the flights without the hotel are equally worthless as the hotel without being able to book the flights) to information (if we do not know the concept of Pareto optimality and there is no definition provided, the fundamental theorems stated above are of no value to the reader). This problem of complementarity is it, which renders the "market solution" of *scheduling* problems impossible: If a resource is needed for ten time slices in sequence and the process is not preemptive (like with the hotel stay), buying the ten time slices in separate auctions leaves me with too high a risk to end up with some slices missing.

- Absence of transaction costs

Neo-classical economics abstracts from transaction costs, i.e. from costs, which are induced by the preparation or execution of the exchange process. In New Institutional Economics the effect of transaction costs is explicitly modeled and for example considered to be one reason for the emergence of companies economizing on transaction costs by being "islands of more centralized control" in a decentralized market.

IV. Towards an Interdisciplinary Theory of Network Effects

A Required modeling power of an interdisciplinary theory of network effects

After the critique of economic network effect theory and the neo-classical paradigm in general the question arises, which requirements have to be met by an *interdisciplinary* theory of network effects, allowing to integrate and explain *social* and *economic* interaction of *human* actors and *automated agents* (e.g. software agents trading at the stock exchange).

- *Modeling of knowledge and uncertainty / bounded rationality*

The network effect theory must allow for modeling knowledge of individual participants (human or automated) and uncertainty concerning this knowledge (in particular concerning the behavior and knowledge of other participants of the multi-actor system, we will call the "society" in the sequel).

- *Evolutionary System Dynamics*

However, since assuming bounded rationality usually implies the impossibility of determining analytical (ex ante) results for an aggregated entity - such as a whole network consisting of individually deciding agents - in terms of the existence and/or efficiency of equilibria, a recourse towards empirical and simulative approaches seems unavoidable.

While historic case arguments like the prominent QWERTY example (Liebowitz/Margolis 1990) or the battle for VCR standards (Liebowitz/Margolis 1994) proved to be at least ambiguous[6], numerical simulations based upon interacting software agents can help to get empirical evidence for such complex systems giving up complete rationality renders the system of interactions to be “unsolvable” to an analytical determination of equilibria and proof of their uniqueness. Therefore, we must rather rely on simulation of system dynamics and analysis of the observed behavior of the simulation model

- *Emergence of system components and links*

The approach should also be able to model the emergence of *new* participants and their "death" in the evolution process (to model for example the establishment or dissolution of institutional participants) as well as the emergence and dissolution of new links between existing actors, i.e. allow for an evolution of network structure.

- *Abolishment of convexity and divisibility assumptions*

Since many of the decisions to be modeled will be *discrete* choice and exhibit interdependence to decisions made by other actors, convexity and divisibility assumptions are totally inadequate and thus have to be dropped (which is less problematic in a setting that has already given up all hope for analytical solvability).

- *Economics of Intermediation*

To overcome the lack of normative results from traditional models, a new approach towards a theory of network effects should consider institutional designs for managing network related dependencies between individual network actors. In this context, the role of intermediaries needs to be emphasized. Generally speaking, intermediaries can compile and/or reallocate information necessary for coordinating dependencies between actors. Considering the uncertainties inherent to novel technologies, intermediaries could contribute to solving coordination problems associated with positive network effects. Quite contrary to the prominent hypothesis of disintermediation due to reduced transaction costs on markets, the benefits associated with IT such as decreasing communication and information processing costs appear to be available to intermediaries, as well. Thus, a new approach should integrate the analysis of intermediate coordination designs, essential data requirements and associated incentives problems for intermediaries to contribute to solving dependency issues problematic for markets.

B Alternatives to a Neo-classical Theory of Network Effects ?

As already stated above, *New Institutional Economics* explicitly addresses the emergence and function of institutions and their change over time. Institutions are considered to be:

- informal rules (habits) as boundary conditions on the social behavior of the individuals
- formal regulations (laws, property rights or contracts)
- instruments for the enforcement of formal and informal regulations

Although sharing much of our criticism, Institutional Economics often neglects the *explicit* modeling of any behavioral assumptions for the actors, and therefore neither analytical *nor* simulative equilibrium models can be formulated and used for answering the question, which institution is best suited to achieve a given social goal. The evolutionary branch of *Game Theory* (Aumann 1994) makes a valuable contribution to close this gap by mainly focusing on discrete interaction and making all behavioral assumptions explicit.

While most game-theoretical approaches still strive for analytical solutions (and are thus restricted to very small models) the research direction of *Agent-based Computational Economics* (ACE) (Vriend 1996, 1999) rejects this goal for being able to model more extensive multi-agent systems with complex behavioral structure, based on a discrete (often distributed) “state-transition” system model. It should be undisputed through all disciplines, that the following "labeled state transition system (LST)" as basic model of the real world would not come with any serious restrictions of modeling power:

In each state $s_i \in$ STATES a subset of the society’s actors is able to execute an action of type *act* which lets the system change its state to s_j. The transitions are labeled because they do not only describe the transition from one state to another, but additionally have to distinguish, which agent initiated this transition. Formally, this may be modeled by L-TRANSITIONS $\subseteq$ STATES $\times$ ACTORS $\times$ ACTIONS $\times$ STATES.

If (for each participant) there exists a preference order over all paths (chains of transitions) of this LST system, it gets possible to not only compare different target states of the systems but also to evaluate different paths of reaching the same target. The social goal now is to find an *institutional setting* that lets the LST system take a *path* which is Pareto-efficient and maximizes or fulfills one or a set of postulated “justice criteria”.

Unfortunately, an immense *complexity problem* results from this introduction of *path-dependent* preferences. As a compromise we may of course restrict ourselves to social preference relations over the “outcome” of the process - in those cases in which an equilibrium is reached - and only analyze the impact of institutional settings on this equilibrium.

Of course, in such a general setting we might ask whether all of the multi-actor networks of cooperating and competing “players” should still be called “economies” or what criteria of a multi-actor network game are necessary or sufficient to call it an *economic* one. Although there seems to be no unanimity, a plausible criteria to distinguish a general social game from the subclass of economic games could be “transferable utility”, presupposing that among other objects there is at least one (common!) class of objects (e.g. money or gold) having the property that the utility of every individual (strictly monotonously) grows with the amount of endowment. For a game of chess or soccer this does not hold or at least paying the other side for letting me win is considered “against the rules”, i.e. breaks the institutional setting of chess or soccer games. Once *transferability* is given, the problem of finding the optimal action sequence can be separated from the distribution of the welfare (e.g. by taxation). Note, however, that transferability of utility does not imply by any means that the welfare maximization problem may efficiently be solved by a decentralized market mechanism.

V. SIMULATION RESULTS

We developed a simulation model of an agent-based computational economy which addresses some of the important requirements outlined above. So far, it should be seen as a first step in the direction of evaluating and improving our approach of an interdisciplinary theory of network effects

[6] Poole (1997) identifies another common misconception when trying to identify winning inferior standards. He argues that the often cited DOS vs. Macintosh example is different from e.g. U.S. 110 volt 60 cycle AC vs. European 220 volt 50 cycle AC since the U.S. AC standard is stable and DOS/WINTEL is still evolving.

rather than a completed study. In the following we will only present the basics of the model and the simulations results. For a comprehensive description refer to Westarp/Wendt (2000) and Wendt/Westarp (2000).

Our simulation is based on a simple model of the individual buying decision in network effect markets. A participant buys a certain product exhibiting network effects whenever the benefits (sum of stand-alone benefits and network effect benefit; the latter depending on the number of other adopters that are linked to this participant) are larger than the costs. In case of competing products in a market, the consumer buys the product with the maximum surplus if this exceeds 0. The decision is discrete, meaning that it is not rational to buy or use more than one unit of the same product or even of different products. This is an assumption which especially makes sense for information goods like software or telecommunication products. The network effects in the utility function only depend on decision behavior of the direct communication network of the potential buyer. This assumption is confirmed by empirical research in the software markets (Westarp et al. 1999) and also pays tribute to the bounded rationality of real-world actors. Therefore, in contrast to the installed base of traditional models, we distinguish between relevant and irrelevant network effects.

All simulations are based on the simplifying assumption that network structure, the consumers' preferences and the prices of the network effect products are constant during the diffusion process. All networks had a size of 1,000 consumers. We also tested our simulations for other network sizes without significant difference in the general results. A total number of 10,000 independent simulations were run until an equilibrium was reached, each iteration of the respective run showing one state of the network during the evolution process. To analyze the diffusion process the distribution of products reached in this equilibrium was then condensed into the Herfindahl index used in industrial economics to measure market concentration (e.g. Tirole 1993). All entities of our model were implemented in JAVA 1.1 and their behavior was simulated on a discrete event basis.

Our main hypothesis was that the (macro) dynamics of network effect markets as multi-actor systems not only depends on the individual (micro) decisions of the participants but also on personal neighborhood structures reflecting institutional patterns of networks. The influence of various determinants on the diffusion process of network effects goods such as price, heterogeneity of preferences, and connectivity, centrality, and topology of networks were tested. The results strongly support our hypotheses.

- The effects of *cost* and *stand alone utility* were analyzed by varying price and the heterogeneity of preferences. In high price markets we find more diversity of products, due to the higher switching costs. We did not find any significant dependency between heterogeneity and market concentration for *close topologies*[7], but a slight but significant negative correlation for *random topologies.*
- The influence of the networks *topology* on the diffusion of innovations in networks was proven. While the *close* topology generally is the basis for a greater diversity of products (since clusters or groups of consumers may decide relatively independent from diffusion processes in the rest of the market), the *random* topology tends to dominance of one or few products.
- *Intensity of communication* (represented by *connectivity*) is the source of *personal network exposure* within the diffusion process and is shown to have a *positive* effect on equilibrium concentration.
- *Intra-group pressure* positively correlates with *closeness* of the network's topology and *closeness* is shown to *negatively* correlate with concentration[8], meaning that although this pressure enforces *group conformity*, it also inhibits *inter-group conformity*.
- *Opinion leadership* has been simulated by *centrality* and *heterogeneity of node sizes* (the latter was used to represent the strength of influence on others). We find a positive correlation between centrality and concentration, showing that some central participants can significantly influence the diffusion process. Differences in power within the network did not have any effect on concentration unless it was combined with centrality.

VI. Conclusion

The increasing pace of advances in information and communication technology and the associated emphasis on compatibility standards constituting networks has brought diffusion processes of standards to a broad public and academic attention. A common finding is the existence of network effects, i.e. the increasing value of a network as the number of its users increases (demand side economies of scale) leading in many cases to Pareto-inferior results of standardization processes.

We propose the hypothesis that assumptions and simplifications implicitly and uncritically used for modeling standardization problems fail to explain the phenomenological variety of diffusion courses in today's dynamic markets and lead inevitably to the described results such as market failure under network effects. In addition, the particular socio-economical environment of interacting adopters is neglected.

We have shown methodological deficiencies of traditional approaches concerning network effects. Together with a critical examination of the neo-classical paradigm we propose a requirements framework towards an interdisciplinary theory of network effects.

An interdisciplinary network theory should incorporate, among others, uncertainty and bounded rationality on behalf of the deciding network actors as well as evolutionary system dynamics, i.e. the emergence of new or the 'death' of existing actors in an evolutionary process. The complexity resulting from these propositions requires empirical methodologies and simulation models in particular. As a first step towards extending theories in the proposed direction we developed a model showing that the dynamics of networks do not only depend on individual decisions but also on their personal neighborhood structures reflecting institutional patterns.

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[7] The network topology is generated by either choosing the *c* closest neighbors measured by euclidean distance (*close* topology) or selecting *c* neighbors randomly from all *n*-1 possible neighbors (*random* topology).

[8] As a direct measure of intra-group pressure we calculated the „relative 2nd order radiality", being the sum of the number of indirect neighbors of each node divided by the hypothetical maximum of indirect neighbors (if there were no double nominations by any direct neighbor). This measure positively correlates (.405) with concentration, since a *low* value indicates strong intra-group links and thus resistance to outside pressure.

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