The Diffusion of System Dynamics analyzed with System Dynamics

- A Diffusion Model Considering Network Externalities

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Abstract

This paper investigates the diffusion of system dynamics as research paradigm. It deals with the question whether the diffusion of system dynamics is influenced by network externalities. Assuming the existence of such network externalities the so called penguin and bandwagon effect must be considered regarding the diffusion. Based on a system dynamics model considering network externalities leverage points will be derived enforcing the diffusion of system dynamics.

Keywords: diffusion analysis, system dynamics, network externalities, penguin effect, bandwagon effect.

Introduction

Although system dynamics must be regarded as a research paradigm which has successfully evolved over several of decades and has become a standard in terms of research and teaching based on a huge community, in particular in countries such as the U.S. or U.K, in some countries system dynamics still is in its infancies in terms of its diffusion. In many countries, system dynamics is barely used in academia so that the great potential of this research method with regards to analyzing dynamic and highly complex problems of socio-economic systems is ignored. In comparison with papers written by authors from the U.S. or U.K, only a few authors outside these countries publish papers using system dynamics. Furthermore, the amount of papers published in the system dynamics review by authors coming from outside the U.S. or U.K. is relatively rare.

Finally, system dynamics cannot be considered as a teaching standard in universities in an international context. All these aspects serve as indicators for the hypothesis that system dynamics has not completely been spread all over the world. Accordingly, it can be assumed there are still many blind spots on the system dynamics world map. Facing its inherent potential, the diffusion of system dynamics is still lagging behind. The interesting question is why system dynamics has emerged as research standard in some countries, whereas in other countries it is still a kind of tool for academic specialists. In this paper some light is shed on this aspect by investigating the question whether the extension of system dynamics is hampered by network externalities.

This paper examines the influence of the underlying effects on the diffusion of system dynamics using the system dynamics approach. Based on the basic diffusion model of Bass, characteristics of network externalities are integrated successively to simulate the diffusion behavior of system dynamics. This analysis helps in understanding causes and effects of network externalities. After that, implications concerning successful strategies for an enhanced diffusion are derived from the system dynamics model. Aspects for further research, in particular in an empirical manner, are indicated at the end of this paper.

Characterization of System Dynamics as a good influenced by network externalities

If the diffusion of system dynamics is to be investigated, the question has to be clarified whether system dynamics has to be regarded as a good influenced by network externalities since the diffusion of such goods differs to conventional goods. In this paper, diffusion is defined as “the process by which an innovation is communicated through certain channels over time among the members of a social system” (Rogers 1983). Following this definition, communication can be regarded as the driving force creating the wish to buy a product. Accordingly, communication—seen as the exchange of information between members of a social system—initiates diffusion and hence influences the speed of the underlying process.

Products that satisfy communication needs such as Email, SMS, etc. often show a special diffusion behavior contrary to conventional products. They are characterized by the fact that their utility cannot be regarded as a constant value. Contrary to conventional products, these specific types of products have a varying utility since the utility is a dependable variable itself. It is a function of the installed base resulting in a distinct diffusion behavior. Katz and Shapiro (1985) state that “… the utility that a user derives from consumption of the good increases with the number of other agents consuming the good”. This effect is referred to as “network externality”.

The usage of system dynamics comprises a wide spectrum of managerial, economic, natural scientific or social aspects. Based on the model development and its analysis learning processes and an improved understanding of the underlying system should be supported. This shows that system dynamics should not be regarded as a conventional good since the continuous usage of this method is important rather than the singular learning which would be equal to a final buying decision of a conventional product. In this context, the learning of system dynamics merely has to be seen as necessary condition; it is important, but the key point is the subsequent usage. System dynamics as a method for solving complex decision problems is a way of thinking that strives to generate problem solutions and communicate them. Hence, the usage of system dynamics depends on the understanding of others.

Following the view conceiving system dynamics as communication media, system dynamics is a good influenced by network externalities. The utility increases with the amount of people in the communication network. Following Metcalf (1995; 1996), every further system dynamics user increases the amount of potential communication partners and therefore heightens the utility of the entire communication network (McAfee and Oliveau, 2002). The more people there are speaking the "language" of system dynamics, the more likely system dynamics as method for system thinking and system simulation will be generally accepted. Using an own system dynamics language information can be shared easily. Everyone dealing with system thinking and system simulation can learn this language helping to express himself in terms of levels, rates, and information feedbacks. That way, system dynamics creates a network as a basis for communication that can be understood in an international context linking system dynamic users all over the world.

Furthermore, due to the exchange with other people using system dynamics learning effects and information spillovers will result. Technical support and competent assistance by experts are easier to find. Additionally, the knowledge about the use of system dynamics will be dispersed faster and hence will in turn lead to a higher knowledge level and to an improved usage by system dynamics users. Accordingly, system dynamics users can communicate with each other no matter where or what they are they are. Information and ideas can easily be shared which in turn will increase the utility of every user.

Hence, system dynamics must be regarded as good with network externalities if it creates a network for communication and data sharing. Correspondingly, the application of system dynamics directly or at least indirectly depends on its diffusion. (Only if system dynamics is understood as good for satisfying personal needs using only its pure functionality by means of autodidactic learning, scenario planning, etc, the utility would be independent from other users and therefore no network effect would exist. In this case, the user does not communicate his ideas and simulation results using them only for private purpose.)

System Dynamics on an Island – A diffusion perspective

In order to shed some light on the idea of the diffusion of system dynamics, we discuss this aspect by means of an analogy. Assuming that system dynamics is still in its infancies in some countries, the metaphor of an island can be used to explain the diffusion behavior. Imagine an island with only one person knowing system dynamics, let's call him Jay. The question is how system dynamics will be spread on the island. In order to disseminate system dynamics Jay has to communicate with other people and convince them about the advantageousness of this approach. If system dynamics is taught to and adopted by other people on the island, they will probably spread it among other people which will result in the creation of a system dynamics community. Finally, it might spread like a wildfire and become a standard on Jay`s island. How system dynamics will be spread on the island can be analyzed by a diffusion analysis. Additionally, further effects must be considered which might have an impact on the diffusion of system dynamics.

Despite the fact that system dynamics can be used by a single person as decision support system, there is an interdependency of people using system dynamics as a research method. Firstly, if a person analyses a dynamic complex problem with the help of system dynamics, he will be easier understood by other people that know system dynamics already. The assumptions and the structure of system dynamics models can be discussed and valuable hints can be given. Therefore, the group of other people functions as the installed base of system dynamics. That way, people can communicate with each other. Hence, system dynamics serves as a research language. Secondly, if system dynamics is accepted as a well known worldwide research method, it is much easier for people to publish their ideas using system dynamics. The more people actively using system dynamics as method in a research network, the better the support and acceptance by others will be. Hence, we assume that system dynamics shows the characteristic of a network effect.

There are different definitions of the term network effects (sometimes also called "positive demand externalities") that can be found in the literature (see, e. g., Church and Gandal 1993, Katz and Shapiro 1985, Brynjolfsson and Kemerer 1996). As a basic definition it can be stated that network effects are present if the utility of a product depends on the number of customers. Following Bental and Spiegel (1995), this network effect can be direct or indirect. As a classical example for a product with direct network effects the telephone can be mentioned (Brynjolfsson and Kemerer 1996). In terms of the telephone, the entire utility of the system increases with the amount of feasible communications. Other, more up-to-date, examples for network externalities are e-mail, SMS, or MMS etc. which are all designed in order to satisfy communication and interaction needs. It's important to note that none of these products can create any utility per se but depend on the existence of an underlying network consisting of the users of the particular product. Due to this characteristic the utility that can be derived from the product changes dynamically with the number of users that is commonly referred to as installed base. Accordingly, the utility of products showing network effects increases with the installed base which leads to an interdependency of users. This is based on two typical effects: the penguin effect and the bandwagon effect.

In the following, we will discuss the bandwagon effect and the penguin effect in the light of system dynamics. In terms of the latter, it would be problematic if a person had learned to work with system dynamics but could not find other people to join his ideas since they are not familiar with this approach. In order to establish a new network, the users must be able to create a sufficient utility from the network. A key problem is that early users cannot derive enough benefit from the network which is still quite small. Since early users depend on the future decision of other potential users, a hesitating behavior can be observed that leads to an imaginary network barrier to enter the network. Farrell and Saloner (1986: 943) call this the penguin effect: "Penguins who must enter the water to find food often delay doing so because they fear the presence of predators. Each would prefer some other penguin to test the waters first."

Accordingly, people might contain themselves learning and using system dynamics since they do not want to back the wrong horse. In order to clarify this point, we again use the metaphor of Jay's island. If he or a few other interested people cannot convince others of the advantageousness of system dynamics, no other people will adopt this approach leaving him and the rest alone with this research methodology. Hence, the required size of a community will not be created. The problem is that people are not sure whether enough other people will adopt system dynamics in the future in order to build up a sufficient network size. As a consequence, they might delay their adoption of system dynamics due to the effort of the learning process. They want other people to enter the community first guaranteeing that the necessary network size will be reached. This will in turn make other people delaying their adoption decision. Hence, there is an interdependency of potential users.

The interdependency of users can also be positive since the more people there are, the bigger the network will be and the higher the utility will be. Correspondingly, the diffusion process will partly grow exponentially which is referred to as the bandwagon effect. This is explained by a metaphor: People follow a bandwagon attracted by the music. The higher the amount of people that decide to follow the bandwagon the more other people in turn will be decoyed (Leibenstein 1950) which leads to a reinforcing process. Despite the fact, that this effect can be observed in terms of conventional products as well ("word of mouth"-effect; Sterman 2000; Mahajan et al., 1984) in case of network externalities the bandwagon effect is much stronger.

Altogether, the discussion shows that the diffusion of system dynamics is influenced by network externalities in terms of the penguin effect on the one hand and the bandwagon effect on the other hand. Both effects have to be considered when analyzing the diffusion behavior since they will significantly change the diffusion. Therefore, the classical diffusion model introduced by Bass will be adopted incorporating the two main effects of network externalities.

A Diffusion Model of System Dynamics with Network Effects

In the following, Sterman's model of the Bass diffusion is used as a fundament (Sterman, 2000) in order to build a system dynamics model analyzing the diffusion of system dynamics considering positive demand externalities, i. e. "the benefit to a consumer of a product increases with the number of other users of the same product" (Xie and Sirbu 1995). The aim is to model the diffusion process based upon the decision process of individuals which have to decide whether they wish to learn about and keep on using system dynamics.

As stated above, the utility of system dynamics depends on the installed base B_t which is defined as the cumulated amount of users at time t (Note: For simplification reasons, it is assumed that the utility of system dynamics is based on the size of the installed base, i.e. the amount of system dynamics users in a relevant society, exclusively). The adoption process is influenced by the installed base which is analogous to the Bass diffusion model with the exception that the utility is not constant. Furthermore, it has to be taken into account that in terms of network externalities the decision to buy this good is not the final element of the adoption process. The following utilization is important for the diffusion process since the adoption decision of other users will be influenced. If the expected utility cannot be achieved, users can decide to discontinue their utilization, which leads to a decrease of the entire network utility. This may induce other users to stop their utilization and so on (Größler et al., 2000).

Diffusion models can be used to describe how communication drives diffusion. Following Kalsih and Lilien (1986) they can be seen as the "the mathematical representation of the process of diffusion". Bass (1969) introduced one of the most popular diffusion models. As a mixed-influence model, it integrates the influence of mass communication and impersonal communication (Mahajan and Peterson 1985). In this model, customers are differentiated between innovators and imitators. Following this approach, innovators become customers of a good based on their interest in novelties. Contrary to that, imitators base their buying decision on other people. Following Bass, the amount of sales x for a specific time period t:

$$x_t = \alpha(N - X_t) + \frac{\beta}{N} X_t (N - X_t)$$

In this formula, N represents the total market potential and X_t shows the cumulated sales from period 1 to t-1. Furthermore, α is called the innovation coefficient and ß is the imitator coefficient. They give insights concerning the influence of innovators or imitators on the diffusion process. Sterman (2000) provides a basic feedback-oriented interpretation for the Bass model consisting of a balancing (advertising) and a reinforcing (word-of-mouth) feedback loop. The behaviour of Bass diffusion model can be shown by a system dynamics model which is depicted in figure 1 (Note that Sterman's (2000) interpretation of parameter β is included and that the innovator feedback loop is not elaborated because it is not in the center of interest in the context of this paper. Note that the values for ALPHA and BETA remain the same in all further analyses).

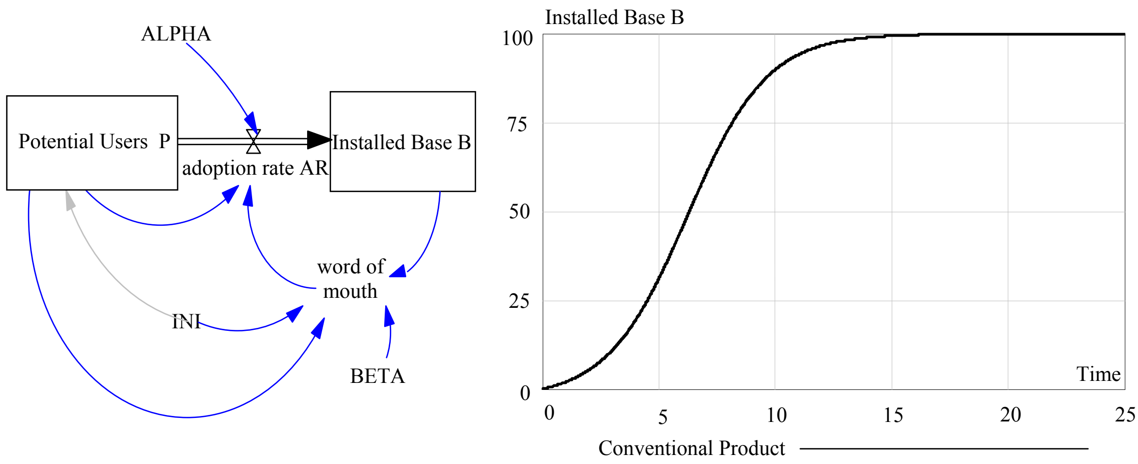

Figure 1: Classical Bass diffusion, modified after Sterman (2000)

Variable names of the two levels are adjusted to the terminology in use when discussing network externalities in terms of system dynamics. The behavior graph shows a "prototypical" diffusion process with default values of parameters. After a certain point in time t, all potential users have bought the product.

In the following, the penguin effect and the bandwagon effect are incorporated into the model (for a detailed description of the underlying model see Größler et al., 2000). Integrating these two main effects of network externalities makes a deeper understanding of the diffusion of system dynamics possible. Hence, the model structure has been changed in order to include the effect of a varying utility. This variable depends on the installed base B which represents the current size of the system dynamics community. The higher the installed base B the more people are attracted by the community. Contrary to that, potential user would hesitate to start learning and using system dynamics due to the small network size. Figure 2 shows the simulation run including the effects of network externalities in comparison to the original run.

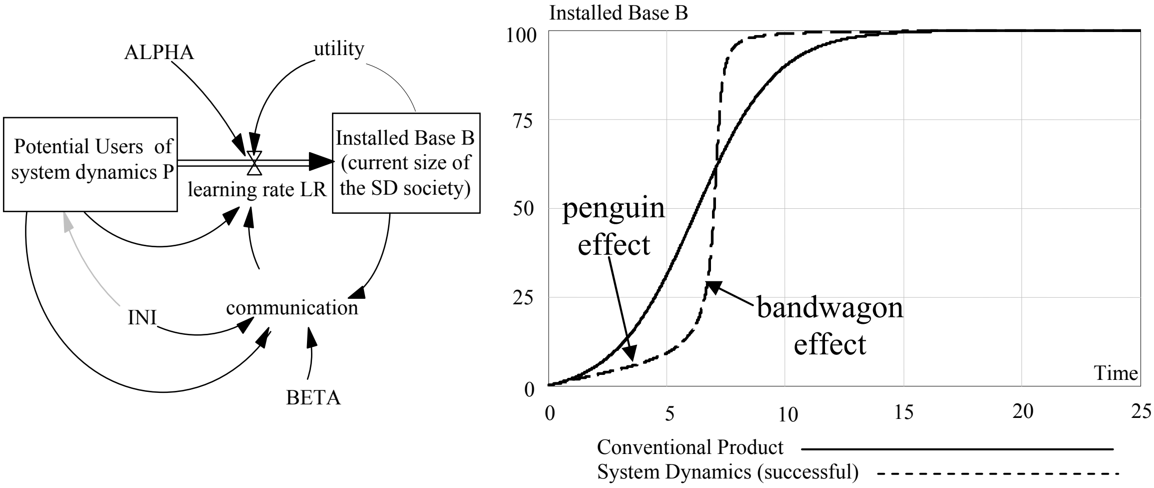

Figure 2: System dynamics diffusion model with network externalities

The simulation run indicates the hesitating behavior at the beginning of the diffusion process in comparison to the first simulation run. After a certain network size has been reached–referred to as the critical mass– the diffusion process shows a growth with saturation. This behavior can be interpreted as penguin and bandwagon effect.

In a further step, the problem that users might discontinue the usage of system dynamics is incorporated into the model. Hence, the model is extended in a way that system dynamics users can leave their SD society since they might be disappointed by the utility of system dynamics. This would decrease the installed base B which is modeled by means of a discontinuation rate. This discontinuation rate is determined by a variable representing the average time of usage. This variable indicates that people who have learned to work with system dynamics will keep on using it to a certain point of time until they quit. It can also be interpreted as the people's patience expressing the time that users are willing to wait for the situation to improve (Größler et al., 2000). Due to this effect, a diffusion process might even fail if the required network size is not reached for a long period making all people stop using system dynamics in the long run. Figure 3 depicts the structure of the refined system dynamics model and its behavior.

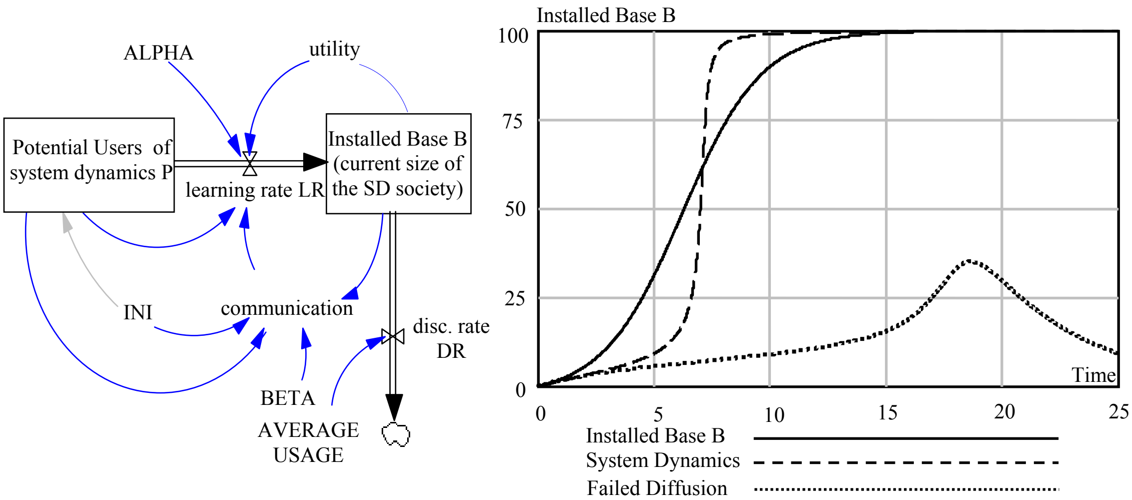

Figure 3: System dynamics model with failed diffusion

Similarly to the situation described above, a delayed diffusion behavior can be observed caused by the existing imaginary network barrier. But in this case, the required utility cannot be developed by the people within the network. There are too few people in their system dynamics society so that they will also discontinue their usage of system dynamics in the long run. Accordingly, system dynamics will fail to emerge as a standard. In the following leverage points for a successful diffusion of system dynamics in an undeveloped society will be elaborated.

Identification of Leverage Points for the Diffusion of System Dynamics

Several aspects can be learned from the system dynamics model. Firstly, the analysis has shown that system dynamics should be considered as a good which is influenced by network externalities. As a consequence the diffusion behavior of system dynamics differs from the diffusion of conventional products since communication and the underlying network determine the diffusion behavior. The simulation analysis reveals that the diffusion process is delayed since potential users of system dynamics show a hesitating behavior. This might lead to a situation that the diffusion of system dynamics will fail in the long run which is primarily based on the strong impact the penguin effect might have. Furthermore, the penguin effect can be accompanied by the effect that people that are already using system dynamics might leave the network.

Accordingly, it is important to act on the diffusion process if system dynamics should become a standard in societies where this approach is still in its infancies. The most important aspect is the consideration of the size of the installed base. This size has a significant impact on the utility the user of system dynamics can derive from the network. Hence, it is important to increase the installed base in the beginning of the diffusion process. This can be realized by putting more effort to activate innovators quickly or by fostering the word-of-mouth effect. Moreover, the trust in the success of the predominant adoption of system dynamics should be fostered making people believe that this approach will evolve as a standard. Furthermore, the continual usage of system dynamics within an existing network is important to create a sustained society. Additionally, it is relevant to make people use system dynamics continuously since their termination would prevent other potential user to enter the community. On the other hand, their further usage of system dynamics would attract other people joining the community in the long run since a sufficient network size can be established.

Besides these obvious points for a successful diffusion of system dynamics, some other aspects will be mentioned in the following. Firstly, the homogeneity of the users within a system dynamics society is an important issue. If the users within a network are too heterogeneous an intensive communication is less likely contrary to a homogeneous group. Correspondingly, the average size of the subgroups within a society should be increased. Thereby, the communication among the users will be intensified leading to a higher average utility. In order to foster this, internet communities can be created in each particular society so that users can share their ideas and discuss them with other users. This way not only bidirectional communication is possible but also multidirectional. Besides the international conference of the system dynamics society, local workshops will increase the network of a small society. Furthermore, special tracks on system dynamics at other conferences in other fields might be useful. Finally, the compatibility with other simulation tools might be interesting as well.

Further Research

The system dynamics model shown in this paper is a first step for the analysis of the diffusion of system dynamics considering the most important effects. Hence, significant points for a successful diffusion can be identified. But there are still some aspects that need further investigation. Firstly, some users can restart using system dynamics after they have quit since the network size has grown. Secondly, the effect of heterogeneous groups can be taken into account. Thirdly, aspects of external motivation can be integrated into the model as well as the existence of other research methods. Finally, it would be worthwhile to examine the results of this paper in an empirical manner which is an important step for further research.

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