

**Business ecosystems:
A research framework for investigating the relation between network
structure, firm strategy, and the pattern of innovation diffusion**

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Abstract

This paper introduces a research framework to study the relation between network structure, firm strategy and the pattern of innovation diffusion. The framework builds on the following notions: 1) that economic agents are embedded in social networks, 2) that the decisions they take are at least partly dependent on the actions or opinions of other agents, 3) that this network structure influences market dynamics, 4) that firms and consumers engage these market dynamics by forming coalitions that we refer to as ‘business ecosystems’, 5) that key firms in such business ecosystems are able to influence the relation between the network structure and market dynamics by exercising network governance and 6) that firms in such business ecosystems are able to influence the relation between the market dynamics and their own performance by choosing the right strategy.

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1. Introduction

It is by now well established that the structure of a network influences the diffusion of technological innovations throughout this network (e.g., Abrahamson & Rosenkopf, 1997). The reason for this is that economic agents do not take their decisions in isolation, but they are influenced by the decisions of others. In other words, economic behavior is ‘embedded’ in social network relations.

The embeddedness approach as introduced in economic sociology (Granovetter, 1985) has received considerable attention in both sociological (Romo & Schwartz, 1995; Uzzi, 1997) and managerial (Gulati, 1995; 1998) literature. The basic premise is that economic agents – consumers or firms – are influenced in their decision making by structures of social relations. Consumers’ purchasing behavior is altered by the structures of social relations in which the transaction is embedded (Frenzen & Davis, 1990). In industrial markets the dyad between buyer and supplier is influenced by relations with other firms (Bonoma et al., 1978; Anderson et al., 1994). Industrial firms rely for example on colleague firms in their search for information and in their buying process (Moriarty & Spekman, 1984).

In economic and management theory and in the theory of demand-side increasing returns this interdependence of decisions has received considerable attention in the study of technology adoption processes. For some technologies, the customer value of products based on a particular technology increases as more consumers adopt products or complementary products based on this particular technology. We may think of examples like telephone, fax, software programs, computers and consumer electronics. This phenomenon is also known as network effects, network externalities or demand-side increasing returns. The theoretical foundations for modeling these effects in economics have been laid in the 1980’s by Arthur (1989), Farrell & Saloner (1985; 1986) and Katz & Shapiro (1985; 1986). In recent years, a number of simulation studies have been performed to gain further insight in the phenomenon, notably Redmond (1991), Abrahamson & Rosenkopf (1993; 1997), Gupta, Jain & Sawhney (1999) and Clark & Chatterjee (1999).

The influence of social networks has not been completely ignored in this literature. The importance of vendors of complementary products on customers’ choice behavior has been

studied (Katz & Shapiro 1994; Gupta, Jain & Sawhney, 1999). In product diffusion literature the importance of word-of-mouth information has been studied, and how this importance changes over time (Mahajan, Muller & Bass, 1990; Mahajan & Muller 1998). The importance of word-of-mouth is likely to be different for different firms, depending on the number of contacts they have with other firms. Firms in dense social networks are likely to receive more word-of-mouth information and are more likely to become aware of a new technology and will experience greater pressure of coordinating their decision which technology to adopt.

Still, the study of social influences on diffusion dynamics remains underdeveloped in some respects. Especially regarding the influence of the network structure on innovation diffusion, and on how to shape firm strategy to make optimal use of this knowledge, relatively little research has been conducted. Abrahamson & Rosenkopf's (1997) paper shows that the effect of the number of links and the social network structure on the extent of innovation diffusion can be quite substantial and that small idiosyncrasies in network structure can heavily influence the diffusion process. Their paper takes a specific type of network – a core-periphery network – as a starting point however. While proving the point that, given this particular structure, there is a substantial influence, the paper does not derive generic relations between network structures and innovation diffusion. The research framework presented in this paper aims at filling part of this gap. It will do this 1) by allowing a broad range of network characteristics to be investigated instead of assuming specific network structures, 2) by recognizing the heterogeneity of economic agents as regards their adoption decision rules and 3) by deriving guidance for firm strategy to influence this relation and for firm strategy to influence firm performance. The central questions for which this paper prepares the research framework are therefore:

- What is the influence of network structure on the diffusion of innovations?
- What are the consequences for business strategy and business performance?
- How can a firm govern networked structure in such a way that the diffusion of innovations optimally serves the strategic interests of the firm?

In this paper, innovations are understood as technological innovations. Innovation diffusion therefore refers to a technology spreading throughout the market (i.e., the network).

The paper is structured as follows. In sections 2 through 5 we will give a broad overview of the issues to be considered regarding the research question. In section 2 we discuss the theory

of interdependence of economic decisions. We will do this building on the theory of demand-side increasing returns, discussing economic network effects and social interaction effects. From this theory we derive generic adoption decision rules of economic agents in section 3, recognizing the interdependence of decisions, recognizing the structure of the network and recognizing agent heterogeneity. In section 4 we address the consequences of this interdependence of decisions for the dynamics of the market, building further on the theory of demand-side increasing returns. The way in which firms and coalitions of firms engage these market dynamics is addressed in section 5. Specifically, section 5 is about ‘business ecosystems’, reflecting the idea that a coalition of firms and consumers around a specific technology is not unlike a biological ecosystem in which the different species are dependent upon each other for survival and growth.

After this broad overview of the issues regarding the research problem, we define a framework for research in section 6. This framework consists of the research model, the intended focus of the research and the proposed ways of proceeding with the operational research projects.

2. Interdependency of decisions

The main reason to assume that the structure of a network influences the diffusion of innovations throughout this network is that economic agents do not take their decisions in isolation. From the theory of demand-side increasing returns it is known that in deciding whether or not to adopt a new product or a new technology, economic agents are influenced by the expectations, the information and the actions of others and that these influences cause positive or negative externalities. These externalities take two separate forms, i.e., network effects and social interactions effects.

2.1 Network effects

Network effects occur when the economic utility of using a product becomes larger as its network grows in size (Farrell & Saloner, 1985; Katz & Shapiro, 1985). The difference between interaction effects and network effects is that while the former is associated with

information search and preference formation, the latter is associated with the economic utility as a result of actual growth in network size (Economides, 1996; Kretschmer, Klimis & Choi, 1999). Network size is determined by the number of suppliers and users of products based on a common technology standard. These networks may be physical, as for example, the cable TV network or the telephone network, or virtual, as for example the network of Microsoft Windows users. Network size is important in many markets, but most visible in the markets like telecommunications, computer equipment and software (see Brynjolfsson & Kemerer, 1996; Church & Gandal, 1992).

When a product's economic utility increases as more customers start using it, this is referred to as 'direct' network effects (Farrell & Saloner, 1985; Katz & Shapiro, 1985). Besides, network effects are also present when products are used in combination with complementary products. The increase in a product's economic utility, as more customers start using complementary products, is referred to as 'indirect' or 'market-mediated' network effects (Katz & Shapiro, 1986). Examples of indirect network effects are the cellular phone and its network infrastructure, the Internet connection and network protocols, the personal computer and its operating system (cf. Katz & Shapiro, 1994). Compatibility, which is necessary to allow products to function in harmony with complementary products, can be ensured by standardization of the technology infrastructure (Farrell & Saloner, 1992). For example, only if there is a common protocol for communication through the Internet, customers benefit from the continuously growing network of Internet-users and content providers. Therefore, compatibility is one of the most important conditions for network effects to materialize. With a growing number of customers who have bought the standard personal computer with an MS-Windows operating system and Intel microprocessor, it becomes more attractive for other customers to do the same (i.e., direct network effects). For suppliers of complementary products, such as software and peripheral equipment, it also becomes more attractive to accept this standard (i.e., indirect network effects). Consequently it becomes more appealing for potential customers to buy these complementary products. In other words, direct and indirect network effects are mutually reinforcing.

2.2 Social interaction effects

Social interaction effects are also known as social network effects (Abrahamson & Rosenkopf, 1997), or social contagion (Burt, 1987; Kretschmer, Klimis & Choi, 1999). Interaction effects occur when a customer's preference for a product is dependent upon the opinions or expectations of other (potential) customers (Bikhchandani, Hirschleifer & Welch, 1992; Cowan, Cowan & Swann, 1997). We refer to interdependence of opinions as 'information exchange' and to interdependence of expectations as 'self-reinforcing expectations'.

Information exchange mainly occurs with high-involvement products that are relatively unknown to customers. Customers can therefore not assess the quality of these products prior to purchase. This means that buying these products entails a large social and/or economic risk for customers. A social risk is the risk of buying a product that is not conforming to the relevant peer or aspiration group. An economic risk is the risk of buying a product that has a very short life cycle or that is based on a technology that does not become accepted as the market standard. As a consequence, customers buying these products run the risk of losing their investment. To assess the social and economic risks customers search for information by consulting opinion leaders and existing product users before making their purchase decision. This information search behavior generates interactions (i.e., information exchange) among customers. Since it is more likely that a customer will find favorable information about a product with a larger market share than about a product with a smaller market share, customers will perceive purchase of the former as less risky and will therefore be more inclined to buy it. Besides product-specific information exchange customers also exchange non-product related information. Feick & Price (1987) refer to customers who supply this more general market-related information to other customers as 'market mavens'. In the case of network technologies, where the complete network of complementary products rather than a single product is at stake, the influence of market mavens on the purchase intentions of other customers can be substantial.

Self-reinforcing expectations also play a role when customers have an interest to invest in products that are compatible to a long-lasting technology network that is widely supported and accepted as the market standard. To assess the risk of investing in a technology network, customers form expectations about the size of competing technology networks (Katz &

Shapiro, 1985; Economides, 1996). This expected network size is dependent on the number of suppliers and customers who have already invested in this network or who will (soon) do so. When a substantial number of suppliers and customers expect that a particular technology network will dominate the market, they will be more inclined to invest in this network. As a result, the network will grow and thereby fulfill the suppliers' and customers' expectations.

2.3 Extent of network and social interaction effects

An important question is under what circumstances we may expect network effects and social interaction effects to occur. In other words, what are the conditions affecting the extent of network and social interaction effects. Those conditions can be derived from the literature on demand-side increasing returns and from the lists of market conditions provided by Scherer & Ross (1990) and Carlton & Perloff (2000). The most important influencing conditions are: the marginal gains of network size, the degree of conformity and individuality of customers, the degree and structure of the economic interdependence in the market, the nature of the product and the technology and the characteristics of the product or technology as indicated by complementarity or substitution and compatibility. These will be discussed below.

Marginal gains of network size

The scope of network and social interaction effects is limited by the marginal economic gains of network size. That is the additional economic utility of adding one extra adopter to the network. Usually, these marginal gains are assumed to be positive up to the point where the entire market is satisfied. Liebowitz & Margolis (1994) argue, however that we may very well conceive of a point at which the marginal economic benefits of increasing the number of adopters are exhausted, e.g. by crowding of the network or by customer preferences for more heterogeneity (Katz & Shapiro, 1994; Helloffs & Jacobson, 1999). Further, while many technologies require 'critical mass', they may not be helped by further participation beyond that level (Liebowitz & Margolis, 1994, p.141). Where marginal gains of network size are exhaustible at network sizes small relative to the market, there is no impediment to the coexistence of multiple networks (Liebowitz & Margolis, 1994, p.141).

Conformity and individuality

Kretschmer, Klimis & Choi (1999) point out that networks are characterized by two competing psychological drives. The first is that of conformity, which means that there are positive marginal social gains of an increase in network size. This is also known as the bandwagon effect (Leibenstein, 1950). The second is that of individuality, which causes negative marginal social gains of an increase in network size. This is also known as the snob effect (Leibenstein, 1950).

The characteristics of the customer population may therefore be an important accelerator or limiter of social interaction effects. As most modern consumer markets are characterized by increasing heterogeneity of consumer behavior (Van Asseldonk, 1998), we would expect that customer individuality is a limiting factor to network size. If everybody wants to be different and unique, network size would be close to 1. Still, this is apparently not the case in many technology networks. The caveat lies in the distinction between the product and the technology. At the level of the technology, there is clearly a drive for conformity, i.e., we buy a 'Wintel' computer because we want to be able to easily connect to others and to the market for complementary products. At the level of the product, however, there is clearly a drive for individuality, i.e., based on the 'Wintel' standard, the choice of different computer models and features is larger than ever.

Degree and structure of economic and social interdependence

Another important aspect of the network and social interaction effect is the degree and the structure of economic and social interdependence between economic agents, customers as well as suppliers. Abrahamson & Rosenkopf (1997) show that the structure of the social network is an important determinant of the extent of innovation diffusion. They show first that a network with a higher density results in a higher extent of diffusion of an innovation, i.e., more agents within the network eventually adopt this innovation. Second, perhaps even more interesting, they show that network idiosyncrasies, i.e., the location of agents in the network that form a boundary between the fully connected network core and a not fully connected network periphery, can have a large influence on the extent of innovation diffusion.

An important aspect of the structure of social and economic networks is whether they are local or global (Bikchandani, Hirschleifer & Welch, 1992; Redmond, 1991). A global

network effect means that consumers are influenced in their adoption decision by the behavior of other consumers in the entire market. As an example, they would base a decision to buy a 'Wintel' or an Apple computer system on the proportions of the total world market for 'Wintel', respectively Apple. Most theoretical models incorporating network effects are limited to the global network effect. They assume that consumers are all identical and that they have perfect information of the size of the network in the market. Most theoretical models incorporating network effects assume that the network effects has a global scope and that consumers have information about the size of competing technological networks in the market. This kind of 'perfect information' will in practice not always be present.

While global network effects may have important influence on a product's utility and consumers' decisions to purchase, consumers are also known to be embedded in a social structure that can influence their behavior to a large extent (Redmond, 1991; Abrahamson & Rosenkopf, 1997). Consumers are more heavily influenced by their direct social environment. For example, while the global network effect will make it more efficient to work with a 'Wintel' computer, a consumer may choose an Apple computer if he is heavily embedded in the graphical sector, where the majority uses Apple computers. Because of localized network and social interaction effects, small 'pockets' or 'niches' in the market may appear or be able to sustain themselves (Redmond, 1991).

Nature of the product

The nature of the product and/or technology has a number of dimensions. The first is whether we are dealing with a consumer product or an industrial product. A consumer product means that it is used by the end-user (consumer), while an industrial product is used by a firm as a means of production. The implication of the consumer-industrial distinction is not unequivocal. On the one hand it might be suggested that industrial buyers are more rational, which could lead us to expect that in industrial markets network effects might be more important than social interaction effects. On the other hand, when facing uncertain pay-offs in choosing a product, will not industrial customers be inclined to collect more information and be more aware of the market expectations regarding the success of new technologies? Therefore, we could also expect the social interaction effects might be more important than the network effect.

The second dimension is whether it is a tangible or an intangible product. The degree of tangibility may be used as an indication of the possibility to assess the quality of the product on beforehand. That is, tangibility provides a clue on whether we are dealing with a search good or an experience good. Of a search good, e.g., a computer, the quality can be determined in advance, of an experience good, e.g., software, this is not the case. Therefore, for intangible goods, the uncertainty is much higher and we would expect social interaction effects to be more important than network effects.

The third dimension, durability versus non-durability, tells us something about the probability that a network effect or a social interaction effect will occur. If a product is durable, the customer will likely make a larger investment than if it non-durable, both in terms of the initial buying price as well as in terms of learning to use the product. It is therefore likely that the network of other customers using the same product or compatible products based on the same technology and the network of customers and suppliers of complementary products will become a more important issue in the adoption decision. Likewise, as the investment is higher, the buying risk rises and customers will be more inclined to adopt on the basis of information they got from others or on the basis of expectations about the value, the extent and the durability of the technology network.

The fourth dimension is technology intensity of the product. Technology intensity is related to uncertainty (Arthur & Lane, 1993), because the market outcome, i.e. which technology will be selected and corner the market, is uncertain. Investing in a product based on a technology that will become locked out means an effective loss of the investment.

The fifth dimension involves the nature of the technology. According to Arthur (1990; 1996), high-technology products are simply more likely to be compatible to a network of users. Examples of what we normally understand as 'high-tech' are computers, software, (portable) telephones, fax machines, etc. It is no coincidence that empirical research on demand-side increasing returns is mostly focused on computer hardware (Tegarden, Hatfield & Echols, 1999), computer software (Brynjolfsson & Kemerer, 1996; Gandal, 1995), computer software-hardware (Church & Gandal, 1992; Cottrell & Koput, 1998; Garud & Kumaraswamy, 1993), digital television (Gupta, Jain & Sawhney, 1999) or telecommunications (Majumdar & Venkataraman, 1998).

Complementarity and substitution

Complementarity means that products are (meant to be) used together and that in this way they have for customers a higher value than when used separately. Formally, complementarity is represented by a positive cross-elasticity of demand. I.e., when products A and B are compatible, the demand for product B will increase with an increase of demand for product A. Examples are a computer and a printer, a video recorder and video tapes, a CD player and CD's. Complementarity can be product-related or technology-related. Examples of complementary technologies are the Windows computer operating system technology and the Intel Pentium computer processor technology for computers, the machine operation technology and the machine's numerical control technology for industrial machines.

Complementarity of at least product is a necessary condition for indirect network effects to exist. Technology complementarity will further extend the possibilities for indirect network effects. Both product as well as technological complementarity will lead to more extensive technology networks and therefore more need for and opportunities for information exchange between customers.

Substitution means that products are competitive, so that a consumer will have either one product or the other. Formally, this is represented by a negative cross-elasticity of demand. That is, when products C and D are substitutes, the demand for product D will decrease with an increase of demand for product C. Examples are a Hewlett-Packard Computer and a Dell computer, a Philips CD player and a Sony CD player. Substitution can also be product-related or technology-related. Examples of technologies that are substitutes are Windows and Apple or Linux computer operating system technology, Intel Pentium and AMD Athlon computer processor technology.

Technologies that are substitutes will cause a technology battle, either parallel or sequential, to appear. A technology battle will enhance uncertainty in the market, so that social interaction effects will be larger. Whether or not there is substitution, may in itself either or not influence the magnitude of the network effects. The same goes true for products that are substitutes when they are based on different technologies. Products that are substitutes but that are based on the same technology will likely enlarge the network effect in the market, as

the market will be served by increased product variety. Only the pay-off for the producing firm may be affected.

Compatibility

Compatibility, which is necessary to allow products to function in harmony with complementary products, can be ensured by standardization of the technological infrastructure (Farrell & Saloner, 1992). For example, only if there is a common protocol for communication through the Internet can a customer benefit from the continuously growing network of Internet-users and content providers. Therefore, compatibility is one of the most important conditions for a technology network to materialize and therefore one of most important conditions for network effects and social interaction effects to be present.

3. Agent decision rules

We will assume that economic agents' decisions can be described by rules with which they decide whether or not they will adopt a product or a technology. In these rules, the positive or negative externalities they experience will be incorporated. Such decision rules may look as follows, e.g., for a shop deciding whether or not to take a new product in its assortment:

- IF [supplier brings out a new product] THEN [take it in assortment]
- IF [my competitors have this product in their assortment] THEN [take it in assortment] or, in case the shop wants to differentiate itself: IF [my competitors do *not* have this product in their assortment] THEN [take it in assortment]
- IF [we make money on this product] THEN [take it in assortment]

Decision rules are agent-specific and can consist of any Boolean combination of IF [event] THEN [action] through the operators AND, OR, and NOT.

3.1 Rules for adopting

For our purpose we may try to generalize these rules, by incorporating both positive and negative externalities, both local and global. To do this, we combine and extend on the models of Redmond (1991), Abrahamson & Rosenkopf (1997) and Clark & Chatterjee (1999). We propose the following generic decision rule:

$$V(x | X_{t-1})_{i,t} = a_i * \left[\frac{x'_i}{x'_i + y'_i} \right] - b_i * \left[0,5 - \frac{X_{t-1}}{X_{t-1} + Y_{t-1}} \right] - c_i * \left[0,5 - \frac{X_{i,t-1}}{X_{i,t-1} + Y_{i,t-1}} \right] \\ + d_i * \left[\frac{X_{t-1}}{N} \right] - e_i * \left[\frac{X_{t-1}}{N} \right]^2 + f_i * \left[\frac{X_{i,t-1}}{N_i} \right] - g_i * \left[\frac{X_{i,t-1}}{N_i} \right]^2$$

Where:

The dependent variable, V is the (threshold) value of technology x for agent i in period t, under the condition of the number of adoptions of technology x until period t-1. The assumption is that the agent will adopt the technology when V exceeds the threshold value.

At the right-hand side:

- The first term is agent i's subjective inherent valuation of technologies x and y. Here x' is the subjective value of technology x, y' is the subjective value of technology y. The term between brackets is the preference for x over y or vice versa. The a designates the weight that agent i gives to this value. By varying the distribution of a across the agents, e.g. by making it negative, we may allow for non-adoption. Redmond cites this as Luce's choice axiom.
- The second term is the global positive feedback effect of the competition between the two technologies. X and Y reflect the total number of adoptions until period t-1 of technology x and y respectively. The b designates the weight that agent i attaches to this term.
- The third term is the local positive feedback effect of the competition between the two technologies. X and Y reflect the number of adoptions in the immediate surroundings of agent i until period t-1 of technology x and y respectively. This is the subjective network of agent i, or the 'closeness'. It can be operationalized by the number of agents that agent i has direct contact with. The c designates the weight that agent i attaches to this term.

Attractiveness of a technology is not only determined by its market share relative to the other technology, but also to the total number of adoptions relative to the total market potential (N).

- The fourth term is the global positive feedback effect of the number of adopters of technology x relative to the total population (potential number of adopters). The d designates the weight that agent i attaches to this term.

- The fifth term is the global negative feedback effect of the number of adopters of technology x relative to the total population (potential number of adopters). This reflects the effect of agents wishing to distinguish themselves from others in the market. The e designates the weight that agent i attaches to this term. (e.g. if $d=1$ and $e=2$, then the effect is weighed heavily when the relative adoption rate is only low and is it weighed less heavy when the relative adoption rate increases; when the relative adoption rate would be 50%, the weight would be 0, over 50% it becomes negative)
- The sixth term is the local positive feedback effect of the number of adopters of technology x relative to the total population (potential number of adopters). The f designates the weight that agent i attaches to this term.
- The seventh term is the local negative feedback effect of the number of adopters of technology x relative to the total population (potential number of adopters). This reflects the effect of agents wishing to distinguish themselves from others in their immediate surroundings. The g designates the weight that agent i attaches to this term.

Less complex models can be made by setting parameters to 0 and by removing distribution of parameters (removing the i 's):

- when we set $a=1$, $b=1$, $c=0$, $d=0$, $e=0$, $f=0$, and $g=0$, we obtain the simplest version of Redmond's (1991) positive feedback model
- when we allow a and b to vary, and we set $c=0$, $d=0$, $e=0$, $f=0$, and $g=0$, we obtain the Clark & Chatterjee (1999) model
- when we allow a and d to vary, and we set $b=0$, $c=0$, $e=0$, $f=0$, and $g=0$, we obtain the basic Abrahamson & Rosenkopf (1997) threshold model ignoring social network structure
- when we allow a and f to vary, and we set $b=0$, $c=0$, $d=0$, $e=0$, and $g=0$, we obtain the Abrahamson & Rosenkopf (1997) threshold model considering social network structure

3.2 Rules for switching

An agent might regret the initial adoption of technology y as the network of technology x becomes larger. The agent might then decide to switch from technology y to technology x .

$$V(x | y)_{i,t} = V(x | X_{t-1})_{i,t} - C_{x,y}$$

Where:

- V is the value of technology x in period t under the condition that agent i has already adopted technology y before.
- C is the cost of switching between x and y .

We assume agents to be maximizing the following function:

$$\text{MAX}_{i,t} [V(x | X_{t-1})_{i,t}; V(y | Y_{t-1})_{i,t}; V(x | y)_{i,t}; V(y | x)_{i,t}; 0]$$

This says that agent i for every period t maximizes the value of:

1. adopting technology x for the first time
2. adopting technology y for the first time
3. switching to technology x provided he previously adopted technology y
4. switching to technology y provided he previously adopted technology x
5. doing nothing or unadopting a previously adopted technology

When assuming homogenous agents, the parameters a through g are the same for every agent in the network. When assuming heterogeneous agents, the parameters differ for different classes of agents in the network.

4. Market dynamics

The presence of network effects and social interaction effects may have large consequences for market structure, i.e., factors such as the speed of diffusion of products and technologies, the dynamics of the market shares of different competing products or technologies and the predictability of market outcomes (Arthur, 1989; 1996).

4.1 Technology battles

In general the market structure will take the form of a competition between different technologies, generally referred to as a ‘technology battle’. Such a technology battle may take

four generic forms. The technology battle may either be parallel, i.e., a competition between two or more equivalent technologies, e.g., Farrell & Saloner (1985; 1986) or sequential, i.e., a competition between an old (existing) and a new technology, e.g. Arthur (1989), David (1985), Katz & Shapiro (1985; 1986). Besides parallel or sequential, technology battles may be evolutionary, i.e., the new technology is backward compatible, or revolutionary, i.e., the new technology is not backward compatible (Shapiro & Varian, 1999). Of course, any combination of these forms is also possible.

Arthur (1989) mentions four properties of such technology battles:

1. the market will eventually be dominated by one of the technologies, which means that there are multiple possible equilibria in the market and it is ex ante unpredictable which equilibrium will be selected (non-predictability)
2. the winning technology will be 'locked in' (inflexibility)
3. it is possible that a sub-optimal technology will be selected (inefficiency)
4. the end result may be determined by historical small events (path dependence or non-ergodicity)

More properties have been added by others, e.g., excess inertia (Farrell & Saloner, 1985; 1986), excess momentum (Katz & Shapiro, 1986) and competition on the network level (Den Hartigh & Langerak, 2001). These properties will be discussed below. Although many of these issues are still heavily debated, it has become clear from both the theoretical and the empirical body of research that the presence of network effects and social interactions effects in markets can have severe consequences for adoption and diffusion of technologies and thereby also for the adoption and diffusion of products based on these technologies.

4.2 Competition at network level

A first consequence of the occurrence of network and social interaction effects – implicit in most theoretical and empirical literature, but seldom explicitly mentioned – is that competition shifts from the product level to the network level (Den Hartigh & Langerak, 2001). As a result of this shift, features like high product quality, low prices, ownership or patents, or exclusive rights on technology are just a 'green fee' for competitive success. The network dimensions of competition, such as the availability of complementary products,

compatibility of these products, size of the network or ‘installed base’ and customer expectations with regard to network growth, are more important for competitive dominance (Shapiro & Varian, 1999). In other words, competition takes place on both the product and the network level. However, many firms have not yet incorporated both levels into their competitive strategy. For example, in the battle for the home video standard between VHS and Betamax, Sony still competed on technical product quality and exclusive rights on technology. In contrast JVC, the first supplier of the VHS system, took network effects into account. By providing licenses for VHS technology to other suppliers and by strongly stimulating the availability of complementary products, i.e., video movies, JVC created a strong network effect around the VHS system that still dominates the home video market today.

The network dimension of competition may become so important that any possible market inefficiencies on the product level may hardly matter. Customers might be prepared to accept lower quality on the product level if compensated by advantages on the network level. For example, in the home video market the VHS technology’s image quality was inferior to that of Betamax (the product level), yet customers favored VHS because VHS-compatible movies were more widely available at video rent shops (the network level). Suppliers often try to win the battle on the network level at the expense of losses on the product level. For example, both Microsoft and Netscape have been striving to dominate the Internet software market (the network level) by offering their Internet browser software free of charge (the product level).

Firms participating in the competitive battle between technologies have to take the aspects of network competition explicitly into account, e.g., availability of complementary products, compatibility of these products, size of the network or ‘installed base’, customer expectations with regard to the growth of the network (Shapiro & Varian, 1999). Product dimensions, such as high quality, low prices, or exclusive ownership of patents are just a ‘green fee’ for participation in this competitive battle.

4.3 Multiple possible equilibria

A second consequence of network and social interaction effects is that a battle for the technological standard occurs in the market, of which the outcome is not ex ante predictable

(Shapiro & Varian, 1999). Instead of balanced equilibria, we see markets where the winner, be it a technology or the firm that sponsors it, takes (almost) all. Well-known examples are, again, the home video market (VHS-format), computer operating systems (Microsoft Windows) and web browsers (Microsoft Internet Explorer). Standardization of technology is not only attractive for customers, but also for the supplier who sets the technological standard. Customers profit from standardization of technology through the compatibility of products. They act in their own interest by choosing products based on the most prevailing technology. Customers who have made their purchase will not easily switch to another technology, because of the investments and learning costs made to adopt this technology. Therefore, the firm that sets the technological standard may expect a rapidly growing group of loyal customers. This so-called installed base enables the firm to optimally profit from scale and learning effects in its own development, production and marketing processes.

The mutually reinforcing consequences of network and social interaction often lead to a very asymmetrical distribution of market shares (Arthur, 1996). Often, the winner takes all and the loser gets nothing. An example of the 'winner takes all' is Microsoft Windows, which dominates the market for computer operating systems. An example of 'loser gets nothing' was Sony's Betamax technology after having lost the VHS-Betamax battle in the home video market. Firms losing the battle for the technological standard will either withdraw from the market or become late followers of the winning technological standard. Other well-known examples of battles for the technological standard are the personal computer standard, Apple versus DOS, the word processor standard, WordPerfect versus MS-Word, Internet browser software, Microsoft Internet Explorer versus Netscape, digital cellular communication technology, GSM versus CDMA and the digital multimedia standard.

4.4 Lock-in

Lock-in describes a situation in which the cost of switching to another technology – even though it may be technically superior – is too large for the switch to take place. In the parallel case of technology battle this means that as one of the technologies gains an edge over the other, it may become more and more popular and therefore eventually corner the market. The higher its pay-off, the more likely it will become 'locked in' and the more likely any rival technology will become 'locked out'. In the sequential case of technology battle there may

also be a lock-in of the existing technology. When a new – better – technology comes to the market, it may take very long for this new technology to gain an edge over the old one. Or it may not happen at all. Arthur (1989) provides the following – simplified – example of a lock-in situation:

U_A = utility of technology A

U_B = utility of technology B

i_A = number of adopters of technology A

i_B = number of adopters of technology B

$$U_A = f(i_A) = 10 + 0,1i_A$$

$$U_B = f(i_B) = 4 + 0,3i_B$$

Without foresight and discounting of pay-offs and without one technology being sponsored more than the other, rational agents will adopt technology A. In this case technology A that is chosen at the outset will become locked in. Of course, this is without counting future pay-offs. Future pay-offs determine the alternative first chosen, depending on height of the pay-off, discount rate, time horizon and degree of uncertainty. It might be conceived that, when already a number of times alternative A has been adopted, alternative B appears to have more future potential. If the difference in future potential between alternatives A and B is large enough to offset the pay-offs from adoption of alternative A, the next adopter i might switch to alternative B.

Under assumptions of rationality and certainty, the alternative with the highest discounted pay-off will be chosen, of course dependent on time horizon and discount rate. If discount rate is high, an alternative will be chosen that has a relatively high pay-off in the short term. This alternative might well become locked in as it is more often adopted. Another alternative will only be adopted if its discounted future pay-off more than offsets the sum of the discounted future pay-off of the alternative chosen at the outset and the accumulated pay-off of this alternative due to the number of adoptions yet. This depends on how fast in time a certain alternative is adopted. If adoption is very slow, a changeover to another alternative might well take place. If adoption is very fast, the alternative is more likely to become locked in.

A consequence of this self-reinforcing process is that once a network becomes dominant, customers and suppliers are virtually 'locked in' to it. This means that compared to new alternative technologies the network and social interaction effects of the dominant technology are so large that customers and suppliers are not prepared to make the necessary investments to switch networks. Which means that the market will be 'frozen' in this particular technological standard and a newer and better technology will find it extremely difficult to break in. Here also, the debate goes whether this represents market failure or inefficiency. From the manager's perspective, this discussion may not be that productive and it may suffice to observe that it may be very difficult to enter the market with a new technology when the existing technology still has the advantage of a large installed base.

Once a solution is reached, it can be extremely difficult to exit from and difficult to break in for competing solutions. Lock-in of a technology therefore becomes a serious barrier to entry for firms that are sponsors of or hold licenses to the locked out technology. This is of course very attractive for firms sponsoring or having licenses to the locked in technology, because it creates a kind of monopoly situation, enabling these firms to appropriate monopoly rents.

4.5 Excess inertia and excess momentum

The interplay between network and social interaction effects has important consequences for the development pattern in the market. In the battle for the technological standard the subjective expectations that suppliers and customers have of market outcomes, i.e., which standard will eventually dominate the market, play an important part. Suppliers' and customers' expectations depend on (1) the installed base and, (2) the expected behavior of other customers and suppliers. All these expectations are mutually dependent and adaptive, which means that they constantly change when new information becomes available. The dynamics of customers' and suppliers' expectations can cause extremely complex or even chaotic market patterns (Hommes, 1995). These patterns are difficult to interpret, virtually unpredictable and therefore hard to manage.

The uncertainty about market developments may cause a market stalemate, i.e., excess inertia, in which both suppliers and customers wait for others to decide first (Farrell & Saloner, 1985; 1986). This impedes a collective switch from an existing technological standard to a possibly

superior new standard of technology. This may result in none of the competing technologies ‘taking off’. Alternatively, it may cause a situation of explosive growth, i.e., excess momentum, in which investments of some suppliers and customers lead to massive investments of others. Ultimately, the market may quickly lock in to one single technological standard (Farrell & Saloner, 1985; 1986).

Here, the concept of ‘critical mass’ is of importance. Critical mass is reached when for the individual adopting agent the network effect is so large that it always outweighs possible negative inherent valuation of a technology. As soon as a technological network reaches critical mass in the perception of customers and suppliers, they expect that this network will dominate or at least maintain itself in the market. By this it becomes a relatively safe network to invest in. When a customer or a supplier decides to make this investment by purchasing or introducing a product, the network increases and with it the probability that it will eventually dominate the market. This induces other customers and suppliers to invest in the network, which sets a self-reinforcing process in motion. Katz & Shapiro (1994) state that, because of the strong positive feedback elements of the network effect, technology competition is prone to ‘tipping’, which is the tendency for one technology to ever-increasing popularity once it has gained an initial edge.

4.6 Path dependence

Path dependence means that the early history of market shares, often the consequence of small events or chance circumstances, can determine to a large extent which solution prevails (Arthur, 1989). It is also referred to as irreversibility, or non-ergodicity.

The mutual influence of the network and social interaction effects leads to irregular movements in the market. Although these movements are unpredictable, they are in retrospect characterized by path dependence (Arthur, 1989). Path dependence means that very small differences in starting conditions may have far-reaching consequences with regard to the final market outcomes. Because of path dependence, a small initial competitive advantage may increase continuously. Conversely, firms that incur small early disadvantages may find themselves increasingly disadvantaged with respect to their competitors.

An example of path dependence is Microsoft's position in the market of personal computer operating systems. In the early 1980s Microsoft became the supplier of the operating system for IBM PC's (MS-DOS) almost by coincidence. Owing to the strong network and social interaction effects in the PC-market, an IBM PC with an MS-DOS operating system became the market standard. In the rapidly growing PC-market an increasing number of MS-DOS copies were sold, which enabled Microsoft to realize enormous scale and learning effects. This enabled them to continuously improve existing product versions and develop new ones. Thus, improved MS-DOS versions remained the standard operating system for most PC's, until they were replaced by MS-Windows. Moreover, because of the complementary nature of the products Microsoft has built a dominant position in the markets for word-processing, spreadsheet, database, presentation and internet browsing software. By optimally capitalizing on network effects and social interaction effects, Microsoft has become the largest software firm in the world, a typical example of how a small initial advantage was continuously reinforced by smart management.

5. Business ecosystems

As a consequence of the importance of the technology network, it is almost impossible for firms to engage the competitive battle on their own. We therefore see patterns of competition emerge that do not match the economic models of perfect competition or even of oligopolistic or monopolistic competition. Rather, competition takes place between a few large coalitions, or networks, of firms around a common technological platform. Such networks, consisting of multiple firms performing different roles, are not unlike biological ecosystems. For such networks therefore the term 'business ecosystems' is increasingly used (Moore, 1993; 1996; Iansiti & Levien, 2004; Witte, 2004).

5.1 Defining a business ecosystem

The term 'business ecosystem' was coined by James Moore in his 1993 Harvard Business Review article *Predators and Prey*. Moore (1996, p.15) defines a business ecosystem as "*The term circumscribes the microeconomics of intense coevolution coalescing around innovative ideas. Business ecosystems span a variety of industries. The companies within them coevolve*

capabilities around the innovation and cooperatively and competitively to support new products, satisfy customer needs, and incorporate the next round of innovation.” There is a strong analogy between business ecosystems and biological ecosystems, as implied by the ‘ecosystems’ terminology.

We define a business ecosystem as a network of suppliers and customers around a core technology, who depend on each other for their success and survival. In our view, the essential characteristic of a business ecosystem is the mutual dependence of its members: when customers leave the network, the value of the network for other customers and for suppliers declines. When a new supplier of a complementary product enters the network, the value of the network for all agents rises. Or, as Iansiti & Levien (2004, p.69) put it: *“Like an individual species in a biological ecosystem, each member of a business ecosystem ultimately shares the fate of the network as a whole, regardless of that member’s apparent strength.”*

What are the boundaries of such a business ecosystem? As with biological ecosystems this is difficult to establish. We think the best way to judge which agent is and which is not part of the business ecosystem is the degree of compatibility and complementarity (see section 2.3) of the products or technologies the agent offers or adopts. For example, Apple will not be considered to be part of the business ecosystem around Microsoft Windows technology, because the Apple operating system is a substitute rather than a complement for Microsoft’s operating system. In this case, the Apple has its own business ecosystem around its OS technology. When we consider the business ecosystem around Microsoft’s Office technology we find that Apple will be part of it, because Apple’s operating system is complementary to this technology. Note that one and the same firm can be part of multiple competing business ecosystems at the same time. A printer manufacturer, for example, will be part of the business ecosystems around both Microsoft’s Windows technology and Apple’s OS technology. The same is true for consumers, when they adopt products from different competing business ecosystems at the same time. For example, a customer can own two computers, one with Microsoft’s Windows technology, the other with Apple’s OS technology.

Note also that a business ecosystem is determined by an anchor point, i.e., that which the researcher defines as the core technology. For example, when we define the anchor point as Microsoft’s Windows technology, Microsoft is likely to be in the core and firms like Intel or

AMD or the large computer firms are important members of the business ecosystem. Yet we may also define the anchor point as the Intel Pentium processor technology. In this case, Intel will be in the core and Microsoft will be an important business ecosystem member. Consequentially, what we define as the business ecosystem is dependent on our research position. Firms and consumers can therefore be considered to be part of multiple business ecosystems at the same time. A consumer owning a computer may be part of the business ecosystems around Microsoft Windows operating system technology, Intel's Pentium processor technology, Philip's flat screen technology, Adobe's Acrobat software technology and many more.

How is a business ecosystem different from an industry? First a business ecosystem does not necessarily – and not even likely – contain all the agents that populate the industry. Second, the network relations between the agents in a business ecosystem are not limited to industry boundaries (Moore, 1993; 1996; Iansiti & Levien, 2004). We fail to see, however, why this boundary crossing per se would be a prerequisite for calling a technology network a business ecosystem.

How is a business ecosystem different from a conventional supply chain? First, its relations are many-to-many (i.e., network) instead of one-to-one (i.e., chain). Second a business ecosystem is not necessarily ordered according to a logical production sequence. Modern concepts of 'networked supply chains' however, may come quite close to the concept of a business ecosystem.

5.2 'Species' in a business ecosystem

Like a biological ecosystem a business ecosystem will be populated by a diversity of 'species', each performing their own unique functions, having their own unique needs and wants and each delivering a unique contribution to the survival and growth of the business ecosystem as a whole. Some examples provided by Iansiti & Levien (2004, p.71) regarding Microsoft's business ecosystem are system integrators, development service companies, independent software vendors, trainers, small specialty firms, internet service providers business consultants, media stores, applications integrators and many others. In other words, all firms that provide products (goods or services) or technologies that are complementary and

compatible to Microsoft's core software technology. Their number may run into the tens of thousands. For our research, we also explicitly include customers in the business ecosystem.

5.3 Strategies in a business ecosystem

Firms may pursue three different strategies with respect to business ecosystems. The first two, 'shaper' and 'follower', are mentioned by Hagel (1996), the third, 'reserving the right to play' is mentioned by Coyne & Subramaniam (1996). Iansiti & Levien (2004) propose another classification, i.e., 'keystone', 'dominator' and 'niche player'. We will address them below.

First, firms can choose to follow a 'shaper' strategy by sponsoring their own proprietary technology that will generate high returns when it becomes dominant in the market (Besen & Farrell, 1994; Shapiro & Varian, 1999). Such a firm in fact tries to develop or maintain its own business ecosystem, with itself and its technology in the core. However, such a strategy is both costly and risky, which means that only a few firms in the market can afford to develop and implement such a strategy. Iansiti & Levien (2004) point out that such a firm can pursue this shaper strategy in different ways. It can try to become a physical or value 'dominator', or a 'keystone'. A 'dominator' is a firm that tries to manage a large proportion of the business ecosystem relations directly and/or tries to internalize the larger part of the added value created in the business ecosystem. The dominator, they state, will eventually become its own business ecosystem, absorbing the network, extracting maximum value in the short term, but destroying the business ecosystem in the long term (Iansiti & Levien, 2004, p.74). Another way for a firm to pursue a shaper strategy is to become a 'keystone', i.e., by providing a common technology platform, by being an important hub in the network, performing the task of connecting network participants and by continually trying to improve the business ecosystem as a whole. Needless to say, according to Iansiti & Levien (2004), this keystone approach is the strategy that will enable the business ecosystem and the keystone itself to grow and prosper.

Second, firms can choose to follow an 'adapter' strategy (Besen & Farrell, 1994; Hagel, 1996). Such a strategy involves joining the dominant technology by acquiring a license for developing products based on this technology. In a situation where the firm is not a sponsor of the dominant technology, it may nevertheless profit from the potential for scale and learning

effects created by the dominant technology. Not by competing with the dominant product or technology, i.e., not focusing on substitution, but instead by either:

- Offering products or technologies that are complementary to (i.e., are used together with) the dominant product or technology (Katz and Shapiro, 1986). In this way these firms may capitalize on indirect network effects.
- Offering a product or technology that is compatible with the dominant product or technology allows the firm to make a connection to the dominant technology network (Brynjolfsson and Kemerer, 1996; Gandal, 1995). In this way, these firms can capitalize on direct network effects and in this way exploit the potential for scale and learning effects created by the dominant technology.

Iansiti & Levien (2004, p.77) refer to this kind of strategy as ‘niche leveraging’, in which firms develop specialized capabilities that differentiate them from other firms in the network. They also mention the leveraging of complementary resources. While we agree to these aspects, we do not think that adapter firms are necessarily niche players. Indeed, they may be focusing their attention not on specific niches, but on the market as a whole. For example, a firm like Hewlett Packard can be considered to follow an adapter strategy with respect to Microsoft’s Windows technology, but we would hardly classify it as a niche player.

Third, firms can choose to wait committing themselves to either technology network in the market. This so-called ‘reserving the right to play’ means doing all that is necessary to create or keep open opportunities in order to acquire a strong position at a later stage (Coyne & Subramaniam, 1996). There is no equivalent of this strategy mentioned by Iansiti & Levien (2004).

6. Research framework

As a basis for the research framework we adopt the industrial organization theory of the firm. The basic assumption of this theory is that market structure influences firm performance through the conduct of the firm. This has become known as the structure-conduct-performance paradigm (Bain, 1959). In the structuralist approach to industrial organization theory, this assumption is taken to the extent that market structure is so constraining on firm conduct that individual management action can virtually be ignored (Spanos & Lioukas,

2001). For our analysis, the major objection to this approach is that it virtually ignores the ability of the firm to take strategic action.

We therefore adopt the behavioralist approach to industrial organization for which e.g. the works of Scherer & Ross (1990) and Porter (1980; 1985; 1990; 1996) are exemplar. The adoption of the behavioralist approach to industrial organization theory implies that in this study we focus on firm performance rather than industry performance, that we do not consider industry structure to be completely stable and fully exogenous and that we assume that the firm can by its conduct influence its performance.

6.1 Generic research framework

The generic research framework is a dynamic variant of the Structure-Conduct-Performance paradigm (see figure 1).

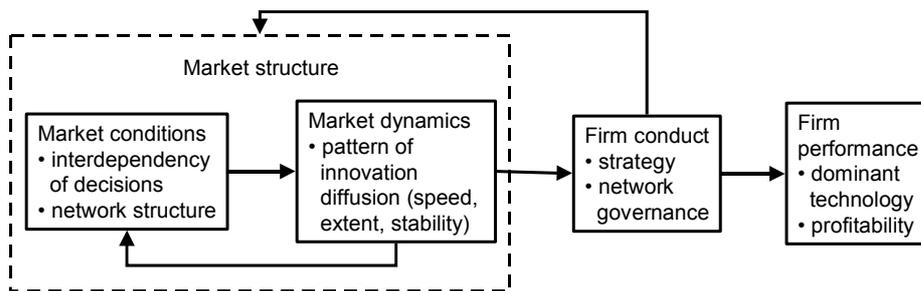


Figure 1: Generic research framework

In this framework, importantly, the market structure component is split in market conditions and market dynamics. The market conditions reflect the art and degree of the interdependency of decisions of the agents (firms and consumers) present in the market as well as the structure of the network of relations between them. The market dynamics reflect the pattern of innovation diffusion. This split in the market structure part of the framework allows us to investigate the relations between the network structure and the diffusion of innovation on an abstract level, i.e., without considering specific firms actions or strategies.

Further, the framework enables us to investigate the relation between market structure and firm performance, mediated by the strategy the firm follows. Even when a firm cannot influence market structure, it can still influence its own performance by selecting the right strategy. For example, a small firm that cannot afford to develop and sponsor new technology itself, i.e., follow a shaper strategy, but it may profitably implement an adapter strategy.

Finally we assume that some firms will be able to influence the market structure, and specifically the relation between market conditions and market dynamics by exercising network governance. Therefore, network governance as part of the firm's repertoire of actions can also be part of the research.

Recalling the central questions of the research, it becomes clear that each of those questions fits the research framework:

- What is the influence of network structure on the diffusion of innovations?
- What are the consequences for business strategy and business performance?
- How can a firm govern networked structure in such a way that the diffusion of innovations optimally serves the strategic interests of the firm?

6.2 Focus of the research

The research framework presented above gives guidance to individual research projects. For every project, a number of important decisions have to be made to define the specific focus of the research.

First, a decision has to be taken as to the level of heterogeneity of the economic agents in the network. The most basic level is to have no heterogeneity at all, i.e., for every agent in the network all the parameters of the adoption decision rules (see section 3) have the same value. Assuming homogenous agents is only relevant for highly abstract research purposes, where managerial relevance is relatively unimportant. The next level is to have heterogeneous groups of agents, where the groups are defined as the different species in the business ecosystem. The assumption is then that there are differences in adoption decision rules *between* but not *within* a species. The highest level of heterogeneity is where every individual agent has its own unique adoption decision rules. This level will probably be closest to reality

and therefore provide the highest managerial relevance. However, for real-world business ecosystems it may be prohibitively difficult or costly to uncover individual agents' decision rules. In such cases, the middle level of heterogeneity is the best alternative.

Second, a choice has to be made for either static or dynamic adoption decision rules. Static decision rules means that these rules stay the same from period to period. Dynamic decision rules means that agents are allowed to change their rules from period to period, e.g., as a reaction to changes in market dynamics and market outcomes or changes in their performance.

Third, it has to be decided whether or not to include competition. Excluding competition means that there is only one business ecosystem and that we study the diffusion of innovations through this particular network. Including competition means that there are two or more competing business ecosystems and that we not only study the diffusion of innovations but also – perhaps even primarily – the competition between different technology networks. This competition may take the form of either a parallel or a sequential technology battle. An example of the first is when two alternative technologies enter the market more or less simultaneously, as in the famous home video battle between the VHS and Betamax technologies. An example of the second is when a new technology appears in the market to replace an older technology, as in the compact disc versus the LP-record technology battle.

Fourth, a decision has to be taken on the possibility for an agent to unadopt or to switch technologies. This refers to including or excluding the second part of the decision rule presented in section 3.2. Excluding this part of the decision rule means that we assume that an agents who has adopted once, has adopted forever. The implication is that the innovation diffusion process will result in a static equilibrium outcome, i.e., when every agent, given its network position and its decision rule, has either adopted or not. Including the second part of the decision rule means that agents may reconsider their decision over time, e.g., depending on the technology diffusion pattern that emerges. The implication is that the diffusion process does not necessarily result in an equilibrium. The long-term outcome may either be a static equilibrium, a dynamic equilibrium or no equilibrium at all (i.e., chaos).

Fifth, a choice has to be made for either a static or a dynamic network structure. A static network structure means that the network is defined at the beginning of the research and does not change as a result of adoption decisions and innovation diffusion patterns. The assumption, then, is that the network structure is a social 'fact' that is not influenced by agents' economic decisions over time. In a static network structure it is impossible for agents to enter or to leave the network. Agents may decide to adopt or unadopt a technology, but the network relation remains the same. A dynamic network structure means that the network structure changes as a result of adoption decisions and innovation diffusion patterns. For example, a consumer who has adopted a technology from a certain supplier may be inclined to adopt again in the next period, because the previous transaction has generated trust and therefore reinforced the network relation. In a dynamic network it is possible for agents to enter or to leave the network.

Sixth, a decision has to be taken whether or not to include firm conduct and firm performance. Including these variables puts the research in the field of strategic management. It also substantially increases the managerial relevance of the research. Excluding these variables means taking a market-level view. This puts the research in the field of complex systems theory and evolutionary economics.

6.3 Research variables

When the above decisions have been taken, the research project can proceed. Depending on the outcomes of the above decision process, the research has to identify, to measure and/or to simulate the research variables, i.e., the market conditions, the market dynamics, the firm conduct and the firm performance. The way of proceeding with each of those variables will be briefly discussed below.

Market conditions

The first research action here is to define the anchor point of the business ecosystem to be studied. This anchor point will usually be a key firm or a key technology related to a firm or to a group of firms. The anchor point determines the boundaries of the business ecosystem (see section 5.1). It also determines the product and technology parameters, i.e., consumer versus industrial products, tangible versus intangible products, durable versus non-durable

products, the technology-intensity of the products, the nature of the technology the products are based on, the degree of complementarity or substitution of products and the degree of compatibility of products (see section 2.3). Expert interviews may quickly deliver valuable insights in all of these parameters.

The next research action is to identify the agents in the business ecosystem and the roles they perform in the system, i.e., which ‘species’ they are. When the agents are known, their decision rules have to be detected. This means gaining insight in:

- agents’ own preferences, i.e., their subjective inherent valuation of the technology
- agents’ valuation of the technology as depending on the technology’s relative market share
- agents’ valuation of the technology as depending on the absolute number of adopters of this technology
- agents’ relative importance attached to influences from their local network versus those from the market as a whole (global network)
- agents’ characteristics with regard to conformity versus individuality

For real-world business ecosystems this may be a large and difficult task to perform. Besides, agent-based simulation tools that could be used to test such heterogeneous decision rules are not yet readily available.

Finally, the network structure of the relations between the agents has to be identified and – when possible – measured. This is the essential step in network characterization. Networks can be measured along different dimensions such as network size, connectivity, concentration and entropy. For the rationale behind measuring these dimensions, we refer to Van Asseldonk, Den Hartigh & Berger, 2003 (i.e., the paper presented at the ECCON 2003 annual meeting). For these measurements, the same is true as stated in the previous paragraph, namely that it may be a large and difficult task to apply those measures to a real-world business ecosystem. Here also, software that can accommodate all the desired network measures is not readily available. It may therefore be necessary to use those network measures that are accommodated by the standard software packages.

Market dynamics

The first research action with regard to market dynamics is to determine what exactly will be measured. There are multiple possibilities:

- measuring the speed of innovation diffusion (the diffusion pattern over time)
- measuring the diffusion pattern over the network
- measuring the extent of diffusion (market share(s))
- measuring the stability/instability of market shares

Second, depending on the specific research project, it has to be determined:

- whether or not there is a lock-in situation
- whether or not there is excess inertia or excess momentum
- what is the degree of path-dependence of the diffusion process

Finally, the selected item has to be measured as accurately as possible. Techniques for doing so are available in the literature. The challenges appear to be, again, in the operational execution of the research.

Firm conduct

The research action with respect to firm conduct has two dimensions. The first is the dimension of firm strategy. This refers to the strategy the firm chooses with respect to the business ecosystem. In section 5.3 three generic strategies have been mentioned, namely a shaper strategy, an adapter strategy and reserving the right to play. These have been related to the business ecosystem strategies mentioned by Iansiti & Levien (2004), namely dominator, keystone and niche leveraging strategies. Each of these concepts has been worked out in literature. Which of these concepts is applicable depends largely on the specific characteristics of the firm and its context.

The second dimension is governance of the relation between the network structure and the diffusion of the technological innovation. We adopt the term 'governance' rather than 'management', because here the firm tries to influence a networked system of which it is not the 'boss'. For a theory on the governance of networked systems, we refer to Van Asseldonk, Berger & Den Hartigh, 2002a (i.e., the paper presented at the ECCON 2002 annual meeting) and 2002b.

Firm performance

With respect to firm performance the research actions are to 1) determine the relevant performance criteria for the specific firm and the specific context and 2) accurately measure those performance criteria. The most straightforward way of accomplishing this is to take generally accepted performance criteria, e.g.:

- (relative) market share
- turnover, growth of turnover
- ratio of turnover versus market potential
- profit (percentage profit margin, firm net profit, return on investment, return on equity)
- percentage of sales from recently introduced products

For the individual firm that acts as the principal or the client of a research project, most of these performance criteria can be expected to be available.

Propositions regarding the relations between the variables

Finally, when data on all the relevant variables is available, propositions can be made regarding the relations between those variables. Which propositions are to be made for individual research projects within the framework is outside the scope of this paper, however.

7. Conclusion

In this paper we have presented a research framework for investigating the relation between network structure, firm strategy and the pattern of innovation diffusion. The necessary underlying theories and concepts for doing research within this framework appear to be largely available. The main challenges appear to be in the operational execution of the research. Individual research projects to be conducted within this framework have to be properly and explicitly focused. A list of decisions to be made to achieve such focus has been presented in the paper. An uncertainty at the moment of writing is the availability of specialized tools and methods (e.g., agent-based simulation programs, software for the statistical analysis of network measures) for conducting the research and for analyzing the results.

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