Dynamics of Social Factors in Technological Substitutions

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Abstract

Diffusion models of technological innovations are often based on an epidemic structure which has a good fit to historical data but whose communication assumptions lack explanatory power. They assume a simplified decision process, uniform decision criteria across adopter categories, and a fully interconnected social structure. The objective of this paper is to show that the dynamics of social factors during technological substitutions have significant effects on substitution patterns. The success of a paradigmatic shift is not only a function of technological characteristics but also depends on change agents and many social dynamics. Such complexity requires analysis at several levels of granularity. We start with cognitive processes at the individual level using concepts from cognitive psychology and decision making under uncertainty and then move to interpersonal communications at the aggregate social level. We show that population heterogeneity generates different decision criteria and a social topology which greatly affect perceptions and the formation of expectations. The structure of interpersonal networks also explains how the relevance and credibility of information impacts the critical mass dynamics of technology adoption. A more complete model accounting for social interactions provides a useful framework for understanding complex substitution patterns and reducing the risk of misreading the market. Brice Dattée's research is funded by the National Institute of Technology Management in Ireland.

Introduction

Most diffusion models of technological innovations are based on an epidemic structure that considers external and internal communications. They are often hybrids of the Bass model with refinements to the analytical formulation. These models have a very good fit to historical data but their structure lacks explanatory power because it oversimplifies the decision making process and does not fully account for market heterogeneity. Their behaviour usually replicates the smooth logistic shape of successful diffusions. The same assessment applies to models of successive generations of technologies. These are usually limited to two competing technologies in the tradition of the Fisher and Pry model. The substitutive interactions are not fully considered. We feel that the concept of diffusion denotes a passive view of technology adoption. In many cases it is a substitution process that takes place. Substitution involves obsolescence, vested interests, and underlying struggles. This recognition causes us to substantially broaden the scope of our analysis when looking at the adoption of a new technology.

There is a need for a more complete framework that is grounded in the principle of social heterogeneity. The objective of this paper is to show that the dynamics of social factors during technological substitutions have significant effects on the substitution patterns. We start by briefly presenting several underlying theories of technological substitution. In Section 2 we discuss how technological trajectories belong to technological paradigms which frame the mental models of the industry's agents. We also differentiate among three diffusion mechanisms: adoption, imitation, and speciation. This is important as many diffusion researchers do not clearly state which mechanisms they are studying and often ignore their co-evolution.

Complexity often implies a hierarchical structure that requires different concepts and descriptions at different levels. We conduct our analysis at different levels of analysis going from a micro-level approach to social aggregation. We believe that in order to understand collective social behaviour we need to start at the level of individual attitudes and then zoom out to take into account the interactions among individuals in the groups embedded in the social structure. At the individual level we use the concept of a system of personal constructs developed in cognitive psychology. This provides a theoretical basis for an individual's perception of external realities. We then describe the cognitive processes involved in decision making under uncertainty and ground our discussion in the subjective utility model. Even at this point it is possible to investigate the interactions between the perception of technological evolution and the formation of expectations. We show that interesting dynamics can already develop involving surprise, disappointment, enthusiasm, delaying, opportunity costs, confidence, overshooting, and eventually the search for alternatives.

From the discussion of heterogeneity at the individual level we then move up to the social aggregation level. Linking personal constructs to attitudes towards risk provides a useful structure for the adopter categories identified by research on the diffusion of innovation. The underlying assumption of diffusion research, that a radical technology is absorbed into a population in stages, corresponding to the psychological and social profiles of various segments within that population. There are three types of heterogeneity in a market: personal constructs, different market segments which value different functionalities, and also the adoption decision criteria for different adopter categories. Obviously those are interrelated. We discuss how a shifting focus from technological considerations to the perceived risk of adoption and the need for credible references makes it difficult for a change agent to “cross the chasm,” i.e., to move from a few lead users to the mainstream market.

Traditional approaches to diffusion have a rather neutral view of the social structure. They assume that the system of interpersonal communication is fully connected. However heterogeneity produces a personal network with dispersed dyadic relations. The frequency of communication is not a constant across the population, and because of differing criteria the word of mouth generated is not necessarily relevant. Accounting for social topology also singles out influential individuals who can act as powerful reference users. In Section 4 we discuss the implication of the relevance and credibility of information using a System Dynamics model of technological substitution that enables us to account for such discounting effects. The simulation results indicate that these kinds of social dynamics can replicate non trivial substitution patterns with adoption occurring in waves.

The implications of a more complete framework accounting for perceptions, the formation of expectations, markets heterogeneity, and social topology are then discussed both in term of more accurate adoption trajectories for diffusion research and for the successful management of technological substitutions.

1. Technological Substitution

The study of technological innovations has produced an immense body of literature from a wide range of research perspectives. Technology forecasting and the diffusion of innovations are among the perspectives that look into the processes of technological development and the adoption of new technology. Substitution occurs when a current practice is rendered obsolete by the adoption of a novel one. We briefly present the underlying theories of these processes and their interactions in the case of successive generations of technology.

1.1. Technological Paradigms

Innovations can be defined as the implementation of inventions. An innovation is the integration of novelties exploiting a form of change (Durand, 1999). Innovations can thus concern a new product, a new process, a new technology or even a new organizational form. The common hypothesis of technological innovation is that most of the time they are cumulative. While technique is built up by the accumulation of experiences so that it is mostly embedded in tacit and non codified knowledge, technology combines technical and scientific knowledge into controlled processes whose underlying mechanisms are mostly understood. Technology is constantly improving because of the cumulative effects of incremental innovations. This is an evolutionary perspective of technology.

Technological change results from the complex interactions and feedbacks occurring within an extended environment. By analogy to Kuhn's scientific paradigms (Kuhn, 1962), the concept of technological paradigm has been introduced by Dosi (Dosi, 1982). Kuhn defined a paradigm as the "entire constellation of beliefs, values, techniques, and so on shared by the members of a given community." Dosi characterises a technological paradigm as "a pattern of solutions of selected technological problems". It refers to all the selective filters (Persson, 1982) that are used when dealing with certain problems, the type of knowledge that is used, and the type of solutions that are created to satisfy a generic need. When a technological paradigm sets in, it structures the mental models of the industry's agents and it becomes the backbone of the maturing process. In effect, this leads to innovations developing along the same strand of solutions, of which a longitudinal view can provide the impression of a trajectory.

1.2. Technological Trajectories

Among different alternatives one of the technologies will benefit most from the search efforts. The perceptions of initial progress encourage expectations, thus creating a self-reinforcing loop which leads to further developments. Small historical events can even favour non-superior technologies which become dominant in situations of increasing returns (Arthur, 1999). This specific behaviour is path-dependent because the trajectory depends on the early stage development. The common vision of a trajectory is an S-shaped curve that describes the evolution of a technology along a specific, and often generic, performance index. Because of diminishing returns from R&D efforts the trajectory eventually converges with its upper limit as the progress potential is depleted.

In parallel, a new technology might be emerging and starting a new trajectory. Often the new trajectory will belong to the same technological paradigm because it relies on the same type of knowledge and solution. This is usually represented as a succession of S-curves (Sahal, 1981). But in some cases the breakthroughs are so radical that they constitute a real paradigmatic shift. During such shifts the habits of an industry are completely shattered and it is the beginning of a new era, a new paradigm. New paradigms represent discontinuities in trajectories of progress as defined within the earlier ones. They tend to redefine the very meaning of progress and point towards new types of problems. Thus their plot alongside previous S-curves is often problematic and requires zooming out to the level of a generic function, e.g., communication, transportation.

Such paradigmatic changes are completely unpredictable even with full knowledge of the search intensity of firms in the industry. In recent years, concepts from the complexity sciences have been introduced in an attempt to better understand the nature of technological invention and innovation. Unpredictable outcomes from technological inventions may result from the properties of the complex system. "An apparently minor invention can result in a major shift in a technology paradigm simply because the technology system was already poised in a critical state" (Barbazon and Matthews, 2003).

Christensen has shown that such radical changes often come from outside the industry and are mostly introduced by new entrants (Christensen, 2003). Often these emergent technologies first develop in niche markets and are offered to customers who value special features or functionality. These emergent technologies, whose performances are not stabilized, are compared in mainstream markets to existing ones according to biased criteria which belong to the previous paradigm and which completely miss the benefits brought by the new technology's way of doing things (Day and Schoemaker, 2000). Van de Ven, therefore, suggests that companies should implement "institutional strategies" aimed at educating the markets and influencing the evaluation criteria (Van de Ven and Schoba, 2000).

Abernathy and Utterback have identified three phases following a radical innovation. These phases illustrate the maturing process along the new paradigm (Abernathy and Utterback, 1978). During the initial, "fluid phase" companies are trying to reduce the technological uncertainty with a variety of product innovations. It operates in some ways from the same variation–selection–retention process proposed in the evolutionary perspective of technological development (Nelson and Winter, 1982). Variations are embodied in features, functionalities and products attributes. The selective pressure arises from market acceptance which in turn depends on many dynamics of social changes. Retention results from perception by the companies of what the market accepts.

This process leads to the appearance of the dominant design. The dominant design marks a complete shift in the market's focus. Product and technology uncertainty have been greatly reduced. During the "transition phase" many firms exit the market. The emphasis then shifts towards process innovations to reduce costs and improve quality. Finally in the "specific phase" the market is dominated by a small number of companies with dedicated infrastructure.

These innovation dynamics are interwoven with three aspects of diffusion. Although each aspect has been extensively researched it is important to differentiate among the diffusion mechanisms.

1.3. Adoption, Imitation, and Speciation

The innovation dynamics depend on co-evolutionary processes. The successive phases described above result from both the adoption of the new technology by the market and the imitation by competitors who integrate the new technology in their offerings. These mechanisms represent respectively the demand and supply side of diffusion. Another aspect of diffusion relates to the propagation of a new technology from one application domain to another which often involves a "speciation" process (Levinthal, 1998).

1.3.1. Market Adoption

Adoption of technological innovations often denotes the purchase of products embedding the new technology but could also refer to the use of new services. The change in the number of adopters in a population is described as a diffusion process. This is the most common perspective on diffusion and will be discussed in more details in Section 3. It is useful to emphasize substitution as diffusion arising at the expense of a current practice, service, product, or technology. However Pistorius and Utterback have shown that modes of interaction other than pure competition, e.g., symbiosis, can arise (Pistorius and Utterback, 1997). In any case market adoption is a key aspect of the innovation dynamics.

1.3.2. Competitors Imitation

The formation of new firms is highly visible, and their product introductions are an important source of early information about technological innovations in progress (Utterback, 1994). This signal can be used by incumbents firms to decide if an innovation represents a threat to their strategic position and whether or not they are going to integrate the technology in their portfolio. Normative isomorphism then leads to the imitative diffusion of a technology among competitors.

In some cases incumbent firms will find themselves with obsolete technologies and will be displaced from the market. This occurs when the new technology diffuses successfully in the targeted markets, and competitive imitation during the fluid phase leads to the transitional phase consolidation. The Abernathy-Utterback model indicates that the number of firms in the industry will peak when a dominant design emerges in the market. Klepper describes it as a "shake-out" phase.

At the industry level the response of incumbents to technological threats would be the behaviour observed by Cooper and Schendel (Cooper and Schendel, 1976). This refers to the issue of what capabilities could be rendered obsolete and which ones have to be developed. Other factors such as architectural knowledge (Henderson and Clark, 1990) and complementary assets (Tripsas, 1997) also have a great influence on the survival dynamics. The willingness to imitate and integrate a technology in the portfolio will be stronger if the innovation has been introduced by firms with a high institutional weight. Some companies act as "reference change agents" and their moves send a strong signal to the rest of the industry. We also can imagine cases were adoption of a technology by a certain company would deter others from following.

1.3.3. Speciation

In light of Christensen's finding that radical changes often come from outside an industry and are mostly introduced by new entrants, it is unclear how to define the beginning of a fluid phase in the Abernathy-Utterback model. Does the fluid phase starts when the new technology first emerges or only when it has developed enough and gained access to a large market? This question relates to the third aspect of diffusion where a technological innovation is introduced into different application domains. Levinthal uses the biological analogy of speciation to describe the fact that adaptive changes accompany this meta diffusion, which in extreme cases can reach ubiquity, e.g. semiconductors. Once new application shores are reached both of the previous mechanisms start interacting to produce innovation dynamics.

1.4. Others Factors

It is important to acknowledge the influence of factors such as public policy, media hype culture, and organizational learning. The cumulative experience of industry incumbents with the previous technology and their installed base often acts as a powerful break that slows their adoption of a new technology. For incumbents the accumulation of tacit knowledge acquired through their experience along a technology trajectory represents core competencies. These competencies yield a competitive advantage in the current paradigm (Prahalad and Hamel, 1990). They concern specific product/service configurations and the advantage provided is increased by the complexity of the established technology or architecture (McEvily and Chakravarthy, 2002). Imitation is slowed by tacitness and complexity.

The accumulation of many competencies results from organizational learning and development of routines. These routines can reduce flexibility because organizations have a tendency to search in the same architectural space (Henderson and Clark, 1996) and to follow established patterns of behaviour, i.e., what Sull calls "active inertia" (Sull, 1999a). Technological breakthroughs can render routines inefficient and competencies obsolete. To adapt to such changes an organization must be able to constantly learn and periodically unlearn, i.e., "learn to unlearn" (Durand, 2000). Adaptation often requires cannibalizing a company's own product portfolio, an unlearning process that is very difficult for most organizations (Sull, 1999b).

The concept of a technological paradigm structuring the mental models of an industry's agents and influencing their choice of filters is powerful and widely accepted. The concept of trajectories was presented to describe the resulting technological evolution. Substitution was emphasised to be a competitive case of diffusion. It was important to distinguish between three mechanisms – adoption, imitation, and speciation – that relate to demand, supply and application domain, and that which so far been investigated individually in diffusion research. Technological substitutions are complex dynamics that result from the interactions of many components at different system levels. This view requires us to substantially broaden the scope of our analysis of diffusion processes. The success of a breakthrough is not only a function of technological characteristics but also depends on the behaviour of change agents, the market's response, and the effects of many social dynamics.

2. Individual Cognitive Processes

In order to investigate those social dynamics, our analysis takes place at different levels of granularity. Before investigating the aggregated social behaviour represented by diffusion, we present concepts of cognitive psychology to present how perceptions are shaped. This should be especially relevant in the case of innovations as they intrinsically refer to novelty. The subjective expected utility model is then presented as a theoretical basis of decision making under uncertainty. Finally, we try to investigate how these processes can combine to create technological expectations that could influence adoption.

2.1. The Psychology of Personal Constructs

The psychology of personal constructs was developed by George Kelly and is based on the implementation of the philosophical assumption that the events we face today can be constructed and interpreted in many ways (Kelly, 1992). It is a theory based on constructive alternativism that says that all our present perceptions are open to question and reconsideration. Banister considers that this can be contrasted to the prevalent epistemological assumptions of accumulative fragmentalism which suggests that truth is collected piece by piece (Banister and Fransella, 1993). However we do not consider that there might be such a distinct contrast because it seems possible that pieces of information are filtered through our perceptions then collected and accumulated for decision making. This is related to the processes of "selective exposure", i.e. the tendency of individuals to listen to messages that are consistent with their prior attitudes and experiences, and also to "cognitive dissonance".

The psychology of personal constructs is based on a fundamental postulate that we believe will find a resonating appeal in the System Dynamics community. The fundamental postulate of personal constructs states that "a person's processes are psychologically channelised by the way in which they *anticipate events*". According to Banister, this fundamental postulate is George Kelly's answer to the classical controversy about the influence of nature versus nurture in our lives (Bannister and Fransella, 1993). The personal constructs psychology answer would be that we react to our peristasis as we see it. This ontological assumption means that as individuals, with our own purposes and issues, we can only work out our own nature in the way we understand an external reality. Our perception will depend not only on the physical factors of our living environment but also on our education, family and social conditions.

Individual anticipate events by "construing" their replications. According to the stimulus-response psychology, a person responds to a stimulus. The personal constructs view considers that one responds to what the person considers the stimulus to be and that this in turn is a function of the kind of constructions the person has imposed upon the universe. We feel that this notion is very close to Pierre Bourdieu's *habitus*. A person's habitus can be defined as "the cumulative, durable totality of cultural and personal experiences that each human being carries around as a result of life experience" (Bourdieu, 1984). An immediate correlate is the heterogeneity of individuality because persons differ from each other in their construction of events. In System Thinking, Jay Forrester has described such processes in his own words as "mental models". These three theories, have a common interpretive epistemological stand whereby individuals use these constructs, habitus, or mental models to understand an external reality.

Individuals have developed a system of personal constructs that are convenient for the anticipation of a finite range of events. *Convenience* describes the degree to which these constructions are usable to understand a certain variety of situations. This system of constructions is stable and is strongly held, although some aspects of reality might force an individual to risk the dangers of change. If a person does not experience the dangers that were anticipated based on their personal constructs, they might be able to weaken links between constructions and, with such feedbacks, modify aspects of the system. This could be understood as the cognitive aspects of uncertainty reduction when faced with change.

Our perceptions of change can lead us to make predictions that sometimes turn out totally irrelevant in terms of the unfolding events. Therefore, we change our constructs systems in relation to the accuracy of our anticipations. This is very close to the underlying principles of adaptive control systems. Kelly introduced another characteristic, *permeable-impermeable*, that refers to the degree to which a construct can assimilate new elements in its range of convenience. Therefore, new implications can be constructed based on initial construct.

This construct will probably play an important role in the innovation-decision process, because innovation deals with novelty. Kelly observed that people are similar because they construe, i.e. they interpret and try to anticipate the implications of events. For most of us, however, our constructs are quite impermeable. Also, a tight construct is one with unvarying predictions, whereas a loose construct is one which leads to varying predictions. Most technical discriminations are tight constructs (e.g. mechanical *vs*. electronic), whereas many evaluative constructs appear loose (stylish *vs*. out of date).

With regard to the diffusion of innovations, it seems that a personal constructs system theory can be used to disaggregate the mechanisms involved in the more generic "willingness to take risk". Personal states such as anxiety or threat can result from the awareness that the events with which one is confronted lie mostly outside the range of convenience of one's constructs system. This is the effect of the "unknown". Threat is the awareness that a comprehensive change is imminent in one's core structure. A person feels threatened when their major beliefs about the nature of their personal, natural and social environment are invalidated.

Fear could be considered as the awareness of an imminent incidental change in one's core structure. Therefore, if an individual as higher level of convenience and permeability, a threat could be absorbed and their fear constructs should be lower. Also, the tightness of a constructs could be linked to the discounting effect of time in decision making theory. Recent events are often given a more important weight in evaluating future outcomes. A short time span could thus imply tighter constructs. Let us here remember how a technological paradigm imposes filters and decision structure upon agents. Thus, this could now help us better understand some aspects of agent's resistance to change as it appears that a paradigmatic shift could sometimes be almost considered as a threat to an individual's ontological security.

Thus, the system of personal constructs can shape individual perceptions of external events and influence anticipations. This will in turn affect the decision process.

2.2 Decision Making under Uncertainty

Decision theory is deeply rooted in mathematics and economy where the approaches have historically been closely related to the debate on rationality in philosophy. The most common definition of rationality says that an action is rational if it is in line with the values and beliefs of the individual concerned (Jungermann, 1983). More precisely, a decision will be rational if it is "logical" or "consistent". Therefore, we can infer a strong relation between the system of personal constructs and the rationality of decisions. Roland Scholz points out that, from Herbert Simon's treatment of heuristics in a theory of bounded or limited rationality, cognitive decision science has been extended which now tries to grasp the cognitive psychological foundations of decision behaviour (Scholtz, 1983). The previous definition specifies rational behaviour normatively.

Decision theory has focused on studying, explaining and interpreting discrepancies between predictions derived from normative models and actual judgment and decisions. Some of the main models used are Baye's theorem and the multi-attribute utility models, and the subjective expected utility model of decision. Decision theory has also borrowed central concepts such as strategy from the political and social sciences mode of thought.

Von Neumann and Morgenstern have established some of the roots of individual decision making modelling with concept of utility, probability of occurrence and the economic principles of rationality such as maximizing profit and expectations. In decision theory, a risk situation is one in which the probability of future negative consequences, potential losts, are known or estimated. In a more general manner, uncertainty could be defined as arising from a situation with unknown outcomes.

2.2.1. Subjective Expected Utility

Decision making under uncertainty often shows systematic and serious errors because of inherent characteristics of the human cognitive system. This is partly due to judgmental biases. Judgments of probabilities of occurrence are often severely biased because people in many situation rely on heuristics which, although generally efficient, can sometimes lead to systematic errors. This is closely related to the convenience and accuracy of constructs. Also, people often judge the probability of an event depending on whether it is representative for them. However their perception is not influenced to the same degree by factors that really influence probability of occurrence such as base rates, sample size and the reliability of information. Likewise, availability of information is used as another heuristics.

The easiness with which information can be retrieved (e.g. from memory) can influence the perception of actual frequency of the event. Thus, a recent occurrence might bend perceptions towards higher probability and lead to systematic judgmental error. This kind of temporal filter can be linked to cognitive decay rates. The most common error in prediction is overconfidence. People are more likely to have clear preferences regarding issues that are familiar, simple and experienced directly.

Preferences over attributes could be considered dynamics and there could be a certain time delay to the occurrence of consequences. A person's perception of such delays can greatly influence the value attributed to the alternative. The economics literature distinguishes between search goods and experience goods (Grant, 2002). Search goods are those whose characteristics are readily observable. On the other hand, experience goods are those whose characteristics can only be ascertained after consumption, and even then there might be a time delay before they are observable.

In the subjective expected utility model of decision making, probabilities are treated as being subjective, while worth is expressed in utility. Fischhoff defines utility as a generalized measure of desirability, and if an absolute standard of worth is available, the term of value is used instead of utility (Fischhoff, 1983). Clinical judgment research has shown that simple linear models are extraordinarily powerful predictors. Therefore, by identifying and measuring the attributes that decision makers consider, it is possible to forecast their decision. However this does not mean that the simple linear model replicates the cognitive structurization of the decision makers. Such models are called "paramorphic in that they replicate the input-output relationships of phenomena without guarantee of fidelity to the underlying processes" (Scholz, 1983).

This is quite analogous to existing diffusion models that are capable of very good historical fit without a high explanatory power. What this shows, however, is that decision makers focus on specific attributes. These attributes might vary across market segments (Tripsas, 1997; Christensen, 2003) because of obvious lack of coherence among agents' preferences. This heterogeneity is critical in technological substitution and will be discussed. If we also consider limited information processing capabilities, this is strongly supportive of Hauser's proposition in marketing research that consumers can only consider a very limited – four to five – set of attributes or brands (Urban and Hauser, 1993). With such a paramorphic approach, called bootstrapping, even if the cognitive process of decision making is not understood, an admittedly paramorphic model identifying the critical variables of decision may be good enough for designing an effective marketing campaign.

2.2.2. Innovation Decision Process

An individual's decision is not instantaneous but rather is a process that occurs over time. "The innovation-decision process is the process through which an individual, or a decision making unit, passes from gaining initial knowledge of an innovation, to forming an attitude toward the innovation, to making a decision to adopt or reject, to implementation of the new idea, and to the confirmation of this decision" (Rogers, 2003). During this process, the new idea or new technology is evaluated against different criteria or attributes. This process deals mainly with reducing all kinds of uncertainties that are keeping from actually substituting a new way for an existing one. These uncertainties result from the perception of novelty inherent to any innovation. The concept of personal constructs can be used to better understand why these uncertainties are generated and how the perceived risk can be reduced by assimilating new information.

When innovations are evaluated by non-compensatory criteria, two different rules can apply which, as we will see, can be used to explain aspects of market segmentation. On the one hand, the conjunctive rule dictates that an innovation has to score fairly high on each attribute to be considered. There can also be certain attributes over which the decision will depend on a threshold value which correspond to the minimum requirement. On the other hand, the disjunctive rule dictates that an option that is adequate on any one attribute is acceptable. However when options are not evaluated simultaneously Simon identified a "satisficing" behaviour by which decision makers are looking for an alternative that is good enough. In effect, this means that the gathering of information (Weiss, 1994, p. 349) stops when a satisfactory option is identified and evaluated (Simon, 1957).

Intuitively, this serial process takes place when one is facing successive generations of technological innovations. Once the first adoption has taken place, successive new alternatives are evaluated relative to the currently used solution. If an innovation provides enough relative utility, upgrading can occur, and the serial evaluation process is truncated. In such a case, the current status corresponds to the reference point against which alternatives are evaluated.

2.2.3. Perceptions and the Formation of Expectations

Technologies evolve along trajectories. Some innovations offer new functionalities or new attributes over which preferences are developed. Bootstrapping models, used for predicting individual decisions, do not estimate the individual's perceptions of these evolutions. They just identify the important characteristics for decision making. Our analysis at the cognitive level, however, suggests that the perceptions of these trajectories generate expectations and are used to "construe", to anticipate, and to forecast. The marginal utility theory indicates that these expectations are then evaluated against a reference point for decision making.

Technological forecasting almost systematically assume idealized logistic trajectories. We now look into an individual's expectations that can develop around such S-shape curves. If we consider that the construing process is based on a linear extrapolation of recent perceived improvements, systematic errors can dynamically develop. Indeed, if we assume that there exist a time delay to perceive the true performance value of a technology, then there is a time lag between the true performance trajectory and its perception in the market. The consideration of a time delay is motivated by the fact that information is not instantaneously available to an individual.

Even if data were available, we can assume that the system of personal constructs, biased criteria or even selective exposure could prevent the individual to perceive their meaning. Based on our previous discussion, we investigate the impact of short term information retrieval combined with linear forecasting. Thus, if at each point in time the perceived rate of improvement is simply projected in the future, it is possible to capture the dynamics behaviour of expectations. This structure is based on a "perspective effect" assumption, whereby closer events are also more salient. Figure 1 illustrate the resulting systematic error for a perception delay of five months and a forecasting scope of one year.

Comparing the expected improvement with the progress actually perceived highlights interesting phases. In the early period the rate of improvement is perceived to be very slow, and this leads to an underestimation of the technology potential. This would translate into early adopters being cautious. Then, during the middle period, perceived improvements exceed expectations and thus creates positive surprises. This could be understood as a sign that the technology is the right one if there were competing alternatives, or simply that this is a promising strong technology. These perceptions reduce some forms of uncertainties and thus stimulate adoption. However the enthusiasm will be counterbalanced by another dynamic process.

Technological expectations also illuminates the benefits of delaying adoption (Rosenberg, 1976; Weiss, 1994; Doraszelski, 2004). During this phase of technological development the perception of a recent positive improvement rate extrapolated over the forecasting period can generate large marginal increase over the current situation. These expectations of future performance value can lead some individual to delay their adoption in the hope that they will get a much higher value if they see fit to wait. The option value of waiting will itself be counterbalanced by different opportunity costs. These costs could include the erosion of a strategic position in the meantime or an increasing knowledge discrepancy that will eventually have to be caught up, with the risk of being left behind.

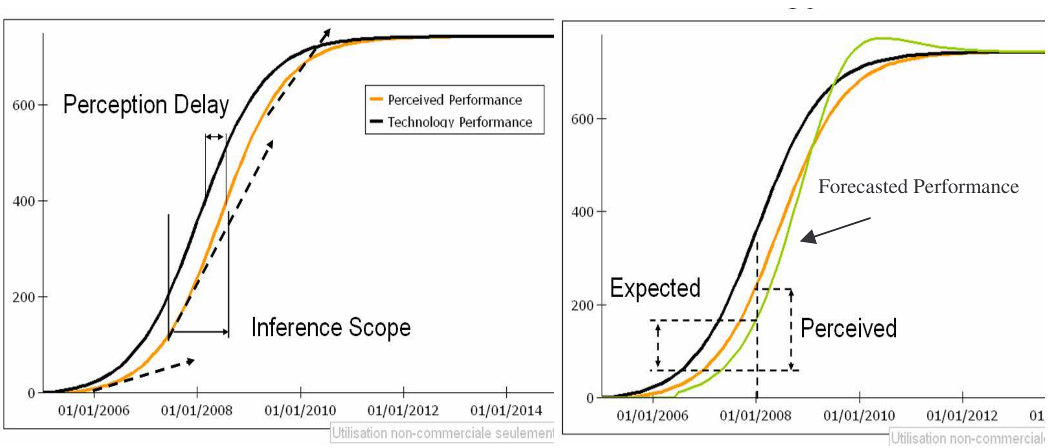


Figure 1: Systematic Forecasting Error of Linear Extrapolation

This simple setting also produces a third period during which the expected trajectory overestimates the potential for further development. This occurs just after a perfect forecast were expectations meet actual perceptions; this is expected to build up confidence in the projection process. However these expectations subsequently get carried away and become largely unrealistic. Individuals who had postponed adoption to later enjoy greater performance, find themselves disappointed and might look for alternatives. This overshooting is gradually absorbed and, as the development potential gets depleted, and through updating expectations finally becomes aligned with true performance.

As discussed above decision making is theoretically based on the marginal utility of adoption compared to some reference point. In some cases expectations about future performance can play a more subtle role and themselves become references. One example which illustrates cultural differences in reference points is found in the innovativeness of the Quebecois versus the French. Many French people have a "glory of the past" attitude regarding their expectations about the future and therefore are often unwilling to jeopardize their present condition. Quebecois consider that the future will be better than the present so it is better to try new things.

When customers compare the value of a new technology to an existing one, they are weighing a combination of subjective information (e.g. perceived technological functionality, perceived information on the installed base and complementary goods) and of their expectations for the future (e.g. anticipated technological advantage, anticipated installed base and complementary goods). This process is captured in the linear additive normative model (Roberts, 1988).

Companies could potentially use a communication strategy to influence the reference mode in order to increase the perceived value of their innovations. The possibility is illustrated by Schilling's description of how firms in the US video game industry have greatly inflated consumers' perception of installed base over actual levels (Schilling, 2003). As a console's utility is increased by the availability of complementary goods (more games) and network externalities (other players, gaming tips), they hoped that increasing perceptions of the installed base would become self-fulfilling. This is because ensuring that a console is perceived as the one that will have the larger future installed base, increases its a priori value.

People's perception of the riskiness of choice alternatives can differ significantly because of heterogeneous individual reference points. These reference points can be manipulated in a number of ways including "outcome framing" (Weber and Milliman, 1997). By altering the reference point, or the perception of the reference point, alternative versions of the same decision problem which are equivalent according to the SEU model could lead to different preferences. According to this view a change agent could therefore deliberately, or inadvertently, alter the desirability of outcomes by shifting the reference point against which they are evaluated. A change agent could therefore shape, distort, or even create expressed preferences. We will see how these communication programs can also create feedbacks effects from the erosion of credibility. This also implies that an individual's views may undergo change over time, and this in turn depends on the permeability of personal constructs systems. We believe this is the cognitive process that is underlying and motivating Van de Ven's call for an institutional strategy when promoting radical technological innovations (Van de Ven and Schoba, 2000).

According to the Bayesian or subjectivist position, uncertainty reflects the limits of our understanding. Some events have consequences that fall outside the prediction capability of our constructs. Staw suggested that the expectancy theory "overintellectualizes" the cognitive processes people go through when choosing alternative actions (Staw, 1977). He then called for "new theories that attempt to also treat the intervening thought processes, or contingency-based models that preserve some of the SEU logic but also incorporate a theory of the environment and the way in which it is sequentially decomposed."

A recent attempt in this direction within the System Dynamics community was made by Cavana and Mares (Cavana and Mares, 2004). They combined critical thinking with systems theory to provide a tool to understand organizations, their policies, and how they operate. This corroborates our effort at looking into the cognitive structures. It is important to note also that from a broader perspective changes in perception filters can also occur from dynamic interactions with the political, economic, and social systems (MacKenzie and Wajcman, 1999).

The system of personal constructs, taken from cognitive psychology was found to provide a useful theoretical basis for discussing cognitive processes such as the perceptions of external events and the construing of expectations. The subjective expected utility was presented as the basic view in decision making under uncertainty. At the fine level of individual cognitive processes, we have shown that a simple linear extrapolation of recent perceived improvements can produce systematic errors and a range of dynamic phenomena. This simple structure highlighted the formation of expectations, a phase of enthusiasm, the potential option value of delaying adoption, the counterbalancing effects of opportunity costs, a time of confidence building, overshooting of unrealistic expectations, and the possible search for alternatives.

3. Market heterogeneity

We now move from the individual cognitive level towards a higher degree of social aggregation which ultimately lead us to the social dynamics underlying the generic processes of diffusion of radical technologies. The previous discussion on personal constructs, perceptions, the formation of expectations and the basis of decision making under uncertainty provides the cognitive background of individuals heterogeneity. Aggregating across a population and studying complex social interactions among heterogeneous individuals could be assimilated to social psychology.

The dominant model of Technology Life Cycle is based on the underlying assumption of diffusion research that a radical technology is absorbed into a population in stages corresponding to the psychological and social profiles of various segments within that population (Moore, 2002; Rogers, 2003). We start by presenting the categories of adopters that have been identified by diffusion research. We will especially emphasize one of three types of heterogeneity. The heterogeneity in individuals constructs has been discussed. The heterogeneity in market segment decision criteria and valued functionalities is well discussed in the literature. We will highlight the heterogeneity in the adopters categories in term of attitudes towards risk and how this affects the evaluation of technology and their decision criteria. We then discuss the challenges that such heterogeneity represents for the successful substitution of a new technology.

3.1. Adopters Categories

Evaluating innovative products in terms of measurable performance attributes could be seen as limited because it does not delve deeply into customers' underlying motivations. In consumers market, very few goods are acquired to satisfy basic needs; most purchases reflects social goals and values (Grant, 2002). For example, the value conferred to certain brands is an embodiment of identity and lifestyle. Although different brands may create value in different ways, common to all strong brand is the capacity to confer competitive advantage. This is achieved mainly by creating awareness and reducing uncertainty over quality of the product. Therefore, well established players carry substantial brand equity in terms of reducing buyer's perceived risk. Melissa Schilling gives a illustrative example of how the reputation for developing exciting arcade games conferred a serious advantage to Sega once in the consoles industry.

Neo-classical methodologies often make strong assumptions with respect to the decision making processes of end-users including complete information, full rationality, and lack of risk perception (Dyner and Franco, 2004). Perceived risk seems to be central for most decision processes. In the case of technological innovation, there are two main sources of uncertainty that can lead to risk situation. Technology uncertainty arises from the unpredictability of technological evolution and the complex dynamics through which technical standards and dominant designs are selected. Market uncertainty relates to the size and growth rate for a new technology but forecasting demand is almost always hazardously based on some form of extrapolation of past data.

Diffusion research has shown that the attitude towards risk is a main driver in the adoption of innovation. Moreover, willingness to take risk, or innovativeness, is greatly influenced by socioeconomic characteristics, personality variables and communication behaviour. From the heterogeneity of all these individuals dimensions, adopters categories have emerged from diffusion research. The hypothesis that the distribution of these categories across total population approaches normality has been widely supported by empirical evidences and the continuum of innovativeness can be partitioned into five common categories: innovators, early adopters, early majority, late majority, and laggards (Rogers, 2003). In the face of high-level of uncertainty about an innovation, an agent turns to others agents who already have experience with the innovation they are considering for adoption. This strongly emphasizes the view of diffusion as a social process, with innovation moving through interpersonal networks.

3.1.1. Innovators and Early Adopters

The first people who adopt a technological innovation are clearly the “technology enthusiasts” (Moore, 2002). These visionary adopters appreciate technology for its own sake and can clearly see the competitive advantage of the emerging technology over existing alternatives. In business market, such enthusiasts are the gatekeepers identified by Tom Allen. They are individuals always on top of their field’s literature and with many outside connections and are therefore best reached by more direct communication media. These individuals, whose constructs are very permeable, are willing to experiment with new technologies. As Dosi suggests, value can be defined as a function of the dominant technological paradigm in the ultimate system of use in the value network (Christensen, 2003). Therefore, technology enthusiasts represent the individuals that actually attribute value to the new technology which otherwise would be dismissed by mainstream criteria. There are not very many innovators in any given market segment, but winning them over is essential because they provide an excellent basis for product trial and refinement and they are the ones that can show that a technology in fact works. However these innovators are often not powerful enough to dictate the buying decisions of others adopters.

Then, there are early adopters, for whom adoption is mainly controlled by their expectations of future performance. Like the visionaries, early adopters are concerned with technology and product characteristics, but they are not technologists. They are individuals who find it easy to imagine, understand, and appreciate the potential benefits of a new technology. In business markets, they will look for the technology that will bring them on the technology edge. In consumers markets, they are the individuals with lower threshold for uncertainty.

Both visionaries and early adopters have very “horizontal” patterns of communication; that is they try to communicate across industry boundaries in search of kindred individuals. However Nelson Phillips has shown the concept of industry boundaries to be very weak during radical technological changes. Applied to the case of photographic technologies, he showed that the convergence trend has completely blurred such “product centred” boundaries. He introduced the very useful concept of “activity network” whereby change agents are trying to influence the market’s reference points (Munir and Phillips, 2002). While early adopters tend to search for reference among very few technology enthusiasts, they do not rely on well-established references in making their buying decision.

3.1.2. Mainstream Adopters

Mainstream markets are dominated by the early majority adopters, who could be described as pragmatists. These pragmatists tend to be accepted as leaders by the late majority of conservatives. On the other hand, their opinion is rejected by the sceptics. For them, adoption of a new technology is motivated by the expectation of incremental improvements. They have some ability to relate to technology but they are “driven by a strong sense of practicality” (Moore, 2002). Risk has a negative appeal for them, because uncertainty means a chance to waste money and time. They consider innovations as passing fads until it is proven by other people that it is worth adopting it. During their buying decision process, they care about the vendor’s reputation, product quality and the infrastructures of surrounding products.

Pragmatists tend to be “vertically” oriented meaning they communicate more with others like themselves within their own industry. References and relationships are very important in this category. They want to see well established references before important investment. This means that it is difficult to gain access to a new industry selling to early majority. A change agent must have earned a reputation for quality and services because switching costs could be incredibly disruptive and pragmatists will only make the move if there are uncertainty reducing proofs. A few number of these pragmatists could be looking for reference users among some of the early adopters. Representing around one third of the total market, reaching them is absolutely key for survival and growth.

The late majority, or conservatives, often are not very acquainted with technology and will only adopt at the end of the technology life cycle simply to avoid obsolescence. At this stage technology is mature, prices are low and products could be considered as commodities. In sum, they wait until the technology has been established as the new standard with very low perceived risk. They base their decision making on a large existing reference base. They do not have high expectations with regards to technology, so they will not pay high prices. Nonetheless, through their share of total market volume they can offer high rewards. This is a call for an effective management of the diffusion dynamics so that a company can successfully “reach” them.

The very last adopters are the laggards, the sceptics who are struggling to point out that the new system is not delivering on its promises. For experience goods and products with high level of network externality, the value of the system is discovered rather than known at the time of purchase. A particularly interesting study of broader system analysis in the case of strong network externalities has been conducted by Pavlov and Saeed in their study of peer-to-peer technology diffusion (Pavlov and Saeed, 2004) For such goods, sceptics continually point to the discrepancies between delivered and claimed value. Therefore, they are particularly reluctant to the technology enthusiasts and do not even consider information from pragmatists as relevant. Sceptics’ word of mouth is negative and contributes to the negative feedback force in the classical “hype” cycle.

3.2. Decision Criteria

In early market, the focus of decisions of technology enthusiasts is dominated by technology and product concerns. The focus of decision making of the early and late majorities, made up of pragmatists and conservatives respectively, is rather on market and company. The heterogeneity in attitudes towards risk can actually account for these differences. Given the surrounding technological uncertainty, a radical change must demonstrate a strong advantage over existing practices. This must then be converted into product credibility in order to access mainstream market where diffusion builds up company credibility.

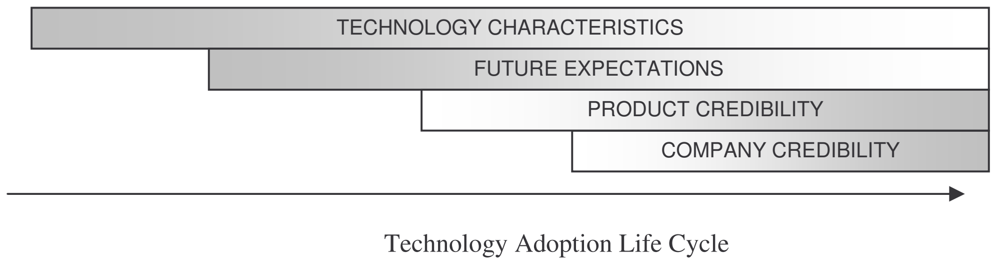


Figure 2: Focus of Innovation-Decision by adopters categories.

During a fervent phase the multi-attribute SEU model might be useful to understand a new technology's relative advantage. However when decision making is later concerned with product credibility, the focus shifts towards expectations. This is particularly true when there exist very strong externalities because switching costs could be high and mainstream adopters are very reluctant to the idea of being stuck on their own with the wrong standard. In the case of interactive innovations presenting network externalities e.g., communication innovations, the utility to a user of an innovation increases as the number of users increases. This process of reciprocal interdependence is commonly known as the Metcalfe's law. Therefore, evaluation considers expectations, e.g. of installed base, and market credibility rather than purely technical information.

A critical mass can be reached in a system when enough individuals have adopted the innovation so that its further rate of diffusion becomes self-sustaining. The concept of critical mass is fundamental in social science because it is based on how individuals relate to their broader system. For a few technologies, once critical mass was attained, profound changes in the social, political, and economic systems resulted from strong interdependencies (MacKenzie and

Wajcman, 1999). Once again, we can find that human behaviour often depends on one's perception of how many other individuals are behaving in a particular way.

The underlying assumption of diffusion research that a radical technology is absorbed into a population in stages corresponding to the psychological and social profiles of various segments within that population. The attitudes towards risks can be found as an underlying characteristics of heterogeneous adopters categories. Innovators have permeable constructs, cosmopolitan patterns of communication and can experiment with technology. Early adopters have lower threshold of uncertainty and understand technology and its potential benefits, but are more concerned with expectations of future performance. The early majority is composed of pragmatists with a strong sense of practicality and who requires established references. The late majority requires very low perceived risk and will eventually adopt to avoid obsolescence. Through the technology life cycle, the evaluation criteria shift from technological concerns to proof of credibility. The obvious challenge is thus to successfully move from a few lead users to the mainstream market by understanding this shift of focus and concentrating the innovation efforts to address these different concerns.

4. Social Topology

Most studies of technological diffusion are analytical model which although have often very good fit to data lack explanatory power. They often assumes importance weights for different sources of information that are constant over the decision process and an homogeneous hazard-rate across the population. Moreover all studies of diffusion, even those that do consider heterogeneity in the uncertainty threshold and requirement for information (Chatterjee and Eliashberg, 1990), in fact assume uniform communication flows. This is very clear in the formulation of the Bass model were the frequency of contact between individual is a constant for the entire population. It is equivalent to considering a plane topology, neutral interactions, or more plainly: ignoring social structure.

In order to understand collective social behaviour, once individual attitudes are known, we must account for the interactions among individuals. A reductionist approach to sociology is uneasy because there are dynamical properties emerging from systemic interactions. These interactions are mediated by the relations structure of the social network. This topology of embedded interactions of a social network identifies individuals with different social roles so that of them are opinion leaders and can act as reference users. The default assumption of diffusion research is that the information exchanged in the population is relevant and credible.

We here discuss the effects of interpersonal network structure (for example among adopters categories), opinion leadership, and the credibility of information on the diffusion patterns of a new technology.

4.1. Interpersonal Communication

In traditional models of diffusion such as the widely used Bass model, diffusion is driven by two types of communication. Word of mouth is the driver of internal communication while exposure to media is modelled as exerting external pressure to adopt. The generic diffusion pattern results from the interaction of these forces. However this assumes a constant importance weights of different information sources over the decision process, and also that communications flows are uniforms across the entire social structure, so that everybody can be connected to everybody else. By disaggregating these communication processes across adopters categories, a simple two step model suggests that the communication messages flow from a source, via mass media channels, to opinion leaders, who in turn pass them on to followers (Rogers, 2003). This two step approach has been widely substantiated in diffusion research, however it is still an oversimplified structure.

By looking into the structure of the system, it becomes evident that there are non-linearities that such traditional models do not account for. Early adopters have a more permeable constructs system and their interpretation of the mass media message stimulus is enough to move them over the mental threshold to adoption. The individual threshold approach explains the micro-level process through which aggregated individual decisions make up the observed diffusion pattern. This concept has been used by Chaterjee and Eliashberg to model diffusion process depending on critical level of information to adoption (Chaterjee and Eliashberg, 1990). However different media are used differently along the information collection process. Mass media are more important at the knowledge stage, and interpersonal channels are relatively more important at the persuasion stage of the innovation-decision process. Less change-oriented later adopters require a stronger and more immediate influence from interpersonal networks and especially from peers (Rogers, 2003).

4.2. Influence in Social Topology

The assumption that the communication flows are uniforms across the entire population is basically equivalent to ignoring the structure of the social network, or to considering a fully interconnected system. The density of interpersonal communications is different not only inside and between adopters categories but also inside and across market segments. Moreover, the relevance and the credibility of information are expected to have an important effect.

4.2.1. Network Structure and Reference Users

In the previous theoretical discussion, we have presented components of social psychology theory. Some aspects, such as social learning, have a direct applicability to diffusion networks. While most psychological approaches to human learning look within the individual cognitive processes in order to understand how learning occurs, the social learning approach looks at information exchange between individuals to explain how human behaviour changes. Both social learning and diffusion theories focus on change in behaviour resulting from interpersonal communications. Information exchanges and network links are key drivers of diffusion. Homophily is the degree of similarity of two individuals who communicate. The exchange of ideas in human communication occurs most frequently between individuals who are alike. Effective communication is more likely between two individuals who share common meanings, beliefs, and whose shared constructs lead to mutual understanding. On the other hand, communication between dissimilar individuals may lead to cognitive dissonance because messages are inconsistent with their respective personal systems.

Technology enthusiasts and early adopters have more social participation than do later ones. Rogers defines cosmopoliteness as the degree to which an individual is oriented outside a social system (Rogers, 2003). This is equivalent to the "horizontal" communication described by Moore (Moore, 2002) and the behaviour of gatekeepers in business markets (Allen, 1977). Innovators will almost pick any signal of technological emergence in their environment due to high interpersonal communications which take place in their local system but also across boundaries. Early adopters will tend to be exposed to these innovators and receive experience information from them. They will also have outside contacts but, unlike technologists, these will mostly be restricted to gatekeepers in other segments. On the other hand mainstream markets are more inwards looking with early majority looking for a referenceable base among their kind. For late majority adopters the risk reduction process is driven by total information about the technology which is not so new anymore. It has displaced the previous technology and has become an established industry standard. Therefore all the information they require is generated more or less from within their industry and deals more with the credibility of products and companies.

Given these interpersonal communication patterns, it is evident that communications flows are non-uniforms. The aggregate view of these network relations provides a topological view of the social structure. The network is almost never fully interconnected, but some individuals have a higher level of dyadic connections which confers to them an ideographic position in the system (Burt, 1977). Therefore, these individual can enjoy higher level of institutional weight, or even prestige. They can act as reference users or opinion leaders for the rest of the market. Opinion leadership is discussed in the diffusion literature. Some networks model of innovation diffusion have been developed which consider individual threshold (Valente, 1996). Once the number of adopters in an individual's personal network has exceeded a certain threshold, the individual's exposure to them will induce adoption. However the individual decision processes are not discussed and we feel that they still represent statistical model of diffusion in a network.

4.2.2. Credibility and Relevance of Information

Generating information is not synonymous with opinion leadership. Opinion leadership is the degree to which an individual is able to influence the attitudes of other individuals in a desired way. Opinion leaders have followers. Interpersonal networks influence individuals by conveying evaluation information in order to decrease uncertainty about a technological innovation. Therefore technology enthusiasts with no internal relationships and who interact primarily with cosmopolite friends located across boundaries are often disdained and perceived as deviants by their fellow members in the local system, the information they generate is just not considered as relevance in the rest of their market segment.

This issue of information relevance is also highlighted by the heterogeneity of decision criteria discussed above. Technological enthusiasm is just not relevant to individuals requiring very low perceived risk of adoption and strongly established references. Thus, when a change agent concentrates communication efforts on innovators, rather than on opinion leader, awareness-knowledge of the innovation may be increased but few are persuaded to adopt. This effect would also be accentuated by the negative word of mouth from sceptics who are considering all this information generation as unfounded enthusiastic “hype”. Moreover, individuals have a tendency for selective exposure by listening to messages that are consistent with their prior attitudes and experiences. As we have seen, mainstream market focuses more on product and company credibility rather than technology performance per se. To access the mainstream market, a change agent should therefore concentrate on creating a pragmatist customer base that is referenceable. These customers will give access to other mainstream prospects. The first challenge is to identify the key influencers and demonstrate a strong sustainability for the new technology.

Therefore, there are two mechanisms limiting the self-sustaining word of mouth for a new technology: density of interpersonal communications and the relevance of information. If a change agent wins over very few customers in each market segment, there might not be enough inter-segment communication to create self-sustaining word of mouth. If a change agents wins over more customers in only one segment, there might be a better chance to attain self-sustaining word of mouth. But given the moderating effect of opinion leadership, if these customers are not key influencers, if they lack prestige or institutional weight, they might just generate information to pragmatists who will discount its relevance.

This structure is very similar to epidemic models of diffusion. In such models the contact frequency, infectivity, and disease duration are constant across the population. The epidemic model can be generalized by incorporating stochastic elements. However the structure of these generalized model is unchanged. In our case, the tipping point behaviour can be modulated as a function of communication behaviour and opinion leadership by disaggregating the structure into the adopters categories identified by diffusion research.

Another variable transposable from epidemic research is the duration of the infectious period. Word of mouth might not be constant for an individual. He might be more willing to generate information when first adopting it, and once the new technology is not so new anymore, his participation in the discussion might decrease while the strength of his beliefs and preferences is increased by familiarity. The word of mouth activity for a technology n+1 also might be dropped if a “double shift” occurs, i.e., if a third technology (n+2) is introduced and is substituting all the hype before the tipping point for n+1 occurs. In such a case, lead users switch to n+2 and thus stop building word-of-mouth momentum before it is self-sustainable.

This tipping point analogy also lead us to evaluate the impact of opinion leadership which could be compared to infectivity. A small number of highly influential individuals who adopt an innovation might represent a much stronger critical mass than an equal or even larger number with little influence. By varying these parameters we should get different scenarios of substitution and understand what makes the difference between an initial spark of enthusiasm and a successful technological substitution? Another set of dynamics happens in the case where a change agent may "correctly identify the opinion leaders in a system but then concentrates attention so much on these few leaders that they become too innovative in the eyes of their followers or become perceived as overly identified with the change agent […]". Thus, a change agent can wear out the credibility of opinion leaders" (Rogers, 2003).

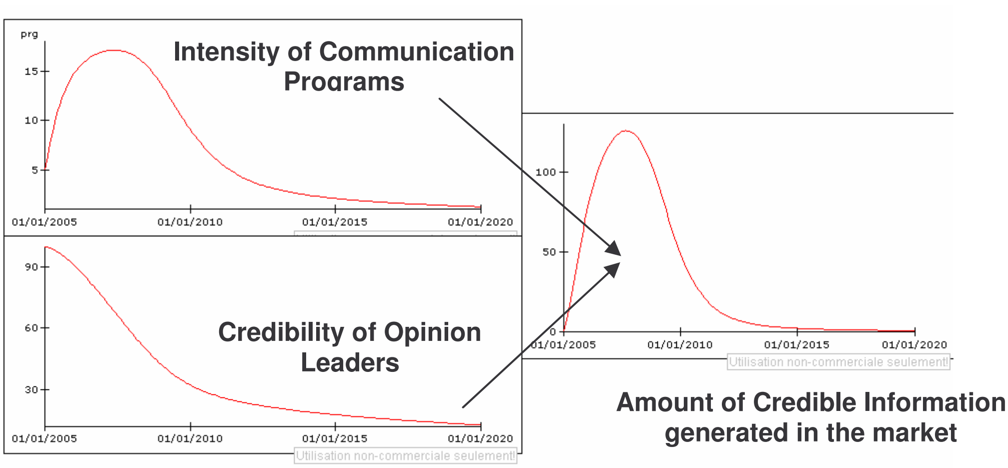


Figure 3: Credibility Erosion of Opinion Leaders

Figure 3 shows the dynamic behaviour of a structure where change agents launch communication programs using the reputation of some references users. As this generates an important stream of credible information in the market, this creates an incentive to launch more programs. However the system is quickly "overdosed" and the credibility of the reference users is rapidly eroded. The change agent perceive the reduced effectiveness of their communication and reduce their number of campaigns. While simplistic, this view illustrates an overshoot and collapse structure, a kind of hype phenomenon, where the opinion leaders' credibility is an non renewable resource.

The diffusion of a radical technology is a social process with experience feedbacks and information flowing through interpersonal networks. Traditional analytical models of diffusion consider uniform communication flows resulting from a fully-interconnected network. This assumes a neutral topology while in fact communications patterns are not the same inside and between adopters categories and across market segments. Moreover, the heterogeneity of decision criteria means that the information generated by some adopters may not be relevant to others. Finally, the structures of social networks point to influential individual whose adoption serves as reference for the rest of the market. This implies that a change agent should identify these reference users in order to successfully reach the main market. We also discussed the possibility that the credibility of these reference users might be eroded by intensive communication programs. This perspective on social network structure is illustrated by Figure 4, which shows potential communication patterns. In each market segment, potential opinion leaders are identified who are capable of sending relevant and credible information to the main market.

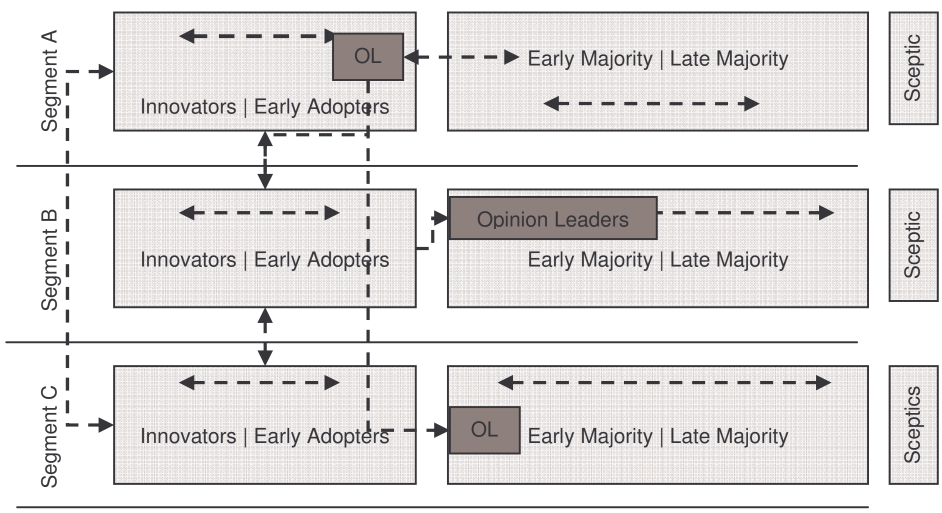


Figure 4: Communication Behaviour of Adopters Categories

4.3. A System Dynamics Model of Substitution

As we have attempted to show in the previous discussion, the dynamics of technological substitution may involve a set of complicated interdependencies among a large number of components involving social factors. We here present a system dynamics model of technological substitution. The complexity of this model makes it difficult to present it here in great details. After presenting its core structure which tries to account for much of the above discussion, the model will be used to investigate the effect of opinion leadership and gain a dynamic view of the resulting substitution patterns. Here, the emphasis is not on forecasting future events but explaining complex problems over time.

Holistic pattern modelling from structural schemes is readily accessible to System Dynamics. Moreover, the use of System Dynamics is particularly interesting for the study of social factors in technological substitution because it considers system causation as endogenous. It is not brought on by external variations or shocks, but by the way feedback structures process external events. In the case of technological substitutions, it is clear that the timing of radical innovations cannot be predicted or even simulated even with full knowledge of the search intensity of companies in the industry. Technological breakthroughs and paradigmatic shifts are clearly considered as unpredictable events outside model boundaries. A System Dynamics model can help us understand events and the behaviour of structures in their broader context. Finally, a system thinking approaches can enable us to identify emerging structural behaviour for a particular combination of feedback loops because socio-economic systems adjust their structures to technological changes through endogenous closed-loop feedbacks.

For our base case, we consider three successive generations of technology. Each trajectory is represented by an S-curve. In order to control for the timing of radical breakthroughs we assume that a new trajectory starts at the inflection point of the previous one. These technological performance trajectories are translated into product attributes levels. Each attribute is given an importance weight in the market segment under consideration. Therefore, a value can be assigned to the product embedding a technology.

We assume a concave utility function because of the diminishing utility of increased performance. Given the price of a technology, which would depend on some learning curve over cumulative volume, a utility price ratio can be determined. We make the economic assumption that this metric is the first dimension of heterogeneity across the population. The individual requirement threshold for utility per price is considered to be normally distributed across each segment, with a mean requirement and standard deviation for each market segment.

We then consider that an aware untapped market stock composed of these aggregated segments will be depleted by a consideration flow. The consideration flow will be technology specific and fill in a potential adopters stocks. The consideration flow is driven by each technological evolution. Individuals that learn about a new technology and consider that at time t it passes over their utility requirement will not adopt instantaneously. Rather they will enter a decision stage during which they gather diverse types of information in order to reduce the surrounding uncertainty and the perceived risk of adoption. Figure 5 presents a simplified view of our model's structure. A more detailed view is presented in Annex 1. Most variables can be indexed by technology generation.

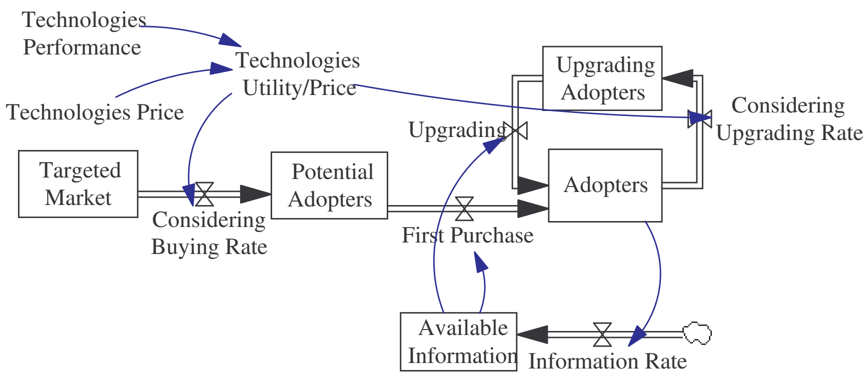


Figure 5: Simplified Structure of the System Dynamics model

We now very briefly present an example of the behavioural advantages of disaggregating the adoption process and integrating the substitutive interactions of all successive generations of technologies. Norton and Bass have applied the Bass model to successive generations of DRAM (Norton and Bass, 1987). Their model yields a significant fit to historical data. However the formulation considers these generations as independent from each other.

The Norton-Bass model creates a smooth life cycle shape with the sales peak for the 16K generation significantly earlier than what actually occurred. If we were to follow the life cycle trend of the 16K generation, we would certainly extend it for a peak later on. Moreover the peak is followed by a sharp decline in sales caused by competition from the next generation of 64K DRAM.

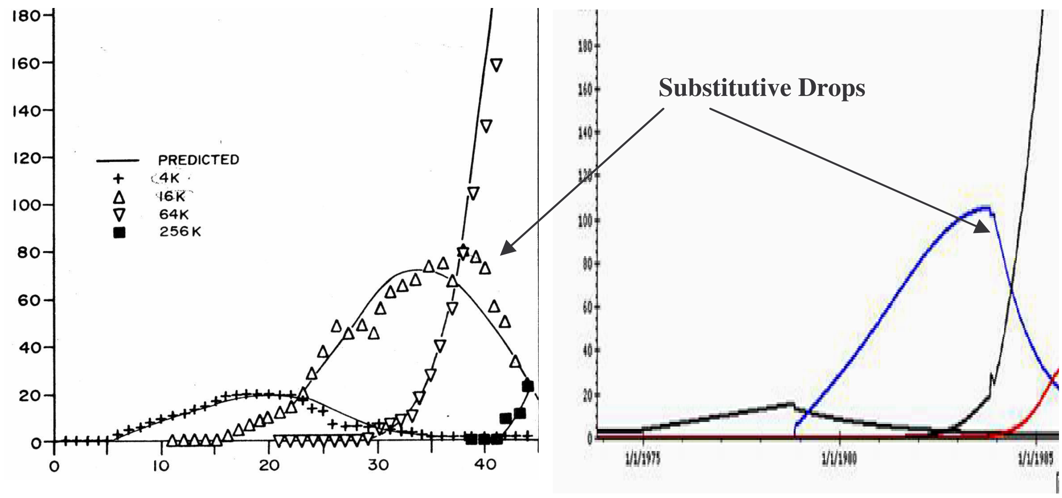


Figure 6: DRAM generations: (Norton and Bass, 1987) vs. Our model.

This substitutive drop is completely ignored by the classical analytical formulation. On the other hand our model replicates such a qualitative behaviour by taking into account the performance and price evolution of the different generations. In fact, this substitutive drop occurred for each DRAM generation, from 4K to 512M, exactly when the next generation took the lead of the Mbit/$ index. This example illustrates that the substitutive interactions between successive generations have a non-negligible impact on the diffusion patterns. Thus, it substantiates our call for disaggregating at a finer level of granularity.

4.4. The Impact of Opinion Leadership

The impact of opinion leadership is here investigated using our System Dynamics model. The contextual scenario considers the arrival of a new technology that is a substitute for a technology that is still diffusing. The simulation gives the sales life cycle of each technology generation but also the fraction of users in the market. This gives us a normalized view of the substitution pattern. In segment A of Figure 4, which was presenting a broad view of the structure of interpersonal networks in different market segments, the early adopters are also considered as reference users in the main market. Once they adopt the "word of mouth" information they generate in the market will be received by mainstream market and the information gathering process described by Figure 5 will work at its full potential. The diffusion patterns in Figure 7 accounts for the heterogeneity of requirements across the population but still represent the classical view of a smooth substitution. This is the reference mode of substitution.

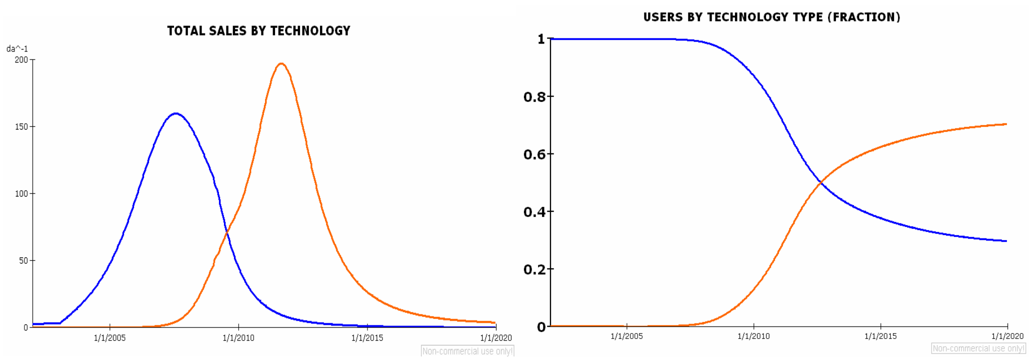


Figure 7: SMOOTH Substitution when Early Adopters ARE also Reference Users

We now investigate a scenario where those innovators and early adopters have no opinion leadership. If these first adopters are considered as "whiz" by the main market, then all the stream of information they will generate could be discounted as technology hype, etc… This is model in our simulation by applying a discounting factor to the accumulating information flow generated by these early adopters. Those first adopters will certainly participate in the noise level surrounding the technology but it will take longer to build a credible momentum from their word of mouth. Figure 8 present the simulation results when we apply a discounting factor to their word of mouth accumulating in the market information. The assumption is that the new technology is inherently attractive to the market segment, so that we control for the utility and investigate only the effect of opinion leadership.

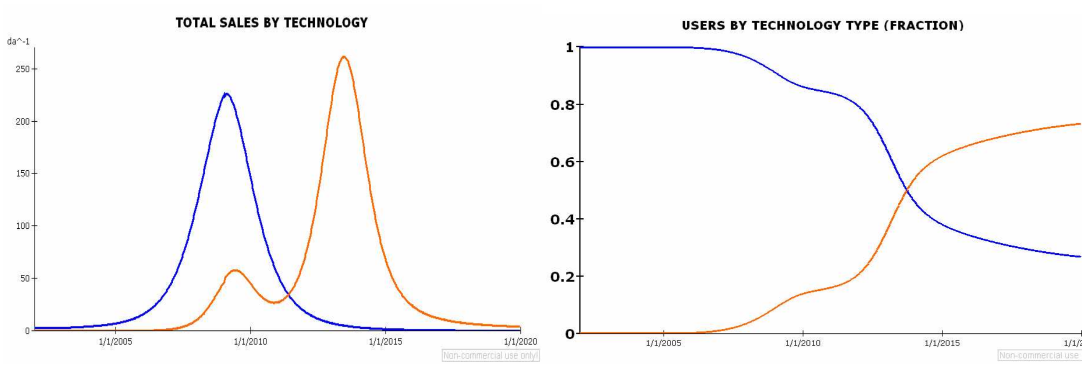


Figure 8: STEP Substitution when Early Adopters ARE NOT Reference Users

The result from this simulation shows that the next technology starts to diffuse among innovators and early adopters. However their word-of-mouth information is discounted before accumulating. The early majority who requires established references will delay adoption until it receives enough relevant and credible information. The assumption is that the early majority discounts the information generated by early adopters who are not opinion leaders but do not totally reject it, so that eventually the information threshold is passed and adoption can occur. Under such conditions, the substitution pattern does not represent the smooth classical view but rather shows that adoption can occurs in waves.

5. Discussion of Implications

The social dynamics presented in this paper have been widely discussed but most often independently in different research streams. Perceptions and the formation of expectations were shown to lead to some interesting adoption dynamics. The underlying assumption of diffusion research that a radical technology is absorbed into a population in stages corresponding to the psychological and social profiles of various segments within that population led us to discuss three types of market heterogeneity, and especially that different evaluation criteria between adopters categories show a shifting focus from technology to credibility. The non-uniformity of interpersonal communications was then emphasized in order to account for the social network's structure. Finally, accounting for social topology singles out individual considered as opinion leaders. We also highlighted the importance of the relevance and credibility of word of mouth information. Moving from cognitive processes at the individual level to interpersonal communications at the social aggregation level provides us with a framework to apprehend the complexity of social dynamics in technological substitution. We will now discuss how to construct a integrated view of these processes and their potential implications for successful technological substitutions.

5.1. Integrated View

Complexity is often characterized by a system whose hierarchical structure requires different concepts and descriptions at different levels and which shows emerging properties resulting from interactions. In our discussion of social dynamics in technological substitution we have used concept taken from cognitive psychology and decision making to present the theoretical bases of individual cognitive processes. This has enabled us to ground our approach in the perspective of heterogeneity. Figure 9 shows a structure which starts from this key concept of heterogeneity of individuals and then represents the interdependences at the aggregated level. This figure captures the essence of our discussion.

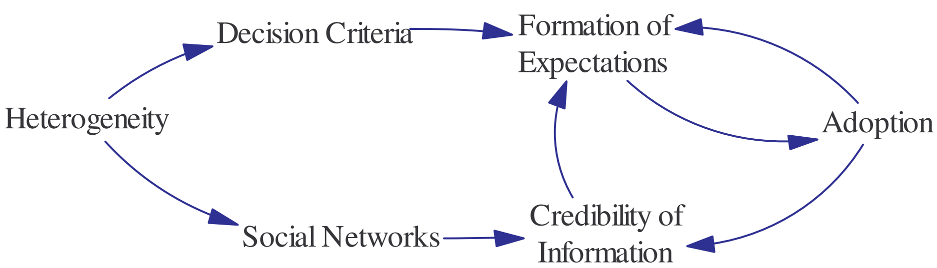


Figure 9: The dynamics of social factors in technological substitution

Individuals have heterogeneous system of personal constructs. This heterogeneity is translated at the population level by different segments who value technology differently, and inside each segment by categories of adopters that evaluate technology differently because of shifting concerns from technological performance to reduced risk and credibility. The decision making process is conducted based on these different decision criteria, and the perception of recent improvement leads to the formation of expectations. This creates different dynamics such as a phase of enthusiasm, the potential option value of delaying adoption, the counterbalancing effects of opportunity costs, a time of confidence building, overshooting of unrealistic expectations, and the possible search for alternatives. These factors obviously participate in the adoption decision.

The number of adopters can effectively feedback to the formation of expectations because as we have discussed the decision making process is based on a marginal utility, and therefore considers a reference point such as the installed base for example. Adoption also plays the classical role in diffusion research of generating word of mouth information that reduced the expected risk of adoption. The heterogeneity of individuals greatly influences the communication relations. Therefore, the structure of interpersonal networks is non-uniform.

Contrary to classical diffusion models, the system of dyadic interpersonal communications is not fully interconnected so that communication frequency is not constant over the social network. Moreover, the heterogeneity of attitudes towards risk and the opinion leadership of a few reference individuals will have a great moderating effect on the word of mouth information generated by adoption. The relevance and credibility of information will affect the dynamics of expected risk of adoption and therefore influence the tipping point of self-sustainable substitution.

5.2. The Dynamics of Substitution

Our system dynamics model shows that accounting for the interactions between successive generations can replicate more accurately the substitutive drops that occur in each generation life cycle. Integrating social dynamics in a more complete model of technological substitution also enables us to generate more complex adoption trajectories. Rather than the smooth classical logistic shape, the heterogeneity of decision criteria and opinion leadership in the social topology can produce sequential substitution patterns. Identifying the opinion leaders in a market segment seems to be critical to reaching self-reinforcing penetration.

It appears that the tipping-point dynamics is dependent on the structure of interpersonal networks. Moreover, the distinction between the early adopters and the reference users relates to the difficulty explained by Moore of crossing the chasm between early adopters and the main market (Moore, 2002). It requires a more effective targeting of the early adopters in order to ensure that the information they will generate will be relevant and credible to others. The effective targeting of opinion leaders and understanding the structure of interpersonal networks can yield a tremendous leverage from communications that will ultimately make the difference between a technological spark and a successful substitution. These social dynamics result from complex interactions within the interpersonal networks. Acknowledging their cognitive basis, and gaining a more complete vision of the aggregated social structure can provide change agents with more realistic expectations for the first phase of the substitution process.

The framework captured by Figure 9 should provide a useful lens to reduce the risk of initially misreading the market. The first misreading could concern a false negative error whereby change agents realize that after an initial enthusiasm for the new technology, sales are just dropping off as in Figure 8 and do not match the expectations of Figure 7 that they had. Under short-term performance pressures and unaware of the effect of social topology change agents might abandon the technology because of what they perceive as a failed launch. As we have seen social dynamics offer another perspective on this initial decline of sales.

Maintaining the innovation effort can help the slower accumulation of word of mouth information reaching the critical mass of self sustainability. In such a case, avoiding a false negative error by not giving up too soon could therefore prove tremendously successful. On the other hand, overconfidence during the initial phase of adoption could lead to overinvestment and put the firm in a difficult situation during the crossing of the chasm. Failure to achieve take off in the main market could also occurs because of the classical mistake of concentrating the innovative efforts on pure technological performance while mainstream adopters requires reduced perceived risk and references that establish credibility.

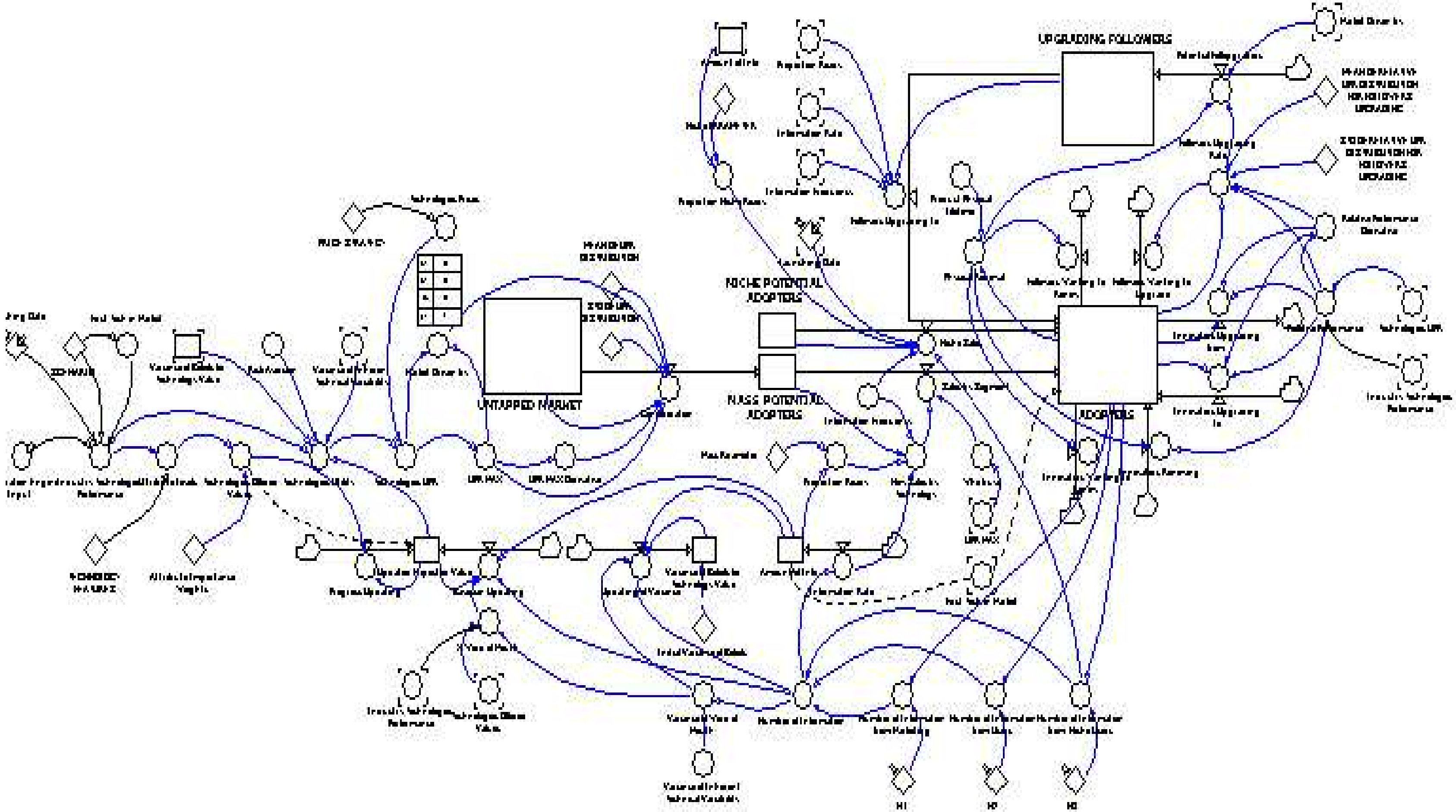
Misreading the market during the initial diffusion among early adopters could also lead to the risk of being surprised by a “double shift”. If change agents have a neutral view of the social topology they could expect a logistic pattern of substitution. Therefore if a third technology is emerging and looks promising they could disregard the threat because they expect the critical mass for their technology (n+1) to be reached before take off of the emerging one (n+2). However if the early adopters are not reference users the main market is not convince straight away. When the third technology emerges, these early adopters could switch straight it, therefore ending the word of mouth for technology n+1 before the tipping point is reach. The diffusion of technology n+2 would just be lethal to change agents of n+1 who find themselves locked and possibly lacking the financial capacity to integrate the latest technology.

6. Conclusion

Our discussion was motivated by the initial thought that traditional models of diffusion often lack explanatory power and oversimplify the structure of the substitution process. Moving from cognitive processes at the individual level to interpersonal communications at the social aggregation level provides us with a framework to apprehend the complexity of social dynamics in technological substitution. We have discussed that perceptions and the formation of induced expectations can produce interesting adoption dynamics. Also, the heterogeneity of individuals is translated at the aggregate level by the valuation of different functionalities but also different evaluation criteria.

Different evaluation criteria between adopters categories show a shifting focus from technology to credibility. Contrary to the assumption in traditional models of a fully connected system of dyadic relations, the non-uniformity of interpersonal communications was then emphasized in order to account for the social network's structure. Accounting for social topology singles out individual considered as opinion leaders. Therefore, we also highlighted the importance of the relevance and credibility of word of mouth information.

A more complete model of technology diffusion that accounts for the dynamics of social factors can replicate more accurately non trivial substitution patterns. It also indicates that more effective targeting of opinion leaders as early adopters could provide effective leverage from communication because of their relevance and credibility as reference users. The broaden scope of our framework also indicates that more realistic expectations could be formed during the initial phase of diffusion. Understanding, the dynamics induced by the structure of interpersonal networks can thus reduce the risk of misreading the market. Such risks include giving up too soon, overconfidence, and the risk of a technological spark that fails to achieve mainstream take-off. The framework also highlights that wrong expectations with regards to the timing of the critical mass can expose change agents to the risk of being surprised by a "double shift".



Annex 1: System Dynamic Model of Technological Substitutions

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