INTEGRATING REAL-OPTIONS REASONING AND THE INNOVATION DIFFUSION CURVE FOR DECISION MAKING UNDER UNCERTAINTY

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Abstract: Dynamic innovation processes are combined for complex technological advances bring about decision-making under uncertainty. This paper reflects the case of strategic decision-making on a technology development project using real options reasoning. Like investment options in financial markets real options introduce explicit risk measures for possible alternatives. Managerial decisions on innovation processes, however, as well entail understanding the inherent characteristics and environments risks of an innovation option. The paper therefore explores conceptual integration of options reasoning with innovation diffusion theory for the modelling of complex innovation processes that better masters the inherent uncertainty of innovation processes.

Keywords: Decision-making, Innovation Diffusion, Real Options, Uncertainty

Introduction

Decision-making is an important and integral aspect of management (Thompson, 1966). And much research has been done in order to support managers to systemise the decision making process. Early examples can be found by the scientific management approaches notably by Taylor (1911) and Fayol (1949). These ideas formed the basis on which scientific techniques were applied to reduce uncertainty in industrial problems (Markland and Sweigart, 1987). After the second Word War, the mathematical underpinnings of these techniques became even more important with the introduction of operations research. Although these structured decision-making processes, induced with mathematical elegance, make tremendous contributions to managerial decision-making, none of theses techniques solve the issue of uncertainty about future but leave it subjective judgement of the decision maker. Raiffa for example states that this judgemental gap might be "…so wide that the analysis does not pass the threshold of relevance; the analysis may fall short of furnishing meaningful insights into the problem." (1968: 296).

Especially in technology-driven firms that pursue innovation strategies, decisions inherently entail uncertainty when long-term R&D investments need be committed with very little knowledge about future and often-short commercialization opportunities in shortening product life cycles. Decision making in these environments therefore often is an unsystematic trial and error process [Eisenhardt, 2000 #1008] that heavily depends on the individual skills of the decision maker to make good judgement.

The aim of this paper is to explore an integrative decision making approach that combines the descriptive power of innovation diffusion models with explicit modelling of risk that of option reasoning which is comparably new to the innovation management research. The contribution to theory is to conceptually position both approaches and illustrating the findings with empirical case findings. The contribution to practitioners is a more systematic approach to decision making on innovation processes. The reminder of the paper is therefore structured as follows. First, I review innovation diffusion literature and its applications to prepare the link with real options reasoning that will be elaborate in the subsequent chapter. An illustrative case is then given an finally conclusions are drawn for future research.

Theoretical Framework

Innovation Diffusion and Complex Innovation Processes

Various models have been developed to explain possible patterns of the innovation process. Foster (1986), for example, developed a model that describes technology progress. Abernathy and Utterback's model (1978) describes the restructuring of industries following an innovation in the three phases 'fluid', 'transitional', and 'specific'. In Marketing, the Boston Consulting Group matrix is broadly used that positions a product as the innovation in its market as the relevant social system. All these models share reference to Rogers model on innovation diffusion (1962). Rogers uses a bell-shaped curve to model innovation as an adoption process of any new phenomenon in a given social system. The accumulated number of adoptions from its first occurrence until the innovation is fully adopted by the given social system over time then is shaped as an S-curve.

Rather than being derived from empirical observation this model is motivated by mathematical elegance and allows the simple application of statistical methods. Taking the middle of the bell-shaped curve as the mean ($\bar{x}$) of a Gauß curve, Rogers uses the standard deviation (σ) as borders to define 5 categories of adopters (Figure 3). Hence the 2.5% first adopters or $\bar{x}$ - 2σ of a given population are innovators, 13.5% are early adopters, 34% each (that is the |$\bar{x}$ -σ| range) are early majority and late majority, and the remaining 16% beyond $\bar{x}$ +σ he calls laggards.

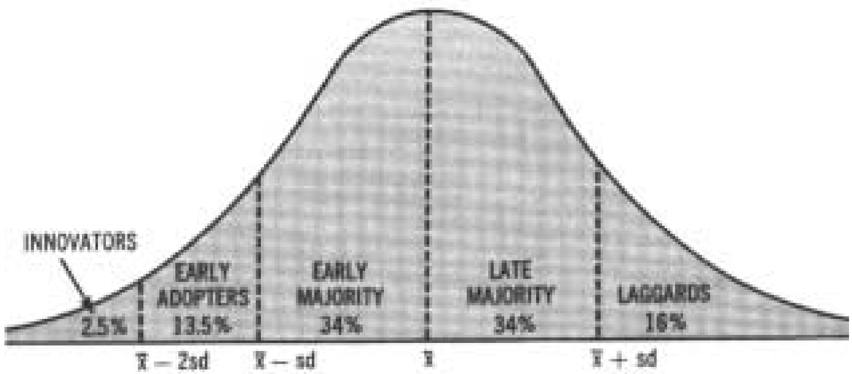

Figure 3: Classification of Adopters (Source: (Rogers, 1962), p.182)

In a further step Rogers elaborates on five ideal types of adopters that correspond to the 5 mathematical categories. The ideal adopter types of adopters have internally consistent sets of characteristics and behaviour. Again, the major achievement is not empirical relevance, even though Rogers undertook extended empirical research, but to establish conceptual building blocks with which more practical theories of complex phenomena can be developed (van de Ven and Poole, 1995) such as the previously mentioned theory examples. Complex innovation processes are divided into distinct phases, in each of which different characteristics (and hence a different type of firm) are required to succeed. In short, the basic assumptions of these dynamic models are (1) that the innovation to be described is known, and (2) that the corresponding adopting social system is known.

The different types of adopters and distinction as borders between different phases of the diffusion process have been a primer interest to research. Most intriguing for academics has been the distinction between the early adopters and the early majority. For Rogers this point was reached, when critical mass occurs “at the point, at which enough individuals have adopted an innovation so that the innovation’s rate of adoption becomes self sustaining” (1962, p.31). It was, however, never possible for him to empirically validate a quantitative level of critical mass for which Rogers estimates between 10% and 25% adoption. He therefore points out that the difference between adopters matter, notably characteristics like: (1) Individuals’ perceptions of the innovation, (2) the availability of the necessary infrastructure and (3) individual thresholds of resistance to adoption (1962, p.33).

Weiber (1995), for example, pushes the distinction between adopter types a step further and observes a diffusion-model that shows two adoption peaks (Figure 5). Based on an empirical study in the telecom industry he concluded that the innovation process could be modelled as the sum of two basic adoption curves. These two curves are based on two distinct social systems of professional users (as early adopters) and private users (early majority). He argues that professional users tend to adopt innovations earlier than private users, and thus two distinct patterns can be created, with similar characteristics as Rogers’ the adoption-curve.

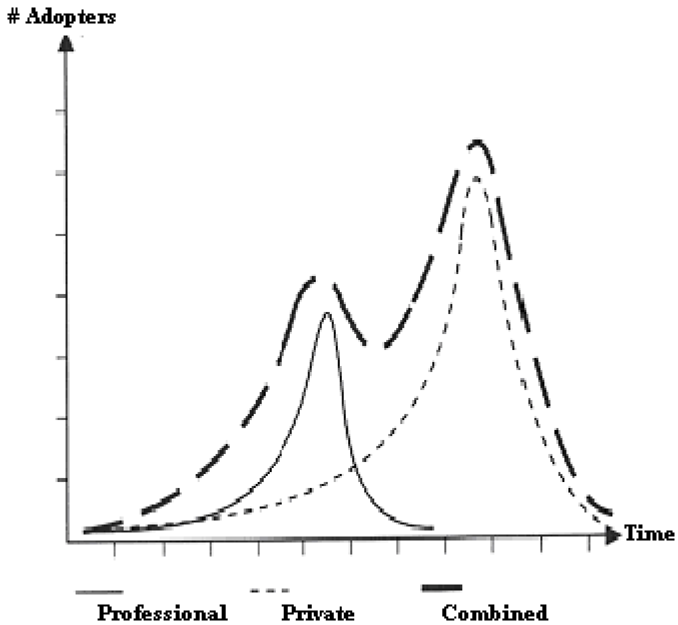

Figure 5: Combined Adoption Curves by Weiber (Weiber, 1995: 60)

Moore (1998, 1999) further emphasizes the independence and promotes the concept of a ‘chasm’. Based on his own consulting experience rather than in literature or empiric research, Moore analysed high-technology adoption processes that do not follow Rogers’ diffusion-curve. Instead he takes the diffusion curve as a reference to conclude that the single phases of adoption do not follow each other continuously but are separated by gaps of uncertainty. The biggest gap, in his eyes, is between the early adopters and the early majority, which he therefore calls the chasm (Figure 6). This gap is attributed to the different attitudes towards innovation of both adopter types. Early adopters intend to use new technologies to make radical changes from old systems to new ones, e.g. to gain competitive advantage knowing that the innovation is not tested but also aware of problems it might cause. In contrast, the early majority type adopter aims at getting incremental changes and productivity advantages from adopting innovations. This group prefers evolutionary solutions, which are properly tested in order to avoid potential "growing pains".

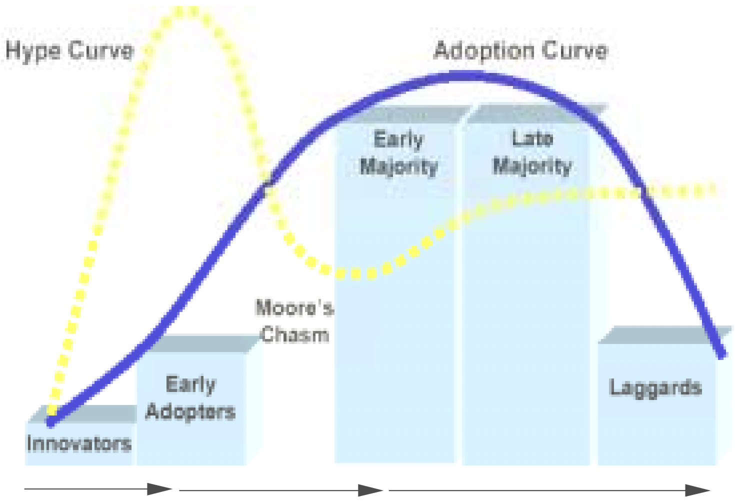

Figure 6: Adoption Curve by Moore (Moore, 1999, p.16)

To conclude, both Rogers and Weiber can be understood as examples of distinguishing innovation diffusion by social systems not simply as phases in the process. Both use the differences between two social systems to model two quasi-independent diffusion curves and combine them to one complex innovation process. Both in Weiber's analysis and Moore's experience moving from innovators to adopters entails risk because of the difference in innovation behaviour, resulting in two independent innovations diffusion curves. Moore's credo to managers therefore is to pay attention the managing the risks of the chasm.

The paper generalizes the argument, as modelling complex innovation processes does not be limited to straightforward accumulation of only two diffusion curves. First, no assumptions have been made that inhibits the establishment of a complex innovation process from a larger (theoretically unrestricted) number of basic diffusion curves. Second, simple accumulation of the curves – as proposed by Moore and Weiber –may not always be appropriate to model combinations of related innovation processes. Understanding and modelling separate risk profiles - like options approaches do - for each adoption curve would allow for more differentiated managerial reasoning.

An Integrative Approach for Complex Innovation Processes

Real Option theory is adopted from financial theories and receives increasing attention in decision sciences with increasingly widespread application areas (Miller and Park, 2000). An option contract represents an investment, which yields the opportunity to purchase an underlying security at a later date (McGrath, 1996). When an investor holds an option, the investor can exercise the option and buy the underlying security but does not need to do so. In essence for decisions under uncertainty the investor limits downward risks to loosing the price paid for the option – which is a fraction of the price of the underlying security, without losing access to the opportunity (McGrath and MacMillan, 2000).

Innovation management can adopt the fundamentals of options reasoning which is referred to as real options. The analogy is that during research and development (R&D) an invention has been created for which a certain price has irreversibly been paid. Inventions, in that sense are an underlying economic good that face uncertainty about the development of their value. Economical attractiveness of buying and exercising a real option therefore depends on how the value of the underlying good develops over time. The value is influenced by environmental and inherent factors, which in the case of innovation adoption can be modelled as Rogers's curves.

Options are sometimes said to be the "knobs" to control the skewness of the alternatives or innovation diffusion curves. At least three conceptual links seem to make an integration of both approaches possible.

Firstly, the different phases in the innovation diffusions curve can be associated with different types of uncertainty. These types can also be interpreted as different types of real options. Hommel and Pritsch (1999), for example, distinguish between learning-options, insurance-options, and growing-options. Learning-options facilitate the enterprise to invest financial resources if the environmental conditions are favourable. The option value created by a learning option relates to the flexibility to wait for new information and only invest if the technical uncertainty is resolved. This is particularly relevant in the very early stages of the innovation process. Secondly, insurance-options gain importance when executives need to react in volatile markets as it is aimed towards risk reduction and allows for innovation risk management. Finally, growing-options refer to the early majority of the innovations diffusion curve, and highlight the fact that an innovation can reach critical mass and turn into self sustained business growth for the owner of the option. It comes at no surprise that all three real options types refer to early phase of the diffusion curve where uncertainty is high.

Secondly, the innovation diffusion curve can contribute to a micro level analysis of each option. The diffusion curve of innovations can serve as an instrument to reduce uncertainty about how the value of the invention will develop in future. Financial options theory is mostly concerned with the mathematical calculations of the option value. An option value, however, is highly dependent on the accuracy of the input data, which remains an obstacle to practical application of real options theory. Following the so far presented argument of the paper, diffusion curves have predictive potential on a micro-level for well-defined innovations in homogeneous social systems and can therefore be used to establish input data for calculation option values. To this extend McGrath work (1997) can prove useful to operationalise the innovation diffusion curve. Her work is oriented towards strategic managerial decision-making, whereby most of the qualitative questions and arguments that she derives from her literature review could be used to specify parameters for a given, specific case of innovation diffusion.

Thirdly, multiple options (or compound options) are relevant for innovation management in the described way. Multiple options, for example the different option types presented above can consecutively describe the different phases of the innovations diffusion curve. Every investment phase can be interpreted as a call option that includes the right to buy a bundle of future investments (Trigeorgis, 1996). But they can as well describe parallel business options for the commercialization of one invention in different social systems. The value of each additional option is then the additionally expected revenues minus the additional commercialization cost. Compound options are conceptually made possible by the parsimonious assumptions of options theory that an option can be established if there is an owner who has the right to buy or sell the underlying good. Unless constrained for example by exclusivity contracts, this assumption is fulfilled.

Research Methodology

This section reflects on a case study (Yin, 1989) to illustrate the so far presented conceptual argument. Data stems from a longitudinal case study of technology development project and encompasses in-depth semi-structured interviews with the projects key stakeholders. This data is enriched with numerous observations at key meetings and workshops as well as internal documents and reports. The study covers a period of over 4 years.

Analysis began with the identification of relevant decision options available to the project. At a point in time the author was an active participant in the projects decision processes, thus integrating an action-oriented experimental element to the research methodology. To complement findings and reflections

An Illustrative Case Study: Virtual Destination Application

The Virtual Destination Application development (VDA) project commenced in 1999 and set out to apply 3D web-based technology for the development of an Internet travel agency. The VDA should allow direct marketing for tourist destinations. Two prominent tourist destinations, Rothenburg ob der Tauber (Germany, www.rothenburg.de) and Davos (Switzerland, www.davos.ch) were implemented as pilot cases in the course of the year 2001 to prove the feasibility of a VDA solution, for which public funding was awarded by the Information Society Technology program of the European Union. The project was designed early 2000 just before the collapse of the Internet hype.

The VDA project anticipated broadband Internet, which - at that time - was expected to become available in the course of the year 2001. Broadband mobile internet services based on the UMTS standard were announced for the year 2002 and would provide further opportunities, which were still to explore. In line with the general feeling of the industry at that time, the expectation was that a start-up firm could quickly take-up the VDA application and in turn should result in mounting valuations for its partners. Private equity firms were consulted throughout the process to further fund commercial growth.

In the course of the year 2001 it became clear that broadband Internet would definitely not be available on time and that 3D-Web technology development would suffer considerable delays. At the same time usability challenges for the application became visible, as direct marketing requires considerable organisational resources and preparation in the destinations. It appeared that these resources are not readily available in most tourist destinations. These developments put project continuation in jeopardy. With the semi-annual project audit due for summer 2001, external auditors had to decide on funding continuation.

Project management clearly perceived the risks and was searching for solutions during spring 2001. They decided to undertake three preparatory workshops to revisit the options for the project. In between the meetings, task forces were assigned to further research and develop the identified options. In the first workshop, the project management team stated its goals, requirement and assumptions along four dimensions: the technical development, market trends, economic environment, and financial performance of the project. This included the identification of risks of the project along these dimensions. The first step was undertaken to exchange views and perceptions about the future of the 3 D-web industries. The outcome of the workshop was an indicative first list of options for the project. In fact, this exercise first introduced alternatives to the project aim of developing an Internet travel agent solution – and with it options reasoning - into the strategic discussion of the project. In the language of real options theory shadow options were made explicit and the project was described as a set of compound options.

In a second step, more detailed information on each option was gathered including market trends, specific risks, and demand. Next to database research a questionnaire was used to raise information from the involved technical experts and the management team. Retrospect analysis of the project documentation revealed that all option description did use the innovations diffusion curve and specified its essential parameters. The third step was to undertake the analysis, model the option and prepare simple financial calculation. Besides positioning the project in the innovations diffusion curve, the task forces that research each option did investigate in the carrying capacity of each option, time delays, and risk factors, which allowed them to come up with meaningful and convincing valuations. In fact, these arguments, much more than the financial values, did matter in the discussion and audit process. These were presented to the auditing board in summer 2001 that adopted the projects' position and confirmed project continuation.

Only a few weeks later, in October 2001, the 3D-Web technology provider had to file for bankruptcy, leaving the project without its technological module. It now was clear that broadband Internet would not be available before several years. The project in fact was ahead of its plan and had already delivered all intermediate results for the end of year audit. Prototypes of the 3D-Web page were achieved, ready for implementation and usability tests at the pilot destinations. Technical developments were finished, which accounted for the bulk of the project investment. Without application tests, however, the technical investment would have immediately been lost. Yet, the project was again at risk.

If the project was to continue, new motivation had to be infused into the project sponsors and replacement had to be found for the technology provider. Abandoning the project was seen as an acceptable solution to many, because the milestones had been achieved and nobody was to blame for that 'force majeur'. Apart from some data gathering for the 3D-Web the pilot destinations had not yet been involved in the project, because application testing had not started. General disillusion about e-commerce had reached destination managers, who on top were absorbed by dealing with the impact of the September 11 events. In fall 2001 former employees of the bankrupt technology provider and a new partner firm could deliver a first commercial implementation of VDA to the city of Wetzlar (www.wetzlar.de). A series of meetings and workshops followed during winter 2001-2002 where project management searched support by private equity managers and business incubators. Again risk and opportunity analysis of the options of VDA were undertaken and resulted in the list of options given in Table 1.

By the end of January 2002, intellectual property right was retained from the liquidator of the technology partner and project continuation was asked and later agreed by the auditing board.

	Options Explanation	Matching
1	The internet travel agent includes the creation of a new internet travel agency or participation with existing ones containing the range of service applications developed in VDA by selling individual holidays directly to the tourist.	Expand option
2	Based on the business plan the solution provider contains a partnership with the city governments, hotels, golf clubs, and museums, etc. In cooperation, an Internet destination portal will be installed for each destination implementing the virtual 3D model and management system and be paid by customers not the tourists.	Expand option
3	The tool Provider (only technical), contains only the 3D Web model of the destination developed by other enterprises and the online booking system sold to the destination tourist office via IT provider. It is only the technical part of the VDA project and includes no service.	Contract option
4	Destination Consultants, means the creation of a consulting enterprise, which only will consult the destination tourism office in destination marketing and e-commerce.	Switch option
5	The VDA Management Service, the VDA package will be commercialized via franchise partners.	Contract option
6	The Knowledge Provider, contains a consulting service provided as content business via Internet directly to the destination or via consulting firms as channel partners.	Switch option
7	The CD ROM travel guide, by using exiting widespread technology to provide the benefits of the VDA package directly via bookstores and direct selling to the customer.	Contract option
8	Mobile Commerce and virtual tourism, a full research and development project that applies for additional funding until sufficient bandwidth (UMTS) will be available.	Defer option

Table 1: Option explanation of the VDA case study

The auditors adopted the presented option valuation and accepted switching to the new technology provider. They further re-allocated resources from the development of 3D technology to the development of organizational consulting and marketing services to complement the technology. In the language of real options theory they herewith exercised switching options. It was further decided to extend the duration but not the funding of the project to allow for longer learning phases with less intensive resource commitment, which in real options terms can be interpreted as exercising a defer-option. The most striking effect of applying real options reasoning in the VDA case is that the project was able to free itself from the constraints of the contracted project plan. Even best performance to develop the Internet travel agent would have led to early termination.

Besides the handy explanation during the decision processes by real options theory therefore changes in project evaluation seem interesting. It has in fact has been re-positioned in the innovations adoptions curve. During the hype-phase of the years 2000, the project was designed for rapid business growth of the early majority adoption phase. By the year 2002 the project was again regarded as being in the innovation and learning phase of early adopters and the decision makers showed considerable flexibility in adapting its structure accordingly.

Discussion

Two observations concerning the project stakeholders' response to uncertainty are most striking in the case of this technology development project. First, real options reasoning did open the decision process for alternatives that were not seen at the outset. There is evidence that those options had an impact on the decision to continue the project. In the course of the decision process project management on ones side changed the targeted business option from developing a travel agent to providing destination-marketing solutions to accommodate the delay in broadband Internet. On the other side this move as well allowed project management to address the options attitude of the stakeholders and maintain commitment to the project. When rapid business growth was no longer achievable, the project did still sell as a learning option on destination marketing, an urgent need for tourism industry at that point.

The second observation concerns the role of understanding and describing project inherent risks. The case shows two major changes of direction within less than a years time span, which itself would count for sufficient reason to abandon the project. Participants in the decision process repeatedly stated that their support for the project during times of turbulent change was furthered by profound arguments. This included the description of essential changes like late introduction of broadband technology and the actions taken by project management to cope with the effects.

Conclusion

In the paper we present a conceptual integration of real options and innovation process modelling, which contributes to decision making under the specific uncertainty of the innovation process. Future research would be needed to develop a more systematic decision making approach for innovation management and broaden the empirical basis from the here presented episodic evidence.

Decision making for innovation is regarded as one concrete example of a 'dynamic capability' (e.g. Eisenhard 2000) that has strategic impact on the performance of the firm in innovation business. In the here presented case improved decision making contributed to project continuation, which is perceived as a success by the project team. Further research is needed to explore the specific conceptual links between strategic resources like R&D and product innovation as underlying assets in options reasoning. It is acknowledged in literature that dynamic capabilities like strategic decision making, need be tightly integrated with the production base, which is confirmed by the here presented case and made explicit by combining real options reasoning with innovation diffusion concepts.

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