Review

Weeds (2002): Strategic Delay in a Real Options Model of R&D Competition

Theoretical Issues in ITM | Andreas Lindinger (Matr.Nr. 0508782)
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Review: Weeds: Strategic Delay in a Real Options Model of R&D Competition

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Contents

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1 Introduction

Weeds (2002) investigates in her article "Strategic Delay in a Real Options Model of R&D Competition" irreversible investment in competing R&D projects with uncertain returns under a winner-takes-all patent system. She looks at two risk-neutral firms that have the opportunity to invest in competing research projects. The firms face both technological and economic uncertainty and successful innovation by one firm eliminates all possible profit for the other one.

The article should be placed in the theoretical field of option games which combines real options valuation (Copeland and Antikarov, 2003; Dixit and Pindyck, 1994; Trigeorgis, 1996) with strategic, dynamic competition via game theory (Fudenberg and Tirole, 1991; Huisman and Kort, 2003; Lim, 1998; Rasmusen, 2006). In contrast to traditional real options models where competition is usually only modeled as playing against nature (Boyer et al., 2004), Weeds incorporates game theoretic principles in her article. Recent contributions in this relatively new field of research include Huisman and Kort (2002, 2004); Huisman et al. (2004); Lukach et al. (2006); Miltersen and Schwartz (2004); Murto and Keppo (2002); Pawlina and Kort (2006) and Smit and Trigeorgis (2006).

In fact, an integrated option games perspective is particularly relevant for oligopolistic and innovative industries that rely heavily on R&D like consumer electronics, pharmaceuticals, biotechnology, or telecommunications (Smit and Trigeorgis, 2006). In addition, real options valuation is theoretically better suited for the valuation of R&D projects than traditional NPV valuation due to the implicit assumption of managerial inflexibility, the ignoration of strategic value from follow-up investments, the simplification of risk through the discount rate and several other limitations in an NPV valuation (Newton et al., 2004).

Generally, an option games model is based on an investment model with stochastic processes for costs, profits and/or economic value (Kong and Kwok, 2005). Weeds models economic uncertainty by a standard Geometric Brownian Motion process whereas technological uncertainty is modeled as a Poisson process where discovery takes place randomly according to a Poisson distribution with a specific hazard rate. Weeds looks at the case of symmetric firms that have the same investment costs and hazard rates.

The resulting stopping time game is described by the stochastic process for the value of the patent and the payoff functions of the two firms. Each firm faces a control problem in which its only choice is when to commence research. Its strategy is simply a stopping rule specifying a trigger point for the patent's value at which it invests. The game ends when one firm makes a discovery.

Weeds first investigates a single firm's investment problem before turning to cooperative and non-cooperative games. She shows that a cooperative, sequential investment pattern is the optimal solution as this gives some possibility of return even when patent value is low, reducing the opportunity cost of delay while holding back from committing all investment at once. In case of joint cooperative investment by the two firms investment takes place later than in the single firm case. In the non-cooperative game the resulting equilibrium depends on the parameter values that are used, namely the relative magnitudes of the leader's value and the value when both firms delay until optimal joint investment. In this case, a preemptive leader-follower equilibrium or a joint investment equilibrium can occur.

In short, the article concludes that competition between a small number of firms does not necessarily undermine the option value of delay. In fact, non-cooperative behavior is inefficient (invest too soon) while joint investment is more favourable. This confirms the observation that cooperative R&D activities are increasing in reality (Cabral, 2000). Weeds also shows that – contrary to standard option games theory – competing firms may even delay investment due to the fear of starting a patent race. This indicates that delay of investment is also due to strategic interactions and not only due to the option effect of uncertainty resolution.

This review aims at discussing the methodological approach and the model of the article. Moreover, based on other scientific articles, possible alternatives in model construction and further extensions will be investigated.

2 Model discussion

2.1 Model assumptions

In the following it will be examined whether the fundamental set-up and assumptions of Weeds' model are suitable for valuing R&D projects and how possible alterations could change the model. The main assumptions are that the obtainment of the patent by one firm eliminates all possible profit for the other firm, that immediate investment would be irrational and that investment is irreversible.

In fact, a patent gives its holder exclusive rights over a product, a particular kind of intellectual property, etc. for a specific period of time and therefore it is clear that only one firm can obtain the patent. For instance, patents are treated similarly in the real options related articles by Schwartz (2004) and Weeds (2000). Secondly, it is also reasonable that the initial value of the patent is so small that no firm will invest at time zero because normally firms try to gain some information about a project before investing. Finally, the assumption that investment is irreversible, meaning that if a firm has invested once then it stays invested, makes sense in this model as Weeds only considers a one-shot investment and not a stochastic cost process where questions of abandoning the investment would be of greater interest.

2.2 Model set-up

First of all, it can be stated that the stochastic processes and the solution procedures for finding the firms' values along with the critical values of investment are implemented according to standard real options theory (Dixit and Pindyck, 1994). Here, the application of dynamic programming is seen to be superior to contingent claims analysis as asset replication is often not suitable for R&D projects (Huchzermeier and Loch, 2001). The implementation of game theoretic aspects follows the general three-step option games approach with (1) setting up an investment model with stochastic processes, (2) deriving the leader/follower value functions and the optimal investment thresholds and (3) studying the investment decisions under the resulting strategic equilibria, as it can be also found for instance in Huisman et al. (2004). By looking at the different forms of cooperative and non-cooperative investment, Weeds performs a straight, clear and comprehensive analysis of investment behavior in a duopoly context. Moreover, she also provides clear interpretations of her results and extensive proofs of her stated propositions.

Weeds discusses two possible alterations in the model, namely the use of alternative stochastic processes or the consideration of more sophisticated R&D techniques. While alternative stochastic processes would yield similar results, a hazard rate that increases with R&D spending due to learning or that decreases over time in case of fruitless research if the probability of discovery is not known a priori could change the preemption incentives.

Concerning the stochastic processes, it is standard real options theory to model the stochastic development of the underlying variable (patent value) via a Geometric Brownian Motion and random, future events via a Poisson process. Other processes, like mean-reverting processes (Biekpe et al., 2001; Hlouskova et al., 2005) or an Arithmetic Brownian Motion (Nasakkala and Fleten, 2005) are far less common.

Moreover, in addition to the value of the patent also a stochastic process for the investment costs could be implemented instead of assuming the same one-shot investment costs for both firms (Tsekrekos, 2001). Unfortunately, this might lead to a higher model complexity and therefore could make other solution procedures like Monte Carlo simulation necessary. Furthermore, the value of the patent or the research output could be different for the two firms, similar to Hsu and Schwartz (2003) who model different degrees of quality of the R&D output as a betadistributed variable in their real options model.

Another process that could be implemented in the model could be a Poisson jump process for the possibility of catastrophic events (Jou and Lee, 2001; Miltersen and Schwartz, 2004; Schwartz, 2004). In fact, a catastrophic event like terrible side-effects of a drug would lead to a situation where the economic value of the patent would jump to zero and abandonment of the project becomes necessary. Nevertheless, it is unclear whether this would have an effect on the main results as it might affect both firms to the same extent and as the option to abandon is not incorporated in the model.

In fact, the option to invest along with the value of waiting to invest is one of the most widely used applications of real options (Newton et al., 2004). Further alterations in the model could address other types of real options. For instance, firms normally posess the option to abandon an R&D project if the expected project value turns negative and/or if certain milestones are not fulfilled. This isn't included in Weeds' article where it is assumed that a firm always stays invested after its first investment. On the contrary, the option to stop and restart investment would generally be of low value in R&D due to competition and/or limited patent protection (Schwartz, 2004).

Finally, the assumption that there are no cash inflows before the patent is acquired does not only make it easier to solve the model but also can be seen as a realistic assumption for research-intensive industries. For instance, an IT company only generates revenue when its software is completely programmed and available on the market or a pharmaceutical company can only sell its drug after it has been approved by regulatory authorities. Moreover, the use of a constant risk-free interest rate is a standard assumption of dynamic programming, although it can be seen as a weakness as it is done by Christiansen and Wallace (1998).

2.3 Model implementation

Concerning the implications for firm behavior as well as the possible problems in case of an implementation of the model, it can be stated that companies could use the model for identifying key (uncertainty) parameters to be able to recognize and influence its key value drivers and its sources of flexibility (Loch and Bode-Greuel, 2001). This is usually done via sensitivity analysis and/or Monte Carlo simulation (Loch and Bode-Greuel, 2001; Schwartz, 2004).

Nevertheless, as it is the case with most real options models, there might arise implementation problems due to the complexity of the model (Newton et al., 2004) and difficulties in parameter estimation. In fact, finding reasonable values for the volatility parameter, the movement of the underlying variable (patent value) or the hazard rate could pose much difficulties to a firm's management and possible solutions like estimating these parameters from market data (Amram and Kulatilaka, 1999; Kellogg and Charnes, 2000; Lee and Paxson, 2001) or through expert interviews (Bode-Greuel and Greuel, 2005) can only be seen as (uncertain) approximations.

Finally, it should be noted that other option games models were applied to various areas like M&A (Lambrecht, 2004), infrastructure investments (Smit, 2003) or corporate investment strategies (Smit and Ankum, 1993) and different industries like real estate development (Grenadier, 1996) or aircraft companies (Shackleton et al., 2004). Nevertheless it is unclear whether this model could also be applied to other areas besides R&D as especially the nature of the winner-takes-all patent system is typical for R&D investments.

3 Extensions

3.1 Weeds' extensions

Weeds proposes several extensions to her model in the article, most notably asymmetric firms, more firms or more complicated effects of rival investment. For example, asymmetry could be implemented via different investment costs (Huisman et al., 2004; Pawlina and Kort, 2006) and would lead to uniquely predetermined leader and follower roles for the firms. This difference in investment costs could be the result of a choice between different types of employed R&D technologies as in Gerlach et al. (2005). Moreover, more complicated aspects of rival investment could include for example congestion effects where the efficiency of R&D could be reduced due to labor shortage. In contrast, an extension of the model to capture more than two firms is not possible as in this case the principle of rent equalization, which is necessary for solving the non-cooperative game and which is also used by other authors like Huisman et al. (2004), would not hold.

3.2 Further R&D characteristics

In many industries, especially in pharmaceuticals and biotechnology where a special form of drug development is legally required, R&D investments are made in several sequential phases (Copeland and Antikarov, 2003; Lee and Paxson, 2001; Newton et al., 2004). The division of the research process in distinct phases could accompany the introduction of financing constraints (Bulan, 2005; Woerner and Grupp, 2003) where different amounts of money would be necessary/available for different R&D phases.

Moreover, sequential investment could be combined with decision trees (Banerjee, 2003; Poh et al., 2001; Yao and Jaafari, 2003) which could better picture the decisions in the particular R&D phases. For instance, Brandão and Dyer (2005) extend their real options model by implementing a dynamic programming method along with an innovative algorithm for the modeling of the stochastic process for the project's value as well as decision trees for the modeling of the real options under application of risk neutral probabilities and a Monte Carlo simulation. The main advantage of decision trees would lie in the consideration of risk and uncertainty as well as their simple and intuitive application (Poh et al., 2001). The main problem can be a rapidly expanding number of trees/branches as well as the methodological need for different discount rates in the different R&D stages (Cassimon et al., 2004). Generally, according to Smith and Nau (1995), real options theory and decision trees should yield consistent results when properly applied.

Although Weeds deals with cooperation in her article, she does not discuss different forms of cooperation in her analysis. Especially in very research-intensive industries like biotechnology cooperation via joint ventures (Chi, 2000; Kogut, 1991), strategic alliances (Jaegle, 1999) or the out-licensing of drug candidates (Baecker and Hommel, 2004; McGrath and Nerkar, 2004) is an important way of expanding/complementing research capabilities and generating early revenue via milestone payments. Moreover, also legal aspects (depending on the form of cooperation) are not considered in this analysis.

Finally, project selection and project portfolio issues can also be implemented in real options models, as can be seen in Childs et al. (1998) or Childs and Triantis (1999). Nevertheless, it might become too complex to analyze more than one project in a strategic duopoly context and therefore this extension might not be suitable for Weeds' model.

3.3 Time-dependent issues

As another extension, the economic value of the patent could be decreasing over time like the project value in Kort (1998). This could be a realistic extension as other firms (outside the model) might be successful in other, more promising and advanced research areas if the two firms delay investment too long and therefore the patent that they are striving for might lose in value.

Moreover, a change in technology could be modeled via technology adoption with progress as in Huisman et al. (2004). Here, technological progress means that a new and better technology becomes available at a stochastic future date where the arrival of the new technology follows a Poisson process and enables the firm to charge a higher price for its project (analogous, in Weeds' article, technological progress could represent the possibility to spot another research area and therefore to get another patent with a higher value). This could change preemption incentives, depending on the arrival rate of the new technology.

In addition, uncertainty could be reduced over time (Huisman et al., 2004; Lint and Pennings, 2001), for instance due to new (imperfect) information like signals about R&D progress (e.g. Poisson jumps) that become available during the project. Here, the outcome might depend on a trade-off between the first-mover advantage and the value of the information spillover. Moreover, various other aspects of information could be incorporated into option games models like imperfect/incomplete information or information spillovers and information time lags (Grenadier, 1999; Kort, 1998; Lambrecht and Perraudin, 2003; Martzoukos and Zacharias, 2001; Weyant and Yao, 2005; Zhu and Weyant, 2003).

4 Conclusion

The critical examination of the article "Strategic Delay in a Real Options Model of R&D Competition" shows that Weeds' model can be described as methodologically correct and traceable. The main assumptions are reasonable for R&D projects and the model is implemented according to the standard option games approach. Moreover, the results are interpreted in a clear and meaningful fashion and provide interesting insights for managers and public policy makers.

Concerning the possible extensions to the model, Weeds proposes asymmetric firms, more firms and more complicated effects of rival investments. Apart from this, this review suggests sequential R&D phases, decision trees, financing constraints, project selection methods, technology adoption with progress and several other aspects as further model alterations and extensions. Nevertheless, as Weeds focuses mainly on the cooperation vs. competition aspect of the duopoly situation, these extensions might probably not change her fundamental results but only make the model a bit more realistic at the expense of disproportionately increasing model complexity.

Finally, it can be stated that the article can bee seen as a valuable and comprehensive contribution to the field of option games analysis, an area which should provide a large potential for research in the future due to the vast individual literature on both topics – real options and game theory (Dias and Teixeira, 2003).

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