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QUAECO-1103; No. of Pages 11

ARTICLE IN PRESS

The Quarterly Review of Economics and Finance xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

The Quarterly Review of Economics and Finance

journal homepage: www.elsevier.com/locate/qref

R&D investment and patent renewal decisions

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ARTICLE INFO

Article history:
Received 14 October 2016
Received in revised form
19 September 2017
Accepted 10 December 2017
Available online xxx

JEL classification:
C61
D81
G13
O31
O34

Keywords:
Patent renewal
R&D investment
Real options
Renewal fees
Uncertainty

ABSTRACT

This study employs the real options model to investigate how uncertainty in patent rewards and the chance of success of the R&D investment affect a firm's likelihood to renew a patent. The firm chooses the date on which to undertake an R&D investment project that offers it a chance of developing an innovation, which is immediately patented and commercialized. Thereafter, the firm must pay periodic renewal fees to keep the patent alive. This paper finds that greater uncertainty does not lead to a universal effect on the renewal probability. When there is no uncertainty, the firm will always renew the patent before a certain date but will never renew it after that date. When there is uncertainty, the renewal probability will decline smoothly over time toward the expiration date. This paper also finds that a firm that is more likely to be successful in its R&D investment is more likely to renew its patent right.

1. Introduction

While firms in a declining industry need to decide the date on which to exit the market (see, e.g., Ghemawat and Nalebuff, 1985; Lambrecht, 2001), notably few studies in the literature investigate this issue with regard to real options. These studies typically assume that firms have the option to exit the market once (Dixit, 1989). However, a firm that receives a patent has the option to decide whether to withdraw its patent more than once before the expiration date. This paper will explore how uncertainty in a firm's patent reward and its likelihood of receiving a patent from the R&D investment affect its renewal probability. The results will then be compared with the renewal probability for patents granted in the U.S. and Europe.

The firm in consideration incurs sunk costs in developing an innovation, and its success is subject to an exogenous arrival following a Poisson jump process. Once the firm successfully develops an innovation, it will be granted a patent and will simultaneously commercialize the patent immediately, thus receiving a reward at each instant that evolves as a geometric Brownian motion. The firm's R&D investment decision is characterized by a date on which the value from exercising the option immediately, net of the investment cost, is exactly equal to the option value from waiting. After being granted a patent, the firm needs to pay a periodic renewal fee to keep the patent alive during the statutory period. Upon paying the renewal fee, the firm benefits from the current returns that accrue to the patent over the coming period, as well as the option to pay the renewal fee and maintain the patent's validity in the following period. Consequently, the firm will not renew the patent unless this benefit exceeds the renewal fee.

As a firm's patent renewal decision involves a series of complex compound options, there is no analytically tractable solution for the decision rule. Consequently, I will use the finite difference method developed by Hull and White (1990) and employ plausible parameter values to do the numerical analysis, which uses the patent statutory period commonly employed in both the U.S. and the European Union, 20 years.

My model allows a firm to have the option to withdraw its patent each year before the expiration date. This contrasts with Dixit's model (1989), which allows an active firm to choose the date on which to exit the market just once. I thus derive two results differing from those of Dixit's (1989). First, not allowing a firm's exit decision to depend on the calendar date, Dixit (1989) finds

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https://doi.org/10.1016/j.qref.2017.12.005
1062-9769/

Please cite this article in press as: Jou, J.-B. R&D investment and patent renewal decisions. *The Quarterly Review of Economics and Finance* (2018), https://doi.org/10.1016/j.qref.2017.12.005

that uncertainty raises the probability of exit. By contrast, I find that greater uncertainty does not exhibit a monotone effect on the renewal probability due to the following reason. When there is no uncertainty, a firm's renewal decision is based on the net present rule such that the firm will renew the patent for sure before a certain date, but will never renew it after that certain date. By contrast, when there is uncertainty the renewal probability will decline smoothly over time toward the expiration date.

Second, while Dixit (1989) finds that a larger investment cost delays the timing of exit, I find that it is not related to the timing of patent withdrawals. Intuitively, in Dixit's model a firm that exits the market has the option to later enter the market such that the firm will consider the entry cost as part of its opportunity cost. By contrast, in my model the investment costs are sunk, and thus are unrelated to a firm's benefit or cost from renewing a patent. However, a firm that incurs larger investment costs will delay the R&D investment, and will thus stay in the market longer, i.e., the renewal probability will increase.

I also derive two results that are not discussed in Dixit's paper (1989). First, a firm that collects a smaller proportion of the reward after the patent expires will delay the R&D investment and accelerate patent withdrawals, and is less likely to renew the patent. The above pattern also appears for a firm that either incurs a larger initial renewal fee or faces a higher growth rate of the renewal fee. Second, I employ the numerical analysis by choosing parameter values that cover a wide range of riskiness of the R&D investment of the pharmaceutical industry and compare the numerical results with those of the literature.

This paper considers patent renewal decisions, and thus closely relates to the study of Pakes (1986), Baudry and Dumont (2006) and Deng (2011). These papers build a discrete-time model that allows for uncertain rewards for developing an innovation and investigate how renewal fees affect a patent holder's decision to renew the patent right. Pakes (1986) derives a threshold below which it is optimal to withdraw a patent. He takes a random draw from the stochastic process to compute a simulated option value and the simulated frequencies of withdrawal for each patent age.[1] Baudry and Dumont (2006) use a broad class of stochastic processes, including that used by Pakes (1986), and derive the exact probability of patent withdrawals. Deng (2011) extends Pakes (1986) into a discrete-time stochastic patent application-renewal model and examines the joint determinants of patent family size and length of patent life.[2] Her paper explains why patents in the pharmaceutical industry have lower initial returns and renewal rates than those in the electronics industry. My paper differs from the above papers by building a continuous-time model that is able to predict how various economic forces affect choices of timing of the R&D investment and patent withdrawals, as well as the renewal probability over patent age.[3]

This paper abstracts from two characteristics of the R&D investment, namely, sequential investment and strategic interactions among firms.[4] Both Reiss (1998) and Takalo and Kanniainen (2000) have considered the first.[5] Reiss (1998) assumes that a firm incurs costs in both applying for a patent and exercising an investment in a new technology project. Depending on the order of these two costs, the firm may apply for a patent first, undertake the investment project first, or simultaneously exercise both options. Takalo and Kanniainen (2000), by contrast, build a three-stage model in which a firm undertakes an R&D investment project first, after which it receives a patent and then commercializes the patent. They challenge the widely held view in the industrial organization literature, which states that patents always speed up technological progress. Both papers allow for a sleeping patent, which indicates that a firm may have been already granted a patent, but lets it sleep for a certain period.[6] Several papers consider both characteristics when investigating the issues of patent races and sleeping patents in a continuous-time framework. Among them, Weeds (1999), Lambrecht (2000) and Leung and Kwok (2012) assume perfect information between firms, while Hsu and Lambrecht (2007) and Leung and Kwok (2011) assume asymmetric information between firms.[7] All of these papers, however, do not consider patent renewal decisions.

The remaining sections are organized as follows. Section 2 presents the assumptions of the model and derives the optimal conditions of the R&D investment and patent withdrawal decisions. Section 3 presents the numerical analysis, while Section 4 presents the study's conclusions and offers suggestions for future research.

2. Model

Consider that a single, risk-neutral firm, which employs a discount rate r, may carry out a research project that has some chance of creating a new product design. When discovery takes place, the firm receives a patent immediately and simultaneously invests in productive capacity and enters the product market. The problem facing the firm involves a compound option: the payoff from exercising the option to engage in research and commercialization is the option to generate a direct monetary return, which in turn, hinges on whether the firm renews the patent each period before the patent expires.

After commercializing the patent, the firm receives net reward P at each instant that follows a geometric Brownian motion[8]

$$dP = \mu P dt + \sigma P dZ, \tag{1}$$

where μ is the drift parameter that measures the expected growth rate of P, σ (>0) measures the instantaneous volatility, and dZ is the increment of a standard Wiener process. The drift parameter, μ, must be strictly less than the discount rate, r, to ensure the value of the firm is finite. The firm also incurs a sunk cost K, which includes the costs of developing an innovation, the fees paid to the

1 Pakes (1986) finds that a 1% increase in renewal fees decreases the proportion of patents renewed by about 0.02%.

2 Serrano (2010) considers the issue of patent transfers. He finds that the probability of a patent being traded increases with gains from trade and patent revenue and decreases with costs of technology adoption and patent age.

3 Two recent empirical studies have considered other economic forces that affect the renewal probability. For example, patent promotion policies (Long and Wang, 2016) and market maturity (Baudry and Dumont, 2016).

4 Dixit and Pindyck (1994, pages 327–328) consider a general two-stage investment project with uncertain returns, where the first stage can be interpreted as research. They abstract from the time-to-build problem and find that a firm will wait until entry is optimal, and then sink both the first- and second-stage investments at the same time. Bar-Ilan and Strange (1998) analyze a two-stage investment model with time-to-build. They find that if the first stage investment lag is sufficiently long and output price uncertainty is high, the first-stage trigger may fall below the second-stage trigger and exploratory investment takes place. I will not consider the time-to-build problem to avoid constructing a model that is too complicated.

5 Roberts and Weitzman (1981) argue that initial investment in the early stages can convey information to the latter stages in a multi-stage project through learning-by-doing. As a result, a firm may undertake exploratory research even though it expects the investment project to have a negative net present value. This idea is extended by Pindyck (1993) and Schwartz (2004), both of whom analyze a model in which the technical uncertainty in completing the investment project and the uncertainty is resolved only after the investment is undertaken. I will not consider the learning-by-doing process here.

6 Some studies use a discrete-time deterministic model and consider symmetric information between firms to investigate the issue of sleeping patents. For example, see Gilbert and Newbery (1982) and Harris and Vickers (1985).

7 See the review articles such as Azevedo and Paxson (2014), Chevalier-Roignant, Flath, Huchzermeier, and Trigeorgis (2011) and Sereno (2008).

8 This follows Lanjouw, Pakes, and Putnam (1998), who indicate that lognormal distributions for patent initial returns fit the empirical data better than either Pareto or Weibull distributions.