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Patent Portfolio Management of Sequential Innovations

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ABSTRACT

This paper develops a model for understanding a firm's decisions regarding the maintenance (renewal) and patenting of sequential innovations and studies how these decisions are affected by the model's parameters, including maintenance fees and filing fees. The model demonstrates that the two prices exert negative effects on renewal and patenting, respectively (i.e. adverse own-price effects). The model also offers a discriminating testable hypothesis, predicated on the cross-price effects, to identify complementarity or substitutability across sequential innovations. Our regression results show that the probability of patent renewal and maintenance fees are correlated negatively and that the patent propensity and application fees are correlated negatively. We also demonstrate that higher application fees are associated with lower probability of patent renewal, which corroborates the case of complementarity in sequential innovations.

Keywords: Renewal, Patenting, Sequential innovations, Patent portfolio, Patent maintenance fees, Application filing fees

JEL Classification Numbers: J63, O32, O34

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I. Introduction

In the past few decades, technological innovations and inventions have become extremely important to firms for their survival in competitive markets. As a result, the management of intellectual properties has become a high priority for innovating firms in many industries, and it has been reported that firms utilize a variety of methods for the management of intellectual properties. For example, via legal protection (patent, trademark or copyright), an innovating firm attempts to prevent competitors from imitating its new products and can thereby protect its market share. Secrecy offers firms an alternative means of securing R&D returns while avoiding both the legal expenses of patent application and infringement prosecution, and the potentially much greater losses from the disclosure of sensitive information to competitors.

Among the various methods of intellectual property management, patenting is considered the most effective legal protection from outsiders (competing firms) as well as insiders (departing research personnel)[1], which renders patent portfolio management a critical issue for innovating firms. In this paper we develop and test a model of patent portfolio management to investigate determining factors of patent portfolio management in an innovating firm.

In general, patent portfolio management involves two activities: the patenting of new innovations and the maintenance (or renewal) of existing patents. Upon the arrival of a new innovation, a firm decides whether to file for a patent or to rely on secrecy. When filing a patent application, it is required to pay application filing fees. Under the current U.S. system, after the examination period (typically 2 years), a patent is granted which guarantees legal

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[1] See Kim and Marschke (2005) for the survey of the role of patents.

protection for 20 years after filing. Every patent grant is subject to payment of maintenance fees, which must be paid to maintain the patent in force. These fees are due at 3½, 7½ and 11½ years from the date on which the patent is granted. In this paper, we examine theoretically and empirically how factors such as application filing fees and maintenance fees affect a firm's patenting and renewal decisions on the firm's sequential innovations. In particular, we investigate the own-price effects of those fees on patenting and renewal as well as their cross-price effects, where the latter effects provide us a testable implication to identify complementarity or substitutability across sequential innovations.

Earlier studies on patent renewal have primarily focused on three broad topics. Using records of patents' renewals and expirations, Pakes (1986), Schankerman and Pakes (1986), Lanjouw (1998), Schankerman (1998) have attempted to estimate the private pecuniary values of patents under the premise that a patent will not be renewed unless its value exceeds the cost of maintenance or renewal. Unlike our paper, these papers do not consider a firm's patenting decisions jointly made with renewal decisions and thus ignore the interrelationship of renewal and patenting. Nor do they consider sequential innovations within a firm. Deng (2005) extends this literature by examining the joint determination of patenting and renewal of a given innovation and using information on both dimensions to estimate the innovation's value, but does not take into account sequential innovations within a firm. In contrast to our paper, all these papers do not directly estimate the sensitivity of renewals to renewal fees. Furthermore, they assume that the revenue across innovations is independent and identically distributed while our model allows for the possibility that revenues across sequential innovations may be correlated and a firm's patenting and renewal decisions on two different innovations are therefore jointly made. Liu et al. (2008) has empirically studied whether a firm is more likely to have its patent renewed when the patent belongs to a sequence of related innovations identified by the USPTO as parent, divisional, and continuation-in-part patents. This paper, however, does not consider the interrelationship between patenting and renewal decision in the context of sequential innovations of a firm.

The second topic concerns the optimal mechanism issues in the intellectual property protection system in terms of patenting and renewal: (1) whether and when the patenting-renewal system is optimal with regard to inducing the proper amount of research efforts, and (2) what are the optimal maintenance (renewal) schedule and fees. Although the literature is not generally optimistic regarding the efficiency of the patenting-renewal system (Wright, 1983), some studies have demonstrated the conditions of an economic environment in which the patent-renewal system is optimal (O'Donoghue *et al*., 1998). Cornelli and Schankerman (1999) showed that the renewal system can shift research efforts toward higher-productivity firms in the presence of asymmetric information. Scotchmer (1999) demonstrated that the renewal system is equivalent to direct revelation mechanisms with asymmetric information on research costs and benefits. These theoretical studies presume that patenting and renewal behaviors, in addition to R&D, are responsive to changes in patent filing fees and maintenance fees, such that efficiency may be achieved by the patenting-renewal system. The empirical component of this paper attempts to provide direct evidence on how responsive these behaviors are with regard to price changes.

The third topic addresses various roles of the patent renewal system. Langinier (2004), Horstmann *et al*. (1985), and Crampes and Langinier (1998) have argued for the strategic utilization of patenting and renewal in order to deter entry. Hall and Ziedonis (2001) stated that firms make patenting decision strategically for a variety of purposes: to keep or establish their position in a technological domain, to block rivals from patenting related inventions, and to expand their portfolio even with lower quality patents, as a defensive strategy. Cohen *et al*. (2000) also claimed that firms manage patent portfolios with patenting and renewal decisions to use them in negotiation with other firms. Our paper offers a new *positive* theory regarding the management of a firm's patent portfolio in an environment of sequential innovations.

This paper is organized as follows. Section 2 lays out a formal model of a firm's patenting and renewal decisions in an environment in which firms develop sequential innovations. Section 3 describes the data and explains our empirical specifications. We report our empirical findings in Section 4. Finally, the paper concludes in Section 5, and it includes a discussion of the quantitative importance of our estimates in explaining observed variations in patenting and renewal behaviors.

II. A Dynamic Model of Sequential Innovations

We start with a firm that lasts for infinite periods and is endowed with a new patentable innovation each period. The firm transforms the innovation to a product whose life on the market ends in two periods. If a new product in period t is patented at the beginning of its life, the firm earns the revenue, θ^t_t ($\in R^+$), during that period. Otherwise, the firm's revenue from the product is ν^t_t ($\in R^+$) over period t. Both θ^t_t and ν^t_t are random variables, which are realized prior to the making of the patent decision in the first period. When the product is patented in period t, the firm decides on patent renewal at the beginning of period t+1. If the patent is renewed, the firm earns θ^t_{t+1} ($\in R^+$) in period t+1, while its revenue is μ^t_{t+1} ($\in R^+$) if not renewed, where both θ^t_{t+1} and μ^t_{t+1} are random variables realized prior to the renewal decision. All of these random variables are assumed to have time-invariant distributions. In order to simplify the analysis, we assume that a product not patented in the first period of its lifespan is not worth patent protection in the second period, and that the firm earns the same revenue in the second period either when the patent for the product is not renewed or when the product is not patented at all (that is, μ^t_{t+1}). Application filing fees and maintenance (renewal) fees are expressed as c_A, and c_R, respectively.

We define V_t and W_t as the value of the firm at the end of period t-1, when the innovation in period t-1 was patented and when it was not, respectively. The firm's decisions regarding patenting (P_t) and renewal (R_t) in period t when the innovation was patented in period t-1 depend on the firm's profit for each combination of patenting and renewal decisions, as is described in Table 1.

Table 1: Profit to the firm in period t

Patent renewed	New product patented	Firm's profit, $\pi_t(R_t, P_t)$
No ($R_t = 0$)	No ($P_t = 0$)	$\pi_t(0, 0) = \mu^{t-1}_t + \nu^t_t + \delta\, W_{t+1}$
	Yes ($P_t = 1$)	$\pi_t(0, 1) = \mu^{t-1}_t + \theta^t_t - c_A + \delta\, V_{t+1}$
Yes ($R_t = 1$)	No ($P_t = 0$)	$\pi_t(1, 0) = \theta^{t-1}_t - c_R + \nu^t_t + \delta\, W_{t+1}$
	Yes ($P_t = 1$)	$\pi_t(1, 1) = \theta^{t-1}_t - c_R + \theta^t_t - c_A + \alpha + \delta\, V_{t+1}$

In this table, δ is a time discount factor ($0<\delta<1$).

Note that the firm's profit is increased by α when the old patent is renewed ($R_t = 1$) and the new innovation is patented ($P_t = 1$) if α is positive. We can show that our profit function $\pi_t(R_t, P_t)$ is supermodular and its two arguments, or decisions, are complements if α is positive.[2] When α is positive, the technology embedded in the succeeding innovation is complementary to that in the preceding innovation, such that having both under patent protection generates additional profits beyond the sum of profits each innovation generates on its own. For example, Athey and Schmutzler (1995) argue that a demand-enhancing (product) innovation and a cost-reducing (process) innovation are in general complementary. If the technologies in sequential innovations are substitutable, such that patent protection on one would reduce the profit from the other, α assumes a negative value. In this case, the profit function is called submodular and its arguments are substitutes.[3] We will show later that our model produces a discriminating testable inference as to whether sequential innovations are complementary ($\alpha>0$) or substitutable ($\alpha<0$).[4]

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[2] A function is supermodular and its arguments are complements if the sum of the changes in the function when several arguments are increased separately is less than the change resulting from increasing all the arguments together. Put differently, increasing one or more variables in a supermodular function raises the return to increasing other variables. This idea of complementarity is equivalent to Edgeworth-complementarity in production factors: factors are Edgeworth-complements if having more of one factor increases the return to the other factor. For the details of supermodularity and complementarity, see Topkis (1978) and Milgrom and Roberts (1990).

[3] Note that complementarity or substitutability among innovations from different firms is not addressed in our analysis.

[4] In general, the firm's revenue from a patent not renewed (μ^{t-1}_t) may be affected by whether or not a new innovation is patented. Or, the revenue from a new innovation that is not patented (ν^t_t) may be affected by whether or not the patent in the previous period is renewed this period. These possibilities are not crucial to the model's

When the innovation in period t-1 was not patented, the firm's only decision to make in period t is whether or not to patent a new innovation. In this case, the firm's profit will be that shown in the first row of Table 1 (when $R_t = 0$ and $P_t = 0$) or in the second row of that table (when $R_t = 0$ and $P_t = 1$).

Case 1: Complementary Technologies ($\alpha > 0$)

First consider the case in which $\alpha > 0$. When the firm has the previous innovation patented, it chooses not to renew the patent ($R_t = 0$) and not to patent a new innovation in period t ($P_t = 0$) if and only if $\pi_t(0, 0)$ is greater than that from any other choice. The conditions are: $(\theta^t_t - \nu^t_t) \equiv \theta_t < c_A - \delta\,(V_{t+1} - W_{t+1})$, and $(\theta^{t-1}_t - \mu^{t-1}_t) \equiv \varepsilon_t < c_R$ where θ_t and ε_t denote net gains from patent protection in the first period and in the second period of the product's life cycle, respectively. The firm does not renew ($R_t = 0$) but patents ($P_t = 1$) if and only if $\theta_t > c_A - \delta\,(V_{t+1} - W_{t+1})$, $\varepsilon_t - \theta_t < c_R - c_A + \delta\,(V_{t+1} - W_{t+1})$, and $\varepsilon_t < c_R - \alpha$. Or, the choices ($R_t = 1$) and ($P_t = 0$) are made if and only if $\theta_t < c_A - \alpha - \delta\,(V_{t+1} - W_{t+1})$, $\varepsilon_t - \theta_t > c_R - c_A + \delta\,(V_{t+1} - W_{t+1})$, and $\varepsilon_t > c_R$. Finally, the firm renews and patents if and only if $\theta_t > c_A - \alpha - \delta\,(V_{t+1} - W_{t+1})$, and $\varepsilon_t > c_R - \alpha$. These renewal and patenting decisions of the firm are depicted in Figure 1 on the θ_t-ε_t space. Intuitively, Figure 1 indicates that the firm is more likely to renew the patent the higher is the net gain from patent protection with renewal (ε_t), given θ_t. Also, the firm is more likely to patent a new innovation the higher is the net gain from patent protection with new patent filing (θ_t), given ε_t.

When the previous innovation is not patented, the firm decides to patent a new innovation

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implications and are thus not addressed in our model.

if and only if $\theta_t > c_A - \delta\,(V_{t+1} - W_{t+1})$. Otherwise, it does not patent the new innovation.

Case 2: Substitutable Technologies (α < 0)

When sequential innovations reflect substitutable technologies, such that $\alpha < 0$, we can derive the conditions for the firm's patenting and renewal decisions in the same manner as in case 1. Figure 2 illustrates the conditions for these choices when the firm has patented the previous innovation. The condition for patenting in cases in which the previous innovation was not patented is the same, regardless of whether the technologies are complementary or substitutable: $\theta_t > c_A - \delta\,(V_{t+1} - W_{t+1})$.

Comparative Statics Analysis

a. Effects of Patent Maintenance Fees

The following proposition describes the effect of a change in maintenance or renewal fees (c_R) in our model.

Proposition 1. An increase in renewal fees (c_R) lowers the probability of the firm renewing a patent, regardless of whether technologies are complementary or substitutable. Rising renewal fees lower the probability of patenting when the technologies are complementary, but its effect is ambiguous when the technologies are substitutable.

Proof: See Appendix A.

If sequential innovations are substitutable (α<0), increasing renewal fees have a direct substitution effect, lowering the renewal probability and raising the patent probability. On the other hand, holding a patent that offers an option of later renewal becomes less attractive as renewal fees rise, and thus $\partial\Delta/\partial c_R < 0$ where $\Delta \equiv V_t - W_t$ denotes the future net benefit of holding a patent. This reduces the patenting probability and consequently favors renewal against patenting (note that a time subscript for the future net benefit is omitted, as all the distributions are time-invariant). This proposition illustrates that the direct substitution effect predominates for the renewal probability, and thus renewal is less likely with rising renewal fees. However, the effect of renewal fees can go either way in terms of the patenting probability. Figure 3 illustrates the effect of an increase in c_R when $\alpha<0$ on the boundaries that divide θ_t-ε_t space into regions of patenting/no patenting and renewal/no renewal. The dashed boundaries in Figure 3 result from an increase in c_R. The shift in boundaries indicates that the firm will renew only for higher draws of ε than before, which is depicted as the contracting area of renewal in Figure 3. The reduction in the future value of patenting due to rising renewal fees lowers the likelihood that the firm patents, and Regions A1 and A3 in Figure 3 illustrate this. However, the substitution effect can increase the propensity of patenting in expense of renewal, which is illustrated in Region A2. If sequential innovations are complementary ($\alpha>0$), this substitution between patenting and renewal will not occur, and the probability of patenting is thus always reduced as is the renewal probability.

b. Effects of Patent Filing Fees

A change in patent filing fees generates a discriminating testable implication as to whether sequential innovations are complementary or substitutable.[5]

[5] A number of papers have empirically examined the complementarity of innovations or innovation strategies. Arora and Gambardella (1990) tested whether various research cooperation strategies between large biotech firms and universities or small/medium sized firms are complementary. Miravete and Pernias (2006) showed significant complementarity between product and process innovations.

Proposition 2. An increase in filing fees (c_A) lowers the probability of the firm patenting an innovation, regardless of whether the technologies are complementary or substitutable. Rising filing fees lower the probability of renewal when the technologies are complementary, but raise the renewal probability when the technologies are substitutable.

Proof: See Appendix B.

The first-order effect of rising filing fees is to raise the renewal probability and lower the patent probability when the firm has substitutable innovations. Renewal becomes more attractive than patenting also in the next period, which means that the value of holding a patent in this period increases. However, the former (first-order) effect is stronger than the latter (second-order) effect, and therefore the net effect of rising filing fees is to raise the renewal probability and lower the patent probability (see Figure 4b). When technologies are complementary, the first-order and second-order effects operate in the same direction: lowering both the patenting probability and the renewal probability (see Figure 4a).

c. Effects of Degree of Complementarity or Substitutability

Variations in the degree of complementarity or substitutability across sequential innovations can affect the propensities of patenting and renewal, as is described in the following proposition.

Proposition 3. When technologies are complementary, a higher degree of complementarity (higher α where $\alpha>0$) raises both the patent probability and the renewal probability. When the technologies are substitutable, a higher degree of substitutability (lower α where $\alpha<0$) lowers the patent probability and has an ambiguous effect on the renewal probability.

Proof: See Appendix C.

Sequential innovations being more substitutable implies that choice (R_t, P_t) = (1, 1) is less attractive due to the lower profits from the choice, which makes patenting and renewal less likely. Moreover, as the future value of a patent is smaller for innovations with higher substitutability, the propensity to patent falls, which renders the renewal probability higher as the result of substitutability. The net effect of higher substitutability is, therefore, to lower the patent propensity, but is ambiguous with regard to the renewal probability.

Higher complementarity in sequential innovations causes higher propensities to patent and renew as the profits from choice (R_t, P_t) = (1, 1) are higher. Higher complementarity further raises the probability of patenting, as well as that of renewing, because the future value of a patent is higher, which raises the patenting probability, and hence the renewal probability as innovations are complementary. In the case of complementary innovations, a higher degree of complementarity thus raises both the patent probability and the renewal probability.

In our empirical analysis, we use as a regressor a proxy for the degree of complementarity or substitutability (self citation rate), in order to test the model's discriminating implication as to whether sequential innovations are complementary or substitutable, by ascertaining whether the variable exerts a positive or negative effect on the propensity to patent.

III. Empirical Implementation

We test our propositions on renewal and patenting decisions against patent-level and firm-level panel data, respectively. In the estimation of renewal decision, we utilize a logit model with the indicator variable for renewing a patent as the dependent variable. A panel-data regression model is employed for the firm's patenting decision, where the dependent variable is the firm's patent count per R&D dollar. The explanatory variables in both models include patent maintenance fees and application filing fees, in addition to firm-level characteristics, such as R&D expenditures and the capital-labor ratio.

Data Description

In 1980, new legislation was introduced in the US patent system mandating that maintenance fees be paid to maintain the status of patents in force: all utility patents which issue from applications filed on and after December 12, 1980 are subject to the payment of maintenance fees. These fees are due at 3½, 7½ and 11½ years from the date on which the patent is granted, and the maintenance fees can be paid with a surcharge during the 6-month grace period. If the maintenance fees and any applicable surcharge are not paid, the patent will expire on the anniversary of the date the patent was granted in the 4th, 8th, or 12th year after the grant of the patent. The maintenance fees are subject to reduction for small entities that are independent inventors, small businesses with less than 500 employees, or nonprofit organizations. Table 2 provides the historical data on maintenance fees in current and constant dollars which are collected from the Official Gazettes published by the USPTO in various years. Note in this table that patent applications filed prior to Dec. 12, 1980 were guaranteed full patent life if granted.

Data regarding application filing fees are also collected from the Official Gazettes (see Table 3). As of 2007, application filing fees include basic fees, fees for applications with independent claims in excess of 3, fees for applications with claims in excess of 20, and fees for applications with multiple dependent claims. The last type of fee was initially introduced for patent applications filed in 1983. Application filing fees have been also subject to reduction for small entities since 1983. Note that variations in maintenance and filing fees in our data occur in the cross-sectional dimension (by firm size) as well as in the time-series dimension (by nominal fee changes and inflation).

Data regarding patent renewals and expirations are taken from the work of Jaffe and Trajtenberg (2002). Data are available for patents filed since Dec. 12, 1980 and cover patents renewed until Oct. 29, 1996. Information regarding the number of patents, R&D expenditures, capital-labor ratio, self-citation rate and other characteristics of firms each year are taken from the NBER Patent Citations Data (see Hall, Jaffe and Trajtenberg, 2005, for details), which were created by carefully matching the patents in the U.S. Patent and Trademark Office to their assignees in the Standard and Poor's Compustat database. The Compustat database provides extensive data (including R&D expenditures) for all publicly traded firms. The NBER dataset contains approximately 1,000 firms in an unbalanced panel, extending from 1965 to 1995 in years of application filing. Table 4 reports the definitions and summary statistics of the variables utilized in our analysis.

Model Specification

The basic specification for our patent renewal analysis is a panel-data logit model with firm-specific random effects:

$$\text{Prob}(R_{ift} = 1) = \Lambda(\alpha + \beta' X_{ift} + u_f + \varepsilon_{ift}),$$

where R_{ift} is a binary variable for the renewal of patent *i* of firm *f* in year *t*, $\Lambda(.)$ indicates the logistic cumulative distribution function, and the vector X_{ift} for patent *i* of firm *f* in year *t* includes variables implicated by our model such as maintenance fees (MAINT), application filing fees (FILING), self-citation ratio (SCITE), and those variables used in other studies on renewal and patenting such as R&D expenditures (R&D) and capital-labor ratio (K/L). In constructing variable FILING, we add basic fees and per-claim fees multiplied by the firm's average number of claims in excess of 20. We also include in this vector both the total annual number of a firm's patents that are subject to maintenance fees (RENEW) and the total annual number of a firm's patent applications (APPLI), because we need to control for the number of innovations, even though a firm is assumed (for simplicity's sake) in our model to have only one innovation per period. There is evidence that citations received reflect the economic value of a patent (Trajtenberg, 1990). In order to control for patent value, we include the number of citations received by the patent in 5 years following grant date (CRECEIVE) as a regressor. In the benchmark specification, we pooled all patents subject to maintenance fees in their 4th, 8th, and 12th years after granting, and thus include in the vector two indicator variables: 8TH_YR for patents in their 8th year, and 12TH_YR for patents in their 12th year. All variables in X_{ift} are adjusted for inflation and in the logarithmic form, except for the indicator variables, CRECEIVE and SCITE, as the latter two variables can take a value of 0. The variable u_f is a random firm-specific constant term and ε_{ift} is the error component.

We cannot adopt the same logit specification for the analysis of patenting decisions as innovations that are not patented cannot be observed. For the patenting decision analysis, we employ instead a panel-data regression model with firm-specific random effects:

$$\mathrm{Ln}(PAT_{ft}/R\&D_{ft}) = \gamma_f + \delta' X_{ft} + v_t,$$

where PAT_{ft} is the number of patents granted to firm *f* that were applied for in year *t*, X_{ft} is a vector of filing fees, maintenance fees, and firm *f*'s characteristics in year *t*, as described above, γ_f is a firm-specific constant term, and Ln denotes natural logs. Note that this specification can be interpreted as a linear probability model to the extent that the number of innovations is proportional to the R&D expenditures.

The construct of the maintenance fee variable in this model differs from that in the aforementioned logit model, because we utilized firm-level data for the regression analysis but employed patent-level data for the logit analysis. We used the weighted average of maintenance fees for the 4th, 8th, and 12th year patents, weighted by the share of the firm's patents in their 4th, 8th, or 12th year in all patents subject to maintenance fees (MTFEE).

IV. Empirical Findings

Trends in Renewal Rate

Table 5 reports the annual patent renewal rates between 1986 and 1996. This table shows that the renewal rate for 4th-year patents increased steadily until 1989, at which time the trend reversed itself. The renewal rate fell from 84.99 percent in 1989 to 78.60 percent in 1995. The table shows a surge in the renewal rate from 78.60 percent in 1995 to 80.98 percent in 1996, which may be attributable to a data truncation problem, namely that the renewal data from Jaffe and Trajtenberg (2002) covers only patents renewed until Oct. 29, 1996. As do Schankerman and Pakes (1986), we also find in this table that patents are less likely to be renewed as they become older.

Figure 5 draws the annual expiration rate of the U.S. patents in the 4th year and the real-term maintenance fees for patents in their 4th year for large entities. Note that the maintenance fees for small entities display the same pattern of change over time. Figure 5 shows remarkably synchronized movements between the two time series: both of which fell until the early 1990's and rose afterwards. This finding shows that renewal decisions are responsive to changes in maintenance fees.

Results from Logit Analysis of Renewal Decision

Table 6 reports our estimation results of the determinants of the firm's renewal decision, employing the random-effects logit model as described in the previous section. The dependent variable is an indicator variable designating whether or not a patent is renewed.

In column 1, we observe that the maintenance fees (MAINT) exert a significantly negative effect on renewal decision, consistent with the proposition of our model. This finding is repeated in the other columns in Table 6.

The filing fee variable (FILING) is shown in column 1 to exert a significant and negative effect on renewal. According to Proposition 2, this finding lends support to the notion of complementarity in sequential innovations. Complementarity may be due to the fact that it is not in the best interests of a firm to do research for innovations that readily replace the firm's existing innovations and erode the revenues from the old innovations quickly.

Higher patent filing fees discourage firms from patenting low-valued innovations, assuming that firms know the value before patenting, or at least can make an informed guess about it. This selection effect implies that patents under the higher-fee regime are more likely to be renewed at any given age, other things equal. Therefore, the estimated negative effect of filing fees on renewal cannot be explained away by the selection effect.

In order to check whether the nature of sequential innovations varies across patent classifications, we introduce the interaction terms of 36 patent category dummies and the logarithm of filing fee variable (FILING) as regressors in column 2. This column shows that all the interaction terms are associated with significantly negative coefficients, which is indicative of complementarity in sequential innovations across all patent classifications. We also ran the same regression specification as in column 1 with a sub-sample for each classification (not reported in Table 6 to save space) and found the interaction term with a significantly negative coefficient for 8 classifications (sub-category number 14, 15, 19, 31, 33, 43, 46, and 64 in Appendix D), with a significantly positive coefficient for one classification (number 61), and with an insignificant coefficient for the rest. This confirms that innovations are complementary in the majority of patent classifications. We also found in those regressions with the sub-samples that the maintenance fee variable (MAINT) is associated with a significantly negative coefficient for most classifications (24 out of 36) and with an insignificant negative coefficient for the rest.

We can expect that the renewal probability for a patent can be influenced by how many other patents to renew a firm has, or by how many new innovations it has. Column 1 shows that the renewal probability for a single patent is negatively associated with the total number of renewable patents (RENEW) in the same year, and is positively related with the number of patentable innovations (APPLI). The latter finding is also consistent with the complementarity in sequential innovations. The effect of the number of citation received as a proxy for patent value (CRECEIVE) is strongly significant and positive as anticipated.

We included R&D expenditures (R&D) in our specification as a proxy for the size of the firm to account for scale economies in patent maintenance. Alternatively this variable may pick up systematic variations in patent values by firm size. If the values of patents owned by larger firms are higher in general, we would expect higher renewal probability for larger firms, given other control variables are constant. R&D expenditures are shown in all columns of Table 6 to exert a significantly positive effect on renewal decision, in accordance with this prediction.

We include the capital labor ratio (K/L) as a regressor, because a firm that has made a large capital investment in a state-of-the-art physical plant may develop products with a short technology lifespan, or the profit streams from those products may be concentrated in early years on the market. The result in Table 6 supports this idea, showing that the capital labor ratio exerts a significant and negative effect on renewal decisions.

We utilize the self-citation ratio (SCITE) as a measure of the degree of complementarity or substitutability in sequential innovations. Regardless of whether the relationship across sequential innovations is complementary or substitutable, a higher self-citation ratio may be reflective of a higher degree of their relatedness. The effect is marginally significant in all columns of Table 6.[6]

As illustrated in Table 5, older patents are less likely to be renewed, which is confirmed by the results in Table 6: the indicator variables 8TH_YR and 12TH_YR are associated with significantly negative coefficients and the coefficient corresponding to 12TH_YR is larger in terms of absolute value than the coefficient corresponding to 8TH_YR.

As the key variables in our estimation may be time-trended, in column 3 of Table 6 we also report the regression estimates of column 1 with a time trend variable (T) and its squared value (T^2) entered as additional regressors. The results in column 3 indicate that the effect of maintenance fees is still negative and significant with these time trend variables included. However, the coefficient corresponding to filing fees is still negative, but becomes insignificant.

Column 4 reports the marginal effect of a 1% increase of each variable (in its linear form) in column 1 on the probability of renewal where the marginal effects are evaluated at the sample means of the regressors. We note quantitatively strong effects of maintenance fees and the number of citations received. For example, an increase in maintenance fees by 1% from its mean reduces the probability by 5 percentage points. We can expect that the elasticity of the renewal probability with respect to maintenance fees is higher in magnitude when patent values are lower. To test this implication, we separate our sample to observations with CRECEIVE bigger than or equal to 6 and those with CRECEIVE less than 6 in column 5 and 6, respectively. The renewal probability is shown to be much more responsive to changes in maintenance or

[6] In their study with US pharmaceutical and biotechnology patent data, Liu *et al*. (2008) show that the self-citation ratio exerts a significant and positive effect on renewal decisions.

application fees among patents with lower CRECEIVE.

In the last three columns of Table 6, we re-estimate column 1 with the sub-sample of those patents to renew in their 4^{th}, 8^{th}, or 12^{th} years, respectively. We find that the estimated effect of MAINT decreases in magnitude and becomes less significant as the patents get older, and the estimated FILING effect becomes larger in magnitude and more significant, although it is insignificant for patents in their 12^{th} years. Columns 7-9 verify that all other regressors exert the same effects on renewal as in the pooled regression model.

We also assessed the sensitivity of our estimates to the distributional assumption for the probability distribution. The estimated effects of our regressors are as pronounced when we assume the normal distribution and thus employ the probit model (not reported in order to save space).

Results from Linear Regression Analysis of Patenting Decision

Table 7 shows our estimation results of the determinants of the firm's patenting decisions, employing the random-effects regression model, as described in section 3. The dependent variable is the logarithm of the firm's patent applications in year *t* which were eventually granted per R&D dollar. The explanatory variables include the logarithms of the filing fee measure (FILING), of the maintenance fee measure (MTFEE), of the number of patents to renew (RENEW), of the capital-labor ratio (K/L), the average number of citation (MCRECEIVE) and the self citation ratio (SCITE).

In column 1, we find that FILING is strongly negatively related with patenting, which is consistent with the prediction of our model. This finding is repeated in other columns of Table

7. The effect of MCRECEIVE is shown to be significant and negative in all columns of Table 7 except column 1. This implies that firms that produce more valuable patents tend to have a lower patent propensity possibly due to quality and quantity tradeoff in patentable innovations. We determine in column 1 that the estimated effect of K/L on patenting is not supportive of the hypothesis that a highly capitalized firm may have stronger incentives to patent than less capitalized firms, as a firm that has made a large capital investment in a state-of-the-art physical plant may wish to develop a diverse portfolio of patents that it can utilize as a bargaining chip to ward off infringement suits, which can cause production stoppage (Cohen *et al*., 2000; Parr and Sullivan, 1996).

Our model predicts that higher self-citation ratio (SCITE) as a measure for the degree of complementarity or substitutability will raise the patent propensity when sequential technologies are complementary, and lower it when they are substitutable. A significantly positive effect of SCITE reported in all columns of Table 7 corroborates the case of complementarity in sequential innovations, which recapitulates the finding in Table 6.[7]

In column 2 we introduce as additional regressors the maintenance fee variable (MTFEE) and the number of renewable patents (RENEW). Note that the number of observations is reduced in this column because we exclude patents filed before 1980, which are not subject to maintenance fees. The estimated effect of MTFEE suggests that higher maintenance fees lower

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[7] In the context of patent litigation, Lanjouw and Schankerman (2004) find that self-citation indicates the presence of a "cumulative innovation" by the patentee, and that there is complementarity among technologically related patents in a firm's portfolio that raises the willingness to protect the property rights of the key, early inventions in the chain.

the firm's propensity to patent. According to Proposition 1, this finding is consistent with the case of complementarity in sequential innovations, which is suggested by the effects of FILING in Table 6 and SCITE in Table 7. Not surprising in this light, we determine that RENEW is related negatively with the patenting propensity.

Attempting to check whether the nature of sequential innovations varies across industries, we include as regressors in column 3 the interaction terms of 17 industry dummies and the logarithm of the maintenance fee variable (MTFEE). The result shows that all but two of the interaction terms are associated with negative coefficients, and are significantly negative for industries with SIC code numbers 20, 28, 30, 35-38 (see Appendix E for the SIC codes). Two industries with SIC code numbers 27 and 29 have interaction terms with positive but insignificant coefficients.

As our key variables in our regression may evidence time trends, we introduce the time trend variable (T) and its squared value (T^2), entered as additional regressors in column 4. The results show that the effects of all the regressors, including maintenance fees and application fees except RENEW, remain intact.

In addition to the random effects specifications, we estimated fixed-effects regression models (results not shown), which qualitatively and quantitatively evidence impacts similar to those of our regressors in the random-effects models. We also assessed the sensitivity of our estimates to the construction method of the maintenance fee variable, MTFEE. The estimated effects of maintenance fees, as well as those of the other regressors, were pronounced when we introduced maintenance fees for 4th-year patents (alternatively, fees for 8th or 12th-year patents) as a regressor in place of MTFEE.

V. Concluding Remarks

In this paper, we developed a model by which a firm's decisions regarding the renewal and patenting of sequential innovations could be understood. In our model, these decisions can be influenced by the own-price effects (effect of maintenance fees on renewal and that of filing fees on patenting) as well as the cross-price effects (effect of filing fees on renewal and that of maintenance fees on renewal). Our model shows that the own-price effects are negative, and yields a discriminating testable hypothesis as to whether sequential innovations are complementary or substitutable, based on the cross-price effects.

Our regression results indicate that the probability of patent renewal and maintenance fees are correlated negatively, and the patent propensity and application fees are also negatively correlated. They also indicate that higher application fees are associated with lower probability of patent renewal, which corroborates the case of complementarity in sequential innovations. Our finding that higher self-citation ratio as a measure for the degree of complementarity or substitutability exerts a positive effect on the patent propensity is also consistent with the notion of complementarity in sequential innovations. Sequential innovations tend to be complements possibly because it is not in the best interests of a firm to do research for innovations that readily substitute the firm's existing innovations and erode the revenues from the old innovations quickly. Our findings are robust to various sensitivity analyses we conducted, including models that took into account time trends in our variables and different distributional assumptions.

Our estimation results are not just statistically significant, but quantitatively significant as well. As is shown in Figure 5, real maintenance fees in 1990 dollars for 4th-year patents rose from 450 (225) in 1990 to 850.36 (425.18) in 1995 for large (small) entities, which represents an 89% increase. During the same period, the renewal rate for 4th-year patents fell from 84.84% in 1990 to 78.61% in 1995, which was a drop of 6.23 percentage points. The result of column 7 in Table 6 predicts a fall in the renewal rate by 2.50 percentage points when real maintenance fees are increased by 89%.[8] We can, therefore, explain approximately 40% (=2.50/6.23) of the actual decrease in the renewal rate.[9]

Our estimation results can also be utilized to project how the USPTO's revenue might change when patent maintenance fees are raised. If the maintenance fees for 4th-year patents were to rise by 100% from the sample mean, our results predict that the revenues from maintenance fees for the USPTO would rise by 92.6%. The revenues would not rise by 100% because the number of patents renewed will be reduced with higher fees.

The average number of patents per real R&D dollar in our data varied across firms. The mean patent-R&D ratio—in which R&D is measured in millions of dollars—is 1.23 with a standard deviation of 4.38. Our empirical estimates suggest that a typical firm's patent-R&D

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[8] This calculation of the predicted renewal rate is based on the estimated coefficients in column 7 of Table 6, assuming that all regressors beside MAINT take the sample means.

[9] We note that the coefficient associated with maintenance fees in Table 6 is estimated with patents mostly assigned to large firms but not independent inventors or small firms due to data availability on firm characteristic variables. We suspect that the estimation based on all patents may provide us with a bigger estimate because the patents assigned to large firms are likely to have higher values than those assigned to independent inventors or small firms. Therefore, the explanatory power of 40% may be underestimated.

ratio will fall by 10 percent if application filing fees (FILING) are doubled.[10]

While the empirical results generally support the implications of our theoretical model, we have left a number of issues unaddressed. First, our model ignores the general equilibrium effects of maintenance and application fees. If competitors alter their decisions regarding renewal and patenting as fees rise, a firm may wish to change its own decisions as a response to the changes in the competitors' behaviors.

Second, the model is simplified such that a firm has a single new innovation in each period rather than having a multiple number of patents to renew or a multiple number of innovations to patent. In the latter case, certain sequential innovations can be complementary, while others are substitutable.

Third, our model assumes that one patentable innovation is endowed in each period and ignores the research and development process through which an innovation is actually produced. In our empirical specification we include R&D expenditures as a regressor to control for research efforts in innovation.

Fourth, as we cannot observe all innovations, patented or not, that a firm generates via research, we did not employ a binary choice model in our empirical estimation for patenting decisions. Ideally, we wished to estimate the effects of our regressors by determining which innovation were patented and which were kept secret. We plan to pursue these issues in future studies.

[10] This calculation is based on the estimated coefficients associated with LnFILING in column 2 of Table 7, assuming that other regressors are not affected by changes in the filing fees. The predicted reductions of the patent-R&D ratio are derived as exp(-0.1505*ln2) = 0.9009.

Appendix A: Proof of Proposition 1

We first consider the case of complementary technologies ($\alpha > 0$). We define $\Delta \equiv V_t - W_t$ as the future net benefit of holding a patent. Note that the time subscript for Δ is dropped since all the distributions are time-invariant. We can show that

$\Delta=$

$$\int_{c_R}^{\infty}\int_{-\infty}^{c_A-\delta\Delta-\alpha}(\varepsilon - c_R)\,dG(\theta,\varepsilon) + \int_{-\theta+c_A+c_R-\delta\Delta-\alpha}^{\infty}\int_{c_A-\delta\Delta-\alpha}^{c_A-\delta\Delta}(\varepsilon+\theta-c_R-c_A+\alpha+\delta\Delta)\,dG + \int_{c_R-\alpha}^{\infty}\int_{c_A-\delta\Delta}^{\infty}(\varepsilon-c_R+\alpha)\,dG$$

.

Differentiating Δ with respect to c_R,

$$\partial\Delta/\partial c_R = \left[\frac{\delta A}{\delta\Delta}\right]\left[\frac{\delta\Delta}{\delta c_R}\right]\int_{c_R}^{\infty}(\varepsilon-c_R)g(\varepsilon)d\varepsilon - A\int_{c_R}^{\infty}g(\varepsilon)d\varepsilon + \int_{c_A-\delta\Delta-\alpha}^{c_A-\delta\Delta}\left(\frac{\partial B}{\partial\Delta}\cdot\frac{\partial\Delta}{\partial c_R}+\frac{\partial B}{\partial c_R}\right)f(\theta)d\theta -$$

$$\delta\left[\frac{\delta\Delta}{\delta c_R}\right]f(c_A - \delta\Delta)\int_{c_R-\alpha}^{\infty}(\varepsilon-c_R+\alpha)g(\varepsilon)d\varepsilon + \delta\left[\frac{\delta\Delta}{\delta c_R}\right]f(c_A-\delta\Delta-\alpha)\int_{c_R}^{\infty}(\varepsilon-c_R)g(\varepsilon)d\varepsilon +$$

$$\left[\frac{\delta C}{\delta\Delta}\right]\left[\frac{\delta\Delta}{\delta c_R}\right]\int_{c_R-\alpha}^{\infty}(\varepsilon-c_R+\alpha)g(\varepsilon)d\varepsilon - C\int_{c_R-\alpha}^{\infty}g(\varepsilon)d\varepsilon\ ,$$

where $A = \int_{-\infty}^{c_A-\delta\Delta-\alpha}f(\theta)d\theta$, $B = \int_{-\theta+c_A+c_R-\delta\Delta-\alpha}^{\infty}(\varepsilon+\theta-c_R-c_A+\alpha+\delta\Delta)g(\varepsilon)d\varepsilon$, $C = \int_{c_A-\delta\Delta}^{\infty}f(\theta)d\theta$, $\partial A/\partial\Delta = -\delta f(c_A-\delta\Delta-\alpha) < 0$, $\partial B/\partial\Delta = \delta\int_{-\theta+c_A+c_R-\delta\Delta-\alpha}^{\infty}g(\varepsilon)d\varepsilon > 0$, $\partial B/\partial c_R = -\int_{-\theta+c_A+c_R-\delta\Delta-\alpha}^{\infty}g(\varepsilon)d\varepsilon < 0$, $\partial C/\partial\Delta = \delta f(c_A-\delta\Delta) > 0$.

Rearranging the equation for $\partial\Delta/\partial c_R$, we can show that $\partial\Delta/\partial c_R < 0$.

If sequential innovations are substitutable ($\alpha<0$), the net benefit becomes

$\Delta=$

$$\int_{c_R}^{\infty}\int_{-\infty}^{c_A-\delta\Delta}(\varepsilon-c_R)dG(\theta,\varepsilon)+$$

$$\int_{\theta-c_A+c_R+\delta\Delta}^{\infty}\int_{c_A-\delta\Delta}^{c_A-\delta\Delta-\alpha}(\varepsilon-\theta-c_R+c_A-\delta\Delta)dG+\int_{c_R-\alpha}^{\infty}\int_{c_A-\delta\Delta-\alpha}^{\infty}(\varepsilon-c_R+\alpha)dG$$

.

Differentiating Δ with respect to c_R,

$$\partial\Delta/\partial c_R = \left[\frac{\partial D}{\delta\Delta}\right]\left[\frac{\delta\Delta}{\delta c_R}\right]\int_{c_R}^{\infty}(\varepsilon-c_R)g(\varepsilon)d\varepsilon - D\int_{c_R}^{\infty}g(\varepsilon)d\varepsilon + \int_{c_A-\delta\Delta}^{c_A-\delta\Delta-\alpha}\left(\frac{\partial E}{\partial\Delta}\cdot\frac{\partial\Delta}{\partial c_R}+\frac{\partial E}{\partial c_R}\right)f(\theta)d\theta -$$

$$\delta\left[\frac{\delta\Delta}{\delta c_R}\right]f(c_A - \delta\Delta - \alpha)\int_{c_R-\alpha}^{\infty}(\varepsilon-c_R+\alpha)g(\varepsilon)d\varepsilon + \delta\left[\frac{\delta\Delta}{\delta c_R}\right]f(c_A- \delta\Delta)\int_{c_R}^{\infty}(\varepsilon-c_R)g(\varepsilon)d\varepsilon +$$

$$\left[\frac{\delta C}{\delta\Delta}\right]\left[\frac{\delta\Delta}{\delta c_R}\right]\int_{c_R-\alpha}^{\infty}(\varepsilon-c_R+\alpha)g(\varepsilon)d\varepsilon - F\int_{c_R-\alpha}^{\infty}g(\varepsilon)d\varepsilon ,$$

where $D = \int_{-\infty}^{c_A-\delta\Delta}f(\theta)d\theta$, $E = \int_{\theta-c_A+c_R+\delta\Delta}^{\infty}(\varepsilon-\theta-c_R+c_A-\delta\Delta)g(\varepsilon)d\varepsilon$, $F = \int_{c_A-\delta\Delta-\alpha}^{\infty}f(\theta)d\theta$,

$\partial D/\partial\Delta = -\delta f(c_A-\delta\Delta) < 0$, $\partial E/\partial\Delta = -\delta\int_{\theta-c_A+c_R+\delta\Delta}^{\infty}g(\varepsilon)d\varepsilon < 0$, $\partial E/\partial c_R = -\int_{\theta-c_A+c_R+\delta\Delta}^{\infty}g(\varepsilon)d\varepsilon$

< 0, $\partial F/\partial\Delta = \delta f(c_A-\delta\Delta-\alpha) > 0$.

Rearranging the above equation for $\partial\Delta/\partial c_R$, we can also show that $\partial\Delta/\partial c_R < 0$ and $\partial(c_R+\Delta)/\partial c_R > 0$. This change with rising c_R is illustrated in Figure 3 (see the main text for explanation).

Appendix B: Proof of Proposition 2

When we have complementary technologies, we can show in the same manner as in Appendix A that $\partial\Delta/\partial c_A < 0$. This implies that the boundaries in Figure 4a shift from a solid line to a dashed line with an increase in c_A, and thus the probabilities for both renewal and patenting fall.

In the case of substitutable technologies, we can demonstrate that $\partial\Delta/\partial c_A > 0$, but $\partial(c_A - \delta\Delta)/\partial c_A > 0$. This indicates that the area for patenting (P_t =1) is shrunk, but that for renewing (R_t = 1) is expanded, as shown in Figure 4b, as c_A rises, which indicates that the patenting probability falls but the renewal probability rises with an increase in filing fees.

Appendix C: Proof of Proposition 3

When technologies are complementary, we can demonstrate that $\partial\Delta/\partial\alpha > 0$, which implies that a higher degree of complementarity raises the net benefit of holding a patent. An increase in α then can be shown to shift the borders in Figure 1 in such a way that the areas for both patenting and renewal are expanded, thus raising the probabilities of both patenting and renewal.

On the other hand, when technologies are substitutable, we can demonstrate that $\partial\Delta/\partial\alpha > 0$, and the area for patenting is reduced when we have a higher degree of substitutability (higher absolute value of α), which means a reduction in the probability of patenting. Note that the higher absolute value of α means a small α, as α is negative in this case. The effect of α on renewal is ambiguous.

Appendix D: Patent Classification, Category and Sub-category Names (NBER Patent Citations Data, Hall, Jaffe and Trajtenberg, 2005)

Category 1: Chemical (Subcategory 11: Agriculture, Food, Textiles; 12: Coating; 13: Gas; 14: Organic Compounds; 15: Resins; 19: Miscellaneous-chemical)

Category 2: Computer & Communication (Subcategory 21: Communications; 22: Computer Hardware & Software; 23: Computer Peripherals; 24: Information Storage)

Category 3 Drug & Medical (Subcategory 31: Drugs; 32: Surgery & Medical Instruments; 33: Biotechnology; 39: Miscellaneous-Drug & Medical)

Category 4: Electrical & Electronic (Subcategory 41: Electrical Device; 42: Electrical Lighting; 43: Measuring & Testing; 44: Nuclear & X-rays; 45: Power Systems; 46: Semiconductor Devices; 49: Miscellaneous-Electronic)

Category 5: Mechanical (Subcategory 51: Materials Processing & Handling; 52: Metal Working; 53: Motors, Engines & Parts; 54: Optics; 55: Transportation; 59: Miscellaneous-Mechanical)

Category 6: Others (Subcategory 61: Agriculture, Husbandry, Food; 62: Amusement Devices; 63: Apparel & Textile; 64: Earth Working & Wells; 65: Furniture, House Fixtures; 66: Heating; 67: Pipes & Joints; 68: Receptacles; 69: Miscellaneous-Others)

Appendix E: SIC Codes

Group 20: Food And Kindred Products; Group 22: Textile Mill Products; Group 25: Furniture And Fixtures; Group 26: Paper And Allied Products; Group 27: Printing, Publishing, And Allied Industries; Group 28: Chemicals And Allied Products; Group 29: Petroleum Refining And Related Industries; Group 30: Rubber And Miscellaneous Plastics Products; Group 31: Leather And Leather Products; Group 32: Stone, Clay, Glass, And Concrete Products; Group 33: Primary Metal Industries; Group 34: Fabricated Metal Products, Except Machinery And Transportation Equipment; Group 35: Industrial And Commercial Machinery And Computer Equipment; Group 36: Electronic And Other Electrical Equipment And Components, Except Computer Equipment; Group 37: Transportation Equipment; Group 38: Measuring, Analyzing, And Controlling Instruments; Photographic, Medical And Optical Goods; Watches And Clocks; Group 39: Miscellaneous Manufacturing Industries.

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Table 2 Patent Maintenance Fee Schedule
for Applications Filed after Dec. 12, 1980

Year when renewing patents	Maintenance fees in Current Dollar (Small/ Large entity)			Maintenance fees in 1990 Constant Dollar (Small/ Large entity)		
	4th year	8th year	12th year	4th year	8th year	12th year
1984	200/400	400/800	600/1200	241.2/482.4	482.4/964.7	723.5/1447.1
1985	225/450	445/890	670/1340	263.3/526.7	520.8/1041.7	784.2/1568.4
1986	225/450	445/890	670/1340	257.7/515.3	509.6/1019.2	767.2/1534.5
1987	225/450	445/890	670/1340	250.8/501.6	496.0/992.0	746.8/1493.6
1988	225/450	445/890	670/1340	242.5/485.1	479.7/959.4	722.2/1444.5
1989	225/450	445/890	670/1340	233.7/467.4	462.2/924.3	695.8/1391.7
1990	225/450	445/890	670/1340	225/450	445/890	670/1340
1991	225/450	445/890	670/1340	217.4/434.8	430.0/860.0	647.4/1294.8
1992	415/830	835/1670	1250/2500	391.9/783.9	788.6/1577.2	1180.5/2361.1
1993	415/830	835/1670	1250/2500	383.1/766.2	770.8/1541.7	1154.0/2307.9
1994	465/930	935/1870	1410/2820	420.3/840.7	845.2/1690.4	1274.6/2549.1
1995	480/960	965/1930	1450/2900	425.2/850.4	854.8/1709.6	1284.4/2568.8
1996	495/990	985/1990	1495/2990	430.3/860.7	865.0/1730.0	1299.7/2599.4
1997	510/1020	1025/2050	1540/3080	436.1/872.3	876.5/1753.1	1316.9/2633.9
1998	525/1050	1050/2100	1580/3160	444.0/888.0	888.0/1776.1	1336.3/2672.6
1999	470/940	950/1900	1455/2910	391.8/783.6	792.0/1583.9	1213.0/2425.9
2000	415/830	950/1,900	1,455/2,910	338.6/677.2	775.1/1550.2	1187.1/2374.3
2001	425/850	975/1,950	1,495/2,990	338.6/677.3	776.9/1553.7	1191.2/2382.4
2002	440/880	1,010/2,020	1,550/3,100	344.6/689.1	790.9/1581.8	1213.8/2427.6
2003	445/890	1,025/2,050	1,575/3,150	341.2/682.5	786.0/1572.0	1207.7/2415.5
2004	455/910	1,045/2,090	1,610/3,220	339.2/678.5	779.1/1558.3	1200.4/2400.8

Note: Patent maintenance fees for applications filed by large entities between Dec. 12, 1980 and Aug. 27, 1982 were subject to the fee schedule for small entities.

Table 3 Patent Application Filing Fee Schedule (current dollar)

Filing year	Basic fees (S/L)	Independent claims in excess of 3 (S/L)	Claims in excess of 20 (S/L)	Multiple dependent Claims (S/L)
1965	65	10	2	
1966	65	10	2	
1967	65	10	2	
1968	65	10	2	
1969	65	10	2	
1970	65	10	2	
1971	65	10	2	
1972	65	10	2	
1973	65	10	2	
1974	65	10	2	
1975	65	10	2	
1976	65	10	2	
1977	65	10	2	
1978	65	10	2	
1979	65	10	2	
1980	65	10	2	
1981	65	10	2	
1982	65	10	2	
1983	150/300	15/30	5/10	50/100
1984	150/300	15/30	5/10	50/100
1985	150/300	15/30	5/10	50/100
1986	150/300	15/30	5/10	50/100
1987	170/340	17/34	6/12	55/110
1988	170/340	17/34	6/12	55/110
1989	170/340	17/34	6/12	55/110
1990	170/340	17/34	6/12	55/110
1991	170/340	17/34	6/12	55/110
1992	170/340	17/34	6/12	55/110
1993	185/370	18/36	6/12	60/120
1994	355/710	37/74	11/22	165/230
1995	365/730	38/76	11/22	120/240

Table 4 Variables Used in the Regressions

Variable	Description	Mean [Std. Dev.]
Whether to Renew	Dummy variable for whether a patent is renewed or not	0.85795 [0.3491]
Patents/R&D	Annual number of a firm's patent grants per R&D dollar	1.2342 [4.388]
MAINT	Patent maintenance fees per patent (1990 constant dollar)	959.66 [554.8]
FILING	Application filing fees (basic fees plus firm-average fees for claims in excess of 20 in 1990 constant dollar)	443.47 [152.2]
MTFEE	Average of maintenance fees for 4th, 8th, and 12th year patents, weighted by the shares of patents in 4th, 8th, and 12th year (1990 constant dollar)	393.06 [517.5]
RENEW	Total annual number of a firm's patents which are subject to maintenance fees	314.60 [341.6]
APPLI	Total annual number of a firm's patent applications	279.47 [400.9]
CRECEIVE	Number of citations received by citing patent in 5 years following grant date	8.9203 [11.71]
MCRECEIVE	Firm's per-patent average of the number of citations received in 5 years following grant date	5.4896 [5.109]
R&D	Firm's annual R&D expenditures in real terms	7.35e+08 [1.08e+09]
K/L	Firm's value of plants and equipments (real dollar) per employee	81,642.3 [105,057]
SCITE	Number of backward citations to a firm's own patents as a fraction of all citations in the firm's patents ($\in[0,1]$)	0.17283 [0.08811]
8TH_YR	Dummy variable for a patent subject to 8th-year maintenance fees	0.29619 [0.4566]
12TH_YR	Dummy variable for a patent subject to 12th-year maintenance fees	0.041281 [0.1989]

Table 5 Renewal Rate

Year	4th-year renewals		8th-year renewals		12th-year renewals	
	A. Patents renewable	B. Renewal rate (%)	A. Patents renewable	B. Renewal rate (%)	A. Patents renewable	B. Renewal rate (%)
1986	10,801	83.26				
1987	41,689	83.39				
1988	63,884	84.09				
1989	68,961	84.99				
1990	71,750	84.84	8,993	75.86		
1991	82,580	83.89	34,765	74.31		
1992	77,809	81.33	53,717	70.13		
1993	95,440	80.07	58,616	67.79		
1994	90,239	79.07	60,873	66.03	6,822	57.26
1995	94,470	78.60	69,280	66.92	25,832	57.58
1996	66,359	80.98	39,485	68.68	24,453	60.08
Total	763,982	81.85	325,729	68.69	57,107	58.61
(Data used in our analysis)	(97,916)	(90.97)	(43,774)	(77.81)	(6,101)	(59.97)

Note: The total number of patents subject to maintenance fees is reported in column A. Column B reports the renewal rate which is the ratio of the number of patents renewed to the number of patents subject to maintenance fees.

Table 6　Renewal Decision

Dependent Variable: Whether to Renew　　　　Random-Effects Logit Model

	(1) Coef.	(1) z	(2) Coef.	(2) z	(3) Coef.	(3) z	(4) dPr/dLnX	(5) dPr/dLnX	(6) dPr/dLnX
LnMAINT	-0.8422	-18.62	-0.8426	-18.60	-0.7790	-13.33	-0.0541	-0.0364	-0.0853
LnFILING	-0.1851	-5.54	#	#	-0.0515	-0.91	-0.0119	-0.0070	-0.0195
LnRENEW	-0.2752	-11.14	-0.2783	-11.24	-0.2705	-9.34	-0.0177	-0.0130	-0.0289
LnAPPLI	0.2229	11.21	0.2223	11.16	0.2271	11.34	0.0143	0.0106	0.0226
CRECEIVE	0.0475	36.96	0.0465	35.60	0.0475	36.96	0.0272	0.0247	0.0263
LnR&D	0.2755	9.47	0.2811	9.64	0.2644	9.04	0.0177	0.0108	0.0249
LnK/L	-0.1914	-3.64	-0.1855	-3.51	-0.1791	-3.40	-0.0123	0.0020	-0.0220
SCITE	0.1936	1.12	0.2067	1.19	0.2077	1.20	0.0022	0.0043	0.0004
8TH_YR	-0.4357	-11.16	-0.4414	-11.27	-0.4812	-10.66	-0.0303	-0.0351	-0.0390
12TH_YR	-0.8298	-13.41	-0.8448	-13.59	-0.8866	-12.46	-0.0742	-0.1002	-0.0827
T					0.0684	2.57			
T^2					-0.0069	-2.94			
Observations	147,791		147,791		147,791		147,791	72,787	75,004
Log Like.	-50257		-50040		-50252				
χ^2 (d.f.)	9632.52 (10)		9961.50 (45)		9650.30 (12)				
p value	0.00		0.00		0.00				

Note: The z columns report the ratios of the coefficient to its standard error. The p value reported is of the test that all coefficients are jointly zero. #Column 2 includes interaction terms of 36 patent category dummies and LnFILING to incorporate distinct effects of the latter variable across patent categories (see Appendix D). The marginal effects on Pr(Renew) of a 1% increase of the variables (in their linear form) in column 1 are reported in column 4. In column 5 and 6, we separate our sample to observations with CRECEIVE ≥6 (col. 5) and those with CRECEIVE <6 (col. 6), and report the marginal effects of the regressors in column 1, using each subset.

Table 6 Renewal Decision (cont.)

Dependent Variable: Whether to Renew — Random-Effects Logit Model

	(7) 4th Year Renewal		(8) 8th Year Renewal		(9) 12th Year Renewal	
	Coef.	z	Coef.	z	Coef.	z
LnMAINT	-0.9048	-14.35	-0.8456	-12.69	0.2388	0.22
LnFILING	-0.0955	-1.87	-0.2458	-5.36	-0.2233	-0.33
LnRENEW	-0.2398	-8.29	-0.3060	-6.49	-0.3567	-3.44
LnAPPLI	0.3444	12.56	0.1942	6.02	0.0537	0.58
CRECIEVE	0.0518	24.59	0.0472	25.71	0.0395	10.85
LnR&D	0.1368	3.84	0.2697	6.04	0.2407	2.63
LnK/L	-0.1681	-2.72	-0.1922	-2.47	-0.0366	-0.35
SCITE	0.2796	1.16	-0.3320	-1.18	0.9254	1.23
Observations	97,916		43,774		6,101	
Log Like.	-25472		-20471		-3740	
χ^2 (d.f.)	1753.38 (8)		1258.59 (8)		133.64 (8)	
p value	0.00		0.00		0.00	

Note: The z columns report the ratios of the coefficient to its standard error. The p value reported is of the test that all coefficients are jointly zero. Columns 7-9 re-estimate column 1 with the sub-sample of those patents to renew in their 4^{th}, 8^{th}, or 12^{th} years, respectively.

Table 7 Patenting Decision

Dependent Variable: Log(Number of Patents/R&D in mil. $) Random-Effects Regression Model

	(1)		(2)		(3)		(4)	
	Coef.	z	Coef.	z	Coef.	z	Coef.	z
LnFILING	-0.2861	-18.86	-0.1505	-3.37	-0.1526	-3.41	-0.2964	-5.31
LnMTFEE			-0.1428	-4.33	#	#	-0.1831	-3.85
LnRENEW			-0.0356	-2.59	-0.0332	-2.41	-0.0068	-0.43
MCRECEIVE	-0.0012	-0.88	-0.0127	-4.40	-0.0128	-4.45	-0.0122	-4.11
LnK/L	-0.3062	-11.82	-0.1925	-4.90	-0.2014	-4.58	-0.1972	-5.02
SCITE	0.1825	1.83	0.2823	2.11	0.3113	2.32	0.2768	2.08
T							-0.1407	-4.67
T^2							0.0096	4.49
Observations	7687 (998 firms)		3518 (634 firms)		3517 (633 firms)		3518 (634 firms)	
R^2	0.0627		0.0362		0.0783		0.0490	

Note: The z columns report the ratios of the coefficient to its standard error. All columns employ firm-level random effects. #Column 3 includes interaction terms of 17 two-digit SIC codes and LnFILING to incorporate distinct effects of the latter variable across industries (see Appendix E for the SIC classification).

Figure 1
Renewal and Patenting Decisions:
Complementary Technologies Case ($\alpha > 0$)

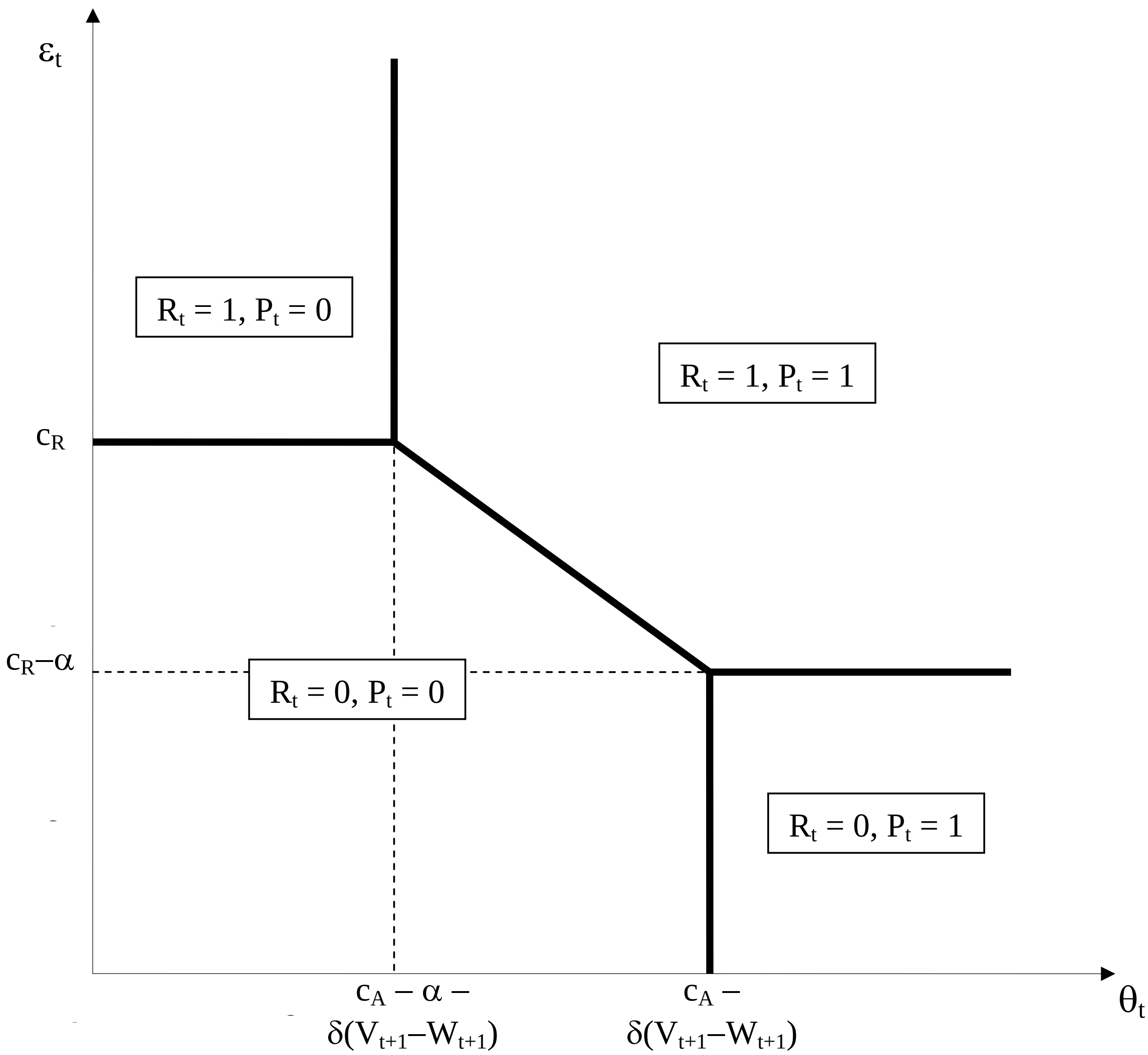

Figure 2
Renewal and Patenting Decisions:
Substitutable Technologies Case ($\alpha < 0$)

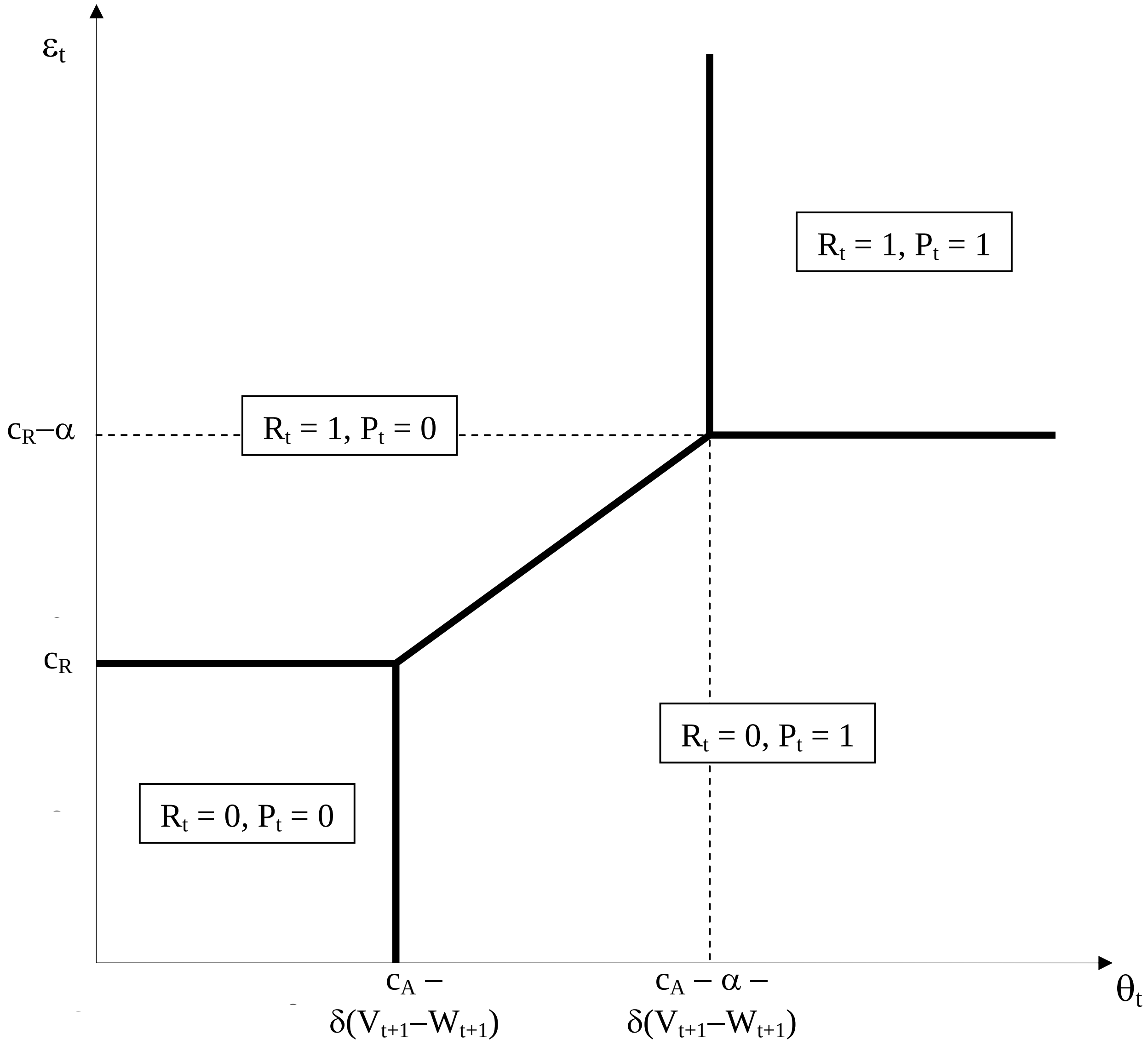

Figure 3
Effect of Renewal Fees in Substitutable Technologies Case (α < 0)

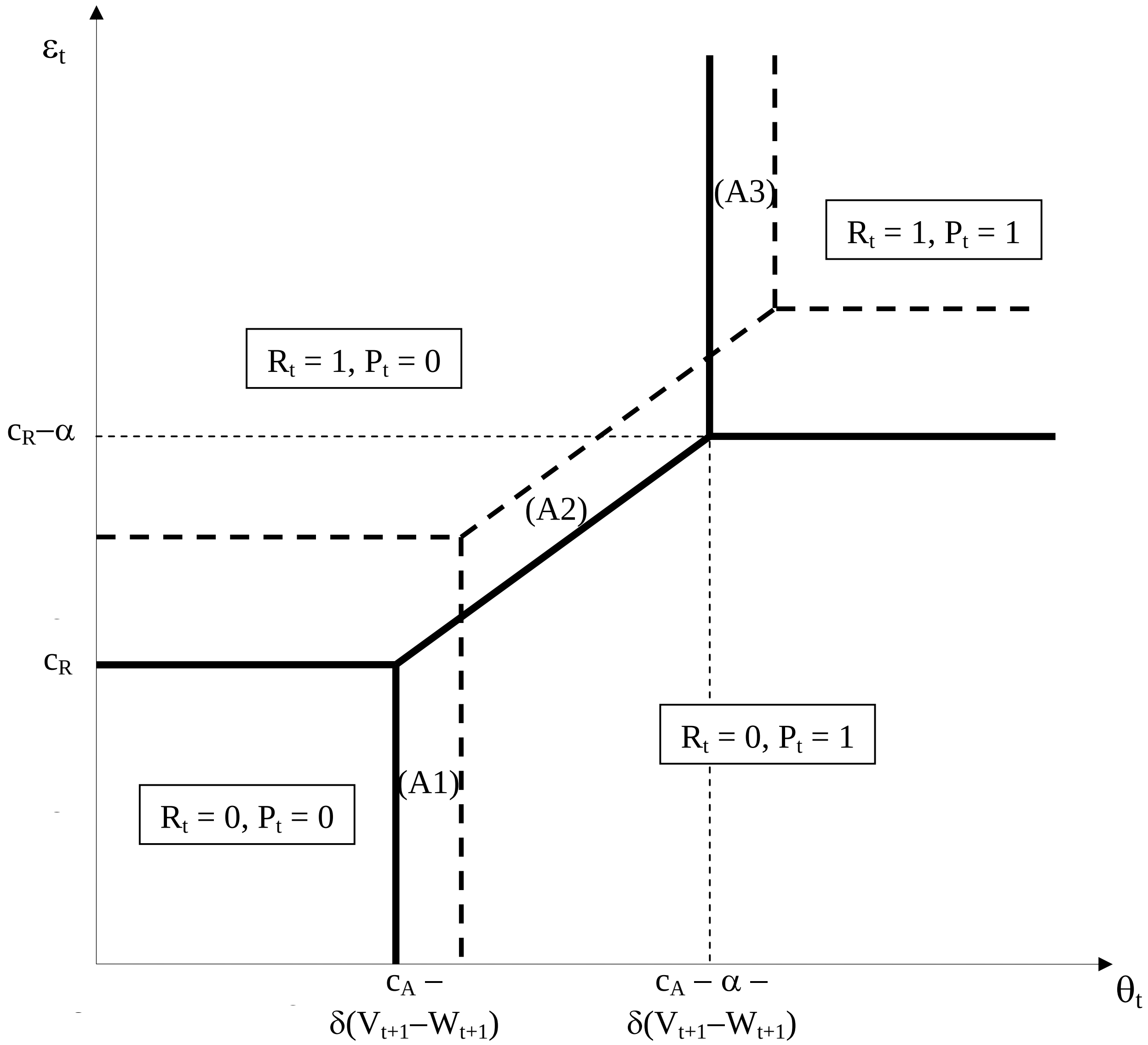

Figure 4a
Effect of Filing Fees in Complementary Technologies Case (α > 0)

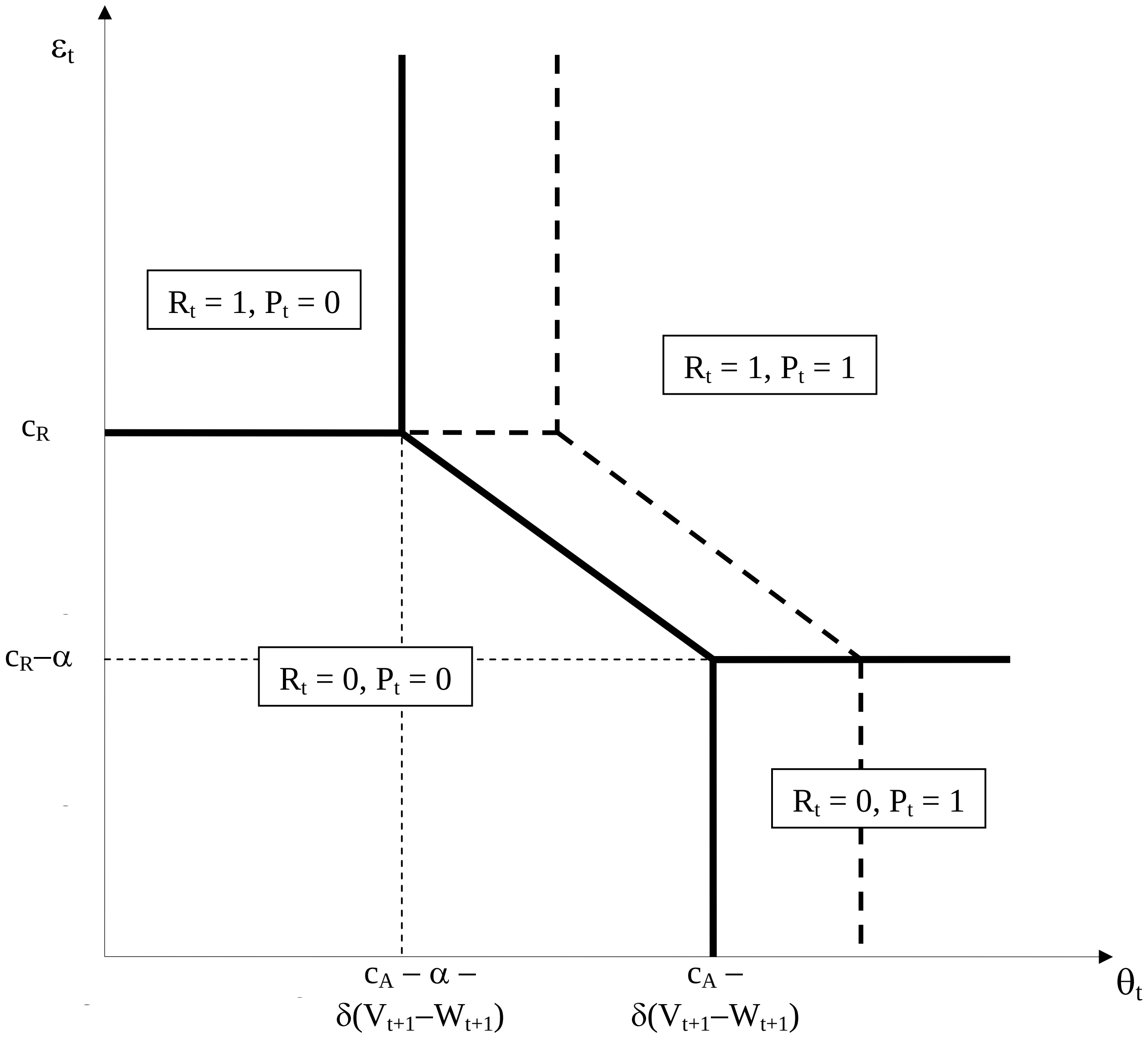

Figure 4b
Effect of Filing Fees in Substitutable Technologies Case ($\alpha < 0$)

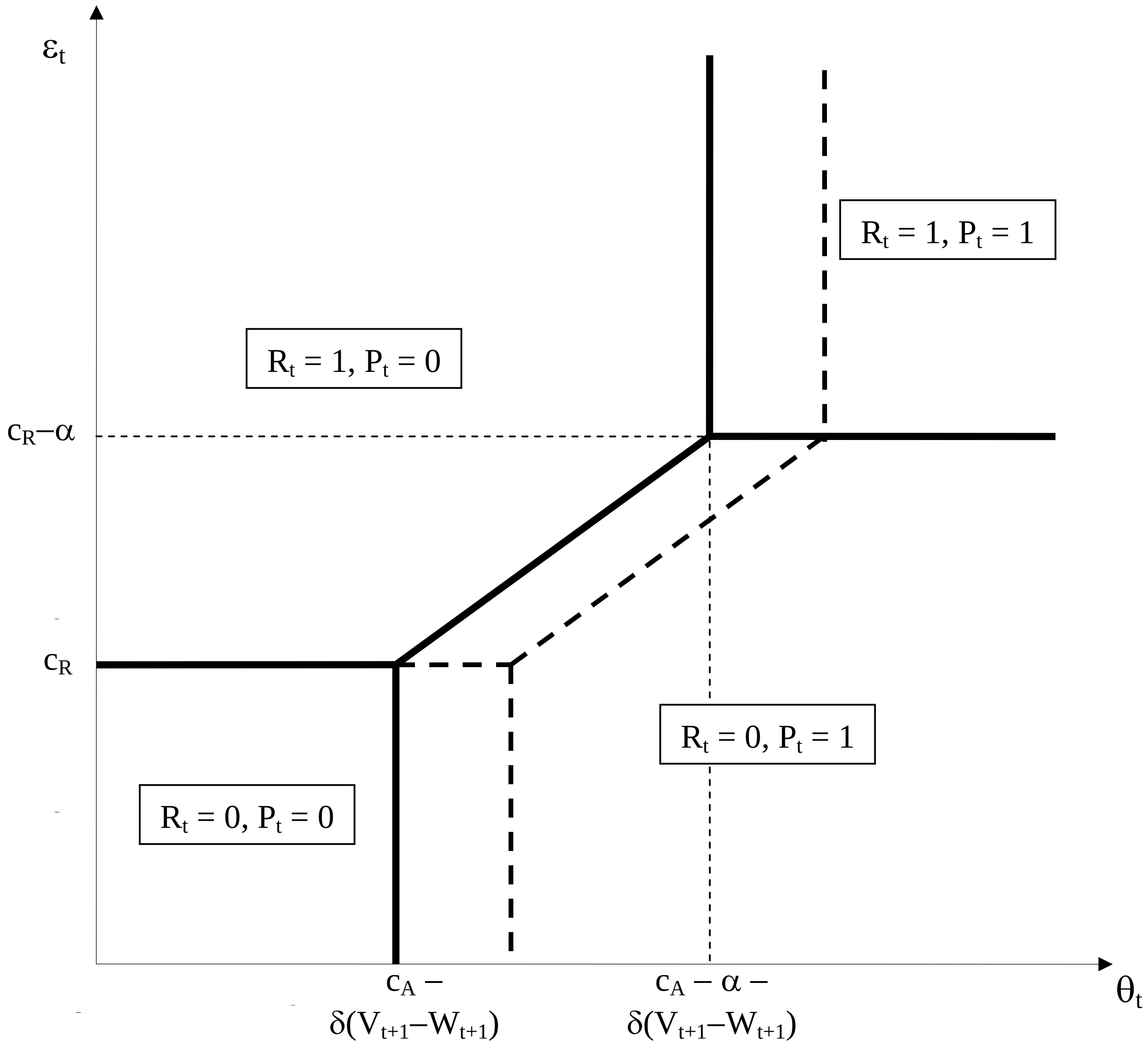

Figure 5
Patent Expirations and Maintenance Fees