The Value of U.S. Patents by Owner and Patent Characteristics

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Abstract: This paper uses renewal data to estimate the value of U.S. patents, controlling for patent and owner characteristics. Estimates of U.S. patent value are substantially larger than estimates for European patents, however, the ratio of patent value to R&D is only about 2%. Patents issued to small patentees are much less valuable than those issued to large corporations, perhaps reflecting imperfect markets for technology. Litigated patents are more valuable, as are highly cited patents. However, patent citations explain little variance in value. These estimates of patent value correspond to estimates of the contribution of patent rents to firm market value.

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Patent value is an interesting economic quantity for several reasons: it informs policy because it is a measure of the reward that the patent system provides inventors; it aids accounting for the value of intangibles; it helps measure the productivity and quality of R&D.

This paper extends the research on patent value by estimating the renewal value of U.S. patents using a rich set of control variables including patent citation statistics, whether the patent was litigated or reissued, the type of patent assignee and technology, and, for a sub-sample of patents issued to publicly listed firms, details of the patent owner's financial and other characteristics, including firm market value, patent portfolio size, R&D, and industry. This extension allows quantitative assessment of the association between patent citations and patent value, more accurate estimation of the subsidy that patent provide to perform R&D, and a reconciliation between renewal estimates of patent value and estimates based on firm market value.

This approach combines two strands of the literature. One strand uses data on patent renewal decisions to estimate the value of holding a patent.[1] The implicit value of a patent is revealed when its owner pays a renewal fee, implying that the patent is worth more than the fee required to keep it in force. Subject to some important assumptions, this approach has been used to obtain dollar estimates of patents. However, most of this research only looks at the aggregate value of patents. Schankerman (1998) and Lanjouw (1998) look at patent value by technology category and nationality of the patentee for French and German patents, respectively. But many other factors that might reasonably influence patent value have not been explored in this context.

The other strand of the literature looks at the relationship between patent value and a variety of patent characteristics with an eye to measuring patent quality, to developing quality-adjusted measures of inventive output and to estimating the contribution of intangibles to firm value. These studies look at correlations between patent characteristics and variables that should be correlated with patent value such as whether a patent is litigated or opposed (Harhoff et al. 2003b, Allison et al. 2004, Lanjouw and Schankerman 2004a, Marco 2005), survey measures of subjective value (Harhoff et al. 1999, 2003a), the number of countries in which the patentee files (Putnam 1996, Lanjouw and Schankerman 2004a), whether the patent is renewed (Harhoff et al. 2003b, Lanjouw and Schankerman 2004a), and firm market value (Hall et al. 2005). Based on such correlations, researchers infer, for example, that the number of citations made to a patent is associated with that patent's value. However, these studies recognize that the relationship between citations and patent value is "noisy" and they have not

1 See Lanjouw et al. 1998 for a review of this literature. Recent additions include Baudry and Dumont (2006), Gustafsson (2005) and Serrano (2006).

quantified the actual increase in value associated with an incremental citation received.

This paper integrates these two approaches. Because a rich set of data is available about U.S. patents, I can combine information about patent renewals with information about the owner and patent characteristics. I model patentees' decisions to renew as a kind of ordered probit—patent renewal fees increase sharply with the age of the patent, sorting the patents by value over time. Variables such as patent citations and firm characteristics can be included on the right hand side of the corresponding regression. The latent variable that represents the patentee's valuation is a linear combination of such characteristics and a stochastic error term. In effect, previous studies have only included a constant and an error term on the right hand side.

There are several advantages to including patent characteristics and owner characteristics in a renewal model of patent value. Using this model, I am able to obtain dollar estimates of the incremental effect of patent citations and other characteristics on patent value. I am also able to estimate how much of the total variance in log patent value is explained by such characteristics. I find, in general, that these characteristics are significantly correlated with patent value but they do not explain much of the overall variation. That is, as other researchers have concluded, these are rather noisy measures of value. Citation statistics may be more informative about the value of the underlying technology than they are about the value of the patent *per se*.

In addition, this approach allows me to measure separately other factors that influence patent value such as the type and firm size of the patentee or the size of the patentee's patent portfolio. I find substantial differences in patent value, for example, between small and large patentees. This has important implications for policy and for what it implies about about the market for patent licenses.

I also relate patent value to the market value of public firms. A substantial literature uses patents as a right hand side variable in regressions on Tobin's *Q* (see Hall 2000 for a review of this literature). Most of these studies treat the market value of the firm as a hedonic variable and patents are one characteristic of a firm that captures information on the value of the firm's intangibles. I address a different concern, namely, whether the value of patents implied by renewal behavior corresponds to the value of patent rents that contribute to firm value. I find that renewal value corresponds reasonably closely to the value of rents, validating the estimates based on renewal data. This is important because estimates of patent value from renewal data are based on strong assumptions about the value distribution of unexpired patents. More generally, I find that although much of the value of firms may consist of intangible assets, patents *per se* only contribute a small amount to firm value.

This finer-grained information about patent owners also allows me to obtain more accurate estimates of the value that patents provide as incentives to perform R&D. Mark Schankerman (1998) argues that the ratio of patent value to the value of the associated R&D is an "equivalent subsidy rate"—under some assumptions, this ratio represents an upper bound on the subsidy that would be needed to elicit the same level of R&D in a world without patent protection. Several patent renewal studies have estimated this ratio either for the aggregate patents of a nation or by technology class, using highly aggregated data. Because I can closely match the value of patents to the value of R&D on a firm-by-firm basis, I am able to obtain more representative estimates of the equivalent subsidy rate.

With the exception of Carlos Serrano (2006), who obtains preliminary estimates of the value of a subset of U.S. patents using patent renewal and re-assignment data, patent renewal data has not previously been used to estimate the value of U.S. patents. Kimberly Moore (2006) reports general features of U.S. patent renewal data.

The paper is organized as follows: the next section presents a model of patent renewal and discusses theoretical issues; Section 2 describes the data, and Sections 3 and 4 present results for patents issued in 1991 and for a panel of patents issued to public manufacturing firms from 1985-91, respectively. Section 5 presents estimates of the equivalent subsidy ratio. Section 6 discusses the significance of the low patent values for small patentees and Section 7 concludes.

1. Model of Patent Renewal and Value

1.1 Patent Value

Researchers have used measures of patent value for a variety of different purposes, including measuring inventive output, measuring the incentive effect of patents, and measuring the contribution of intangibles to firm value. Different uses can imply different definitions and different methods of measurement, so it is helpful to set out some initial distinctions (see Harhoff et al. 2003b for a different set of distinctions).

I aim to estimate the value of incremental rents that patents earn. Patents can provide their owners a degree of market power that conveys a stream of profits that exceeds the profits they could earn without patents. These profits can be realized either through the ability to exclude others from product markets, in which case product prices rise above the level without patents, or through the ability to exclude others in the markets for technology licensing or sale. This notion of patent value corresponds to the "reward" theory of patents—patent rents are the reward. As I show below, this notion of patent value can also be incorporated into a model of firm value.

The value of patent rents, however, is distinct from the value of the underlying technology. This divergence occurs for two reasons. First, innovators also appropriate value from technology by non-patent means such as lead-time advantage and trade secrecy. The value of patent rents is incremental, that is, it is measured relative to an alternative value appropriated by these other means. In general, not all of the inventions nor all of the technical knowledge of a new technology is protected by a patent, so in general, the value of a technology exceeds the value of the associated patents.

Second, the value of patents is, to some extent, endogenous. Patentees can exert varying degrees of effort in the prosecution of patents and in their enforcement. This effort at patent "refinement" affects the strength of the patent rights and hence the value of the rents derived. For instance, patent applicants can invest more effort in drafting a patent by including more claims (to broaden the scope of the claims and to make them more resistant to invalidation challenges) and more citations (to immunize the patent against possible prior art). Patent owners can strengthen patent claims by obtaining a re-issued patent. Innovators can also obtain more patents on a technology and related technologies. A larger number of patents may simply reflect that an owner is protecting more inventions with patents, or that owner may be "fencing" off the technology by patenting possible substitute technologies or building a patent "thicket." Below I find evidence that patentees do increase aggregate patent value through such measures.

This endogeneity means that variation in the value of technologies does not necessarily correspond closely to the variation in patent rents. A firm with highly valuable technology may obtain relatively *more* patents on that technology, so that the average value of rents *per patent* does not entirely reflect the value of the technology. This means that patent value, in the sense used in this paper, does not serve well as a measure of "inventive output." It will, in general, be less than the value of the underlying technology, although these two measures are likely correlated.

1.2 Patent Renewal

The model I use is a simple variant of the model initially developed by Pakes and Schankerman (1984). Patentees derive rents from their patents only so long as those patents remain in force. If the expected stream of rents is not larger than the fees required to keep the patent in force, patent owners will let the patent expire. This means that patent renewal and expiration decisions implicitly reflect the value of the associated rents. Let $r_i(t)$ be the annual flow of rents for the ith patent at time t.

Following the literature, I assume that this profit flow depreciates at a constant rate, d, so that

$r_i(t) = r_i(0) \cdot e^{-d\,t}$. A patent might depreciate because of technological obsolescence (the underlying invention becomes less valuable) or because competitors are able to "invent around" the patent.

Although constant depreciation is a common assumption, there are several reasons why the actual depreciation pattern might deviate from it. First, there is some evidence of a "learning" effect where patent value actually increases during the first few years after the patent issues. Pakes (1986) and Lanjouw (1998) find evidence of this, however, they also find that this effect is largely complete by the end of the fourth year after issue. Since my first observation occurs at the end of the fourth year, this effect means that my estimates may have a small upward bias. Another deviation may occur because of economic shocks that occur during a given renewal year. For instance, Schankerman (1998) finds evidence of oil shocks in French patent renewal data. To control for such shocks, I run one set of regressions over panel data with dummies for different cohorts. Finally, some groups of patentees, such as foreign patentees, might experience a different time pattern of depreciation. I discuss this below.

Profit flow may also be a function of observable characteristics of the patent or of the patent's owner. Let X_i be a vector of such characteristics such that

(1) $$\ln r_i(0) = \beta \cdot X_i + \epsilon_i ,$$

where ε is a normally distributed stochastic error with zero mean and standard deviation σ such that $\ln r_i(0) \sim N(\beta \cdot X_i, \sigma)$. In most of the renewal literature, X_i is treated as a simple constant.[2] In this case, three parameters are estimated, d, σ, and the constant mean, and these are sufficient to determine the median and mean values of patents. However, my data permit X_i to also include characteristics of the patents, such as citations received, and characteristics of the owner. Then estimates permit calculation of the direct dollar value effect of citations and these other characteristics.

The assumption of a lognormal distribution is also common, but not uncontroversial. Researchers find that a lognormal generally fits the distribution of invention values well (Harhoff et al. 2003a) and patent renewal data are consistent with a lognormal distribution as well (Pakes and Schankerman 1984). However, much of the total value of patents derives from the upper tail of the distribution. Since the most valuable patents are renewed to full term, their value is not directly registered in the patent expiration data. This means that estimates of mean patent value based on patent renewal data are extrapolations, although estimates of *median* value are typically not. In Section 4 I check these estimates of patent renewal value by estimating the contribution of patent rents to the market value of public firms.

2 Putnam (1996) and Harhoff et al. (2003b) use a multivariate approach in slightly different contexts.

1.3 Estimation

The observations in the data set concern patentees' decisions whether to pay renewal fees to keep their patents in force for additional time periods. Patents applied for on or after December 11, 1980, accrue fees after 3.5, 7.5 and 11.5 in order to remain in force beyond 4 years, 8 years and 12 years, respectively. The fee schedules vary over time and they also depend on whether the assignee has "small entity" status—small firms, individuals and non-profit organizations pay fees that are only half of those paid by "large entities."

As in Europe, the fees increase with the age of the patent, that is, 12^{th} year fees are much large than 4^{th} year fees. This is important because it means that the patentees' optimal renewal decision rule need only consider the current renewal period. That is, it is straightforward to show that if a patentee finds it unprofitable to renew at year 4, it will be even more unprofitable to renew at years 8 and 12, so an optimal rule will be to renew if and only if it is profitable to renew for the next immediate period. Specifically, if the payment of the fee keeps the patent in force for T more years at time t, then the patentee will renew the ith patent if and only if the present value of profits during those T years exceeds the renewal fee, c_{it}.

The present value of profits from t to $t+T$, is

(2) $$\int_t^{t+T} r_i(\tau)\, e^{-s\tau}\, d\tau = r_i(0)\, z_t, \quad \text{where} \quad z_t = e^{-dt}\,\frac{1-e^{-(d+s)T}}{d+s},$$

and s is the discount rate. I follow the literature and use a discount rate of 10% per annum. Then the decision rule is to renew if and only if

(3) $$\ln r_i(0) \geq \ln \frac{c_{it}}{z_t}.$$

Given the lognormal distribution and substituting (1) into (3), the probabilities that a patent will expire at each given year are

(4) $$\begin{aligned}
P[\text{patent } i \text{ expires at } 4] &= \Phi\left(\frac{\ln c_{i4}/z_4 - \beta\cdot X_i}{\sigma}\right)\\
P[\text{patent } i \text{ expires at } 8] &= \left[1-\Phi\left(\frac{\ln c_{i4}/z_4 - \beta\cdot X_i}{\sigma}\right)\right]\Phi\left(\frac{\ln c_{i8}/z_8 - \beta\cdot X_i}{\sigma}\right)\\
P[\text{patent } i \text{ expires at } 12] &= \left[1-\Phi\left(\frac{\ln c_{i8}/z_8 - \beta\cdot X_i}{\sigma}\right)\right]\Phi\left(\frac{\ln c_{i12}/z_{12} - \beta\cdot X_i}{\sigma}\right)\\
P[\text{patent } i \text{ expires at } 17] &= 1-\Phi\left(\frac{\ln c_{i12}/z_{12} - \beta\cdot X_i}{\sigma}\right)
\end{aligned}$$

where Φ is the cumulative standard normal distribution function. This structure is, in fact, the same as that of an ordered probit, with the additional estimation of d (z is a function of d; also, σ here provides more than just a scaling constant). I estimate this model by maximizing the likelihood function implied by (4). That is, each patent's contribution to the log likelihood function is the log of the right hand side given in (4) corresponding to that patent's expiration date.

1.4 Calculating Patent Value

To estimate the net present value of patents, I perform a Monte Carlo simulation using the actual data. With estimates of the parameters, $\hat{\beta}$, $\hat{\sigma}$, and $\hat{d}$, in hand, I first determine bounds on ε_i for the ith observation conditional on observed renewal decisions made for that patent. For example, if the ith patent was allowed to expire after eight years, then

$$(5) \qquad \ln \frac{c_{i4}}{z_4(\hat{d})} - \hat{\beta} \cdot X_i \;\leq\; \epsilon_i \;\leq\; \ln \frac{c_{i8}}{z_8(\hat{d})} - \hat{\beta} \cdot X_i$$

For each observation in each Monte Carlo iteration, I select ε_i as a random draw from the lognormal distribution determined by $\hat{\beta}$ and $\hat{\sigma}$, conditional on (5) (or the corresponding bounds for patents with different expiration dates). Given this random draw, I calculate the corresponding $\ln r_i(0)$, and, from this, the present value of the patent at the time of issuance net of the discounted value of renewal fees that will be paid. I repeat the Monte Carlo iterations a sufficient number of times so that the total number of observations exceeds 500,000.

2. Data

2.1 Samples

This study uses two datasets. The first consists of almost all U.S. utility patents issued in 1991 (patents assigned to governments and foreign individuals are excluded). The second is a panel of patents issued from 1985 through 1991 and assigned to publicly listed, R&D-performing firms whose primary line of business is in a manufacturing industry.

I used 1991 as the terminal year because this is the last year for which the final patent renewal decision can be observed (in 2003).[3] Patents applied for before December 11, 1980 are exempt from renewal fees. Because of this 1985 was the earliest year with few such exempt patents.

I obtained patent expiration data from the website of the U.S. Patent and Trademark Office

3 Patentees who miss the deadline for paying the fees are given a grace period during which they can pay with a penalty. They can also appeal expirations arising from missed payments. For this reason, 2004 data can only just now be used.

(PTO).[4] This data also included the patent's "entity" status at the time each fee was paid. The PTO designates individuals, small businesses and non-profit organizations as "small" entities. For most patents, the renewal fees for small entities were half those for large entities. In addition, the fee schedule was changed regularly and the fee for any given patent also depended on its issue date and, in some cases, on its application date.[5] Some patents were reissued—a procedure where the patent owner can modify patent claims. I tracked reissues through to their final expiration as well. A small number of patents are reported as having missed a payment, but have petitioned to have the patent reinstated. I record these as if the last reported payment had been made.

Of the 96,513 patents issued in 1991, I obtained patent expiration information on 94,343. I excluded 1,962 patents issued to governments or foreign individuals. Also, 33 patents were issued before December 11, 1980 and were thus exempt from renewal fees. This left 175 patents that I could not find in the PTO's database.

In addition to this data for 1991, I assembled a panel of data for firms to explore additional variables, to explore the regressions over time, and to validate estimates of patent value using firm market value measures. To this end, I assembled a panel of patents owned by publicly listed manufacturing firms from 1985 through 1991. I drew this panel dataset from a larger sample developed for another project (Bessen and Meurer 2005) that matched patent data to firms in the Compustat dataset of firm financial information. The USPTO provides an assignee name for every assigned patent after 1969. To match the USPTO assignee name to the Compustat firm name, we began with the match file provided by the NBER (Hall et al. 2001). To this we added matches on subsidiaries developed by Bessen and Hunt (2004), we manually matched names for large patenters and R&D-performers, and we matched a large number of additional firms using a name-matching program. In addition, using data on mergers and acquisitions from SDC, we tracked patent assignees to their acquiring firms. Since a public firm may be acquired, yet still receive patents as a subsidiary of its acquirer, we matched patents assigned to an acquired entity in a given year to the firm that owned that entity in that year.[6] The matched group of firms accounts for 96% of the R&D performed by all U.S. Compustat firms, 77% of all R&D-reporting firms listed in Compustat and 62% of all patents issued to domestic non-governmental organizations during the sample period. Sample statistics show that this sample is

4 https://ramps.uspto.gov/eram/patentMaintFees.do

5 I obtained the details of the fee schedule over time from the Federal Register and Public Laws. This information is available from the author.

6 This dynamic matching process is different from that used in the original NBER data set which statically matched a patent assignee to a Compustat firm. These data were developed with the help of Megan MacGarvie, to whom I am indebted.

broadly representative of the entire Compustat sample, although it is slightly weighted toward larger and incumbent firms.

From this larger sample, I selected a panel of firms from 1985 through 1991 that had a primary line of business in a manufacturing industry, that performed R&D, and that had at least four years of non-missing data in key variables. The left me with a sample of 112,836 patents issued during this time period to 1,082 firms.

To conduct Tobin's *Q* regressions, I also constructed the corresponding panel of firm-year data for these firms for the years 1981 to 1991. I included all observations for each firm that had at least one patent application from a patent that was also in the patent panel. After screening, this produced a panel of 4,875 firm-year observations.[7]

2.2 Variables

Most of the variables used in the 1991 sample derive from the patent data itself. Using the NBER patent data file (Hall et al. 2001), I was able to assign patent citation and assignee information to each patent. Using a dataset developed by Bessen and Meurer (2005) from Derwent's Litalert Database, I was also able to identify those patents that had been litigated one or more times by 1999.

The panel of public firms also includes several constructed variables. The market value of the firm consists of the sum of all the claims on the firm, namely, the sum of the value of the common stock, the preferred stock (valued by dividing the preferred dividend by Moody's Index of Medium Risk Preferred Stock Yields), long term debt adjusted for inflation (see Hall 1990 and Brainard et al. 1980), and short term debt net of current assets.

The total capital of the firm is the sum of the value of accounting assets plus R&D stock. The value of accounting assets is the sum of the net value of plant and equipment, inventories, accounting intangibles, and investments in unconsolidated subsidiaries all adjusted for inflation using the method of Lewellen and Badrinath (1997).[8] The R&D stock is calculated assuming a 15% annual depreciation rate and an 8% pre-sample growth rate (Hall 1990).

In this calculation, I simply add the two capital stocks together to obtain aggregate capital. However, the value of aggregate capital might be a weighted sum of capital stocks with unequal weights (Hayashi and Inoue 1991). To test this, I ran a nonlinear regression of

7 The dependent variable in a Tobin's Q regression is the log of a ratio and is thus particularly sensitive to measurement error in the denominator. For this reason, I followed the literature (e.g., Hall et al. 2005) and excluded 89 observations where Q was less than .05 or greater than 20.

8 Thanks to Bronwyn Hall for providing Stata code to compute this. The code was developed by Bronwyn and Daehwan Kim.

$\ln V/A = \ln(1 + \beta \cdot K/A)$ (similar to Hall et al. 2005) where A is accounting assets. I obtained a value of 1.08 for β, suggesting that the marginal productivities of the two types of capital (in dollar terms) are roughly equal, and so the weights should be equal.

I also constructed patent stocks for the firm-year panel based on the application year of the patents. I include all patent applications that resulted in a grant by 2002. Since not all patents applied for by these firms are in the patent expiration panel, I build a conventional patent application stock using a 15% depreciation rate.[9] I also calculate patent citation stocks (stocks of citations received through 2002), using a 15% depreciation and adjusting for truncation using the method described in Hall et al. (2005).

3. Estimates of Patent Value

3.1 Patent Value by Groups

Table 1 shows summary expiration and renewal data by major groups for the 1991 sample. Overall, only 41.52% of patents were renewed to full term, with roughly equal groups dropping out at each renewal stage. The mean renewal fees were not large, however, increasing from $814 after four years, to $1,562 after eight years, to a final mean payment of $2,327. About 29% of the patents were issued to patentees who were "small entities" at year four. In most cases, these patentees pay fees that are half as large as those paid by large entities.

Among assignee types, patents that were unassigned at issue or issued to individuals had the lowest rate of renewal to term, 22%, while publicly listed U.S. firms had the highest rate, 50%. Relatively few publicly listed U.S. firms and foreign organizations rated as small entities. Similarly, patents awarded to small entities in general were much more likely to expire despite lower fees—only 25% were renewed to full term compared to 48% for patents held by large entities.

Table 1 also shows these variables for six technology categories defined by Hall et al. (2001), based on each patent's primary technology class as assigned by the PTO. Computer and communications patents had the highest rate of renewal to full term, while "other" technologies had the lowest rate. Drug and medical patents had the highest proportion of small entity patents.

Table 2, column 1, shows a basic regression for all U.S. patentees (excluding patents assigned to foreigners and governments). Because fees differ sharply depending on the patentee's entity status and

9 I estimate patent depreciation rates that are slightly lower using the expiration data, however, those data also take into account patent expirations. In the perpetual inventory patent stock, expirations are not taken into account and so a slightly larger depreciation rate is appropriate.

because there may also be important differences between large and small entities, I control for small entity status in all regressions. Of course, entity status can change over time. Small firms grow and, more frequently, valuable patents owned by small patentees are acquired by large firms. These regressions include a dummy variable if the patentee was a small entity in year four, and dummies if the entity status changed (up or down) from year four to year twelve. I also estimate σ and the depreciation rate and I report median and mean net present values for these patents calculated using the Monte Carlo technique described above.

The estimates for σ (1.86) and the depreciation rate (14%) are broadly similar to the corresponding parameters found in studies of European patents. However, the means are quite different, generating much higher patent values. Converted to 1992 U.S. dollars, Pakes (1986) estimates patent mean values for UK, France and Germany from $9000 to $25,841; Pakes and Schankerman estimate values (based on year 5 of the patent) using a different method for the same countries ranging from $10,638 to $30,564; Lanjouw (1998) estimates the mean value of German patents over different technology classes ranging from $9,695 to $27,571; Schankerman (1998) obtains similar estimates for technology classes in France, ranging from $6,893 to $31,704. All of these studies use patent cohorts that were issued in 1980 or before. Baudry and Dumont (2006) estimate the expected value of French patents from the 2002 cohort of $1,570 in 1992 dollars. Gustafsson (2005) estimates the value of Finnish patents (1970-89) at $29,800 ($1992).

By contrast, I find a mean value of $78,168 and a median value of $7,175, also in 1992 U.S. dollars. It is not surprising that these values are so much larger because the U.S. market is much larger than any of the national European markets. My mean estimate is slightly larger than an estimate made by Carlos Serrano (2005). He makes preliminary estimates of patent value using both renewal and re-assignment data for a group of U.S. organizations that do not patent heavily. In 1992 dollars he obtains a mean value of $48,000 and a median value of $17,000. Note that means are much larger than medians because, as is well-known, the distribution of patent values is highly skewed.[10]

On the other hand, my estimates are significantly smaller than survey-based estimates of the value of European patents (Harhoff et al., 2003a, Gambardella et al. 2005). However, this may simply reflect that survey respondents may be estimating the value of the technology rather than the value of

10 Putnam (1996) estimates the value of worldwide patent rights on the select group US inventions that were patented in multiple countries in 1974 to be $249,000 ($1992). If one third of this value derived from US patents alone (see Section 4.3), then the US patents in this select group would be worth about $80,000 each; the *average* US patent would be considerably less, so Putnam's estimate also suggests a smaller value for US patents than mine.

the patent *per se*.[11]

The coefficients on the entity size dummy variables suggest that patents owned by small entities are dramatically less valuable than patents owned by large entities, on the order of one sixth as large. This is confirmed by separate regressions in columns 2 and 3 for patentees who were small and large entities in year four, respectively, although the difference in the means is not as great as the fivefold difference in the median values or the implied profit flows. Also, the small number of patents that were owned in year four by a small entity but owned by a large entity in year 12 were substantially *more* valuable than most other patents.[12] This suggests a selection effect: the most valuable patents owned by small entities are acquired by large entities.

A similar selection effect may explain part of the reason small entity patents in year four are less valuable than large entity patents—some patents initially issued to small entities are acquired by large entities by year four. I do not have data on the initial status of each patent. However, the aggregate numbers on small entity patents suggest that this selection effect is not large because relatively few patents are transferred during this interval. At issuance, 30.17% of 1991 patents were owned by small entities while 29.33% were at year four.[13] Assuming, say, that patents transferred to large entities have a log profit flow that is 3.93 larger (Column 2), then counting the patents that transferred would mean that the log profit flow of small entity patents was only 1.81 less than the log profit flow of large entities at issuance.

In simpler words, patents owned by individuals, small companies and non-profit organizations have much lower values than those owned by large companies even after taking into account a selection effect. This is important because it is sometimes argued that patents are particularly valuable to small patentees, since large firms may have more alternatives to patent protection, such as complementary products or services. These results suggest, instead, that patents do a relatively poorer job of earning returns for small inventors compared to large firms.

I explore this further in Table 3, which looks at regressions by assignee type. Individual assignees, including patents that were not assigned at issue (and therefore owned by the individual inventors by default), have the lowest patent values, $25,598 in the mean. Patent values from

11 Survey questions ask inventors at what value the patent's owner would be willing to part with the patent. However, it may be hard for respondents to mentally separate parting with the patent from parting with the technology, since firms may be unlikely to sell a patent without also selling the technical know how, etc., and, perhaps, firms may abandon production and sale of the technology themselves when they sell the patent rights.

12 Among the 24,015 patents owned by small U.S. entities in year four, 1,309 were owned by large entities in year twelve.

13 The latter number comes from Table 1. The former is derived from data on 1991 issuance fees in Lehman (1993). Large entity issuance fees for utility patents collected were $67,122 and small entity issuance fees, at half the rate, were $29,004 (in thousands). 29004/(29004 + 67122/2) = .3017.

organizational inventors (mostly firms) are larger, as seen in columns 2 and 3. Interestingly, non-public organizations receive substantially larger values than do public firms. But the lower values of patents owned by small entities is not just a matter of individual inventors—similar relative values are found across all types of assignees. In Section 6 below, I explore the significance of this apparently robust effect.

Finally, foreign organizations, which were not included in the previous regressions, appear to earn nearly $3 million per patent (see column 4). Previous estimates based on renewal data have also reported exceptionally high patent value for Japanese patents and a majority of the foreign patents in this sample are from Japanese inventors.[14] However, there may be a good reason why these estimates may not be reliable. The model assumes a constant rate of depreciation for the profit flow from a patent. It may well be that this assumption does not hold for foreign patenters. For example, foreign patenters may apply for a patent long before they are ready to market the invention in the United States. U.S. priority rules require that a U.S. patent be filed within a year after the invention is used or publicly disclosed, but typically a firm markets an invention first to its domestic market, only later rolling out sales and production to foreign markets. In this case, the pattern of profit flow for foreign patentees may diverge substantially from one with constant depreciation. There is some evidence that the estimate is off in this regard: the estimated depreciation rate in column 4 is nearly twice that of the other regressions. To control for this possibility, I repeat the same regression in column 5, but hold the depreciation rate constant at 15% per annum. With this change, the estimated mean net present value is $107,906, just modestly larger than the mean present value estimate for U.S. public firms.

Table 4 reports the results of separate regressions for different technology classes, similar to estimates for French technology classes by Schankerman (1998) and estimates for German technology classes by Lanjouw (1998). The technology categories I use were developed by Hall et al. (2001) and are based on the USPTO patent classification system. Contrary to the European studies, I find the highest mean patent values in chemicals and pharmaceuticals and the lowest values in computers, communications and "other." Schankerman finds that pharmaceuticals and chemicals have the lowest mean values and he attributes this to price regulation for pharmaceuticals in France. Lanjouw finds a middling value for pharmaceutical patents. Note also that although computers and communications patents have the second lowest mean value, they also have the second highest *median* value. This suggests that perhaps the mean values are low because there are just fewer "blockbuster" patents in this

14 I also ran regressions by nationality, however, after Japan the numbers were too small to obtain reliable results.

technology.

3.2 Patent Value and Patent Characteristics

As noted in the introduction, many researchers have related patent characteristics to patent value. My model permits some of these associations to be quantified. Table 5 includes patent characteristics in the regression. Column 1 shows characteristics that depend on choices made by the patentee. A patentee, aware that some patents are more valuable than others, may take efforts to make sure that the patent is more successfully enforced. These efforts at patent "refinement" include litigating, making more citations and claims in the patent application, and, possibly, re-issuing the patent. A re-issuance procedure permits a patentee to modify claim language, in some cases increasing the scope of the claim.

Each of these actions has a positive and statistically significant coefficient, suggesting that patent value is, to some extent, endogenous. Previous literature has also found positive and significant relationships between patent claims and patent value as reported by survey respondents and between patent citations made and reported value (Harhoff et al. 2003a). Using the coefficients in the Table, I can quantify all of these relationships. The last column of the table reports the percentage increase in profit flow associated with an incremental increase in the variable (e.g., one additional citation). A litigated patent is, all else equal, nearly six times more valuable. At the mean, a litigated patent is worth nearly half a million dollars. This corresponds well with what we know about litigation costs for plaintiffs, since patentees should only litigate those patents that are more valuable than litigation costs. In 1994, according to a survey of intellectual property lawyers (AIPLA 1994), the median cost of a patent lawsuit was $190,000 through the discovery phase (after which many suits are settled) and $301,000 through trial (costs have escalated substantially since then). A re-issued patent, all else equal, is nearly three times as valuable as other patents. Each additional citation made increases value about 1% and each claim increases value about 2%.

In column 2, I break out citations made to an assignee's own patents (self citations) from those made to others' patents and I add patent citations received. It appears most of the value realized through citations made occurs from citations made to the patentee's own patents. This may be an indicator of "fencing" or "thicket building" behavior (Hall et al. 2005) where patentees strengthen their patents by also patenting related technologies or alternative technologies. Each self-cite increases patent value about 3%.

Since Trajtenberg (1990), researchers have used the number of citations that a patent receives as an indicator of patent or invention value. Previous research has found correlations between patent citations received and patent value reported in surveys (Harhoff et al. 2003) and between patent citations received and firm market value (Hall et al. 2005). My coefficient on citations received is significantly associated with patent value and this statistic does seem to have greater statistical significance than the coefficients on citations made and claims. The economic significance of an additional citation received is also greater—an additional citation increases estimated profit flow by about 5% in this specification.

Column 3 drops the litigation and reissue dummies and adds statistics (calculated in the NBER database) for generality and originality. Generality and originality are measures suggested by Trajtenberg et al. (1997) that range from zero to one and capture the technological diversity of citing and cited patents, respectively. If the patents that cite the subject patent come from a large (small) number of technology classes, then generality will be high (low). If patent citations correspond to *use* of the technology in the cited patent, then high generality suggests that the cited invention is a general purpose technology with many applications. Correspondingly, if a patent cites other patents from a large (small) number of technology classes, then it will have a high (low) originality index. Both of these measures have statistically significant coefficients, with a positive coefficient for generality and a negative one for originality.

Column 4 explores non-linearity in the effect of citations received by adding the square of this variable. The negative and significant coefficient on the squared term suggests diminishing returns to this effect. At the sample median (four citations received), an additional patent citation received increases profit flow by about 7% under this specification.

These results confirm general findings about the correlation between citation statistics and patent value in the literature. But my results also suggest that these associations have relatively small economic significance. At the sample mean, for example, an additional patent citation received corresponds to an increase in patent value of between three and five thousand dollars. This is substantially less than the effect suggested by some other research. For instance, Hall et al. (2005) estimate the relationship between firm market value and patent citations. Their results imply that at the sample mean, an additional citation received on a single patent corresponds to an increase in firm value of about $327,000 ($512,000 at the sample median).[15] This large difference likely just means that we

15 They report that an increase of one citation/patent for all the patents a firm owns increases firm market value by 2.7% at the mean. Mean market value is $916.33m and mean patent stock is 75.72, yielding an increase of $327,000 in market value with one citation on one patent.

are measuring different things. Hall et al. measure the relationship between a patent citation and the value of the technology to the firm generally; I measure specifically the effect of a patent citation on the value of the rents generated by a patent *per se*. As noted above, the value of the technology may be much greater than the value of the patent.

In addition, my estimates can be used to evaluate the portion of total variance in patent rents that can be "explained" by citation statistics. Given a vector of citation statistics, $\overline{X}$ which are a subset of the right hand variables, *X*, and given coefficients on these citation statistics of $\overline{\beta}$, the portion of variance accounted for by these statistics is

$$\frac{\text{var}(\overline{\beta}\cdot\overline{X})}{\text{var}\left(\hat{\beta}\cdot X\right)+\hat{\sigma}^2}.$$

I calculated this quantity for the various specifications in Table 5 for all of the citation statistics and just for citations received. In no case did the portion of variance explained exceed five percent. In other words, as other researchers have also concluded, patent citation statistics are correlated with patent value, but they are very "noisy signals." This analysis indicates just how noisy they are.

Another way of looking at this is to examine just the most highly cited patents. Of the top 10 percent of patents ranked by citations received in 1991 (with 15 or more citations), 37% were not renewed to term. Among the top 5 percent (with 21 or more citations), 32% were not renewed to term. Thus even among the most highly cited patents, many are not even worth the full set of renewal fees, after accounting for depreciation.

This analysis emphasizes not only that patent citations are "noisy," but also that care must be taken in interpreting the meaning of correlations involving citation statistics. Patent citations may be a good (but noisy) indicator of technology value, but they appear to be only only weakly related to patent value. For this reason, they are not meaningful as a measure of patent "quality."

4. Estimates for Public Manufacturing Firms

4.1 Patent Value

This model of patent renewal is based on two strong assumptions: a constant rate of depreciation in the profit flow from a patent, and a log normal distribution of initial profit flows. This section tests the robustness of my estimates by using panel data for public U.S. manufacturing firms. First, I explore whether year effects may alter the estimates obtained for 1991. Below, I use a market value regression to obtain an upper bound on any effects related to the upper tail of the distribution of profit flows.

Table 6 first compares panel and single year estimates for patents held by this group of firms. Column 1 shows a regression just for patents granted to public manufacturing firms in 1991. The mean patent value, $60,296 is similar to, but about one third lower than the estimates for other public firms in Table 3. However, the estimate for patents issued from 1985 to 1991 for this group of firms in Column 2 is half that size, $28,842.

One explanation for this discrepancy is that macro-economic effects in one or more of the renewal years for 1991 (1995, 1999, 2003) may have caused a deviation in renewal rates for that year. For example, if 1999 were a "bubble" year and patentees placed a temporarily high valuation on their patents, they would have renewed them at a greater than normal rate, leading to a higher than normal estimate of patent value. The estimates for the panel from 1985 – 1991 tend to average out any such temporary effects, providing a more representative estimate of long run patent value.

Another explanation is that, perhaps, patent value increased rapidly during the interval from 1985 to 1991. To test this, I ran the regression in Column 2 with dummy variables for each grant year and then again with dummies for each application year. These dummy coefficients are shown in Figure 1. These suggest, instead, that mean patent value decreased somewhat during this interval, so the estimates for 1991 may well be inflated.

This modest decline in patent value over time for patents issued from 1985 through 1991 is also interesting for what it suggests about the simultaneous increase in patenting rates. As is well-known, patenting rates in the U.S. increased sharply during this period and this has been a subject of several studies (Kortum and Lerner 1999, Hall and Ziedonis 2001, Henry and Turner 2005, Sanyal 2005). A decline in patent value suggests that technologies were not becoming more valuable during this period (although the number of inventions per R&D investment may have been increasing) and it suggests that patent protection was not becoming "stronger" (although patentability standards may have dropped). Patent value estimates may shed some light on the factors promoting patenting, but this is a subject for future research.

The remaining columns of Table 6 explore firm characteristics. In Column 3, patent value increases with firm size and with firm R&D spending. This is consistent with the view that more valuable patents are correlated with more valuable technology. However, the larger the patent stock of the firm, all else equal, the *smaller* the mean patent value. This suggests that patent value is endogenous and that there are diminishing returns to patenting. Column 3 also includes a dummy variable for "new" firms, that is, firms that have been publicly listed for fewer than 5 years. It is sometimes argued that patents are particularly valuable to new firms, helping them secure financing. This regression does not support that view.

Column 4 reports industry dummies. Computer and electronics industries have the largest patent value, and "other" (the omitted category) has the lowest.

4.2 Patent Rents and Firm Value

Patent rents should relate to a firm's market value. This suggests that firm market value regressions might provide a way of validating these renewal estimates of patent value for publicly listed patent owners. Following Griliches (1984), a substantial number of studies include firm patents as a right hand side variable in firm market regressions (see Hall 2000 for a review of this literature). These studies mainly use a hedonic model of firm value, where patents convey a quality characteristic to investors. As such, these studies do not measure the value of patent rents *per se*. In these regressions, the coefficients on patent stocks represent a broader concept of technology value.

However, Hayashi (1982) has identified a relationship between Tobin's Q and the value of rents for firms with market power. Under assumptions of constant returns to scale and profits as a function of an aggregate capital stock, K, for the jth firm at time t,

$$(6) \qquad Q_{jt} \equiv \frac{V_{jt}}{p_{It} K_{jt}} = q_t \left(1 + \frac{W_{jt}}{p_{It} K_{jt}}\right)$$

where V is firm market value, p_{It} is the price of the aggregate capital good at time t, W is the firm rents, and q is "marginal q" which reflects short term disequilibrium in capital markets and I assume is constant across firms at any one time. This equation captures the intuition that firms with market power earn sustained supra-normal profits reflected in a higher market value. For my purposes, K includes the R&D stock as well as the stock of tangible capital.

Since the aggregate renewal value of a firm's patent stock should equal the value of its patent rents, (6) provides a framework for validating the renewal values. Let w^P be the firm's patent stock times the mean patent value estimated from renewal data. Then, assuming that rents are not a large portion of firm value and using the approximation, $\ln(1+x) \approx x$ for small x,[16]

16 For my sample, patent value is less than 1% of firm value. However, non-patent rents may be larger. Implicitly, (7) includes non-patent rents in the time dummy, however, if they are large, the approximation to a log linear form will lead to biased estimates. Median $\ln Q$ is about .08, perhaps reflecting the value of non-patent rents. This means that estimates of β may be about 10% too low.

$$\text{(7)} \qquad \ln Q_{jt} = \beta \frac{w^P_{jt}}{p_{It} K_{jt}} + \delta_t + \epsilon_{jt}$$

and β should be about one if the estimates of patent value do indeed equal the value of patent rents. If, on the other hand, these estimates are too small, for example, if the upper tail of the patent value distribution were "fatter" than the assumed log normal tail, then β would be substantially larger than one. I estimate (7) next.

4.3 Firm Market Value and Patent Rents

One concern about estimates of patent value based on renewal data is that patentee renewal decisions do not directly reveal the values of the most valuable patents. All of the most valuable patents in the upper tail of the distribution are renewed to full term. This means that although estimates of median value are based on an observed distribution, estimates of mean patent value are based on an extrapolation, assuming that the distribution observed among expiring patents (in my case, a log normal distribution) is the same distribution among the most highly valued patents. This means that if the true distribution is not log normal, these estimates may be off.

Harhoff et al. (2003a) have explored this issue using survey data from U.S. and German holders of German patents. They conclude that the log normal distribution provides the best fit of value estimates for the full range of survey responses (but see also Silverberg and Verspagen 2005). However, actual behavior might differ from behavior based on self-reported value estimates, so it is still desirable to have a further test of the robustness of the estimates based on a log normal distribution.

Equation (7), provides a possible means of validating the estimates. I show estimates of this equation in Table 7. Aggregate capital is measured as the current value of accounting assets plus the firm's R&D stock. Q is measured as the ratio of firm market value to the current value of capital. I estimate w^P by multiplying the firm's patent stock (calculated by the perpetual inventory method with a 15% annual depreciation) by the annual mean patent value estimated using a regression similar to those in Table 6.[17]

In theory, β should capture the ratio of actual patent rents to the aggregate estimated value of patents. In practice, there are two reasons why β might be biased upwards. First, as mentioned above, patenting behavior appears to be endogenous and, specifically, the size of the firm's patent stock might

17 This regression includes industry dummies, dummies for small entity status, litigation and reissues, and the log of patent citations received plus 1. This was used to calculate annual mean patent values for the panel. The annual estimates of mean patent value are similar to those listed in Table 6, ranging from $29,867 to $34,760 in 1992 dollars.

be correlated with the error term. This occurs if "surprises" in innovation quality encourage the firm to patent more.

Second, I only calculate the value of U.S. patents, yet firms also receive rents from foreign patents on the same inventions. Indeed, Putnam (1996) and Lanjouw and Schankerman (2004a) argue that patent value is correlated with the number of countries in which an invention is patented. The most valuable inventions are likely patented in many countries. Putnam estimates that international patents rights are valued at about five times single-nation patent rights. This means that the value of U.S. patents serves as a proxy for the international value of patent rights. Consequently, β should be greater than one—even without an endogeneity bias, β should equal the ratio of the value of international patent rights to U.S. patent rights. E.g., if firms obtain half their patent rents from U.S. patents and half from foreign patents, then β would equal two.

Column 1 of Table 7 shows estimates from a simple OLS regression; the estimate of β is 3.31. This is significantly greater than 1 (at the 5% level), but this does not control for either of the potential biases. Column 2 controls for contribution of foreign patents by dividing patent value by the share of domestic pretax profits in the firm's total pretax profits.[18] Not all firms report foreign pretax profits separately, however, so I also include the unadjusted ratio of patent value to capital for these firms. The adjusted patent value has a coefficient of 1.16, quite close to 1, while the unadjusted patent value has a coefficient of 3.45, similar to the value in Column 1. The coefficient for firms that do report foreign profits has a substantially smaller standard error, suggesting that the adjustment has added important information.

It is possible that U.S. patent value may especially understate total future patent rents for startup firms. A new firm may obtain valuable patents in foreign markets long before it actually realizes significant profits from those markets because new firms typically ramp up domestic production and sales first. Column 3 further controls for new firms by including a dummy variable for new firms (firms listed in Compustat for fewer than 5 years) and by interacting this variable with the ratio of patent value to capital for firms that do not report foreign profits (new firms account for 27% of the observations that do not report foreign profits). The coefficients reported in Column 3 suggest that the patents owned by startup firms do, indeed, have substantial value beyond their domestic value. On the other hand, the coefficient on patent value for established firms that do not report foreign patents is measured

18 I summed domestic pretax profits and foreign pretax profits for all years in the panel that reported both values and took the ratio using these sums. I excluded firms where the sum of pretax profits was negative. For firms that did not report both figures for any year, I coded this variable to zero, recording a positive value for the variable identified as "patent value / capital * (foreign profits not reported).

imprecisely and is not significantly different from zero (or one). The coefficient for firms that do report foreign profits is a bit higher in this regression, 1.64.

Column 4 runs the regression only for those firms that report foreign profits, obtaining a coefficient of 0.93. It is possible that high tech industries might have a different distribution of patent values than other industries. Column 5 reports the regression just for high tech industries (SIC codes 283, 284, pharmaceuticals, 357, computers, 365, 366, 367, electronics and semiconductors, and 384, medical instruments) that report foreign profits. The coefficient is a bit higher, 1.31, but still not significantly different from 1. I also ran separate regressions for different industries, but found the standard errors to be too large to draw reliable conclusions.

To test for possible endogeneity, I also ran several of these regressions using instrumental variables least squares. For instruments, I used lagged ratios of patent value to capital and the ratio of R&D stock to accounting assets. These instruments were apparently not very good, however. The estimates had high standard errors and a Hausman test could not reject the hypothesis that differences between these estimates and the OLS estimates were not systematic.

Another possible bias might arise if the true distribution of patent values were close to a Pareto distribution with a shape parameter of less than one. In this case, the expected value of a firm's patent portfolio would have an infinite mean and variance and the estimate of β would be biased towards zero (Scherer 1965). If this were the case, however, the regression residuals would be independent of the patent portfolio size. On the other hand, if the patent value distribution had a finite mean, then the residuals would be heteroscedastic with a variance that decreased proportionally to 1/portfolio size. I tested the regressions for this heteroscedasticity by regressing the square of the residuals against 1/portfolio size (regressions not shown). I found a robust negative coefficient, even after adding fixed effects and controls for R&D intensity and other measures of firm size. This is consistent with a patent value distribution that has a finite mean, in which case my estimates are not biased (and I use robust standard errors). Note that *invention* values may nevertheless follow a Pareto distribution (Silverberg and Verspagen 2004)--because patenting is endogenous, patent values may be considerably less skewed than invention values (valuable inventions induce more patenting).

Overall, this analysis suggests that the estimates obtained using renewal data are not too far off the mark as estimates of the rents that patents contribute to firm value. Estimates made taking account of the contribution of foreign patents suggest that patent rents are about equal to patent value, not exceeding a ratio of 1.64 in the highest estimate. This suggests that the assumption of a log normal distribution does not appear to introduce substantial bias.

More generally, these estimates suggest that patent rents contribute relatively little to the market value of firms on average. Estimated at the mean, even the highest estimate of β implies that patent rents only account for 1.6% of firm value (0.8% at the sample median). Intangible assets do, of course, account for a substantial share of firm value generally. However, apparently most of this value is realized by other means of appropriation than patents. Hedonic market value regressions find that patent statistics have substantial explanatory power. But, as with the citation statistics mentioned above, my estimates of patent value suggest that this may just imply that patents are correlated with valuable technology, not that the patents themselves necessarily contribute substantially to firm value.

5. The Patent Subsidy

Patent rents represent the "reward" that patents afford inventors. Mark Schankerman (1998) suggests that this reward can be considered as equivalent to an R&D subsidy. He asks what subsidy would be needed in order to induce firms to make the same investment in R&D as they are induced to make by patents. He suggests that the ratio of a patentee's aggregate patent value (= patent rents) divided by the associated R&D expenditure can be considered an upper bound estimate of this "equivalent subsidy rate."

Schankerman (1998) and Lanjouw (1998) point out that this may be an upper bound estimate for several reasons. There may be diminishing returns to R&D. A cash subsidy may be relatively more valuable to risk averse investors, so they might require a smaller equivalent subsidy. Also, this analysis does not take into account strategic interaction; to the extent each firm's patents reduce the rents that other firms earn, the subsidy needed in a world without patents would also be less.

Previous researchers have calculated the ratio of patent value to associated R&D using the values of European patents (Pakes 1986, Pakes and Schankerman 1986, Lanjouw 1998, Schankerman 1998). Estimates for patent cohorts from the 1970s range from 4% to 35% (see Addendum to Table 8).

However, these ratios were calculated using aggregate national data apportioned to the country where the patent was granted. My data allow a much closer match between the patent value and the R&D performed by the patent owner. As I explain below, this is important because R&D, or innovative effort, is not well-measured for many patentees. For this reason, my estimates should more accurately represent the actual incentives that patents provide to R&D performers.

Table 8 shows a variety of estimates calculated at different levels of aggregation. The first two rows display aggregate data for all U.S. patentees, using the estimated value per patent from Table 2, Column 1. The aggregate value of patents granted in 1991 to U.S. patentees was about $4.4 billion in 1992 dollars. I calculated the corresponding R&D investment using data from the National Science Foundation (NSF) survey of U.S. firms. Since the patents granted in 1991 were applied for over many years, Column 4 displays a weighted sum of real R&D spending where the weights are allocated based on the proportion of 1991 patents applied for in each year R&D was performed. Column 6 displays the equivalent subsidy rate. The first row shows the calculation using all industrial R&D, the second row shows the rate using just company-funded R&D. These estimates are within the range of some of the estimates based on European data, but at the bottom of that range.

However, much of the value of patents is contributed by patentees who are not surveyed by the NSF or for whom R&D is poorly measured. Indeed, individual inventors are not included in NSF surveys and small private companies without separate R&D labs are unlikely to be surveyed. Small firms also often do not have the same tax incentives to report R&D as do large firms. R&D is better measured for public firms since accounting regulations require the reporting of material R&D expenditures and the regulations standardize the treatment of R&D-related expenditures (FASB 1974). The remaining rows reports estimates using data on firm R&D spending for publicly listed firms in the Compustat database. These estimates are conditional on firms' choosing to patent (about 15% of R&D is performed by firms that do not patent).

The third row reports the calculation for all publicly listed firms that I have matched to patent data. The R&D figure in Column 4 is a weighted sum of each firm's R&D expenditure for the application year for each patent granted in 1991, the weights apportioning each year's R&D equally across all patents for that year. The patent value comes from Table 3. Even though the value per patent is higher, the estimate of the equivalent subsidy rate is much smaller, 2.9%. The main reason is that the ratio of patents to R&D is much lower (see Column 5) because so much more of *measured* R&D is performed by public firms.

Manufacturing firms may more accurately measure R&D than non-manufacturing firms. For example, much of the activity that may go into developing a patent in a service firm may not be classified as R&D. The fourth row repeats the calculation just for patents granted to manufacturing firms in 1991 and the fifth row repeats the calculation for patents granted to manufacturing firms in the panel from 1985 to 1991, using the mean patent value estimates from Table 6, Columns 1 and 2 respectively. These estimates are a bit lower, 1.8% and 0.7% respectively.

Thus these estimates suggest that the upper bound of the equivalent subsidy rate provided by patents is no more than 2%, plus or minus 1%. This number may seem surprising since it is an order of magnitude lower than the estimates obtained using European patent renewal data, and especially since my estimates of patent value are several times *larger* than the corresponding estimates for the value of European patents (see the Addendum to Table 8).

The difference is in the procedures used to allocate R&D to patents and the measurement of that R&D. The European studies use aggregate national data, even though R&D may be poorly measured for many patentees, and they allocate each nation's R&D to patents in another nation. My data afford the ability to match patents to R&D much more closely. In addition, R&D may have been significantly under-reported prior to the 1980s because accounting regulations did not require it and because R&D tax credits did not provide incentives for separate reporting.[19]

The difference in the measurement of R&D shows up in the rate of patent applications to R&D. In the last three rows of the table, I allocate each firm's R&D to that firm's patents, obtaining rates of patent applications to R&D ranging 0.25 to 0.31 (Column 5). In contrast, the patenting rates assumed in the European studies from the 1970s are on average 7.6, about 25 times higher (see Addendum). Most firms would find an R&D productivity of 8 patents per million dollars of R&D to be exceptional, let alone patenting rates of 23 patents per million dollars.[20] If the European equivalent subsidy ratios are recalculated using the more representative patenting rate of 0.31 (see last column), then the estimates of the equivalent subsidy ratio average 0.9%, somewhat smaller than most of my estimates. Thus with this correction, these estimates do not seem very different from mine.

Arora et al. (2003) estimate an equivalent subsidy ratio using a structural model incorporating survey data and firm-level R&D data. Their estimate is not directly comparable to these because it represents the return on worldwide patent rights and their model incorporates diminishing returns. A simple calculation (available from the author) obtains an estimate of about 3% for the equivalent subsidy for US patent rights.

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19 U.S. accounting regulations for R&D were introduced in 1974. R&D tax credits were introduced in the U.S. in 1981, in France in 1983 (see Hall and van Reenen 2000, Mansfield 1993).

20 For firms with over $1 million in R&D spending in 1991, the simple ratio of successful patent applications to deflated R&D has a median of .14, and mean of .40 and a top percentile at 6.0.

6. Small Patentees and the Market for Patents

One surprisingly large and surprisingly persistent result is that small patentees—individuals, non-profits and firms with fewer than 500 employees—have patent values that are far smaller on average than the values of patents owned by large firms. In the 1991 sample, the median of large firm patent values was about five times larger; in the panel of manufacturing firms, large firm patent values were over twice as large. Moreover, these differences persist across technologies, industries, and assignee types. Arora et al. (2003) also find a large disparity between large and small US firms. Gustafsson (2005) finds a large disparity in patent value between individual and firm patents in Finland. On the other hand, Gambardella et al. (2005) find that individuals and small firms claim higher patent values than large firms in a survey. This, however, may reflect greater optimism on the part of smaller inventors rather than greater actual value.

This finding of sharply lower value for small inventors contradicts a popular view that small patentees have particularly valuable patents. It also contradicts the conclusion of Allison et al. (2004), who argue that since patents need to be valuable in order to be litigated, and since small entity patents are more likely to be litigated, then small entity patents must be more valuable. I find that litigation *is* correlated with patent value, but that small entities still have patents with sharply lower values on average. Of course, if A is correlated with B and if B is correlated with C, it does not logically follow that A is necessarily correlated with C. The probability of litigation is determined by more than just the value of the patents involved. In a more complete model, large firms obtain more patents, but their probability of disputes with other firms does not go up proportionately, so their rate of litigation *per patent* is smaller (Bessen and Meurer 2005). Then large firms may have both lower litigation rates per patent and greater value per patent. Note that the substantially higher rate of litigation per patent for small entities also suggests that the value disparity cannot be explained by lower litigation costs for large firms.

Of course, part of the difference in the patent values between large and small entities arises because of the particular nature of individual inventors. Individuals may be motivated to patent for non-pecuniary reasons, such as vanity. Macleod et al. (2003) find that British inventors in the 19th century often patented inventions that did not or could not work (e.g., perpetual motion machines), suggesting non-pecuniary motivation. Also, individual inventors may be manipulated by unscrupulous patent agents. And the serendipity of discovery may lead them to make less valuable inventions—e.g., individuals may be more familiar with pets than with petroleum cracking, and pet-related patents may be inherently less valuable. However, these factors can only explain a portion of the discrepancy. The gap between large and small patentee's values holds for private corporations, public corporations and for all technology classes. Indeed, specialized chemical engineering firms have held some of the important patents on petroleum cracking.

Moreover, there are other reasons to expect *a priori* that small patentees should have *more* valuable patents on average rather than less valuable ones. First, as Lanjouw and Schankerman point out (2004b), small patentees face higher costs of enforcement because they have higher litigation rates per patent. They may also face higher patent prosecution costs, despite the lower fees charged by the Patent Office to small entities. With higher costs of patenting, they should only patent more valuable patents on average, all else equal.

Second, as Arora and Merges (2004) argue, stronger "property rights unleash the high-powered incentives of arm's-length contracting." Small patentees should have greater incentives than inventors in large integrated firms, therefore they should invent more valuable patents. Also, they should value their patents highly because these patents allow them to write development contracts with larger firms. Arora and Merges argue that stronger patent rights make for efficient markets for technology, leading to a " 'post-Chandlerian' economy, where smaller, specialized firms play a prominent role."

But contracting over technology is notoriously difficult and markets for technology are notoriously incomplete. These markets face a serious "lemons" problem: buyers often have little information about the quality of the technologies offered for sale or license. Private information can lead to a failure to make mutually beneficial contracts. Although patents may facilitate contracting *at the margin* (Arora and Ceccagnoli 2006, Gans et al. 2002), the general picture of markets for technology may be one where small firms and independent inventors have difficulty capturing the value of their inventions. Indeed, in a large survey of European patentees, Gambardella et al. (2006) find that only 61% of patentees who wanted to license their patents were able to do so. Caves et al. (1983) find that licensors typically realize less than half the value of their technologies.

Imperfect technology markets may explain the value disparity. Large firms can realize value from their patents by using them directly to exclude competitors from their (large) markets. But small firms can only realize limited value from exclusion and must rely, instead, on the licensing or sale of their technology in order to realize much value. If technology markets worked perfectly, then small firms would capture the full value of their technology. But if small inventors only capture a fraction of the value of their technology through licensing (because licensing does not occur or because it occurs on disadvantageous terms), then their patents may be less valuable than large firm patents, despite higher patenting costs and greater incentives.

Anand and Khanna (2000) argue that "stronger" patent rights in the chemical and pharmaceutical industries facilitate arm's-length technology contracting. They study press announcements of inter-firm alliances, finding evidence of a higher rate of contracting in these industries. I, too, find that these industries have "stronger" patents, at least in the sense that patents in these technologies have higher value (Table 4). However, small patentees are at a similar relative disadvantage in patent value in these technologies as in other technologies.[21] The higher rates of contracting in these industries may have less to do with the strength of patent rights than with other factors such as the role that academic science now plays in these industries (Branstetter and Ogura 2005).

Of course, there are distinct industry niches where vertical dis-integration works well and patents may combine with other factors to facilitate arm's length contracting. Hall and Ziedonis (2001) find evidence that patents played an important role in facilitating the rise of "fabless" semiconductor design firms who outsource all manufacturing. I identified 111 patents issued to these semiconductor design firms in the 1985-1991 panel of public firms.[22] Of these, 85% (94) were renewed to full term, suggesting that these were, indeed, valuable patents. But this is the exception that proves the rule. Most small firms (not all of the semiconductor design firms were small) do not realize such value from their patents and so this sort of vertical dis-integration may be atypical, dependent on idiosyncratic features of this industry. Indeed, Hall and Ziedonis note that in addition to patents, MOS (metal oxide semiconductor) production technology facilitated the rise of fabless design firms.

If this interpretation is correct, then the low value of small entity patents reflects imperfections in the market for technology. Patents by themselves may only make these markets slightly more efficient and any emergent "post-Chandlerian" economy may be limited to those niches where patents and technologies combine to facilitate arm's length contracting over technology.

7. Conclusion

I have used U.S. patent renewal data to estimate the value of U.S. patents to different groups of domestic patentees and to analyze some of the determinants of patent value. Among my findings:

- I estimate that patents granted to U.S. patentees in 1991 were worth about $78,000 in the mean ($7,000 in the median) to their owners. This is substantially larger than estimates made

21 The same value disparity also occurs in a regression (not shown) of public firms in the pharmaceutical industry, as opposed to pharmaceutical patents identified by technology class.

22 Thanks to Rosemarie Ziedonis for sharing her data with me.

using similar data for European patents. Estimates for a panel of patents granted to public manufacturing firms were lower in the mean, about $29,000, but higher in the median, $11,000. I find that these estimates of patent value roughly correspond to the contribution that patent rents make to the value of the firm, which does not exceed 2% of firm value.

- Despite this larger per patent value, I find that the ratio of patent value to R&D—a measure of the subsidy that patents provide to R&D investment—is only about 2%. Nevertheless, in aggregate, the value of U.S. patents granted to U.S. owners in 1991 was over $4 billion. This is large, but it is substantially smaller than other government programs to encourage R&D. For example, direct Federal funding of industrial R&D in 1991 was over $26 billion.
- There are large differences in patent value across different groups of patentees. Small entities—individuals, corporations with fewer than 500 employees and non-profit organizations—have patent values that are on average less than half as large as the values obtained by large corporations. Contrary to lore, patents do not seem to work particularly well for small inventors and this may be evidence of serious imperfections in the market for patent licenses and sales.
- I quantify the association between litigation and patent citation statistics and patent value. A litigated patent is worth nearly six times as much as a non-litigated patent. An additional patent citation received increases patent value by 4-7%. Although patent citations are significantly correlated with patent value, they only explain a small portion of the variance in patent value, so they are not meaningful measures of patent value of patent quality. Patent citation statistics may be more meaningful as measures of the value of the underlying technology.

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Table 1. Summary Statistics

	Percent Expired During			Percent	Percent	
	4th Year	8th Year	12th Year	Full term	Small	Number
ALL	20.21	20.95	17.31	41.52	29.33	94,342
Assignee type						
Unassigned & individuals	36.05	26.14	15.43	22.38	88.24	17,786
Non-public organizations	18.21	20.41	17.00	44.38	45.34	17,229
Publicly listed firms	13.70	19.37	16.58	50.35	9.77	21,904
Foreign organizations	17.43	19.66	18.78	44.13	2.34	37,423
PTO Entity Status						
Small	32.22	25.72	16.66	25.40	100.00	26,768
Large	15.46	19.06	17.57	47.91	0.00	67,574
Technology Category						
Chemical	19.10	21.19	18.63	41.08	15.73	18,175
Computers & communications	11.74	17.46	17.56	53.24	14.51	9,816
Drugs & medical	20.11	20.66	15.13	44.10	36.87	8,288
Electrical & electronic	16.28	19.28	17.45	46.99	18.91	16,481
Mechanical	21.65	21.62	17.72	39.00	31.73	21,561
Other	27.11	23.22	16.34	33.33	51.82	20,021
Mean fee ($92)	814	1,562	2,327			

Table 2. Regressions for U.S. Patentees by Size Status

	All	Small Entities	Large Entities
	1	2	3
Small entity, year 4	-1.92 (0.04)		
Entity change (small to large)	3.78 (0.11)	3.93 (0.14)	
Entity change (large to small)	0.54 (0.10)		0.54 (0.10)
Constant	8.45 (0.09)	6.72 (0.09)	8.37 (0.09)
σ	1.86 (0.05)	1.93 (0.07)	1.88 (0.06)
d	0.14 (0.01)	0.16 (0.01)	0.13 (0.01)
Median net present value	7,174.6	2,942.9	14,310.2
Mean net present value	78,167.7	70,100.2	105,916.2
Number of observations	56,816	24,015	32,801
Log L	-72,444.1	-31,600.7	-40,809.9

Note: Robust standard errors in parentheses. Entity change dummy variables reflect change in status between the fourth year and final year. Patent values in 1992 $ and discounted at 10%.

Table 3. Regressions by Assignee Type

	U.S. Assignee				
	Unassigned or individual	Non-listed Organization	Publicly Listed Firm	Foreign Organization	Foreign Organization with d = .15
	1	2	3	4	5
Small entity, year 4	-1.56 (0.06)	-1.39 (0.06)	-1.27 (0.11)	-1.94 (0.07)	-1.54 (0.04)
Entity change (small to large)	3.91 (0.19)	3.53 (0.20)	2.89 (0.23)	4.55 (0.24)	3.34 (0.13)
Entity change (large to small)	0.83 (0.18)	0.64 (0.16)	0.92 (0.20)	1.61 (0.25)	0.89 (0.16)
Constant	7.87 (0.13)	8.71 (0.22)	8.38 (0.12)	9.93 (0.18)	8.43 (0.01)
σ	1.79 (0.08)	2.06 (0.13)	1.80 (0.07)	2.82 (0.11)	1.93 (0.01)
d	0.14 (0.01)	0.16 (0.02)	0.13 (0.01)	0.27 (0.01)	0.15 --
Median net present value	2,588.9	19,206.3	49,297.7	62,326.5	16,421.5
Mean net present value	25,597.6	206,286.3	90,787.8	2,905,760.7	107,906.3
Number of observations	17,786	17,229	21,904	37,423	37,526
Log L	-23,338.6	-21,770.5	-26,962.9	-48,269.4	-48,443.2

Note: Robust standard errors in parentheses. Column 5 fixes the depreciation rate at 15%. Entity change dummy variables reflect change in status between the fourth year and final year. Patent values in 1992 $ and discounted at 10%.

Table 4. Estimates for Technological Categories for Patents held by U.S. Patentees

	Median Net Present Value	Mean Net Present Value
Chemical	33,856.6	497,199.6
Computers & Communications	21,286.6	45,246.7
Drugs & Medical	12,691.8	120,419.3
Electrical & Electronic	11,927.7	68,458.9
Mechanical	8,170.7	86,033.1
Others	4,573.5	38,626.5

Note: Technology categories are from Hall et al. (2001). Patent values in 1992 $ and discounted at 10%.

Table 5. Regressions with Patent Characteristics

	1	2	3	4	Proportional Increase
Small entity, year 4	-1.89 (0.04)	-1.38 (0.04)	-1.84 (0.06)		
Entity change (small to large)	3.65 (0.11)	3.06 (0.12)	3.51 (0.15)	-1.82 (0.03)	
Entity change (large to small)	0.44 (0.10)	0.55 (0.12)	0.38 (0.11)	3.57 (0.10)	
Litigation	1.77 (0.132)	1.36 (0.172)		0.48 (0.09)	487%
Reissued	1.02 (0.179)	0.84 (0.235)			179%
Citations made	0.007 (0.001)		0.004 (0.001)		1%
self citations		0.027 (0.005)			3%
citations to others' patents		0.000 (0.001)			0%
No. of claims	0.017 (0.001)	0.006 (0.001)	0.013 (0.001)		2%
Citations received		0.046 (0.003)	0.039 (0.003)	0.069 (0.003)	4 - 7%
Cites rec'2 ^2 / 1000				-0.405 (0.048)	
Generality			0.173 (0.04)		
Originality			-0.106 (0.04)		
Constant	8.13 (0.09)	8.07 (0.11)	7.97 (0.14)	8.05 (0.07)	
σ	1.85 (0.05)	1.85 (0.07)	1.80 (0.09)	1.83 (0.05)	
d	0.14 (0.01)	0.14 (0.01)	0.14 (0.01)	0.14 (0.01)	
Number of observations	56,816	38,236	48,990	56,816	
Log L	-72,014.8	-46,816.4	-60,891.0	-71,331.4	

Note: Robust standard errors in parentheses. Litigation dummy is one for patents that were the main patent in one or more lawsuits filed by 1999 and listed in Derwent's Litalert service. Citation statistics are from the NBER patent database and are described in Hall et al. (2001). Entity change dummy variables reflect change in status between the fourth year and final year.

Table 6. Firm Characteristics for U.S. Public Manufacturing Firms

	1991		1985 - 1991					
	1		2		3		4	
Small entity	-0.85	(0.11)	-0.80	(0.03)	-0.86	(0.03)	-0.85	(0.03)
New firm					-0.05	(0.02)		
Ln R&D					0.07	(0.01)		
Ln employment					0.06	(0.01)		
Ln patent stock					-0.18	(0.01)		
Industry								
Pharmaceuticals							0.23	(0.02)
Electrical & instrument							0.24	(0.01)
Electronic & computer							0.57	(0.01)
Metals & transportation							0.08	(0.01)
Constant	8.15	(0.08)	8.05	(0.02)	8.50	(0.05)	7.85	(0.03)
σ	1.68	(0.05)	1.29	(0.01)	1.29	(0.02)	1.27	(0.01)
d	0.11	(0.01)	0.11	(0.00)	0.11	(0.00)	0.11	(0.00)
Median net present value	44,707.3		10,969.0		11,114.7		10,957.4	
Mean net present value	60,296.0		28,842.7		29,658.4		28,910.6	
Number of observations	17,862		112,836		112,836		112,836	
Log L	-22,001.7		-136,160.0		-135,615.9		-135,071.4	

Note: Robust standard errors in parentheses. The new firm dummy is one if the firm has been publicly listed for fewer than 5 years. R&D is deflated R&D stock, employment is in thousands, and patent stock is calculated using the perpetual inventory methods at a 15% depreciation. Patent values in 1992 $, discounted at 10%.

Table 7. Regressions on ln *Q*, Manufacturing firms,1981-91

Dependent variable: Log (firm market value/ (assets + R&D stock))

	1	2	3	4	5
Sample	All	All	All	Foreign profits reported	High Tech, foreign profits reported
Patent value / capital	3.31 (1.07)				
Patent value / (capital*domestic share)		1.16 (0.49)	1.64 (0.46)	0.93 (0.51)	1.31 (0.43)
Patent value / capital *(foreign profits not reported)		3.45 (1.09)	-0.20 (0.79)		
Patent value / capital *(foreign profits not reported) *(new firm)			8.07 (1.83)		
New firm			0.29 (0.03)	0.16 (0.04)	0.27 (0.07)
No. of observations	4,875	4,875	4,875	1,909	516
R-squared	0.036	0.037	0.100	0.043	0.050

Note: Robust standard errors in parentheses. Year dummies included in all regressions. Q is firm market value divided by the sum of accounting assets plus R&D stock. Patent value per capital is the current mean value of patents for the sample for the given year times the firm's patent stock divided by the sum of accounting assets plus R&D stock. Domestic share is the ratio of domestic pretax profits to the sum of domestic and foreign pretax profits for firms that reports foreign pretax profits separately. New firms are firms that have been listed on Compustat for fewer than 5 years. "High tech" firms are firms whose current primary line of business is in one of the following SICs: 283, 284 (pharmaceuticals), 357 (computers), 365, 366, 367 (electronics and semiconductors) and 384 (medical instruments).

Table 8. Equivalent Subsidy Rate

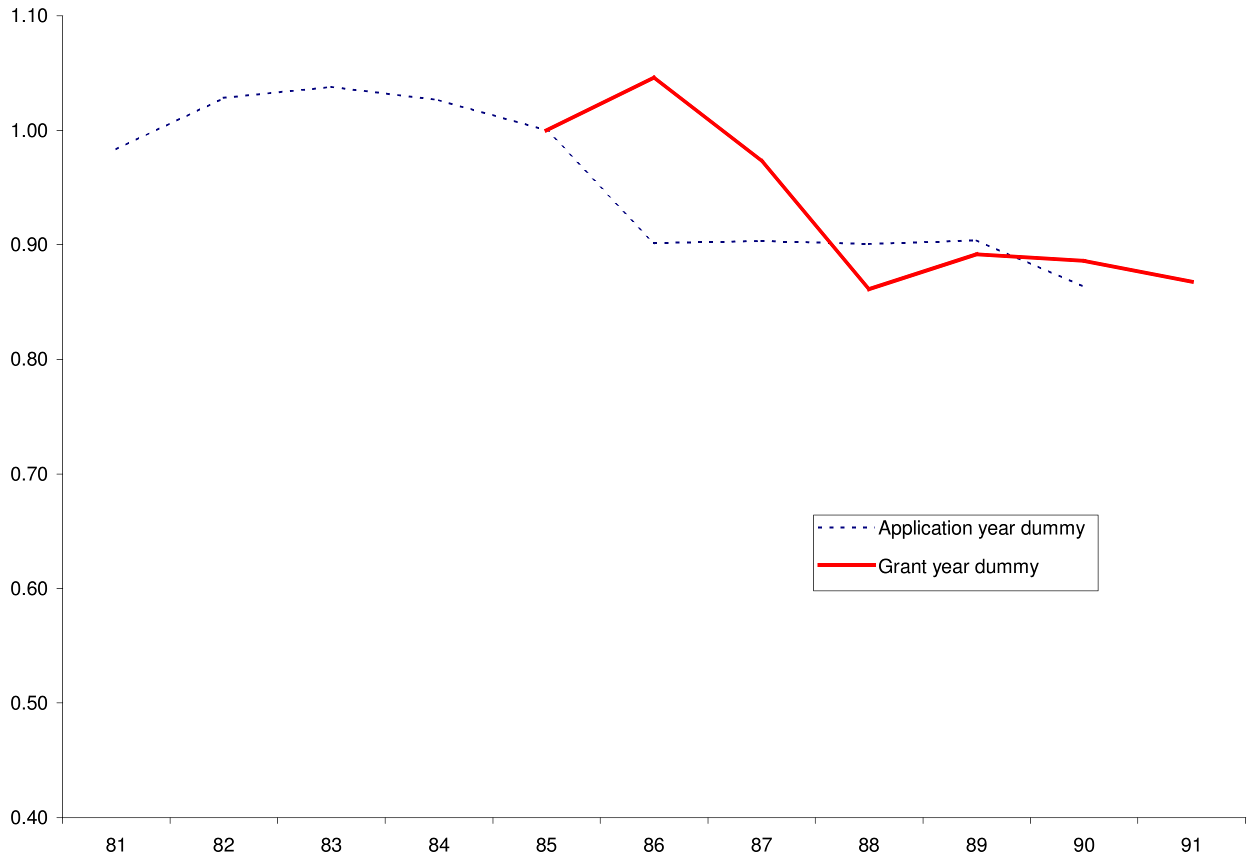
1 Patentees	2 Aggregate Patent Value (mill. $92)	3 R&D Source (allocated over patent application years)	4 Deflated R&D (mill. $92)	5 Patents / $ mill. R&D	6 Equivalent Subsidy Rate
1991 Sample					
All U.S. patentees	$ 4,441.2	NSF - Total U.S. R&D	$ 115,891.6	0.49	3.8%
All U.S. patentees	$ 4,441.2	NSF - U.S. Company R&D	$ 84,291.2	0.93	5.3%
Publicly listed U.S. Firms	$ 1,988.6	Firm R&D - Compustat	$ 69,751.7	0.31	2.9%
Publicly listed U.S. manufacturing firms	$ 1,078.5	Firm R&D - Compustat	$ 61,050.9	0.29	1.8%
1985 - 91 Panel					
Publicly listed U.S. manufacturing firms	$ 3,254.5	Firm R&D - Compustat	$ 446,597.1	0.25	0.7%

Addendum: Estimates from European Patents during 1970s

Study	Cohort year	Nation	Industry	Mean Patent Value ($92)	Original ESR	Patents / $m R&D	Recalculated ESR
Pakes and Schankerman (1986)	1970	UK	All	11,128	26.4%	5.16	1.6%
		France	All	10,638	21.7%	6.44	1.1%
		Germany	All	30,564	15.2%	1.85	2.6%
Lanjouw (1998)	1975	Germany	computers	13,027	10.4%	4.47	0.4%
			textiles	9,695	38.3%	23.26	0.3%
			engines	27,571	5.7%	1.37	0.9%
	1967-80		pharmaceuticals	15,219	6.8%	2.28	0.5%
Schankerman (1998)	1970	France	pharmaceuticals	6,893	4.1%	5.99	0.2%
			chemicals	7,942	7.2%	9.14	0.2%
			mechanical	24,165	29.9%	12.48	0.7%
			electronics (exc. Japan)	31,704	35.4%	11.22	1.0%
MEAN					18.3%	7.60	0.9%

Note: Estimates for firms are conditional on firms choosing to patent. Patents per R&D for the European studies is computed from reported (or implied) patent grants per R&D converted to the equivalent ratio for 1992 U.S. dollars. Mark Schankerman has confirmed in private communication (11/28/2004) that the patents to R&D ratio reported in his 1998 paper should be 10 times larger the printed figures. The recalculated equivalent subsidy rate uses the estimated mean patent value and a patenting rate of .31 patent applications per million 1992 dollars of R&D. Estimates for the equivalent subsidy rate for Pakes and Schankerman (1986) have been adjusted to represent value at grant date as described in Schankerman (1998). Equivalent subsidy rates for Schankerman (1998) use only business R&D.

Figure 1. Year Effects



Note: dummies are normalized to equal 1 in 1985.