ESSAYS ON ECONOMIC VALUATION OF PATENTS IN INDIA

Ph.D. Thesis

By

MOHD SHADAB DANISH

DEPARTMENT OF ECONOMICS

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ESSAYS ON ECONOMIC VALUATION OF PATENTS IN INDIA

A THESIS

Submitted in partial fulfillment of the
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by

MOHD SHADAB DANISH

DEPARTMENT OF ECONOMICS
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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **ESSAYS ON ECONOMIC VALUATION OF PATENTS IN INDIA** in the partial fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY** and submitted in the **DEPARTMENT OF ECONOMICS, Indian Institute of Technology Indore**, is an authentic record of my own work carried out during the time period from July 2016 to March 2021 under the supervision of Dr. Ruchi Sharma, Associate Professor, School of Humanities and Social Sciences (HSS), Indian Institute of Technology Indore.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

Mohd Shadab Danish

24 March 2021

(MOHD SHADAB DANISH)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Ruchi Sharma 24 March 2021

(Dr. RUCHI SHARMA)

MOHD SHADAB DANISH has successfully given his/her Ph.D. Oral Examination held on 14 July 2021.

Ankhi Ray		Ruchi Sharma
Signature of Chairperson (OEB) Date: 14/07/2021	Signature of External Examiner Date: 14/07/2021	Signature(s) of Thesis Supervisor(s) Date: 14/07/2021
		Pritam Ranjan
Signature of PSPC Member #1 Date: 14/07/2021	Signature of PSPC Member #2 Date: 14/07/2021	Signature of PSPC Member (External) #3 Date: 14/07/2021
	Nirmala	
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Dedicated to my beloved parents and late grandparents

SYNOPSIS

Introduction

The valuation of Intellectual Property (IP) plays an essential role in the technology market. For instance, IP, including patents, are being traded more regularly between companies. Keeping the patents' significance as a central deducing force of this work, we endeavour to estimate patents' value in the Indian setting from the inventors’ perspective. Various notions of value are found in the literature with a different perspective (legal, economic, strategic, accounting, and taxation) depending on the valuing agency's specific context and objective. The patent's value can be perceived as the value of the underlying technology that a patent protects. Patent rights' value may also refer to the incremental value above any profit that can be captured without patent protection (Arora et al., 2008).

One of the difficulties we face while estimating the monetary value is the asymmetric information on the patent's marketability (Lemley and Myhrvold, 2007), and dependence on highly idiosyncratic details (Cohen et al., 2000). The patent valuation studies are arranged into two classes, i.e., qualitative, and quantitative. The former endeavours to appraise the strength of invention through patents *due diligence* which is an in-depth investigation of patent’s characteristics to determine the firms' most valuable innovations. The qualitative studies identify the factors that contribute towards the valuable patents. The quantitative methods estimate a single patent's value (patent portfolio) in monetary terms. Over time, scholars have developed various methods to estimate patent value. They have used litigation, renewal decision, and citation information as a proxy of value indicators in the absence of any direct measure of patent value. Further, as most patent systems levy renewal fees, the patentee's renewal decision is also tied to patent rights' value (Sullivan, 1994). The patent renewal data provides information on the private value of patent rights. The renewal fee is charged annually from the patentee by the respective patent office to keep a patent enforced for an additional year. The failure to renew cancels the exclusive rights of the patentee. Thus, an assignee/patent holder will pay the renewal fee for an additional year when the returns from holding the patents exceed the renewal cost. In this thesis, we use renewal information to estimate the private value of patents in India.

India's patenting activities has increased significantly over time; for example, in 1995-96 the total domestic patents filed were 1606, and non-resident filing was 5430 at Indian Patent Office (IPO). In 2018-19, the patent applications are 50,659, which is 5.9% higher than 2017-18. (IPO Annual Report, 2018-19). However, the increasing patenting activity does not capture the quality of the invention, which is the focus of this doctoral dissertation. Based on the above discussion, the thesis has the following four objectives:

1) To estimate the determinants of survival of a patent filed at IPO.
2) To identify valuable technology at the disaggregated level.
3) To estimate the monetary value of expired patents.
4) To estimate the forward value of non-expired (enforced) patents.

Each of the abovementioned objectives has been addressed in the four essays of this dissertation. These four essays though independent yet are closely linked with patent value as a common thread. First, we estimate the determinants of patent value (survival length) in the Indian context. We examine the impact of patent indicators on the survival life of the patent. Since R&D volumes and patenting efforts vary across the assignee category, controlling these variables gives ample information about the patent's quality. Second, we identify the valuable technology at a disaggregated technological level. The third essay estimates the value of expired patents in monetary terms. Finally, we estimate the forward value of unexpired patents. We capture patent values using different measures based on renewal data that necessitate the use of different methodologies. Such an approach allows us to gain insights into the India's innovation quality. Further, the patent's embedded information reveals plenty of information about its general features and value.

Literature Review

Various, fundamentally different approaches to patent valuation exist in the literature. This methodology expands on expert knowledge of the technology, markets, production facilities, legal effectiveness of the patents, etc. The scholars in the field of economics and management argue that the patent data itself can be used to derive valid indicators of patent value (Hall et al., 2005; Reitzig, 2004). Experimental investigations on patent valuation verify the theoretical plausibility of patent indicators. For example, forward citation, family size, and ownership variable show the highest degree of theoretical and empirical validation (Reitzig, 2004). The backward citation and forward citation have been validated as an indicator of patent value in various surveys along with the family size, e.g., by Lanjouw and Schankerman (2001). All these studies differ from each other with respect to the quality of the research design, the sample size, and the ownership of the patentee's country.

The estimation approach of the monetary value of patents is classified into three broader groups. The first approach is based on the survey method in which investors are directly asked to estimate their patents' value (Scherer and Harhoff, 2000). The second approach is based on the valuation made by external investors, either by stock market valuation or by venture capital valuations (Hall et al., 2005). The third approach relies on patent owners' observed behavior (Schankerman and Pakes, 1986). To estimate the private value of a patent, Schankerman, and Pakes (1986), utilize information about renewal fees and renewal rates. The intuition is that the patent owner keeps the patent if the patent's return is larger than the renewal cost. Gupeng and Xiangdong (2012) and Zhang and Zhou (2014) explore Chinese patents' private value in the developing countries context using the renewal and infringement data, respectively. They find that patent-owned foreign countries in China are more valuable than resident patents. However, in the Indian context, we do not find any study that uses data on the renewal, technology, ownership (resident and non-resident), and assignee categories to assess patents' value.

Data and Methodology

Data

The data comprises a set of Indian patents applied during 1995-2005. We constructed our data by selecting only granted patents across the technology group. Total patent applied between 1995 to 2005 are 100170 (IPO annual reports). Out of the total patents, 56151 were granted over the period (PatSeer). We collected patent-level information from the IPO website and found that many patents do not have complete information. In such a case, we dropped the patent for which the renewal information was not available from the sample. The final sample of both enforced and expired patents has 40131 patents. This study follows International Patent Classification (IPC) technology classification developed by World Intellectual Property Organization (WIPO). An IPC code is assigned based on patents technological category. Due to the multiple classifications of documents, a patent belongs to more than one technology group. To avoid double-counting, this study uses each patent's first classification code to determine the technology class.

Methodology

We use the parametric Accelerated Failure Time (AFT) model to estimate the patent's determinants of survival length. From a survival analysis point of view, if a patent has expired, it is coded as 1 (and referred to as the "event"). If the patent has either matured (completed 20 years of renewal life) or still in force (censored) at the time of data collection (31st December 2018), then the patent is coded as 0 (and referred to as the non-occurrence of the event). We use different patent attributes and see their impact on the survival length controlling for technology and ownership across the assignee categories.

In the second essay, we use the ordered dependent variable (1, 2….4) based on the renewal fee scale. Patents falling in a category 1 are considered as lower value patents, and patents falling in the higher category of 4 are considered the most valuable patents. We estimate the generalized ordered logit model (GOLM) to estimate the result for disaggregated technology level. We want to see that which technology at the disaggregated level is most likely to fall in the higher category of patent value. We use five major technology categories followed by 35 sub-technology categories.

In the third and fourth essays, we use the renewal model proposed by Schankerman and Pakes (1986) based on a patents' life in which the patentee decides to keep the patent in force to internalize the streaming returns. Here the aim is to estimate the incremental rents that patents earn. This model is based on two assumptions. First, technology depletes at a constant rate. Second, the initial return-function of observable characteristics- follows a log-normal distribution.

Based on the data we have, the i-th patent falls into one of the following three scenarios at a time. First, a patent that is never renewed. Second, the patent is renewed till statuary time. Third, the patent expires between 3 to 19 years (renewal fee starts from the third years, and the last renewal decision is taken in the 19th years, since the maximum life of a patent 20 years). To estimate the forward value of a patent, we use an additional decision criterion where the patent is renewed in previous years and are still enforced at the time of study execution.

We follow an evolutionary optimization technique called the Genetic Algorithm (GA) for finding the maximum likelihood estimates (MLE) of $\Omega = (\sigma, \mathrm{d}, \boldsymbol{\beta})$. Using the parameter estimates $(\hat{\sigma}, \hat{\mathrm{d}}, \hat{\boldsymbol{\beta}})$, we estimate the bounds for each patent value conditional on corresponding renewal decisions made by the patentee. Using Monte Carlo simulation, we estimate the initial return $\mathrm{r_i}(0)$ of the patent, thus $\mathrm{r_i}(\mathrm{t})$ value is calculated using fixed depreciation rate as demonstrated by Bessen (2008) and Gupeng and Xiangdong (2012).

Empirical Results

The synthesis of determinants of patent survival studied in essay 1 and presented in Table 1 reveals that the patent attributes influence the survival length across the assignee categories. We find strong evidence that non-resident patents compared to resident patent survive longer across the assignee category. This reflects the gap of both innovation capability and innovation quality between India and the developed countries as most non-resident patents originate from U.S, Europe, and other developed countries. Further, the impact of patent attributes on the survival length varies with the assignee categories. For example, larger claims affect survival length positively in the individual and firm’s category. However, it negatively influences the institution category patents. Such contrasts might be clarified by either the composition of patents or within-group quality differences. Patent family size as an indicator of international patent scope positively impacts the patent's overall survival length. This makes sense because of the huge costs involved when a patent is filed in multiple jurisdictions.

This study finds that technological scope is positively associated with the patent's renewal life across the model except for institution patents. The average technology scope among the assignee category is the lowest for the institution patent category. This result reveals that the technology breadth of institution patents is lower than firms and individual patents. Similarly, the grant lag is positive and significant across the models. Further, our investigation finds that the inventor metrics are critical across the models aside from individual categories. This implies that patents invented in the collaboration are more valuable.

In essay 2, there are likewise contrasts in the value of patents from different technology fields. Electrical machinery apparatus and computer technology of electrical patents are less likely to be renewed than pharmaceutical which is the base category. In contrast, audio-visual tech, digital communications, telecommunication, and basic communication patents are relatively more likely to be renewed. In the sub-category of “instrument”, biological materials and medical technology is less likely to have a higher value, whereas “control” patents are more likely to have a higher value than pharmaceutical. Organic fine chemistry and food chemistry of chemical fields have a lower probability of having high-value patents. In contrast, basic material chemistry, biotechnology, environmental technology, basic material chemistry, and materials metallurgy patents are more likely to have a higher value as compared to pharmaceutical patents. In India, the present study reveals that biotech patents are more likely to be maintained than patents belonging to simple devices (less complex technology). Such technology is considered less expensive in terms of R&D. The difference in value might be principally concerned with the market development.

In essay 3 (Table 3), we have estimated the monetary value of expired patents. The renewal fee in India is meagre compared to many developed nations. Our results show that many patents (19.63%) are never renewed—many patent lapses between 7 to 15 years of life. In India standard patent length is 11.68 years, which is higher than Chinese patents and at par with many developed nations. We discover the depreciation rate d=0.49, which suggests that India's protected innovation deteriorates at a higher rate than such innovation in China (24.28%), as indicated by Gupeng and Xiangdong (2012).

We also examine how the private value of patents differs among technologies. For example, electrical patents hold the highest mean value, followed by instruments and mechanical patents. Somewhat, this result is different from the developed economies (Bessen, 2008) highlighting the market demand differences between the countries. The dollar estimate for Indian patents is marginally smaller than estimates for non-resident patents. We also find a significant difference in the value of patents across the categories of institutions, firms, and individuals. We find that the distribution of Indian patents' value is skewed; therefore, patent counts are not a good measure for innovation output.

In essay 4 (Table 3), we find that enforced patents' private value is higher across the assignee and ownership categories compared to expired patents. The patent value is a diminishing with time. The distribution of enforced patents also reveals the skewed distribution of patent value. In terms of ownership differences, non-resident patents' values are generally higher than those locally owned patents. However, in the enforced category, value of non-resident patent is marginally lower than the patent value from resident countries. The net present value for the enforced patents compared to expired patents is more valuable. This study finds different results from what is commonly observed in western countries. We find that higher value for electrical and mechanical patents while chemistry patents are not so valuable. These differences should be attributed to the heterogeneous technological market structure and patent rules in the country. Among the assignee category, institution-owned patents are 1.24 times greater than firms patent and 1.26 times greater than individual owned patents. Although foreign inventors own the maximum patents in the institution category, it points the higher research productivity across the institutions.

Table 1: Multivariate analysis of patent survival rate with the generalized gamma model

Variables	Individual Coef.	Institution Coef.	Firms Coef.	All Coef.
Ownership	0.105***	0.104***	0.099***	0.0836***
	(0.02)	(0.02)	(0.01)	(0.01)
Claims	0.001**	-0.002***	0.000*	0.0002
	(0.00)	(0.00)	(0.00)	(0.00)
Inventor size	0.009	0.025***	0.003***	0.0078***
	(0.01)	(0.00)	(0.00)	(0.00)
Technology scope	0.003**	0.001	-0.0003	-0.0004
	(0.00)	(0.00)	(0.00)	(0.00)
Grant lag	0.067***	0.053***	0.052***	0.0537***
	(0.00)	(0.00)	(0.00)	(0.00)
Family size	0.002**	-0.001	0.001***	0.0013***
	(0.00)	((0.00)	(0.00)	(0.00)
Electrical	-0.006	-0.045*	0.041***	0.0317***
	(0.03)	(0.02)	(0.01)	(0.01)
Mechanical	-0.009	-0.046***	-0.032***	-0.0368***
	(0.02)	(0.02)	(0.01)	(0.01)
Otherfield	-0.066**	0.052	-0.040***	-0.0489***
	(0.03)	(0.04)	(0.01)	0.01)
Instruments	-0.032	-0.062***	0.023***	0.0024
	(0.03)	(0.02)	(0.01)	(0.01)
Const	1.932***	2.153***	2.162***	2.1622***
	(0.04)	(0.04)	(0.01)	(0.01)
LR $\chi^2(1)$	316.72***	429.12***	3548.77***	4228.27***
No. of Observations	2,498	3310	28358	34166

Note: Here, ***, **, and * denote p < 0.01, p < 0.05 and p < 0.10, respectively.
Reference category is chemistry across the models

Table 2: GOLM analysis by technology sub-categories (reference category: pharmaceutical)

	Renewal level 1		Renewal level 2		Renewal level 3	
Variables	**Coefficient**	**Std.Err.**	**Coefficient**	**Std.Err.**	**Coefficient**	**Std.Err.**
Electrical machinery apparatus	-0.02	0.08	-0.136*	0.08	-0.162**	0.08
Audio-visual tech	0.233**	0.12	0.061	0.1	0.248***	0.09
Telecommunications	0.388***	0.09	0.253***	0.09	0.490***	0.08
Digital communication	0.225	0.17	0.263*	0.14	0.635***	0.13
Basic communication	0.007	0.19	0.334**	0.17	0.360***	0.14
Computer technology	0.088	0.1	-0.178**	0.09	-0.051	0.09
IT Methods for management	0.423	0.42	0.423	0.42	0.423	0.42
Semiconductors	0.166	0.16	0.166	0.16	0.166	0.16
Optics	0.008	0.14	0.008	0.14	0.008	0.14
Measurement	0.272**	0.11	0.147	0.11	0.065	0.1
Analysis of biological materials	-0.323*	0.17	-0.323*	0.17	-0.323*	0.17
Control	0.277*	0.15	0.277*	0.15	0.277*	0.15
Medical technology	-0.197***	0.09	-0.305***	0.09	-0.211**	0.09
Organic fine chemistry	0.049	0.08	-0.01	0.07	-0.122*	0.07
Biotechnology	0.253***	0.09	0.253***	0.09	0.253***	0.09
Macro-molecular polymer	-0.053	0.08	-0.053	0.08	-0.053	0.08
Food chemistry	-0.156	0.15	-0.005	0.13	0.227*	0.12
Basic material chemistry	0.125*	0.07	0.125*	0.07	0.125*	0.07
Materials, metallurgy	0.237***	0.07	0.237***	0.07	0.237***	0.07
Surface technology	0.059	0.11	0.059	0.11	0.059	0.11
Chemical engineering	0.106	0.07	0.106	0.07	0.106	0.07
Environmental tech.	0.298*	0.18	0.104	0.15	-0.212	0.14
Handling	-0.101	0.09	-0.101	0.09	-0.101	0.09
Machine tools	0.08	0.09	0.08	0.09	0.08	0.09
Engines pumps turbines	0.292**	0.12	0.125	0.1	-0.168	0.09
Textile and paper	-0.122	0.09	-0.230***	0.09	-0.303	0.09
Other special machines	-0.136	0.09	-0.136	0.09	-0.136	0.09
Thermal processes	0.041	0.11	0.041	0.11	0.041	0.11
Mechanical elements	0.072	0.12	-0.198**	0.1	-0.246	0.1
Transport	0.245**	0.11	-0.139	0.09	-0.488	0.1
Furniture, games	-0.565***	0.15	-0.565***	0.15	-0.565	0.15
Other consumer goods	-0.181*	0.11	-0.181*	0.11	-0.181	0.11
Civil engineering	-0.206**	0.11	-0.206**	0.11	-0.206	0.11
Constant	1.368***	0.09	-0.575***	0.08	-1.398	0.08
Pseudo R^2	0.0392					
LR chi square	2162.24***					
Number of observations	21,562	21,562	21,562	21,562	21,562	21,562

Note: Here, ***, **, and * denote $p < 0.01$, $p < 0.05$ and $p < 0.10$, respectively. Reference category is pharmaceutical.

V

Table 3: Maximum likelihood estimates of $\boldsymbol{\Omega} = (\boldsymbol{\beta}, \boldsymbol{\sigma}, \boldsymbol{d})$ obtained via Genetic Algorithm

Independent variable	Expired patents Estimate $\boldsymbol{\beta}$	Enforced patents Estimate $\boldsymbol{\beta}$
Claims	326.96***	12.42***
	(13.59)	(4.29)
Family size	123.09***	6.45***
	(12.50)	(2.87)
Inventor size	89.28***	102.30***
	(8.77)	(28.17)
Grant lag	-256.77***	-1.61***
	(2.78)	(0.76)
Tech scope	74.60***	11.50***
	(13.18)	(3.16)
Chemistry	184.83***	75.47***
	(65.35)	(8.53)
Mechanical	447.30***	79.49***
	(77.10)	(10.14)
Electrical	376.48***	74.90***
	(70.89)	(11.04)
Otherfield	106.98	62.78***
	(80.66)	(20.11)
Firms	179.41***	50.04***
	(37.31)	(11.05)
Institution	1062.37***	106.29***
	(98.51)	(19.23)
Ownership	292.03***	22.83***
	(43.02)	(6.29)
σ	1311.71***	55.21***
	(7.55)	(4.50)
d	0.50***	0.48***
	(0.00)	(0.01)
Constant	-516.41***	-205.41***
	(44.75)	(9.49)
Observations	18864	27100

Note: All values in parenthesis are standard error. # denotes dummy variable. p-values for all estimates are less than 10^{-6}, hence significant at 1%level.

Policy Implications

Our findings have implications for the R&D managers and policymakers. The recognizable indicia of value, importance, or probability of renewal give the knowledge to help the patent law reforms. For example, the value of patents concentrated in few technological fields suggests that the law needs to be tailored to address these specificities. Further, to weed-out low-quality patents from the system, the patent office needs to make certain changes. For example, the Indian patent office should strategically increase the renewal fee for commercially utilized patents. The sharper increase in the renewal fee schedule for productive firms may yield significant gains. One of the important observations of this dissertation is that India's average patent life is around 12 years. Since most of the patentee's learning occurs in the beginning of the patent filing, the maintenance fee schedule can be inverted. Higher support charges toward the front and lower over the long run encourage more rapid transfer to the public domain. The skewed value distribution reveals the patent's heterogeneous nature to measure the innovative capacity, thus, one should include quality indicators instead of the simple patent count. These findings gain relevance in view of the recent measures introduced to capture innovation through different indices across countries and across states in India by the government.

The outcome suggests that the individual assignees' patents have a lower value than institutions and firms' patents. Thus, if the patent is seen as a good incentive mechanism for innovation, policy intervention could improve patent revenues' internalization, at least for individuals and small firms. For instance, individual patentees (small entities) or institutions need to accumulate more data before figuring out how to utilize patents. The intervention of policymakers and the government can make this challenging task easy by initiating a platform for innovators who fail to commercialize their inventions due to lack of finances. Further, as we find wider patent is more valuable, R&D team needs to pay special attention to the writing of the claims. The collaboration outcome is also positive and significant on the patent value, and therefore, companies should invest time and money in the collaborative projects.

Contribution of the Study

This study contributes to the existing literature (especially in the developing country context) by estimating the patent value for different technology fields. Besides, this study estimates the value of resident and non-resident patents in India. The value estimation for the different technology fields reveals India's trajectory of innovation by resident and non-resident. Further, this study contributes at the methodological level where we apply the parametric model (AFT), generalized ordered logit model, and maximum likelihood estimation (MLE) to estimate the study's different objectives. Further, to estimate the monetary value of patent use, we simulated the renewal decision of the patentee for each patent. This study builds on strong logic that the patent is renewed only when realized return from the patent is greater than the renewal cost.

Limitations and Future Research

There are a few limitations of this examination that need consideration in future work. First, the monetary value of the patent assessed in this thesis utilizes a fixed depreciation rate. Further, applying a dynamic model where depreciation rate changes with time and technology field we may explain the technology life cycle. Second, this study considers detailed patent-level information. However, it misses some vital information from the patent, such as forward citation and proportionality of Indian inventors. We recommend using detailed information on the patent claims instead of straightforward claims count. Third, this study does not include firm-level information such as R&D intensity, firm size, and profitability.

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Journal article under review

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ABBREVIATIONS

AFT	Accelerated Failure Time
AIC	Akaike Information Criterion
BIC	Bayesian Information Criterion
CDF	Cumulative Distribution Function
CNIPO	China National Intellectual Property Administration
Cox PH	Cox Proportional Hazard
EPO	European Patent Office
FS	Family Size
FS*	Filing Strategy
GA	Genetic Algorithm
GL	Grant Lag
GOLM	Generalized Ordered Logit Model
IID	Independent identically Distribution
inPASS	Indian Patent Advanced Search System
IP	Intellectual Property
IPC	International Patent Classification
IPO	Indian Patent Office
IPR	Intellectual Property Rights
JPO	Japan Patent Office
MLE	Maximum Likelihood Estimator
NC	Number of Claims
NI	Number of Inventors
NPV	Net Present Value
OC	Ownership Characteristics
OLM	Ordered Logit Model
OW	Ownership
PATSEER	Patent Search and Analysis Software
PC	Patent Count
PCT	Patent Corporation Treaty
POM	Proportional Odd Model
R&D	Research and Development
RL	Renewal Level
TR	Time Ratio
TRIPS	Trade-Related Aspects of Intellectual Property Rights
TS	Technology Scope
USPTO	United States Patent and Trademark Office
VIF	Variance Inflation Factor
WIPO	World Intellectual Property Organization

Chapter 1

Introduction

1.1 The Background

Schumpeter (1934) established that innovation, and especially technical innovation, is one of the driving forces behind economic growth. A large part of economic growth is contributed by technological change (Abramovitz, 1956; Kendrick, 1956; Solow, 1957). Arrow (1972) identified that a perfectly competitive market hinders an optimal level of investment in innovation due to public good nature of the knowledge. Thus, intellectual property rights are required to ensure appropriability of the investments made in research and development (R&D). The significance of intellectual property rights (IPRs) to guarantee economic growth is shown by endogenous growth models (Romer, 1990; Aghion and Howitt, 1996; Sala-I-Martin and Barro, 1995). Studies further examine the role of patents[1] in incentivizing innovation, technology transfer and analyze the specific characteristics of patent documents to unravel different aspects including value of innovation. In this thesis, we attempt to estimate the private value of Indian patents based on renewal data.

Today, the importance of valuing patents is expressed in many circumstances. For instance, intellectual property (IP), including patents, are traded regularly between companies. Banks often accept patents as a collateral for credit, which requires a valuation. Moreover, the valuation of patents is required on account of liquidation while repaying investors. To make right decision about the patent filing in other countries, the patent must be valued. The more progressive occasion of such conditions makes the need to face patent valuation unavoidable. The choice to make a patent application and to renew it, are based on whether the costs identified with the choice are supported

[1] Patents are among the seven intellectual property rights and are also the focus of this research.

or not. Therefore, patents involve a high degree of managerial flexibility where a patent owner can choose a wide range of options such as abandon, continue or expand.

Keeping the patents' significance as a central deducing force of this work, we endeavor to estimate patents' value in the Indian setting from the inventors' perspective. Various notions of *value* are found in the literature with a different perspective (legal, economic, strategic, accounting, and taxation). To begin with, the value of patents depends on the specific context and objective of the valuing agency. Precisely, the patent's value in this study refers to the value of protection right, that is, incremental value above and beyond any profit that would have been realized without patent protection by the patentee (Arora et al. 2008).

Against this backdrop, for Indian patent data, this doctoral dissertation, measures the determinants of patent survival length for different technology groups, assignee groups, and ownership categories. Further, we use the patent level characteristics and their behaviour to identify the valuable technology at a disaggregated level (35 technological categories). The fourth and the last study combine the possible indicators of patent value in a renewal model developed by Pakes and Schankerman (1984) to estimate the expired patent value as well as enforced patent value.

1.2 Why do Significance of Patents Varies across the Industrial Sector?

The global patenting activity has seen an upward trend since 2004, except in 2009, where the patent application declined 3.8 percent due to the financial crisis. Along with other developing countries, India has also seen an upsurge in the overall patenting activity. The total patent applications at Indian Patent Office (IPO) in 2009 were around 34000 (resident and non-resident), which increased to approximately 50000 in 2018 (WIPO statistics). In 2018, India issued 12.3 percent more patents than the previous years (IPO Annual report 2019). The gradual but steady increase in innovative activities has improved India’s position in the Global Innovation Index (GII). There is a plenty of research available highlighting the importance of innovation and technological development for the economic growth and welfare (e.g., Baumol, 2002; Rosenberg and Nathan, 1982; Rosenberg and Birdzell, 1987; Schumpeter, 1934; 1942; Solow, 1956; 1957). However, IP management studies have traditionally been limited to highly developed nations (Granstrand, 1999; Hanel, 2006). The transition in the patenting activities started somewhere in the mid-1990s when Trade-Related Aspects of Intellectual Property Rights (TRIPs) came into existence (e.g., Granstrand, 1999; Pisano, 2006; Pisano and Teece, 2007; Reitzig, 2004; Somaya, 2012).

The increasing importance of the knowledge economy led researchers to investigate various aspects of India's IP strategy, economic growth and organizational growth. In the Indian context, Narayanan (1998) estimated the impact of the deregulation policy introduced in 1980 on technology acquisition and competitiveness. He infers that distinction in the technology acquisition among firms' is generally because of differences in the organizations' capacity to achieve technological paradigm and trajectory shifts. Chadha (2009) concludes that technology proxied by foreign patent rights has a positive impact on exports. The follow-up research on the various aspects of innovation and firm’s performance in India has been conducted by Basant and Mishra (2014), Ambrammal and Sharma (2016), Sharma et al. (2018), and Ivus et al. (2020). The literature on the importance of innovation recognized that patent's role and find that its’ effect varies considerably across industries.

The patent is used differently across the industrial sector and technology field is not startling, considering the different roles that patent play in the innovative process. In general, patents provide three fundamental functions:

a) Patents are a tool for shielding innovation from impersonation, giving supra-normal profit and thus incentive to expensive innovative activities that would not have been extracted in any case.

b) Patents assume an essential part in disclosing information about innovation which may have been usually left well secret, along these lines encouraging further technological progress.

c) Patents support the advancement of markets for technologies (Arora et al., 2001) and encourage the development and commercialization of innovations (Arora et al., 2001; Lamoreaux and Sokoloff, 1999).

Empirical studies on the effectiveness and on the utilization of patents are very few and, in general, are not completely conclusive (Guellec and Pottelsberghe, 2007; López, 2009).

To begin with, Levin et al. (1987) and Cohen et al. (2000) pointed out that (a) the adequacy of patents as an instrument for appropriating the return from R&D fluctuates across firms and industries, and (b) patents are more powerful for product innovation than for process innovation. The effectiveness of patents is connected to the attributes of the innovation and the R&D interaction based on the nature of the market and the pattern of competition. Generally, patents are more likely to be filed in a sector where R&D cost is high and imitation is cheap (e.g., chemicals, pharmaceuticals, machinery). Additionally, the nature of R&D also plays a vital role in determining the importance of the patent. For example, patents tend to be of high value when R&D is highly capital intensive and highly uncertain (pharmaceuticals). On the other hand, when technical change is exceptionally fast and the effective life of innovation is short, a patent may not adequately reward innovators (Orsenigo and Sterzi, 2010).

Further, the heterogeneous nature of patents in the different technology fields is captured through the distinction in complex vs. discrete technologies. Complex technology is inherently more difficult to imitate and therefore the value of a patent is, in this regard, lower. Also, since innovations in a complex technology usually require the granting of a many patents, it gets more diligently to appropriate the income through the intellectual property system. Cohen et al. (2000) argue that firms working in the field of discreet technology areas are more likely to patent. Areas described by discrete product technology are commonly drugs, chemical compounds, steel, and metal items, while example of complex product technology are hardware, programming and semiconductors (Roycroft and Kash, 1999; Kingston, 2001). Based on the above discussion this dissertation estimates the patent value across the technology field in India.

1.3 Basic Principles of Patent Valuation

The central role of innovation is to incentivize innovation, improve its competitive position, and maximize welfare. Before discussing the estimation process, it is essential to distinguish between the value of underlying technology and the value of protection. Former talks about the discounted cash flow of profit generated throughout the invention's economic life. However, the value of patent right (or private value of patent) is defined as an additional value extracted from the patent after grant (Lanjouw, 1998). The patent right can be profoundly important and assumes a critical part in numerous fields of business. The literature in the economics and management field has identified measures and drivers of patent value, beginning from Pakes (1986) and Schankerman and Pakes (1986). In the current competitive environment, a patent needs to be valued more frequently from different perspectives for a broader set of stakeholders (Kamiyama et al., 2006). The patent's valuation process is carried under the different context; internal decision, i.e., patent filing and renewal decision, and external decisions such as licensing and sale opportunities, accounting purposes, calculation of damages in lawsuits. In this section, we define the basic principle of patent valuation. We also discuss the various methodologies and major challenges in the patent valuation practices.

1.3.1 Definition of Patent Value from the Economic Perspective

The patent involves an intricate arrangement of potential outcomes. Along these lines, it is difficult to quantify the financial incentive as we do effectively in the other investment projects where we have some underlying expenses and certain future returns. Inventors have little idea about the commercialization or strategic success of a patent in the beginning. However, the inventors usually know how significant and advance it is compared to other technologies in the field. After the innovators, the immediate person is the patent agent who drafts and prosecutes the application to know about the scope and quality of the patent protection that might be obtained. Lastly, the person who takes responsibility for the marketing of underlying technology knows the innovation's potential. Ideally, the valuation method shall be constituted using the experience of all these three parties who are directly involved in the different stages of patent life. In any case, two issues exist when consolidating this data for the valuation; first, the absence of a commonly accepted objective valuation method to process this information and second, the decision processes involved in valuation are subject to several potential biases (Cotropia, 2009).

Valuation of a patent is one of the trickiest and challenging tasks for managers, law experts, or economists. The legal dimension of patent worth clarifies through the dependability and enforceability of the patent rights. From the economics point of view, a patent’s private value refers to the economic rewards earned by directly excluding competitors from the market or licensing/selling the patent to the third parties. There are two important terminologies regarding the patent value that explain the patent's private value more clearly. First, the value of the underlying technology that a patent protects and the value of the patent per se. Former refers to the profit that a patentee might earn from an invention without seeking the patent protection. Second, patent rights’ value refers to the incremental value above and beyond any profit that can be captured without patent protection (Arora et al., 2008). However, the biggest challenge for a researcher is to measure patent value for these two categories separately.

Further, a valuing agency must have a clear idea about what is being valued. “Patent” is often used in a very loose sense meaning either the underlying technology alone, the patent right alone, or both. Furthermore, in some cases, “the invention” refers to a particular embodiment; in others, anything within the scope of a patent’s claims (Pitkethly, 1997). Having said that, the patent entails a complex series of possibilities. Therefore, it is not easy to measure the monetary value as we do easily in the other investment projects where we have some initial costs and certain future returns. Precisely, the direct financial value of a patent application *per se* is defined as the incremental earnings due to patent protection compared to the value of innovation without patent protection (Arora et al., 2008).

There are two specific characteristics of a patent that make the valuation difficult and time-consuming. First, a patent is an intangible asset, mostly an idea or knowledge, i.e., non-physical. Thus, unlike other assets in the business, a patent does not have spatial characteristics. Secondly, patents are not frequently sold and purchased in the conventional market. Therefore, assigning monetary value in the absence of direct information on the sale and purchase of patents becomes challenging. The patent’s valuation issues gain further complexity due to initial uncertainties about the commercial success of a patent in a competitive market. The underlying uncertainties are about the legal challenges that a patent might face during the application and subsequent enforcement. The patent valuation literature advancement has broadened the valuation understanding and proposed different valuation methods in the past two decades. The patent’s renewal life has been frequently used as the quantitative proxy along with forward citations received (Hikkerova et al., 2014; Squicciarini et al., 2013).

The value of patents has attracted enormous attention from economists, innovators, managers, and policymakers, as patents represent a claim to garner financial returns from science and technology's novel outcomes. The scholars such as Sellers-Rubio et al. (2007), Bessen (2008), and Suzuki (2011) investigated the potential determinants of patent value based on econometric models. The burgeoning body of academic research has mainly focused on the factors that may influence the market value: the financial return on the patent right. The quantitative value obtained using the various econometric models in the academic research is generally called the private value of patent (Gronqvist, 2009). A study by Hall and MacGarvie (2010) defines the patent's private value as the financial benefits obtained by patent holders from introducing an invention in the market.

1.3.2 Patent Valuation Approach: Estimates from the Renewal Model

Now we discuss the various approaches and data sources that have been used in the economic and management literature to value patents. The literature on patent valuation is classified into three different categories. The first set of studies estimate a single patent or patent cohort's value using patent owners' decisions to renew a patent (Pakes, 1986; Putnam, 1996; Lanjouw, 1998; Bessen and Maurer, 2008) and commercial transactions (Serrano, 2005; Sneed and Johnson, 2009; Sakakibara, 2010). These studies are based on the renewal information (whether a patent is renewed or not) and the patent's commercial transaction to determine its value. The second approach uses a survey method to estimate the value of a single patent. In this method, researchers directly ask inventors to price their innovation if they sell in the market at that point of time (Harhoff et al., 1999; 2003a; 2003b; Gabbardella et al., 2008). A third approach resorts to the valuation made by external investors, either by analyzing the stock market valuation of patent portfolios of publicly listed companies or the valuation made by venture capital firms of IP-based start-up companies

(Bessen and Maskin, 2009; Hall et al., 2005; Bloom and Reenen, 2002).

The utilization of patent renewal data to estimate the private value of patent began with seminal works of Pakes (1986) and Schankerman and Pakes (1986). The patent renewal data generally provides information only on the private value of patent rights. Since the social return on the innovation is difficult to appropriate, it is presumed not to influence the inventors' decision to renew a patent. The renewal fee is charged by the patent office where a patent is sought for protection. To keep a patent maintained for an additional year (the most extreme existence of the patent is 20 years from the date of application), patentees are needed to pay a renewal fee on a given due date. However, failure of renewal payment cancels the exclusive rights of the patentee on the invention. In India and Europe, the renewal fee is charged annually, whereas the United States (US) patent renewal fee is paid every three years after the grant. Therefore, this approach's underlying rationale is that the assignee/patent holder will pay the renewal fee for an additional year when the returns exceed the renewal cost.

The earliest studies on the economic valuation of patents used aggregate data, that is, information on the proportion of patent - or dropped every year. The first set of Pakes (1986) studies and Schankerman and Pakes (1986) use a model of perfect foresight on a sample of a different cohort of patents applied between 1950 and 1979 in the United Kingdom, France, and Germany. In subsequent work, Schankerman (1989) uses the patent applications in France for 1969-1982 and patent renewals for 1970-1987. Lanjouw (1998) estimates patent value for different technology areas in a similar vein- computers, textiles, combustion engines, and pharmaceuticals. They find that the distribution of patent value- across the country and in different technology areas- is highly skewed.

Schankerman and Pakes (1986) patent renewal model assumes return from the patent is deterministic, i.e., the patent owner has full knowledge about the patent return and optimum life. Later, Pakes (1986) relaxes this deterministic assumption and estimates patent value using a stochastic model where owners can learn about the technology more effectively. The gowning importance of patent value in an organization for internal and external purposes led to more diversified and sophisticated data (Deng, 2005; Baudry and Dumont, 2006). The renewal model has various advantages since it is based on patent owners observed behavior, exploiting the availability of large, longitudinal datasets. It also allows to include country, ownership, and industry characteristics in the renewal model to understand how much these characteristics explain the patent value.

1.3.3 Patent Valuation Approach: Estimates from a Commercial Transaction

A second approach that is still at the preliminary stage assesses patents' economic value based on the actual patent transactions. Ideally, this approach gives the most reliable estimate because it considers the patent market prices in the open market. Unfortunately, the IP markets are relatively less developed, and asset exchange information is not easily accessible. Consequently, identifying appropriate comparable values is difficult. Nevertheless, a limited number of studies have recently been conducted based on patent rights' commercial transactions (Serrano, 2005; Sneed and Johnson, 2009; Leone and Oriani, 2008; Sakakibara, 2010).

Serrano (2005) examines the reassignment data from United States Patent and Trademark Office (USPTO). The new owner notifies the patent's transaction to the patent office, which maintains such information in the registry. Serrano's (2005) study focuses on the small innovators who obtained less than five patents per year, and analyses 453683 patent transfer for years 1981 through 2002. The estimation strategy is based on the decision to trade and renew patents and several underlying assumptions about patent values distribution. The author estimates the parameters to simulate patent value distribution using patent transaction and renewal rate information.

The second source of information on patent value is an auction where they currently show their willingness to sell or license their patents. These electronic and live marketplaces for sale and license of intellectual property rights widely acknowledge over the last year, although its effectiveness is yet to be proved given the idiosyncratic characteristics as tradable assets. Such an organized market is still not very common in the developing countries, especially considering India, which is at a nascent stage from the IP market perspective. Several companies, individuals, and institutions own valuable IP that they do not use or cannot use commercially and need an organized market to get an appropriate value of their IP. Sneed and Johnson (2009) use auction data of 99 patents traded at the live auction by the US IP-firm Ocean Tomo[2]. Typically patents of the same industries with similar technology in group sold at the auction. It provides an opportunity to also consider those lots which were not sold. In such cases, researchers can apply appropriate econometrics techniques such as the Heckman two-step model. This model provides a fair comparison between the patent which were not sold and patent lots sold in the auction. The third approach in this category of patent value uses licensing transactions to determine the licensor and licensee's economic status. However, such information is not easily available in the public domain due to confidentiality reasons.

In summary, although studies on the patent valuation using a license, auction, and reassignment data are still limited in number and some cases, are still nascent stage as working paper, they show a novel and promising approach to estimate patent value. Such an approach’s main strength resides in actual information on the patent transaction between the owner and buyers. It also allows using the seller and buyers’

[2] OceanTomo, the Intellectual Capital Merchant Banc™ firm, gives companies monetary services related to intellectual property.

characteristics to know how this influence the transaction price. In the Indian context, these approaches are yet to be used for reliable estimation of patent value.

1.3.4 Patent Valuation Approach: Estimates Based on Inventors' Survey

In the survey method, inventors are directly asked to define their invention's price to a prospective buyer. This method was popularised in the late nineties and early 2000 by Harhoff et al. (1999; 2003a; 2003b) and Gambardella et al. (2008). This approach requires an extensive inventor's survey to execute the successful valuation method. Gambardella et al. (2008) contributions to the valuation study are twofold. First, it estimates the economic value of patent value using comprehensive data drawn from a large-scale survey conducted in Europe. The Pat-value survey collects 9000 patents data out of 27000 questionnaire mailing. The survey data include extensive information about the innovation, including the context in which an innovation is developed. Second, it assesses the relationship between the survey method and another indirect valuation approach. Before Gambardella et al. (2008) study, Harhoff et al. (2003a) use a survey method to determine the patent's value. The question formulates a hypothetical situation where inventors are assumed to have full information about the patent's value at the patent grant time. In survey method, the patentee is asked to quote the price of their patent. This method of patent valuation captures only the strategic component of the patent, not the renewal value.

The survey method treats patents as an asset, which estimates the patent value from the inventor's perspective. The estimated value reflects both the invention's value and the patent's premium. It, therefore, provides a higher value of patent then compared to estimates based on renewal date. However, an important question in this respect is whether the scale of patent value used in the survey is reasonable. Gambardella et al. (2008) find that less than 1 percent of patents had more than 300 million Euros. The survey method usually has an upward bias. The reason for that upward bias is that respondents to boost their performance inflate the reported value. Often, respondents do not want to respond if the patent zero value or are reluctant to answer if they have less value.

To sum up, this method's relative advantage allows for estimating the value of a single patent. It considers a series of information such as the characteristics of inventors, ownership, and technology field. It estimates the value of invention along with the commercialization and exploitation strategy.

1.4 Renewal Fee

As per Section 53, Rule 80 of the Indian Patent Act 1970, every patent holder must pay a patent maintenance fee annually (3rd year onwards from the date of application) after the grant to keep a patent in force. This study follows the fee structure as per “The patents rules 2003” of the Indian patent act 1970. There has not been any change in the renewal fee schedule (until the execution of this study 2018). Renewal payments are different across the countries and the duration of payments. In US the first fee that the patentee will be required to pay will come due 3.5 years after the patent has been granted. Once paid, this will allow the patent to stay in force past the fourth year ($1600), the second renewal fee will be paid in 7.5 years ($3600), and the final renewal fee will come due in 11.5 years ($7400). Indian patent renewal fee is relatively smaller in all categories. We compared china and India's renewal fee in Table 1.1.

Unlike USPTO, the patent office in India does not provide additional time onto the patent term if the granting delayed more than three years from the filing date. The renewal fees are also charged from the 3rd year from the date of application irrespective of the granting year. For example, if a patent is filed in 1999 and granted in 2010, the renewal fee will be charged from 2002 if the patentee wants to continue his/her patent in 2011. In this study, we find that a significant number of patents lapse in the initial years.

Table 1. 1: Patent renewal fee schedule for India and China

Renewal Years	1	2	3	4	5	6	7	8	9	10
China	NA	138.04	138.04	184.05	184.05	184.05	306.75	306.75	306.75	613.50
India	NA	NA	53.96	53.96	53.96	53.96	161.88	161.88	161.88	161.88
Renewal Years	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
China	613.50	613.50	920.25	920.25	920.25	1226.99	1226.99	1226.99	1226.99	1226.99
India	323.76	323.76	323.76	323.76	323.76	539.59	539.59	539.59	539.59	539.59

Note: Renewal fee information is taken from respective patent office website (CNIPA and IPO). Renewal fee converted in dollars (2020 price).

Baudry and Dumont (2006) establish in a theoretical model that an increase in patent renewal fee would proportionately discourage low-quality patents. Rassenfosse and Jaffe (2018) empirically find that an increase in the renewal fee led to the weeding out of low-quality patents. Moore (2005) finds significant numbers of patents issued each year at USPTO expire before completing twenty years. Thus, the renewal fee creates de facto differentiation in patent value. Although the patent application fee is much higher than the patent renewal fee, significant numbers of patents expire at the early stage in India. Like other developed and developing countries, India follows the incremental renewal fee. Patent owners do not pay renewal fee to reduce their losses by letting less valuable patent expire.

A patent's value can be revealed based on its owner’s assessment of patent cost and benefits. Many studies in the past hypothesized that renewal fee creates a recurring investment. Therefore, it is expensive for the patent holder to keep a patent in force until its statutory life limit, particularly when the renewal fee is increasing in nature (Baudry and Dumont, 2006). However, the renewal model's criticism is that it measures the patent value from the patentees’ point of view. Further, such valuation excludes other incidental expenses such as attorney costs, internal company costs, and therefore the value of patents is likely to be underestimated (Pitkethly, 1997).

1.5 The Motivation for Our Study

The earlier studies on patent valuation are mostly carried in a developed countries context (mostly the US and Europe) (Smith and Parr, 2000). However, with the increasing importance of IPs in the past two decades, researchers in developing countries have also started looking at valuation aspects of innovation (Gupeng and Xiangdong, 2012). Even though the countries agreed to harmonize their regional patent system as per the TRIPs agreement, their laws and procedures vary. For example, US takes a more illustrative approach where it states what can be patented, whereas Indian patent law state what cannot be patented. The basic objectives of patent system are broadly the same throughout the world; differences exist mainly in each system's procedures. In India and Europe, two types of patents are issued, namely product and process, whereas in the US, there are three types of patents given, namely, utility patents, design patents, and plant patents. Thus, the patent system’s procedure's differences create an unavoidable difference in the value; therefore, studies on patent valuation in the US and Europe (Sellers-Rubio et al., 2007; Hall et al., 2007) cannot be generalized in the Indian context.

The differences in the patenting procedures followed by patent system and the quality of R&D by the firms, individuals, or institutions create a fine differentiation in the value of patents. For example, Gupeng and Xiangdong (2012) find that patent owned by Chinese firms (residential patents) are having lower value compared to the overseas owner (Japanese and US patents) filed at China National Intellectual Property Administration (CNIPA). Thus, the larger gap in the value/quality of patents implies important differences in the motive of patenting and R&D quality between China and those technology-intensive sources, usually from economically advanced countries and regions.

The absence of formal study on India's patent value becomes necessary to address the nuances of valuable technologies and direction of R&D by the firms in the country. We also need to understand what are factors that determine the higher value of patents in India. Besides, earlier studies have estimated the value of expired patents. However, this thesis tries to estimate the value of unexpired patents or estimate patents' forward value. Subsequently, the thesis's motivation is to investigate the in-depth value of patents in India, which has not been discussed before in this specific renewal model framework. It is especially intriguing to break down the value of the patent in the Indian setting when India's worldwide rank on innovation index is improving continually. This framework's basic reasoning is that the assignee will decide to renew their patents only if the value of holding over an extra year exceeds the expense of the renewal. In this way, the value acquired by utilizing the renewal model framework gives information about the private value of patent right for the assignee, probably not affected by the social return that a firm cannot appropriate.

It is particularly interesting to estimate India's patent value because Indian innovation capabilities have increased in the last 25 years, especially after compliance with the TRIPs agreement. Patent value provides an interesting economic quantity that informs about the policy because it measures the patent system's reward for inventors. It also helps to account for the value of intangibles that measures the productivity and quality of R&D (Bessen, 2008; Gupeng and Xinagdong, 2012).

Regarding the patent, three important questions have not been discussed in the Indian context. First, does an increase in the patent filing also reflect the quality of the patent? Second, do patents owned by resident and non-resident have any difference in value? Third and the last question about patent valuation is that which technology in India produce quality patent? Keeping the above question in mind, we have formulated the following four objectives that are investigated in the four essays, separately.

5) To estimate the determinants of survival length of a patent filed at IPO for technology, ownership, and assignee category.

6) To identify valuable technology at the disaggregated technology level.
7) To estimate the monetary value of expired patents using the renewal model framework.
8) To estimate the forward value of non-expired (enforced) patents in India.

The fundamental thinking behind patent filing is that inventors anticipate better yield from a patent than the filing expenses (including legal charges). Similarly, after a patent is issued, the inventor’s decision to renew a patent for an additional year depends on the expected profit and the renewal cost. If a patent's expected benefit is lower than the renewal costs, the patentee will rather be inclined to lose the exclusive rights. The information about the expenses of the patent filing and other expenditures can be assessed with reasonable certainty. Accordingly, to estimate patent value, this thesis follows a quantitative and qualitative methodology. Albeit the procedure embraced in both the approaches are different, the patent life is utilized normally as a proxy of patent value.

The thesis contains four independent essays that are closely linked to each other, and patent value is a common thread mentioned in all the essays. First, we estimate the determinants of patent value (survival length) in the Indian context. Second, we identify the valuable technology at a disaggregated technological level. The third essay estimates the value of expired patents in monetary terms. Finally, we estimate the forward value of unexpired patents. The advantage of estimating the private value of patents in four different essays while changing methodology and data allows us to gain more information about India's innovation quality.

1.6 Data

The data comprises a set of Indian patents applied for during the period of 1995-2005. One of our interests is to examine the relationship between patent indicators and subsequent decision to renew a patent.

We constructed our data by selecting only granted patents across the technology group. Total patent applied between 1995 to 2005 in 100170 (source: IPO annual report). Out of the total patent, 56151 were granted over the period (Source: PatSeer). We collected patent level information from the IPO website. While collecting the data from the IPO website, many patents do not have complete information. In such a case, we dropped the patent whose renewal information was not available from the sample. The final sample of both enforced and expired patents is 40131 patents. Details of renewal information by technology group presented in (Appendix 1). Detail description of the data is given in each essay based on the study's requirement.

This study follows International Patent Classification (IPC) technology classification developed by World Intellectual Property Organization (WIPO). The first version was published in 1992, comprised 29 technology classes. Since then, technology classification has been amended several times. Furthermore, international classification was substantially revised in the 8th edition in 2006. This includes new codes that were not available in the previous documents of the ISI-OST-INPI classification. The international patent classification (IPC) code is assigned based on patents technological category. Due to the multiple classifications of documents, a patent belongs to more than one technology group. However, the effect is limited. To avoid the double-counting of patents, this study uses the first classification codes of each patent. Appendix 2 present the technology classification broken into more fields and differentiated at a finer level. The methodologies used in the four essays vary as necessitated by the different research problem addressed. These methodologies along with specific variables (dependent and independent) are discussed below in brief.

1.6.1 Essay 1 - Determinants of Patent Survival in Emerging Economies: Evidence from Resident and Non-Resident Patents in India

In the first essay, we estimate the patent's survival length using Cox-PH model and Accelerated failure time (AFT) model. The survival time model assesses patent span since patent life (length of the patent term) offers reliable support to patent renewals' widely accepted perspective as value indicators. Along these lines, to catch the value distinction by technology and ownership group, we divided patent data into different technology fields (sorted based on IPC class) and ownership category (resident and non-resident) patents. Further, we divided patent into different assignee categories (firms, individuals, and institutions).

A large part of previous research considered that a patent that survives for an extended period is supposed to be of high value (Zeebroeck and Pottelsberghe, 2011). To identify the determinants of patent survival, we include the number of patent level characteristics (number of claims, family size, grant lag, technology scope) along with ownership, assignee, and technology dummies. Sevensson (2012) finds that valuable patent shares common characteristics such as a higher number of citations, mostly litigated, and broader technology scope. Such patents are more likely to be renewed and commercialized (Sevensson, 2012).

Other studies in the field find that the patent's survival length typically depends on the quality of the R&D, marketability of the invented product, license or sale of the invention, and nature of the technology (Pakes and Simpson, 1989; Tong and Frame, 1994). To understand the survival length of the Indian patent (resident and non-resident), we collect the patent information filed at IPO from 1995 to 2005. This study does not include recent patents because it is based on the renewal life of the patent. The most recent patents will not have sufficient renewal observation to estimate the patent's survival length. Moreover, this study divides the patents into different technological categories based on the 4-digit IPC class (WIPO). We estimate the patent's survival probability for five different technology classes (electrical, instruments, chemistry, mechanical, and ‘otherfield’). Further, this study estimates the patents' survival probability for three assignee categories, individuals, institutions, and firms. Lastly, we estimate the survival probability among resident and non-resident patents.

To analyze the underlying distribution of ‘failure time’ and the factors that influence the event to occur, we apply the semi-parametric survival model (Cox proportional hazard model). However, the proportional hazard assumption was violated, and therefore, we switch to an alternate model called the accelerated failure time model (AFT). The AFT model is used to estimate the relationship between predictor and survival time. It accommodates censored observations (patents that are still enforced at the commencement of this study). The AFT model's important characteristics are that the error terms are independent and identically distributed in the traditional regression model but does not follow the normal distribution. The generalized gamma distribution is selected among all these distributions when we conduct a formal model-selection (AIC and BIC criterion).

1.6.2 Essay 2 - Identification of “Valuable” Technologies via Patent Statistics in India: An Analysis Based on Renewal Information

Essay 2 adds value to the literature of the qualitative approach for patent valuation. It follows a systematic way to assign a single patent (or patented technologies) to different value classes (such as ‘most valuable’, ‘valuable’, ‘less valuable’ and ‘negligible’) to establish ranks of comparable (Razagaitis, 2009). This method is used for an internal management decision due to its restrictive simplicity compared to the quantitative valuation method (non-monetary value).

We start with the assumption that the patents that get renewed for maximum time are at least the subset of those valuable patents. To do this, we build a comprehensive data set of 21,562 granted Indian patents (resident and non-resident) applied between 1995 and 2002 at the Indian patent office (IPO). Despite having a uniform patent term across the industry, technology, ownership, and renewal fees create a de-facto differentiation in patent terms. Thus, based on the literature, the determinants of patent length are clustered into four groups. First, the *inventions' complexity* is measured by patent technology scope (4-digit IPC class), several inventors, and the grant lag. Second, the *filing* *strategy* includes the structure and quality of the drafted document (number of claims) and protecting the same patent in a different jurisdiction (family size). Third, *assignee characteristic* that is patent owned by India (resident) or foreigners (non-resident) and fourth is a technological field.

This study's outcome variable is used in the ordinal form (1, 2, 3, 4) ranges not so valuable to most valuable patents. To estimate the model, we apply the order logit model as in Williams (2016). However, we realized the parallel regression assumption is violated in some cases. Therefore, we apply the alternative less restrictive model-generalized ordered logit model (GOLM).

1.6.3 Essay 3 - Valuation of Patents in Emerging Economies: A Renewal Model-Based Study of Indian patents

The earlier two essays estimate the patent value using a qualitative approach usually carried for the internal decisions on managing patent portfolios such as filing of the new patent, decision on renewal, and geographical extension. These decisions are important for the firms owning a large patent portfolio, but they are also critical for younger firms and startups. The common thread in two earlier essays and the following essays is that the patentee will renew the patent only if its value is higher than the renewal fee.

This essay follows a quantitative approach where it estimates the monetary value of single patents. In this study, we follow Pakes' seminal work (1984; 1986) and Schankerman and Pakes (1986). To do so, we take expired patent granted data applied between 1995 to 2005. The final data includes only expired patents or patent ceased due to non-payment of the renewal fee. The methodology is based on the patent life using data on an inventor's renewal fee to keep the patent enforced. The sequence of renewal increases monotonically in India. This model is based on two assumptions. First, technology depletes at a constant rate. The second assumption is about the distribution of patent value. It assumes that the initial returns are a function of observable characteristics that are lognormally distributed. The uniqueness of this study is that it combines two-generation indicators of patent value. The first generation of patent value indicators includes more general economic aspects, such as assignee categories and ownership status. Second generation indicators include more specific patent-related economic indicators such as filing decisions, renewal decisions. The third-generation indicators focus on more detailed patent-related information- number of claims, text components, etc.

1.6.4 Essay 4 - Capturing the Future Value of Patent through Renewal Model for different Assignee, Ownership, and Technology Category in India

One of the major limitations of earlier studies based on the renewal model was that they valued the patents that has completed 20 years or expired due to non-payment of the renewal fee. The idea was that data from expired patents could be utilized as the best indicator for the value of patent with changed term lengths. These investigations disregard patents that are currently enforced, and these patents are more pertinent to updated technology markets.

Likewise, prior investigations, for example, Zeebroeck (2007), Maurseth (2005), Svensson (2007), and Nakata and Zhang (2012), restricted their study to the possible determinants' factors of patent life or correlated factors over effective patent lifecycles. Nevertheless, these investigations are significant for patent value examinations when corresponding influencing factors are considered. However, this study extends the patent valuation literature by incorporating expired and enforced to estimate patent value among different owner groups and different technical fields.

1.7 Organization of the Dissertation

This thesis shows how patent valuation models can ne be applied to a real data set from a different angle. The organization of the thesis is as follows. Chapter 2 estimates the determinants of patent survival in detail. We list out all the parameters used in the study with the associated importance in survival analysis. Further, we review different literature on patent survival. The last section in Chapter 2 focuses on results and conclusion and shows how our work stands out from the other works.

Chapter 3 starts with the new objective, where we systematically identify valuable technology using the ranking method. We review different methods used to identify valuation of patents and discuss why we use the generalized order logit model. In the data section of this chapter, we discuss the technology class in detail. The last section of this chapter focuses on the results in detail.

Chapter 4 extends our valuation study from a quantitative methodology point of view. In this chapter, we estimate the monetary value of the expired patents. We begin with various definitions of the patent value from different perspectives. We further discuss the renewal model in detail and the parameter estimation process. We apply the simulation techniques to obtain each patent's initial return belonging to a different technology, assignee, and ownership group. The last section of Chapter 4 discusses the results and conduct a comparative analysis of Indian patents with other studies on valuation.

Chapter 5 introduces both the enforced and expired patent in renewal model of patent valuation. We followed a similar principle used in of expired patent data. We also discussed the differences in the patent value obtained using expired patent data, and the combination of both expired and non-expired patents.

Chapter 6 presents a summary of the four essays. We further discuss the relevance of the results in the Indian context with policy implications. The last section of this chapter notes certain limitations of the dissertation and accordingly outlines directions for the future research.

Chapter 2

Determinants of Patent Survival in Emerging Economies: Evidence from Resident and Non-Resident Patents in India

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2.1 Introduction

Patent lives are divided into three phases: first, starts from the date of filing to the date of the request for examination date; second, from the date of the request to the grant date; and third, is the period between grant and lapse date (Nikzad, 2011). Whereas, Maurseth (2005) and Svensson (2007) divided patent life into two phases: the pre-grant period called 'provisional' life, and the post-grant period called 'active' life. To protect the entitlement of patent, the patent office charges an annual renewal fee from the patentee. Patent life depends upon the value generated during the protection period for the inventor against compulsory renewal fee. Hence, valuable patents are more likely to be renewed. Schankerman and Pakes (1986) argued that the patent's renewal decision is purely based on economic criteria and patent holders pay an annual renewal fee only if the renewal cost is lower than the value generated by those patents.

This study estimates the patent's life, which is the time between the patent filing date and lapse of the patent at the IPO. The survival period is important for IPO and also for the economy. On the one hand, the main source of income for IPO is the maintenance fee patent applicant pay during the patent's lifetime. therefore, longer patent life means higher income for IPO. Also, the lag between lapse date and filing could be measure for the value of patent because more valuable patents are more likely to pay a maintenance fee. However, longer patent life indicates extended monopolistic power in the market, which could be harmful to consumers. Thus, shorter patent life is good for consumers. To our best knowledge, this is the first study that analyses India's patent applications in this context.

Based on India’s patent data of all technology fields from 1995-2005, and using the term of patent right as the measurement of patent value, this study presents a survival function of patent maintenance in India. It makes a comparison study in terms of three aspects: the quality of resident and non-resident applicants, different technical fields, and different types of assignee categories.

The rest of the chapter is organized as follows. Section 2.2 presents an overview of the study on the determinants of patent survival and brings the necessary discussion on the results reported by various studies. Section 2.3 presents the data and descriptive statistics. In Section 2.4, we propose the empirical model. The estimated results are presented in Section 2.5. We conclude our results in Section 2.6.

2.2 Literature: Patent Survival

A brief review of different literature related to survival analysis from the valuation perspective is presented in this section. Patent count is a weak proxy of innovation (Trajtenberg, 1990) as such a measure does not reflect on the heterogeneity among the patents. Therefore, we often end up making the wrong judgment about the quality and value of innovation. However, disaggregated information revealed in the patent documents brings richness to the patent data. The survival studies find that a long patent life is an indicator of a higher value patent. Over the period, the renewal length of a patent has been studied by many scholars to estimate the value of patents (Pakes and Schankerman, 1984; Schankerman, 1998; Lanjouw et al., 1998). To keep a patent alive after issuance, the patentee must pay the renewal fee. The renewal fee varies with the age of the patent and the corresponding patent offices. In return, the patent generates implicit profit to the patent owner during the coming year. However, if the patent renewal fee is not paid, the patent expires permanently, and therefore, after the return on that patent becomes zero (Lanjouw et al., 1998).

Most previous studies have used patent renewal information to estimate the value distribution of patents (Schankerman and Pakes, 1986; Griliches, 1990). The literature on patent valuation finds that patents that survive longer have a higher value than patents that lapsed at an early age (Bessen, 2008). It is assumed that owners are well aware of the patent's usability and quality, and the decision about the renewal of the patent is based on the economic principle (Svensson, 2012). The owners' patent renewal decision is influenced by other uncontrolled factors such as the future marketability of the patented products, the advancement over the earlier invention, and so on.

Serrano (2011) finds that the acquired patent is more likely to be renewed than non-acquired ones. Maurseth (2005) and Svensson (2007) propose two unique endeavors to show the patent renewal choice utilizing survival time investigation. The result of the observational assessment shows patent citation connects decidedly with renewal life and commercialization considerably builds the likelihood of renewal. Zeebroeck (2007), in his investigation of European patents, depicted the effect of patenting strategies on the patent length. Huang et al. (2017) explore Carbon Fiber Reinforced composite material technology's patent validity using a survival model. The result indicated that foreign patent in China has longer validity compared to domestic patents. Similarly, university patent validity is longer than research institutes and individual patents.

The recent study on patent quality in China reveals many unexplored facets. Huang et al. (2020) investigate Chinese enterprise innovation quality using about 73.8 thousand patents applied during 1985 and 2011. The study utilizes patent renewal information to estimate the patent value return. The study also compares the patent value of public and private patent enterprises. They find that public enterprises' value is relatively lower than private firms.

The selection of the explanatory variables and the sampling methodology varies widely across the studies. The common explanatory variables across the studies used are patent citation, the number of claims, family size, and technology scope. These variables proved to be reliable patent value measures (Bessen, 2008). The valuation studies have extensively used citation information and legal disputes, and renewal information to measure patents' value (Moore, 2005; Allison et al., 2003). The patent value determinants are grouped into four different categories of a variable in the equations: (1) different characteristics of the patent application (PC), (2) ownership characteristics (OC), (3) some contextual information collected through the survey if any (4) and the filing strategy of inventors (FS*) (Zeebroeck and Pottelsberghe, 2011).

The length of patent rights is an issue of extensive significance in the plan of the patent system, and its optimality has been talked about in academic writings. This dimension-the patent length as an indicator of its value has been considered in the literature as a direct sign of the private value of patent. Although patent filing in India has increased multiple folds in the last couple of decades, the assessment of its patent value is still unknown. The growing Indian market attracts enormous foreign patenting, which is critical of the country's knowledge prowess. This is the key inspiration behind this essay. It is important to understand the survival length of patents that reflect on their value in the Indian context. Such an inquiry will give us important insights regarding the competitiveness of Indian patents in global markets. Relying on the comprehensive data set on the renewal length of the patent and patent characteristics filed to IPO from 1995 to 2005 and granted, this study presents the survival time analysis of the determinants of patent length in India.

Svensson (2012) study is based on the patents owned by small firms and individuals. However, the present study conducts a comprehensive analysis of different categories' survival data divided into resident and non-resident, assignee type, and technological field. The present study further builds on previous literature by including a diverse set of patent value determinants such as a number of claims, family size, technology scope, and grant lag.

The rationale for each assignee category's separate survival estimation is that patent R&D expenditure and renewal trend vary significantly. This study estimates the separately for each assignee category, so all parameters are allowed to vary across the assignee category. Since the renewal decision is associated with the patentee, looking at each assignee provides ample information about the renewal approach and survival length of the technology field in different assignee groups.

2.3 Data and Variable Description

The data used in this study consist of all patents applied between 1st January 1995 and 31st December 2005 that were eventually granted by IPO. The total number of patents filed at IPO during the study period was 1,24,119. These patents' granting period was between 1st January 1997 (minimum two years since the filing date) and 31st December 2018 (the data collection date). Out of the total application, 56,085 patents are granted over a period of time. The patent level information was collected from the IPO website[3] and PatSeer[4]. We removed the patent from our sample if the complete renewal information was not available. The final sample for survival analysis is 40132 patents.

2.3.1 Variable Description

Over the time, economists have utilized many patent-based measures of innovation: simple patent count, weighted forward citation (Trajtenberg, 1990), renewal information (Pakes, 1986; Schankerman and Pakes, 1986; Pakes et al., 1989), patent family size (Putnam, 1996),

[3] https://ipindiaservices.gov.in/publicsearch

[4] PatSeer is a private patent database owned by Gridlogics Technologies Pvt Ltd.

and technology scope (Lerner, 1994). Another important variable picked up by researchers to measure the value of innovation is the number of claims. Tong and Frame (1994) reason the number of claims a proportion of the size of innovation and show that claims-weighted patent counts are more closely related to the R&D spending. Lanjouw and Schankerman (1998) show that the quantity of claims is identified with the likelihood that patent litigation. Since the number of patent claims varies widely, utilizing claims information may help represent the enormous heterogeneity in patents' value.

In this investigation, we break down the new data set of IPO patents that detailed information on patents in India during the time frame 1995 to 2005. This data gives us different indicators of the patent's unobservable quality, as evaluated not long after the patent application is made. We now briefly describe each of these variables:

i. **Claims:** A patent is involved a bunch of cases that portray what is ensured by the patent. The principal claims explain the fundamental novel highlights of the innovation in their broadest structure, and the subordinate claims describe a feature of innovation. In this dissertation, we take a total number of claims as a determining factor of renewal decision. The patentee intends to increase the claims as much as possible to get a maximum incentive from the innovation. The examiner may require that the claims be narrowed before granting.

ii. **Family size:** To protect innovation in various countries, a patentee should get a patent in every country. To ensure innovation in various countries, a patentee should get a patent in every country. a group of patents protecting the same invention. We call it 'family' (these are also called parallel patents). Because filing and maintaining a patent in different countries is associated with high costs, only a fraction of patents seek protection outside their home market. Therefore, the family size indicates the importance of the patent for the patentee. This study includes the number of family size as an independent factor of patent value.

iii. **Technology scope:** The examiner assigns each patent a 9-digit code based on the IPC classification system. Our data disaggregate patents at a 4-digit subclass level. Using these classifications, we classify each patent into one of five broader technology groups: chemistry, electrical, instruments, mechanical, and ‘otherfield’. We use the 4-digit subclass count in a patent to describe the technology scope. The broader the technology higher the count of the 4-digit subclass in the patent.

iv. **Grant-lag:** The grant lag defined as the time elapsed between the filing date and issued date is associated with patent value. Harhoff and Wagner (2009) and Régibeau and Rockett (2010) find evidence of an inverse relationship between patent value and the grant lag. However, Régibeau and Rockett (2010) suggest that granting decision is depends on the effort made by the filing party. Our study includes the grant lag as an influencing factor of patent value in the Indian context.

v. **Inventor size:** A few creators are substantially more productive than others in the patenting activities (Narin, 1993). A company's technological performance regarding patent quantity and quality is often driven by a small group of key inventors (Ernst et al., 2000). In this way, a co-inventor's patent is more likely to be significant along these lines. The matric created utilizing the number of inventors contended to identify with the size of the investment made for the R&D project, which should be identified to estimate the project's output (Gambardella et al., 2006).

vi. **Ownership:** We construct the variable for the ownership of each patent. We classify the ownership category into resident and non-resident patents. Patent assigned to India at

IPO is called resident patents. However, patent assigned to other than India at IPO is called non-resident patents.

vii. **Technology field:** we use 4-digit subclass codes to assign a technology field for each patent. Since a patent falls in more than one technology class, we have assigned a technology field on the basis of a maximum 4-digit subclass in one patent.

viii. **Assignee category:** we have also categorized patents on the basis of assignee categories. This category is selected on the basis of the assignee name of the patent. We checked all patents if they are assigned to individual, firms, or institutions.

2.4 Summary Statistics

Table 2.1 summarizes the patent level characteristics for this data. We only considered the patents with complete details on renewal length and these patent characteristics.

Several patent characteristics presented in Table 2.1 have also been discussed in the literature earlier (Xie and Giles, 2011; Zeebroeck and Pottelsberghe, 2011). However, we have included additional features like ownership characteristics and technology categories (4-digit IPC subclass). We have included all patents assigned to India (including foreign subsidiaries in India) as resident patents. Whereas patent assigned other than India at IPO has been classified as a non-resident patent. The detailed discussion of the explanatory variables has been given in subsection 1.5.2 of chapter 1 and not mentioned here to avoid repetition.

Table 2. 1:Summary of patent characteristics of all patent (censored and non-censored)

Patent characteristics	Determinants [Acronym-Notation]	Mean/count Non-censored
Life (survival/renewal length) of a patent	Difference between filing and expiry date	11.69
Geographical scope (Family size)	Number of countries (worldwide a patent is sought) [FS]	14.40
Drafting style	Number of claims made by the patent [NC]	14.19
Complexities	Number of inventors involved in the patent [NI]	2.72
Technology scope	Number of 4-digit IPC classes of a patent (five technology groups have been identified for this data: Chemistry, Electrical, Mechanical, Instruments and 'Other field') [TS]	8.11
Grant lag	Time of uncertainty; time elapsed between filing date and grant date [GL]	7.01
Applicant profile	Whether a patent is assigned to resident (0) or a non-resident (1) [OW]	1=27524 0=6642
Assignee category	Patent assigned to Individual	3310
	Patent assigned to Institutional	2410
	Patent assigned to Firms	28358
Technology group	Chemistry	15353
	Electrical	7214
	Mechanical	7476
	Instruments	2907
	Otherfield	1316

Note: Author's calculations on the basis of information available in CGPDT and IPO website.

The dependent variable in this study is the patent renewal duration (or survival length). From a survival analysis point of view, if a patent has expired, it is coded as 1 (and referred to as the "event"). If the patent has either matured (completed 20 years of renewal life) or still in force (censored) at the time of data collection (31st December 2018), then the patent is coded as 0 (and referred to the non-occurrence of the event).

We also present descriptive statistics for different assignee groups. Tables 2.2 and 2.3 presents descriptive statistics of censored categories for the individuals, institutions, and firms separately. The average renewal length in the non-censored category is 10.63, whereas, in the censored category, it is 14.98. The highest renewal age is observed for institution category patents in both censored and non-censored categories. The number of claims in the censored and non-censored category is highest for firms followed by the individual. We observe that firms are more into collaborative research. Further, the patent's technology scope and international outreach are most increased for the firm's patents in both the sample category. Note: The mean and standard deviation are for non-censored observations only. Therefore, the mean of patent lifetime and patent grant time is understated in Table 2.2 and over stated in Table 2.3. The table 2.1 observation include both censored and non-censored sample which considered in the survival estimation.

Table 2. 2:Summary statistics of variables by assignee category Non-censored sample

Non-censored	All		Individual		Institution		Firms	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Renewal years	10.63	6.38	8.65	6.62	12.07	5.36	10.69	6.40
Number of claims	13.71	14.21	11.73	13.26	9.65	9.82	14.36	14.61
Inventor size	2.66	2.00	1.55	1.16	3.35	1.92	2.71	2.03
Family size	14.36	16.40	10.29	11.10	6.73	9.53	15.62	17.16
Technology scope	7.70	10.67	4.34	6.36	3.36	6.62	8.54	11.20
Grant lag	7.14	2.78	6.68	2.74	7.78	2.59	7.12	2.79
Observations	30,372		2700		2706		24966	

Note: Author's calculations on the basis of information available in CGPDT and IPO website.

Table 2. 3: Summary statistics of variables by assignee category censored sample

Censored	All		Individual		Institution		Firms	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Renewal years	14.98	1.60	14.91	1.54	15.50	1.71	14.93	1.59
Number of claims	15.67	16.85	14.33	21.90	10.60	11.97	16.31	16.78
Inventor size	2.91	2.16	1.78	1.46	3.98	2.56	2.87	2.11
Family size	14.54	14.33	11.72	10.69	8.79	10.11	15.36	14.77
Technology scope	9.41	11.09	6.55	8.90	4.36	7.72	10.15	11.36
Grant lag	6.63	2.67	6.04	2.51	7.38	2.42	6.59	2.69
Observations	9,759		594		886		8,279	

Notes: Author's calculations on the basis of information available in CGPDT and IPO website.

2.5 Model Description

2.5.1 Semi-Parametric Model (Cox-PH Model)

Survival data measures how long a situation lasts or how much time elapsed before a particular event occurs. The non-negative random variable (renewal years) T represents the life between application and expiration dates. Here, the objective of survival analysis is to model the underlying distribution of the failure time, T, a patent expiration event due to non-payment of renewal fee under 20 years of patent life from filing. The dependent variable (renewal years) is assumed to have a continuous probability distribution $f(t)$ and cumulative distribution function $F(t)$, where

$$F(t) = Prob(T \leq t) = \int_0^t f(s)ds. \qquad (1)$$

The corresponding survival function is $S(t) = 1 - F(t) = Prob(T \geq t)$, and the hazard rate (or hazard function) can be estimated as follows:

$$h(t) = f(t)/S(t). \qquad (2)$$

A hazard function $h(t)$ indicates the instantaneous rate of patent lapse at time t, given the patent survived up to time $t - 1$.

For a more in-depth impact analysis of patent characteristics on the survival length, we use Cox proportional hazard regression model (in short, referred to as Cox-PH model) initially suggested by Cox (1972). The model is expressed by the hazard function denoted by $h(t)$, which measures the risk of getting a patent expired at time t. A set of time-invariant covariate vector characterizes the hazard function x_i and a time-dependent baseline hazard h_0 – which corresponds to the value of hazard rate if x_i is equal to zero. The model is written as follows:

$$
\begin{aligned}
h(t|x_i) &= h_0(t) \cdot \exp(x_i^T \boldsymbol{b}) \\
&= h_0(t) * \exp\big(b_1 \cdot NC + b_2 \cdot NI + b_3 \cdot FS + b_4 \cdot TS + b_5 \cdot OW + b_6 \cdot D_{chem} \\
&\quad + b_7 \cdot D_{elec} + b_8 \cdot D_{mech} + b_9 \cdot D_{inst} + b_{10} \cdot D_{other} + b_{11} \,.\, D_{individual} \\
&\quad + b_{12} \,.\, D_{Institution} + b_{13} \,.\, D_{firms}\big),
\end{aligned} \tag{4}
$$

where x_i is a 13-tuple vector of covariate values that correspond to the patent characteristics: NC, NI, FS, TS, and OW, described in Table 2.1, and $D_{chem}, D_{elec}, D_{mech}, D_{inst}$ and D_{other} – the dummies for the five technology categories as per the 4-digit IPC classification. we also use the dummies for the assignee types (individual, institution, and firms' patents).

A popular summary statistic of interest, called the hazard ratio, is defined by exp (b_i), which implies that if the i^{th} covariate value increases, the hazard (or the chance of patent expiring) increases, and the length of survival decreases. This implies that if the i^{th} covariate value increases, the event hazard increases, and thus the length of survival decreases. More precisely, if the value of the hazard ratio is greater than one, the covariate is positively associated with the event probability and negatively associated with survival length.

The basic assumption of the Cox model is that hazard curves are proportional and independent of time t. This implies that if a patent, as compared to others, has a double risk of expiring at some initial time point, then all the later time risk of getting expired remains the same. One can use various approaches to assess the validity of the proportionality assumption of the Cox-PH model, for instance, the graphical techniques based on Schoenfeld residuals and tests built using hazard ratios. Even Kaplan-Meier curves can indicate the violation of the proportionality assumption. However, when the proportional hazard assumption is violated by any of the predictors the

Cox-PH model is no longer suitable. The alternate of the cox-PH model is the accelerated failure time (AFT) model.

2.5.2 Parametric model: accelerated failure time (AFT) model

The AFT model is a parametric model seldom used in the case of survival data. To determine the role of key covariates on patent survival, we estimate AFT models. The AFT model describes the relationship between the response variable and the survival time. The AFT model's parametric form is capable of offering a reasonable statistical solution if PH assumption is violated[5]. Unlike the Cox-PH proportional hazard assumption, this model assumes that covariates' effect acts multiplicatively (proportionally) with respect to the survival time. Take an example of patent data with one independent variable ownership category with two levels 0 for resident and 1 for non-resident patents. The proportion of patent that survived in the resident patents' category at any time point t_1 is the same as the proportion of those who survived in the non-resident category at any time t_2=φt_1 i.e., the time ratio (TR) $t_1/t_2 = \varphi =$ constant.

The survival function for a group of patents with covariates $\left(x_1, x_2 \ldots. x_p\right)$can be expressed as:

$$s(t/x) = s_0(\exp(\beta' x)\, t \; for \; t \geq 0 \ldots \ldots \ldots \ldots (5)$$

Where $s(t/x)$ is the survival function at of a patent at time t and the $s_0(\exp(\beta' x)\, t)$ represent the baseline survival function at the time t. The AFT model states that the survival function of an individual (in our case it is patent) with covariates x at time t is the same as the baseline survival function at time t in the baseline equation $\beta' = \left(\beta_1, \ldots. \beta_p\right)$. The factor exp $(\beta' x)$ is known as the acceleration factor that represents the ratio of survival times corresponding to any fixed value of survival time. The acceleration factor evaluates the effect of the predictor variable on survival time.

[5] The AFT model can be used with the Weibull distribution if the PH assumption of Cox model is satisfied, whilst if PH assumption not met the AFT model is used with distributions other than Weibull.

In this model, the survival is considered in the logarithmic form and includes an error that follows a specific probability distribution. The distribution chosen for survival time indicates the distribution of the error term. Thus, if the distribution is prespecified as the Weibull distribution, the error term is assumed to follow an extreme-value distribution. Similarly, if it is modeled using log-logistic or log-normal distribution, the error term is deemed to follow logistic or normal, respectively. The general linear representation of AFT model is given as

$$logT_i = \mu + \beta_1 x_1 + \cdots + \beta_p x_p + \sigma\varepsilon_i \dots\dots\dots..(6)$$

Where log T_i is the log-transformed survival time, $x_1 \dots\dots x_p$ are independent variables with the coefficients of $\beta_1 \dots\dots\dots \beta_p$; ε_i is the deviation of the values from the survival time variable from the linear part of the model. As mentioned above error term follows a specific distribution. μ is the intercept and σ represents the scale parameter. For each ε_i there is a corresponding distribution of T_i. If ε_i has an extreme value distribution, then T_i follows Weibull distribution and if ε_i follows normal distribution then T_i follows a log-normal distribution.

The AFT model is mainly used to estimate the relationship between predictor and survival time. It is similar to the conventional linear model (George et al., 2014). However, traditional regression and AFT models differ in the following aspects: (1) The predictor variable in the AFT model is affected even time multiplicatively (proportionately); (2) the AFT model accommodates censored observations; (3) The error terms are independent and identically distributed as it is in the traditional regression model but does not follow the normal distribution. Since the event times are positively valued and generally follow skewed distribution the choice of normal distribution will lead to biased result. Therefore, in place of the normal distribution, exponential, Weibull, generalized gamma, log-normal, and log-logistic are suggested in the literature. To decide which distribution is most suitable for the patent survival data in this study, we followed penalized metrics provided by model selection indices such as the Akaike information criterion (AIC) or Bayesian information criterion (BIC). These methods are less subjective than graphical probability plots because they allow for numeric comparison. The choices of distribution may not be based on which distribution gives a favorable p-value. While fitting the model, we must keep in mind that no distribution provides a perfect fit, and it is very much possible that more than one distribution fits the data.

The AFT is similar to the other parametric model, which can also be estimated using MLE (maximum likelihood estimation). The likelihood function of the survival length of patent n observed times $t_1, t_2, \ldots \ldots \ldots, t_n$, with unknown parameters $\beta^n = (\beta_1, \beta_2, \ldots \ldots, \beta_n), \mu,$ and $\sigma,$ which contain $(n-r)$ right-censored data, expressed by

$$l(t; \beta, \mu, \sigma) = \prod_{i=1}^{n} f_i(t_i)^{\delta_i} * S_i(t_i)^{1-\delta_i},$$

Where $0 \leq r \leq n$, δ_i is indicator variable which is equal to one if t_i is observed and equal to zero if t_i is censored observation. The density and survival function are $f_i(t_i)$ and $S_i(t_i)$, respectively.

The AFT model is appropriate to analyze the change in the time scale by a factor of exp $(-x_i\beta)$. The AFT model predictor is interpreted as time ratios (TR) where the ratio represents the acceleration factor. Contrary to a hazard ratio (HR), TR is greater than one means that an event is less likely to occur, or the investigator has to wait longer for the event to happen. Similarly, if TR is less than one explains that the event is more likely to happen.

2.6 Results and Discussion

2.6.1 Cox-PH regression model

If the proportionality assumption holds the two (or more) curves should be approximately parallel and should not cross. However, the result estimated using the semi-parametric model (Cox-PH model) unfortunately violate the proportional hazard assumption obtained Schoenfeld residuals after fitting a model with stcox (see Table 2.4). The Schoenfeld residuals (goodness of fit) testing method provides test statistics and p-value for assessing the PH assumption for given the predictor of interest (Kleinbaum and Klein, 2012). The estat phtest command tests is used to check the proportionality assumption for individual covariates and globally. The rejection of the null hypothesis (hazard ratio are proportional) leads to conclusion that PH assumption is violated. In the prob>chi value less than 0.05 means rejection of null hypothesis and acceptance of alternative hypothesis (that hazard ratio are not proportional).

Table 2. 4: Cox estimates of the hazard ratio

Variables	Haz. Ratio	Std. Err.	P-Value	Prob>chi2
Ownership	0.84	0.02	0.00	0.00
Claims	1.00	0.00	0.32	0.92
Family size	0.98	0.00	0.00	0.43
Technology scope	1.00	0.00	0.00	0.77
Grant lag	1.00	0.00	0.00	0.00
Inventor size	0.89	0.00	0.00	0.00
Institution	0.88	0.03	0.00	0.00
Firms	0.91	0.02	0.00	0.00
Electrical	0.89	0.02	0.00	0.00
Instruments	0.98	0.03	0.46	0.11
Mechanical	1.07	0.02	0.00	0.19
Otherfield	1.10	0.04	0.01	0.41
LR χ^2(1)				2530.46***
Ph-test (global)				1584.79***
Observations				34,166

Note: Here, ***, **, and * denote p < 0.01, p < 0.05 and p < 0.10, respectively.

2.6.2 Accelerated failure time model

To investigate the importance of key variables on patent survival, we estimate AFT model, with covariates discussed earlier. Unlike the proportional hazard model, the AFT model, which is similar to the linear regression model, establishes a direct relationship between the predictors and the survival time, making its interpretation easier. In practice, the appropriate distribution is selected by comparing the model fit for several different distributions. In this study, we selected the ggamma (generalised gamma) distribution based on penalized metrics provided by model selection indices such as the Akaike information criterion (AIC) or Bayesian information criterion (BIC) (see Table 2.5).

Table 2. 5: Model selection indices using several parametric distributions

	Individual		Institution		Firms		All	
Distribution	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC
ggamma	**3166.03**	**3294.14**	**2941.46**	**3075.76**	**30760.87**	**30942.43**	**37180.21**	**37365.87**
Weibull	3398.90	3521.19	3185.42	3313.62	32335.16	32508.47	39149.82	39327.04
Exponential	5318.89	5435.36	6701.51	6823.61	56588.24	56753.30	68614.5	68783.28
lognormal	3205.96	3328.25	2958.66	3086.86	30839.40	31012.71	37274.51	37451.73
Loglogistic	3249.05	3371.34	3009.37	3137.57	31530.34	31703.64	38042.45	38219.67

Once the distribution is decided, we focus on the effect of the variables of interest on the survival of the patent. The effect of individual predictors in the AFT is interpreted using time ratio (TR) where the ratio represents the acceleration or deacceleration factor. Contrary to HR, a time ratio greater than one implies that an event is less likely to happen. Similarly, if the TR is less than one, then the event is more likely to happen. The survival curve for each category of patents (Individuals, institutions, and firms') is displayed in figures 2.1 to 2.6.

Figure 2. 1: Estimates of survival function of Individual category patents by technology group

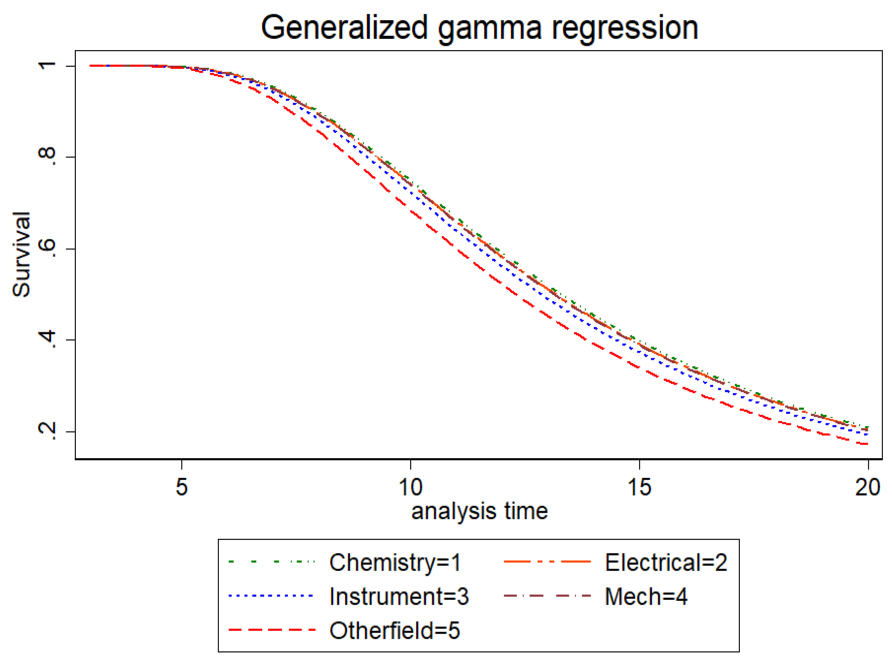


Figure 2. 2: Estimates of survival function of Individual category patents by ownership group

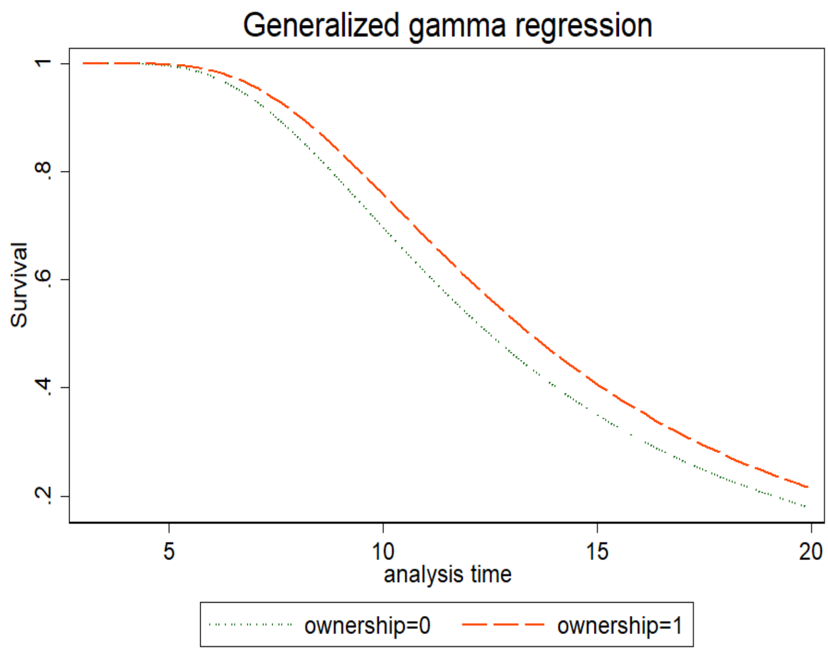


Figure 2. 3 Estimates of survival function of Institutions category patents by technology group

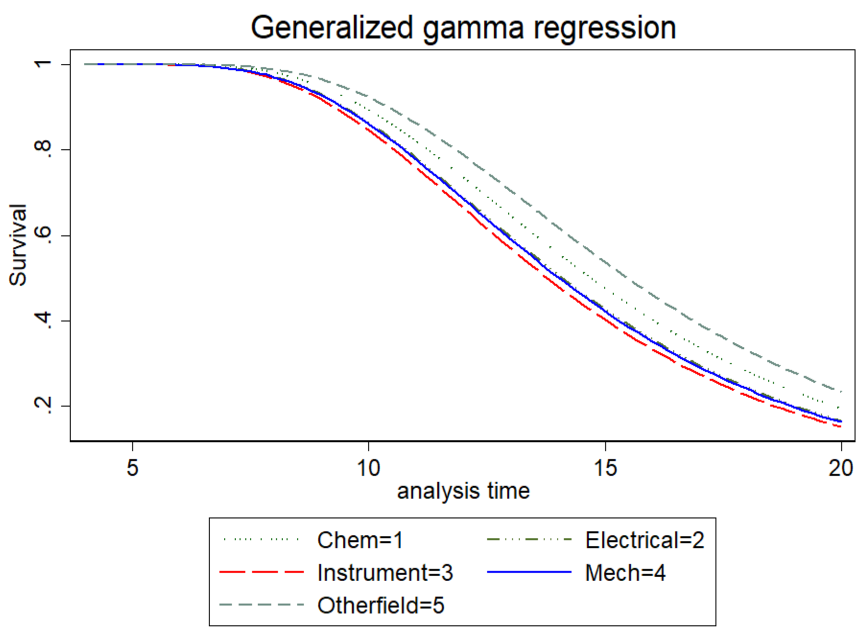


Figure 2. 4: Estimates of survival function of Institutions category patents by Ownership (resident and non-resident)

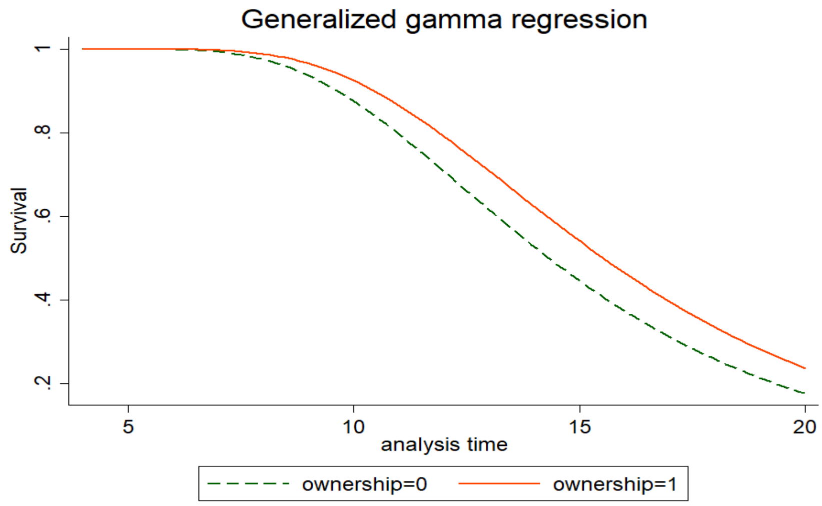


Figure 2. 5: Estimates of survival function of Firms category patents by technology group

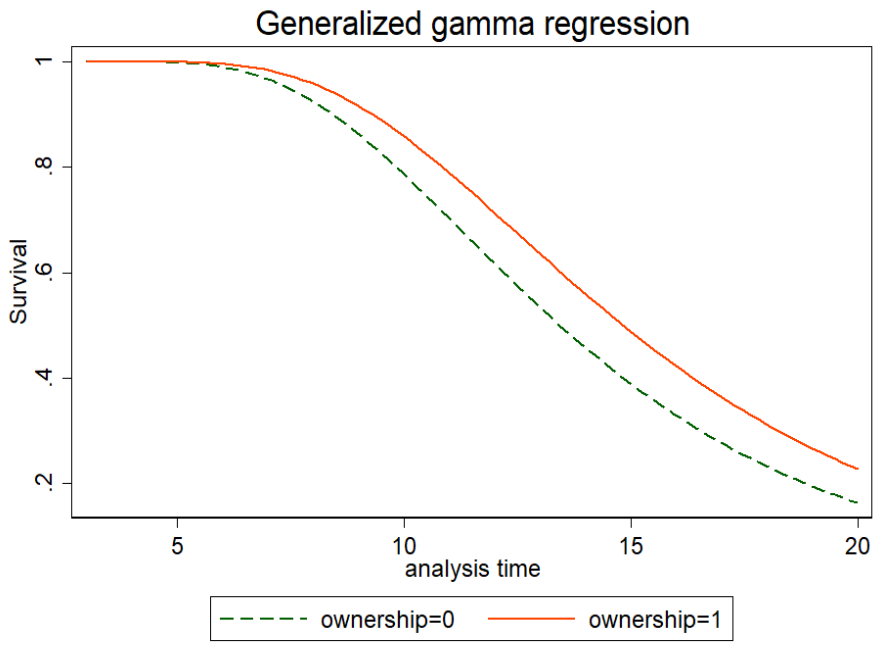
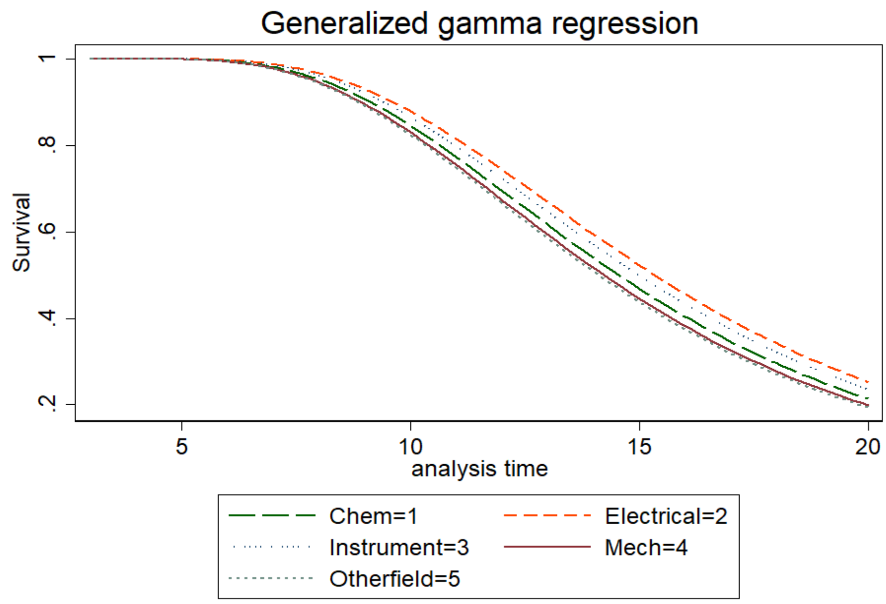


Figure 2. 6: Estimates of the survival function of Firms' category patents by Ownership (resident and non-resident)



Models 1 to 3 in Table 2.6 presents the outcomes for different assignee categories. Model 4 analyzes the outcomes for the complete sample. Doing survival analysis separately for each assignee category allows to estimate separate distribution for survival length.

A non-resident patent =1 deaccelerates the time to event by a factor of 100*[exp(0.105)-1]. That is 11% longer survival time compared to baseline survival in the individual patent category. Similarly, compared to resident patents in institution and firms category, non-resident patents survive by a factor of 100*[exp(0.104)-1]=10.91% and 100*[exp(0.099)-1]=10.40% in respective categories. Besides, overall results of resident vs. non-resident patents show the same trend. This reflects the gap of both innovation capability and innovation quality between India and developed countries.

The coefficient of the number of claims are positive and significant in the individual category. This implies that increasing one unit of claim in the individual category deaccelerates the event by a factor of 100[exp(0.001)-1]=0.1% that is having higher claims increase the survival time of patent for individual patents. However, a similar result does not hold for the institutions' patents. In that case, the results suggest that having higher patent claims accelerates the time to the event by a factor of 100[exp(-0.002)-1]=0.19%. The claims variable was found insignificant in the firms' category. The overall model suggests the insignificant impact of patent claims on survival length. This result reveals two important points. First, the number of claims as a significant indicator of patent renewal suggested by Moore (2005) has not been found so relevant in the Indian context. Second, further separate observations of dependent and independent claims are warranted.

Having an additional family size in the individual patents' category deaccelerates the time to the event by a factor of 100[exp(0.002)-1]=0.20%. However, the coefficient of the family size was found insignificant for the institution category. In model 3 of firms' category, the impact of family size on survival length of the patent is positive and significant. The result says that having an additional country in the family deaccelerates the time to the event by a factor of 100[exp(0.001)-1]=0.10%. The overall results of family size on survival length are consistent with individuals and firms' category patents. The result implies that the number of countries in which the owner has obtained patent protection on the same invention reveals the value of the patent.

A few researchers have used the number of different USPTO or IPC classification as a measure of technology breadth as an indicator of the private patent value (Lerner, 1994). The technology scope exponentiated coefficient is positive and significant for individual category patents. In the individual patents' category, higher technology scope deaccelerates or decelerate the time to the event by a factor of 100[exp(0.003)-1]=0.30%. This implies that if the patent belongs to more than one technology group it is more likely to survive. However, the result of technology scope was insignificant for the institution, firms, and overall category.

Grant lag is found positive and significant across the different models. This explains that patents with higher grant lag survive by a factor of 100[exp(0.06)-1]=6.18% in individual category, 100[exp(0.053)-1]=5.44% in institution category, and 100[exp(0.0520-1]=5.33% in firms category. This result can be explained in two ways. First, a common observation that inventors put an effort to get an early grant for its most valuable patents dos not hold in the Indian context. Second, the valuable patents take time to grant because of procedural and examiner extensive scrutiny of the claims.

Patent co-invented is more likely to be valuable (Narin, 1993; Leptien, 1996). Our study finds that the size of investors is significant across the models except for individual category patents. Thus, having an additional inventor size leads to an increase in the survival length by a factor of 100[exp(0.025)-1)=2.53% in the institution category and 100[exp(0.003)-1]=0.30% in firms category. The overall model supports (i.e., 100[exp(0.0078)-1]=0.78%) the results obtained for institution and firms patents.

In the technological field, compared to the base category (chemistry), electrical patents accelerate (lower survival length) time to the event by a factor of 100[exp(-0.45)-1]= 36% of institution patents. however, electrical patent in the firms category is found to survive more by a factor of 100[exp(0.041)-1]=4.18%. Overall electrical patents survive by a factor of 100[exp(0.0317)-1]=3.22%. However, the result was found insignificant for Individual category patents.

Further, Instrument patents of institution category survive lesser by a factor of 100[exp(-0.062)-1]=6.01%. However, instrument patent in the firms ‘category survive more by a factor of 100[exp(0.023)-1]=2.32%.

Mechanical patent survives lower by a factor of 100[exp(-0.046)-1]=4.49% in institution category. The time to even accelerate by a factor of 100[exp(-0.032)-1]=3.14%, and 100[exp(-0.0368)-1]=3.61% in firms' and over all result. Similarly, 'otherfield' survives lower by a factor of 100[exp(-0.066)-1]=6.38% in individual patent category, 100[exp(-0.040)-1]=3.93% firms' category, and 100[exp(-0.0489)-1]=4.77% in the overall model.

Table 2. 6:Multivariate analysis of patent survival rate with the generalized gamma model

	Model 1	Model 2	Model 3	Model 4
	Individual	Institution	Firms	All
Variables	Coef.	Coef.	Coef.	Coef.
Ownership	0.105***	0.104***	0.099***	0.0836***
	(0.02)	(0.02)	(0.01)	(0.01)
Claims	0.001**	-0.002***	0.000*	0.0002
	(0.00)	(0.00)	(0.00)	(0.00)
Inventor size	0.009	0.025***	0.003***	0.0078***
	(0.01)	(0.00)	(0.00)	(0.00)
Technology	0.003**	0.001	-0.0003	-0.0004
scope	(0.00)	(0.00)	(0.00)	(0.00)
Grant lag	0.067***	0.053***	0.052***	0.0537***
	(0.00)	(0.00)	(0.00)	(0.00)
Family size	0.002**	-0.001	0.001***	0.0013***
	(0.00)	((0.00)	(0.00)	(0.00)
Electrical	-0.006	-0.045*	0.041***	0.0317***
	(0.03)	(0.02)	(0.01)	(0.01)
Mechanical	-0.009	-0.046***	-0.032***	-0.0368***
	(0.02)	(0.02)	(0.01)	(0.01)
Otherfield	-0.066**	0.052	-0.040***	-0.0489***
	(0.03)	(0.04)	(0.01)	0.01)
Instruments	-0.032	-0.062***	0.023***	0.0024
	(0.03)	(0.02)	(0.01)	(0.01)
Const	1.932***	2.153***	2.162***	2.1622***
	(0.04)	(0.04)	(0.01)	(0.01)
LR $\chi^2(1)$	316.72***	429.12***	3548.77***	4228.27***
No. of Observations	2,498	3310	28358	34166

Note: Here, ***, **, and * denote p < 0.01, p < 0.05 and p < 0.10, respectively.

2.7 Conclusion

This study's main ingenuity is to systematically investigate the factor influencing patent survival (time to event analysis) by utilizing a rich set of data on Indian patents assigned to resident and non-resident from 1995 to 2005. We use both parametric and semi-parametric approaches -AFT and Cox (1979)- to estimate the decision of patent renewal. The Cox-PH (1979) model in this study fails to satisfy the proportional hazard assumption. Therefore, we use an alternate method called accelerated failure time model (AFT), for which a restrictive PH assumption is not required. The advantage of the AFT model is that it utilizes full likelihood to estimate the parameters and provide an estimate in terms of survival instead of the outcome's hazard. The generalized gamma distribution is selected among all these distributions when we conduct a formal model-selection (AIC and BIC criterion).

This study's basic premise is that if a patent is valuable, the patent owner will renew it until it reaches maturity time. However, the criterion of being a valuable patent depends on the objective of the patentee. There are times when a patent is not commercially utilized but has greater importance for the patentee because it possesses some strategic importance. Therefore, the renewal pattern differs across the technology field, ownership category, and assignee group. For example, individual patents' average renewal age stands 9.8 years, whereas institution and firms' average patent age is 12.91 and 11.74 years, respectively.

We conclude that the number of claims a patent makes significantly affects the patent's survival length in the individual category. However, it is negatively affecting the survival length of the institution patents. The result implies that broader academic patents do not survive longer than narrow patents in the institution category. Unlike Moore (2005) study on UPSTO patents, the overall impact of a number of claims is insignificant.

The international reach of the patent has a positive influence on the survival length of the patent. This result validates the general hypothesis that the broad international protection of patents leads to longer survival length. However, family size has no impact on institution category patents. This reveals that an institution's patents are geographically centralized whist family size positively influences the survival length of patents. The higher technology scope of a patent reveals the multiple applicability of the patent. However, the overall result of broader technology scope has no significant impact on the patent's survival length.

Once the invention is developed, IP right is sought and enforced, but the granting process takes time depending on the patent office's capacity and other factors. Delay in the grant of a patent is a source of potential uncertainty. However, some literature found that important patent takes longer than usual time; therefore, it positively impacts the survival length. Similarly, the inventor size deaccelerates the time to the event by a significant factor. The collaboration seems to have a stronger impact on the quality of the patent. Among the technological category, electrical patents are more likely to survive in firms and whereas mechanical and ‘otherfield’ patents lapse early compared to the baseline category.

The present study finds that domestic patents are of a low quality than the foreign patents filed at IPO. Similarly, patents filed by institutions are having lower value compared to firms and individual patents. This study concludes that in India, despite the surge in patenting activity in recent years, patent quality has not risen proportionately. Thus, the Indian government needs to take policy initiatives to improve residential patent quality. Also, the industry-specific policy can improve the quality of the patent. Reitzig (2004) finds that metrics used to gauge the patent quality have several limitations, and therefore, an individual matric cannot emphasize too heavily. The future study can include a patent's commercial success in the quality matrices and a citation along with other determinants used in this study.

This study highlights the indicators of patent value in Indian context. This study focuses only on the determinants of survival length. However, the survival length is used as proxy for the patent value. Till now we have shown results for five major technology group. The next chapter conduct a systematic study to identify the valuable technology at disaggregated level. The micro level of technology analysis will be useful to future knowledge prowess of the country.

Chapter 3

Identification of “Valuable” Technologies via Patent Statistics in India: An Analysis Based on Renewal Information

3.1 Introduction

The previous chapter's focus was to identify the factors influencing the patent's survival length for different assignees, ownership, and technology category. The present essay compliments the earlier work on determinants of valuable patents by extending technology classes to more disaggregated levels. The information about the patent's value at disaggregated level enhances the knowledge about the country's technological prowess. Continuing with the dissertation's overall theme, this essay also assumes that the longer a patentee continues to renew, the more valuable the patent is. However, in some cases, the patent value might be realized quickly for fast-moving technology fields.

It has been for quite a while argued that the "quality" (or value) of patented invention moves extensively, starting with one patent then onto the next and that the likelihood to patent innovation of a certain quality varies at both firm and industry levels (Scherer, 1965). The manners in which innovators use patents is probably going to characterize the overall part of these function. For example, a patent is filed more frequently in the industry where R&D cost is high, but imitation is cheap. Patenting behaviors have kept on evolving throughout the evolution of the industry (Orsenigo and Sterzi, 2010).

It can additionally be explained through discreet versus complex technology writing, in discrete technology, a single patent secure distinct product that can be brought to the market independently. By contrast, complex technologies are described by complementary patents building so-called patent thickets, for example, a thick web of overlapping patents (Shapiro, 2000). Many scholars argued that distinction between complex and discrete technologies affects indicators' performance in the theoretical literature (Roycroft and Kash, 1999; Kingston, 2001). On the basis of above theoretical argument this study raises a set of questions. First, can we record the patent value differences across the technological field and develop a conceptual framework for clarifying this diversity? Second, how patent system should deal with these differences? This study mainly focuses on the first question to capture the value differences among different technological fields. Based on the outcome, we discuss tangentially the Intellectual Property law to deal with these differences.

However, without an in-depth analysis of the patent quality indicators, it is not appropriate to conclude the patent systems' relevance for different technology fields separately. To determine whether there are any observable indicia of patent value or patent's lack of value, Moore (2005) compared expired and unexpired patents across a large number of variables. Unlike USPTO, the patent renewal fee in India is levy annually. The annual renewal fee provides a higher degree of freedom to observe the valuable patents in different technology groups.

In this essay, technology field is defined on the Schmoch (2008) disaggregated into 35 categories. Further, based on the literature, the determinants of patent length are clustered into four groups. First, the *inventions' complexity* is measured by patent technology scope (4-digit IPC class), inventor size, and the grant lag. Second, the *filing strategy* includes the structure and quality of the drafted document (number of claims) and protecting the same patent in a different jurisdiction (family size). Third, the *ownership group* that is patent owned by India (resident) or foreigners (non-resident), and fourth is a technological field.

This essay systematically identifies valuable patents from different technology and ownership groups by ranking them according to the renewal fee scale. In India, the renewal fee changes every 7th, 11^{th,} and

15^{th} year of the patent life. We argue that the change in the fee scale is likely to influence the renewal decision of the patentee. Thus, the observable patent value is given an ascending order from 1 to 4 (lowest to highest value). This analysis complements our earlier work on determinants of patent value, giving a richer sense of how to measure a patent's worth at disaggregated technology level. Since the outcome variable is ordinal, we propose using an ordered logit model as suggested by Williams (2016).

The rest of the essay is organized as follows: Section 3.2 presents an overview of the literature on patent valuation and formulate working hypotheses. Data collection and the statistical models are discussed in Section 3.3. Section 3.4 presents the regression results by technology and ownership category. Section 3.5 concludes the chapter by discussing the implications of these findings for evaluating the need for IPRs in India.

3.2 Literature Review and Hypothesis Development

The literature review is categorized into two different segments: an overview of patent valuation and the development of different hypotheses.

3.2.1 Overview of Literature on Patent Value

The accurate valuation of a patent enables technological originality, progressiveness, and commercial potential (Kuznets, 1962). However, the concept of patent value is not found in absolute and abstract terms, and it varies with the perspective of the valuing agency. The importance of IP on firms' competitive advantage has encouraged scholars to study IPs' effective value and management (Klaila and Hall, 2000). There are three common ways to estimate patent value from different perspectives. The first set of studies measure the patent value primarily based on a company's market value and other performance indicators. The second category of studies adopt innovation survey methods where inventors are asked to gauge the value of their patents; and the third type of literature considers qualitative variables along with other patent level information as the determinants of patent value (Zeebroeck, 2011; Lagrost et al., 2010; Reitzig, 2004). The nature of patent value is divided into two components: the intrinsic and the extrinsic dimensions. The intrinsic value theory argues that a patent's value is derived from its technological significance (Argandoña, 2003; Thoma, 2014). Under this framework, it is assumed that a valuable patent will be in-forced after they are granted and complete 20 years of the legal term. On the other hand, a patent's extrinsic value is captured through market value, product development, novelty, inventive steps, and geographical scope (Grimaldi and Cricelli, 2019).

In this chapter, we focus on the intrinsic value of the patents. Under the intrinsic value theory, various patent value indicators are suggested, including backward citations, forward citations, claims, patent family size, and litigations. The patent data's legal status gives essential information about the legal events, including expiration of a patent, renewal information, claims, change of legal identity, and other related information. Patent value indices constructed based on legal status are grant index (Zeebroeck, 2011), litigation index (Lanjouw and Schankerman, 2001; Hsieh, 2013), inventor index (Caviggioli et al., 2013), claim index (Trappey et al., 2012) and renewal index (Hikkerova et al., 2014). Since all these indices are based on literature, their applicability and validity can be verified. Hikkerova et al. (2014) study the patent life cycle in European context. They argue that patent and their renewals are critical because they protect inventions and reinforce information about the utility and quality of invention. Similarly, utilizing a litigation index, Lanjouw and Schankerman (2001) find that cost of participating in litigation over IP assets lessens their value as an incentive to put resources into research. Also, they show that there is a substantial variation across patents in their exposure to litigation risk.

Besides, there are several other patent value indices available in the literature, such as the technology index (Thoma, 2014), market conditions index (Grimaldi et al., 2015), and finance index (Ernst and

Omland, 2011). Since the information on the return from a patent (in monetary terms), citation information, and litigation information are not available in India, this study uses legal information, i.e., the patent renewal information, to construct the value index. Econometric studies on patent valuation have found that patent renewal fees are strictly related to patent rents' value, and most valuable patents are kept in-forced for a longer time (Hikkerova et al., 2014).

3.2.2 Valuable Technology

The patent's value is connected to the particular attributes of technology and the R&D process, and the nature of the market and competition pattern. It is possible to identify important attributes of valuable technologies that build taxonomies and generalizations. The patent's role is higher when imitation is accessible, i.e., when the ratio between imitation costs and innovation costs is lower (e.g., chemicals, pharmaceuticals, machinery). Additionally, patents generally are more significant in the technologies where R&D is exceptionally capital concentrated and highly uncertain (pharmaceutical). When technical change is quick and the effective life of innovation is short, patents may not adequately reward innovators (semiconductors and software are good examples).

Moore (2005) formulates an ordered logit model to identify the worthless patents filed at USPTO. Even though there is a uniform patent term for all patent (20 years from the date of application), renewal expense charged at regular intervals (once in three years after grant) by USPTO make a true differentiation. Despite having a uniform patent life term across the technologies, Moore’s study finds that patent expires in the early stage due to non-payment of renewal fee share identifiable characteristics. Also, she finds that 53.71 percent of patents lapsed due to non-payment of renewal fees at some point in the renewal cycle. It shows that patentees have an idea of sunk cost, and therefore they do not want to further increase their loss by renewing not so valuable patents.

In the Indian context, no study has considered patents' characteristics to measure patents' innovative output. The data-based patent valuation has two unique advantages. First, it can be performed for any patent without the requirement for exclusive or classified information since data is public and accessible in the electronic data set. Second, patent information-based valuation is objective, quick, and economical.

As per Section 53, Rule 80 of the Indian patent act 1970, if a patent must be kept enforced, the patentee has to pay an annual patent maintenance fee (3rd year onwards from the date of application) after the patent has been granted. The present essay follows the Patents (Amendment) Act, 2002, which became effective from 20th May 2003. The renewal fee is taken for each patent depending upon its application date. The renewal fee schedule is shown in Table 3.1 converted in dollar value at 2020 price.

Table 3. 1: Annual renewal fee schedule in India

Renewal Years	3 to 6	7 to 10	11 to 15	16 to 20
India	\$56.09 (INR 4000)	\$168.30 (INR 12000)	\$336.60 (INR 24000)	\$561.00 (INR 40000)
Renewal level	1	2	3	4

Source: Indian Patent Office (IPO)

This study is based on an analytical framework where technological indicators (technological scope and technological domain of the patent), legal factors (number of claims, grant lag, family size), and ownership characteristics (inventor size, patent ownership, i.e., resident, or foreign) are taken into consideration. Technological domains are assigned based on four-digit IPC classification. The sequential order of patent value is arranged in four categories from 1 to 4 (1 refers to the least valuable patent, whereas 4th category patents are the most valuable patents in the sample). Our model estimates three cutoff points which divide the probability distribution into four regions such that patents with a value less than the first cutoff points expire in six years. Patents with values in between the first and second cutoff points expire in ten years, patents with values between the second and third cutoff points expire in fifteen years. Patents with values greater than the third cutoff value are maintained to sixteen to twentieth years (full legal term).

3.3 Selection of Explanatory Variables and Hypothesis Development

In order to determine whether there are any observable indicia of a patent value or lack of value, we estimate the likelihood of renewal across a large number of variables. In particular, we examine the role of following characteristics in influencing the likelihood that a patent owner would fail to pay the maintenance fees: number of claims, family size, technology scope, grant lag, the number of inventors listed in the patent (inventor size), and whether the patent was assigned to the foreign resident or if assigned to a resident of India. Further, we disaggregated the technology at the 4-dight subclass level. Recognizing that there are shortcomings with broad technology classifications, we split technology into 35 different technologies in a finer analysis. We now briefly describe each of these variables:

Claims: A patent has a bunch of claims that portray what is ensured by the patent. The principal claim explains the fundamental novel highlights of the innovation in their broadest structure, and the subordinate claims describe a feature of the innovation. In this dissertation, we take a total number of claims as a determining factor of the renewal decision. The patentee intends to increase the claims as much as possible to get a maximum incentive from the innovation. The examiner may require that the claims be narrowed before granting.

Family size: To protect innovation in various countries, a patentee should get a patent in every country. A group of patents protecting the same invention, we call it 'family' (these are also called parallel patents). Because filing and maintaining a patent in different countries is associated with high costs, only a fraction of patents seek protection outside their home market. Therefore, the family size indicates the importance of the patent for the patentee. This study includes the number of jurisdictions (patent offices) in which a patent is filed, family size, as an independent factor of patent value.

Technology scope: The examiner assigns each patent a 9-digit code based on the IPC classification system. Our data disaggregate patents at a 4-digit subclass level. Using this classification, each patent is assigned into one of the five broader technology groups: chemistry, electrical, instruments, mechanical, and 'otherfield'. We use the 4-digit subclass count in a patent to describe the technology scope. The broader the technology higher the count of the 4-digit subclass in the patent.

Grant-lag: The grant lag defined as the time elapsed between the filing and grant date is associated with patent value. Harhoff and Wagner (2009) and Régibeau and Rockett (2010) find evidence of an inverse relationship between patent value and the grant lag. However, Régibeau and Rockett (2010) suggest that granting decision depends on the effort made by the filing party. Our study includes the grant lag as an influencing factor of patent value in the Indian context.

Inventor size: The matric created utilizing the number of inventors contended to identify with the size of the investment made for the R&D project, which should be identified to estimate the project's output (Gambardella et al., 2006). In this study we use the inventor count given in the patent data as an indicator of the size and complexity of the project.

Ownership: We construct the variable for the ownership of each patent. We classify the ownership category into resident and non-resident patents. Patent assigned to India at IPO is called resident patents. However, patent assigned to other than India at IPO is called non-resident patents.

Technology field: We use 4-digit subclass codes to assign a technology field for each patent. Since a patent falls in more than one technology class, we have assigned a technology field on the basis of a maximum 4-digit subclass in one patent. Table 3.2 summarizes these patent characteristics.

Table 3. 2: Description of the response variable (renewal level) and independent variables (patent characteristics) used in the regression models.

Variable	Description	References
Renewal level (RL)	Each patent is classified in one of the four categories (1, 2, 3, and 4) based on the number of years a patent has been renewed (see Table 3.1).	Reitzig (2004); Moore (2005); Bessen (2008)
Family Size (FS)	The number of jurisdictions a patent is filed in.	Kabore and Park (2019); Harhoff et al. (2003)
Number of Claims (NC)	Number of innovations claimed in a patent.	Reitzig (2004); Caviggioli et al. (2013)
Grant Lag (GL)	Time elapsed between filing and grant date.	Harhoff and Wagner, (2009)
Technology Scope (TS)	Number of technological domains a patent belongs to. Four-digit IPC-code captures the information.	Squicciarini et al. (2013); Lerner (1994)
Inventor Size (NI)	The number of inventors involved in a patent. It also measures the R&D size and scale of a patent.	Kiehne and Krill (2017)

3.3.1 Patent Value Estimation by Different Technology

This includes the patent technology domain defined based on IPC industrial class. The importance of the patent system varies as the technology domain changes. Mansfield (1986) utilized a random example of 100 US firms showing that patenting is a critical strategy in the pharmaceutical, chemical, and petroleum industries. On the other hand, patenting in primary metals, electrical equipment, metals, and textile industry is less required. Consequently, the technology domain influences the probability of getting a patent renewed to full term. For US patents, Moore (2005) found that Chemical, Drugs and Medical, and “Other Industries” are relatively less likely to be renewed than mechanical patents. Whereas "electrical and electronics", and "Communications and Computer", patents are more likely to be maintained. However, for developing countries like India, technology's structure and usage are different from many for advanced countries. Thus, it is better to refrain from generalizing Moore (2005) or any other US-based study in India's context. This study hypothesizes that *the value of patents of different technologies is a function of certain observable characteristics*.

3.3.2 Identifying Valuable Technologies by Ownership Category

To understand the valuable technology by ownership category, this study divided patents into two categories: the patents filed by Indians at IPO (resident patents) and patents filed by foreigners at IPO (this is referred to as the non-resident patents). The main hypothesis we wish to test here is that *non-resident patents are more valuable as compared to domestic patents*. There is no prior study on this topic to explore the valuable technologies in India. Ownership characteristics is an essential part of the patent quality. In order to differentiate the quality of R&D among India and foreign countries, we need to look into the value of patent separately. Gupeng and Xiangdong (2012) study on patent valuation in China's context found that resident patents have a lower value compared to Japanese and US patents in China. This reveals an important fact, though patent filing in China in the last couple of decades topped in the world has not improved accordingly. To have a better innovation policy, we need to know the intensity of patent filing and its value.

3.4 Data Description

We examine the granted patents that were filed from 1st January 1995 to 31st December 2002. This section focuses on the sources of data, processing, and model specification.

3.4.1 Data

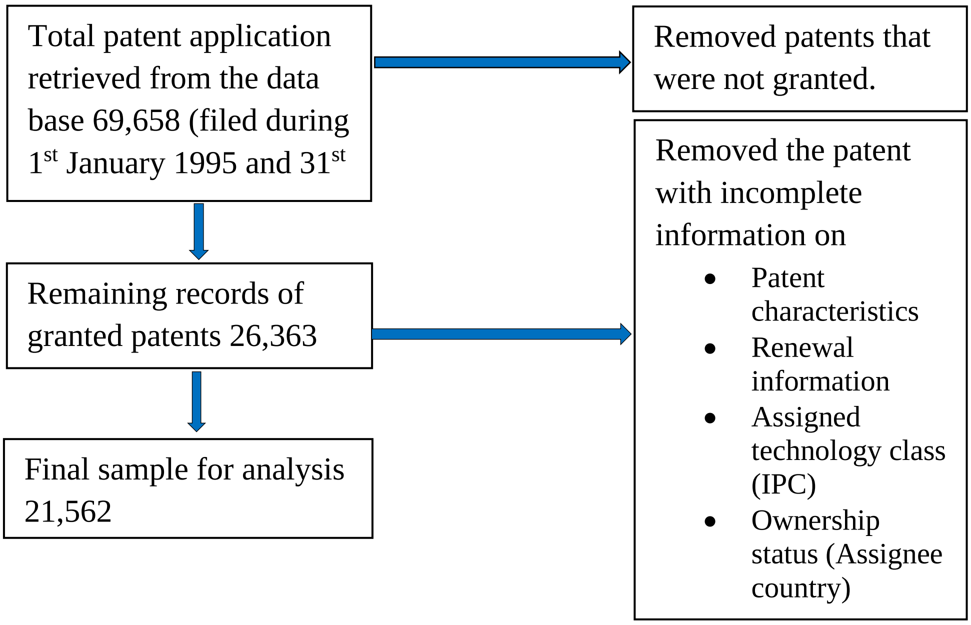
We collected patent-wise information from IPO for all granted patents filed/applied between 1st January 1995 and 31st December 2002. The total number of patents applied at IPO by resident and non-residents during the sampling period were 69,658, out of which, 16,863 patents are resident while 52,795 patents are non-resident. Among 69,658 patents only 26,362 patents were granted. Furthermore, only 21,562 patents contained complete information on the renewal time and all patent characteristics considered in this chapter (see Figure 3.1).

The data is divided based on ownership (resident and non-resident) and technological fields along with patent level information such as the number of claims, family size, technological scope, and inventor size. The share of non-resident patents in the total sample is around 83 percent (18078) and residents' 17 percent (3484). Empirical studies on patent valuation have used these variables as ex-post determinants of patent valuation (Hall et al., 2001; Lanjouw et al., 1998; Putnam, 1996). We added dummies for ownership status (0 if resident and 1 otherwise) – defined based on assignee country information.

Technologies are defined on the basis of Schmoch's (2008) classification (as updated in 2010 and 2011) which relies on the International Patent Classification (IPC) codes contained in the patent documents. The five major sector-electrical, instruments, chemistry, mechanical, and "otherfield"- is divided into 35 sub technology group (see Annexure 2).

Due to the multiple classifications of documents, a patent belongs to more than one technology group. However, the effect is limited. To avoid the double-counting of patents, this study uses the first classification codes of each patent.

Figure 3. 1: Different stages of data collection from Indian Patent Office (IPO)



3.5 Empirical Models

The dependent variable in our regression models is defined by the four ordered categories of the patent renewal life guided by the renewal fee structure in India (referred to as "renewal level" in Table 3.1). Given that the dependent variable is divided into more than two categories with a meaningful sequential order, one can apply ordinal logit models for efficient analysis of patent valuation with respect to different patent characteristics and technological domains.

3.5.1 Proportional Odds Model

A common approach for modeling such an ordinal response is to use the proportional odds model (POM) developed by McCullagh (1980), also known as the cumulative logit regression model. If the response variable Y (here, the renewal level) has J ordered categories ($J = 4$, as per Table 3.1), then the model is given by (McCullagh 1980)

$$\log\left(\frac{\Pr\,(Y \leq j|x)}{\Pr\,(Y > j|x)}\right) = \tau_j - x'\boldsymbol{\beta}, \quad j = 1,2,\ldots,J-1, \qquad (1)$$

where j represents the patent value category (i.e., $j = 1,2,3$), $\boldsymbol{\beta}$ is the vector of regression coefficients corresponding to the input vector (i.e., the patent characteristics), and τ_j is the cutoff effect between response category boundaries. The negative and positive signs of $\boldsymbol{\beta}$ coefficients are interpreted similarly as in the OLS regression. The proportional odds model assumes regression coefficient vector $\boldsymbol{\beta}$ to be the same across the logit equations, except the proportionality constant, τ_j – categorical boundary cutoff.

On several occasions, this proportional odds assumption is violated. Consequently, the results obtained are biased, which may lead to an unrealistic interpretation of the results. There are several ways to test the proportional odds/parallel lines assumption of the ordered logit model. One of the most popular tests is proposed by Brant (1990), which uses an omnibus chi-square test. A significant test statistic would indicate that the parallel regression assumption has been violated. Next, we present an alternative model called the Generalized ordered logit model (GOLM), suggested by Williams (2006; 2016).

3.5.2 The Generalized Ordered Logit Model

The main idea here is that both the intercept and the regression coefficient vector $\boldsymbol{\beta}$ (corresponding to the patent characteristics) can vary across the J categories of response (i.e., renewal level). The model statement is given by

$$\log\left(\frac{\Pr\,(Y \leq j|x)}{\Pr\,(Y > j|x)}\right) = \alpha_j - x_j'\boldsymbol{\beta}_j, \qquad j = 1,2,\dots,J-1, \tag{2}$$

where J is the number of outcome categories of the ordinal dependent variable, α_j if the relative cutoff effect for category j and $\boldsymbol{\beta_j} = (\beta_{j1}, \beta_{j2}, \ldots.\beta_{jk})$ correspond to the regression coefficients with respect to the k independent variables (patent characteristics and technological indicators). Note that the proportional odds model is a special case of GOLM, where the regression parameter vector $\boldsymbol{\beta_j}$ are the same for each categorical level $j = 1, \dots., J-1$.

The econometric model applied in this study simplifies the real-world process and contains the salient feature of patent valuation phenomena. The objective is to apply a simple model to explain a complex phenomenon.

3.6 Empirical Results

We start by summarizing the data from various standpoints and then discuss the results of the two logit models (POM and GOLM). We particularly focus on the assessment of technological domains in influencing the patent value measured via the “renewal level”.

3.6.1 Descriptive Statistics

The most basic summary (mean and standard deviations) of the patent characteristics as per our dataset are presented in Table 3.3. A few notable findings are as follows. The average grant lag for patents filed and applied during 1st January 1995 and 31st March 2005 at IPO is 8.18 years. There is a number of reasons for higher grant lag in India. For example, the examiner's average experience in India is 3.8 years, which 4 times lower than most of the countries (WIPO statistics). In recent times, India's average grant lag is reduced to 64 months (5 years), which is still higher than 22 months in China and European patent offices and 24 months in the US (WIPO, 2019).

In India, the average number of patent claims is 13.16, whereas, at the Japan Patent Office (JPO) it is 10.4; at European Patent Office (EPO), it is 14.7, and at the China National Intellectual Property Administration (CNIPA) this number is 8.1 (IP5 Statistics Report, 2017). Patent claims describe what is truly protected. Broad claims suggest that the patent could all the more successfully block the access to incremental innovation based on original technology. Thus, the breadth of claims is one of the important determinants of patent value.

To check the linear independence (equivalently multicollinearity) among the regression models' independent variables, we compute the pairwise correlation matrix (see Table 3.3). None of the values are high. The two variables “Family Size” and “Technology Scope” exhibit the highest correlation of 0.6259.

Table 3. 3: Summary statistics and correlation matrix of patent characteristics

	Claims	Inventor size	Family size	Technology Scope	Grant lag
Claims	1				
Inventor size	0.05	1			
Family size	0.15	0.08	1		
Technology Scope	0.18	0.15	0.62	1	
Grant lag	-0.04	0.04	-0.09	-0.08	1
Mean	13.16	2.62	17.30	6.86	8.18
Std Deviation	12.95	1.92	19.89	9.20	2.52
Observations	21562	21562	21562	21562	21562

We also computed the VIF (variance inflation factor) values to check for multicollinearity. It is clear from Table 3.4 that all VIF values are very small (close to 1) and hence reject multicollinearity among the predictor variables.

Table 3. 4: Variance inflation factor (VIF) values of the patent characteristics

Variable	VIF	Tolerance (1/VIF)
Technology Scope	1.69	0.59
Family Size	1.65	0.6
Claims	1.04	0.96
Inventor Size	1.03	0.97
Grant Lag	1.01	0.99
Mean VIF	1.29	-

The frequency distribution of patents reveals a somewhat increasing trend in the number of patents concerning the “renewal level”. Table 3.5 presents the exact figures. This is expected because, if someone has made an effort to file a patent, then the patent is likely to be worthy enough to be renewed for at least a few years. Several studies have found that the patents' renewal life is shorter, especially in developing countries compared to developed countries (Gupeng and Xiangdong, 2012). The lower survival length of the patent in developing countries may be associated with the patent's incremental nature. We have found that 56% of all patents filed between 1995 and 2002 lapsed by the 10th year.

Table 3. 5: Distribution of patents in different response category (renewal level)

Patent life	Renewal level	Freq.	Percent	Cum.
0 to 6th year	1	3697	17.14	17.14
7th year to 10th year	2	2729	12.66	29.80
11th year to 15th year	3	5767	26.75	56.54
16th year to 20th year	4	9371	43.46	100.00
	Total	21562	100	

Source: Authors' calculation.

Further analysis of patents with respect to the technological fields reveals that electrical patents are more likely to be maintained by their owners. In contrast, the mechanical patents expire more often at an early age (see Table 3.6). Moreover, a high percentage of patents belonging to instruments and "otherfield" have never been renewed by their owners'. Around 16.76% of the total patents across different technologies have never been renewed, and 56.5% of patents expire before the 16th year. Grönqvist (2009) reports an average patent length of 10.1 for the French patent data. This implies most of the learning from the patent happens in the early stage of the patent application. In the later stage, patentees do not find their innovation valuable enough to renew. Thus, the maximum patent expires without completing 20 years of the lifetime.

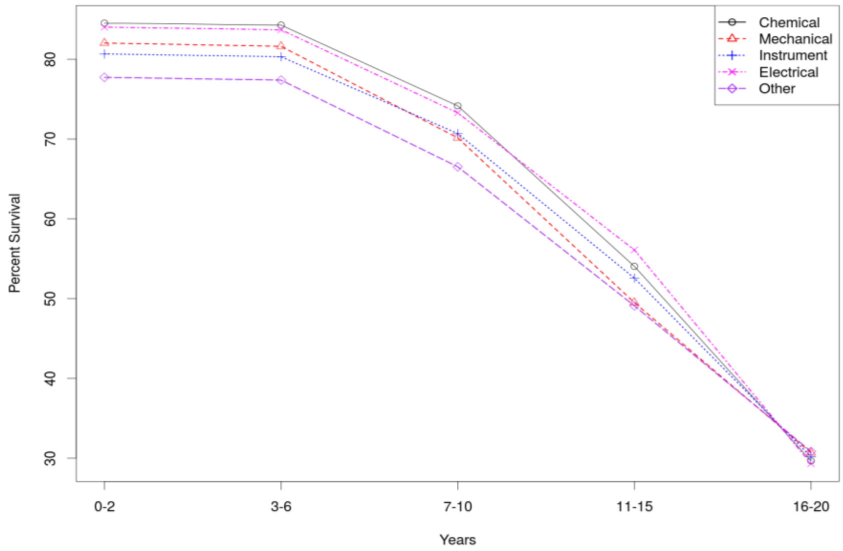
Table 3. 6: Patent survival rate in different technology fields

	Never Renewed	3rd to 6th	7th to 10th	11th to 15th	16th to 20th
Electrical	15.96	0.39	12.44	23.45	47.76
Instruments	19.32	0.43	11.99	25.63	42.64
Chemistry	15.46	0.29	12.01	27.12	45.12
Mechanical	17.95	0.51	14.05	29.43	38.06
Others	22.25	0.45	14.04	26.18	37.19
Total	18.18	0.38	12.66	26.75	43.46

Note: All values are in percentage of total patents for each category.

Figure 3.2 depicts the patent survival rate for different technology categories. It is clear from Figure 3.2 that the number of patents that expire between 0-2 years of patent life is highest in "otherfield" category and lowest in chemistry. As expected, the differences in patent survival rates decline across the technology as it approaches the 16th year of their life.

Figure 3. 2: Patent survival curve for different technology group



3.6.2 Regression Results by Technologies

First, we fitted the proportional odds model (POM) to all 21,562 patents using STATA. Table 3.7 presents the overall goodness of fit statistics and estimated regression coefficients for different patent characteristics. We also conducted a Brant test (1990) for validating the parallel regression assumption in POM. The large values of chi-square test statistics shown in Table 3.7 suggest that most of the patent characteristics violate the proportionality (or parallel) assumption. Thus, we need to investigate alternative models like the generalized ordered logit model (GOLM).

Table 3. 7: Regression coefficients of proportional odds model and Brant test results

Ordered logistic regression			Brant Test of Parallel Regression Assumption		
Variables	**Coefficient**	**Std. Err**	**Chi Square**	**p-value**	**Df.**
Claims	0.000	0.00	19.25	0.00	2
Inventor Size	0.063***	0.01	10.87	0.00	2
Family Size	0.012***	0.00	28.39	0.00	2
Technology Scope	-0.008***	0.00	10.44	0.01	2
Grant lag	0.083***	0.01	1008.76	0.00	2
Ownership	0.232***	0.04	39.01	0.00	2
Electrical	0.160***	0.05	6.09	0.05	2
Chemistry	0.135***	0.05	1.27	0.53	2
Mechanical	-0.080	0.05	20.93	0.00	2
"Otherfields"	-0.222***	0.07	1.55	0.46	2
Pseudo R^2	0.0133				
LR chi square	731.57***				
Log likelihood	-27207.235				
Number of obs.	21,562				

Note: Here, ***, **, and * denote $p < 0.01$, $p < 0.05$ and $p < 0.10$, respectively.

GOLM assumes that the regression coefficient vector $\boldsymbol{\beta_j}$ may vary across different logit equations with respect to different "renewal levels" $j = 1,2,3$. The regression coefficients and overall goodness of fit test statistics are reported in Table 3.8. The chi-square test checks the null hypothesis that all regression coefficients in the model are equal to zero. The results are presented in three panels corresponding to $P(Y \leq 1)$, $P(Y \leq 2)$, and $P(Y \leq 3)$[6]. That is, the first-panel analyses the model for "renewal level" category 1 vs. 2, 3, and 4; the second panel presents the regression coefficients for "renewal level" category 1, 2 vs. 3, 4; and so on. The consecutive orders of patent worth are organized in four classifications from 1 to 4 (1 alludes to the low value patent and 4 refers to the most important patent). A patent value less than the first renewal level expires in 6th years, patent values between 1st and 2nd renewal level expire in the 10th years. A patent value between the 2nd and 3rd renewal level expires in 15th years, and patent

[6] Precisely jth panel gives cumulative result in which categories 1 through j have been recoded to 0 and categories j+1 through M have been recoded to 1 (Williams 2006).

value between 3rd and 4th renewal level point expires in 20th years (maintained to full legal term).

Table 3. 8: Analysis of Generalized logit regression model (GOLM) (Reference category: instruments)

	Panel I	**Panel II**	**Panel III**
	Renewal level 1 vs. 2, 3, 4	**Renewal level 1, 2 vs. 3, 4**	**Renewal level 1, 2, 3 vs. 4**
Variables	**Coefficient**	**Coefficient**	**Coefficient**
Claims	-0.002 (0.00)	-0.001 (0.00)	0.001 (0.00)
Inventor Size	0.064*** (0.01)	0.064*** (0.01)	0.064*** (0.01)
Family Size	0.013*** (0.00)	0.015*** (0.00)	0.011*** (0.00)
Technology Scope	0.001 (0.00)	-0.004 (0.00)	-0.012*** (0.00)
Grant lag	0.519*** (0.04)	0.466*** (0.03)	0.073*** (0.03)
Grant lag square	-0.031*** (0.00)	-0.021*** (0.00)	0.001 (0.00)
Ownership	0.139*** (0.05)	0.101** (0.04)	0.344*** (0.04)
Electrical	0.157*** (0.05)	0.157*** (0.05)	0.157*** (0.05)
Chemistry	0.086 (0.05)	0.207*** (0.05)	0.110** (0.05)
Mechanical	0.028 (0.06)	0.027 (0.05)	-0.164*** (0.05)
“Otherfields”	-0.214*** (0.07)	-0.214*** (0.07)	-0.214*** (0.07)
Constant	1.222*** (0.09)	-0.767*** (0.08)	-1.672*** (0.08)
Pseudo R^2	0.0333		
Wald Chi square	2680.15***		
Number of obs.	21,562		

Note: Here, ***, **, and * denote $p < 0.01$, $p < 0.05$ and $p < 0.10$, respectively. Numbers in parentheses are standard errors.

From Table 3.8, we see that the “number of claims” has a negative and insignificant coefficient. The negative sign of technology scope shows that patent with higher technology scope is less likely to fall in higher category patent. However, in the lower cutoff, the technology scope is found to be insignificant. This implies that a patent with a broader technology class is less likely to fall in the upper category of patent value. But the result in the lower type of patent value is insignificant, which shows no impact. This result goes in line with Lanjouw et al.

(2001). The theoretical establishment of the innovation scope indicator is not satisfactory: it stays hazy if technological scope truly is a proportion of the patent's scope offered by patent claims. If a narrower patent performs better, on average, than those of general technologies, it may negatively impact innovation scope on value (Omland, 2011). Given the ambiguous theoretical foundation, it does not surprise the empirical evidence is mixed. The coefficients of inventor size are positive across the three panels (corresponding to the renewal level cutoff), suggesting that a patent with many inventors and large family size is more likely to be maintained to full term.

The geographical scope or international outreach of a patent (family size) is another important patent value factor. Since patents are territorial in nature, the invention is only protected in those countries in which patentees see the potential benefits. The existence of a patent in one country has no meaning in the legal system of other countries. The theoretical argument has been well established in the literature (Basberg, 1987; Putnam, 1996; Lanjouw et al., 1998). Reitzig (2004) conducted interviews with patent attorneys that confirmed that a patent's value is associated with the patent family size. Our study in the Indian context finds the positive impact of family size on the patent's renewal life. This implies that patents in other countries of the same invention is effective for identifying valuable patents.

The coefficient of the grant lag is consistently positive though declines across the panels. This implies that a patent with a higher grant lag is more likely to be renewed, but the coefficient's magnitude is very small. However, when we take the square of grant lag, we find that inverted U shape relationship. It implies that higher grant lag leads to higher renewal life to an extent but after the point of inflection, that starts declining. This outcome of this study upholds Régibeau and Rockett (2010) study where they argue that essential patents are approved more rapidly. The coefficients of ownership (coded as foreign=1 and domestic=0) are positive across the panels. This suggests that non-resident patents are more valuable as compared to resident patents. Looking at India's patenting trend data, we find that majority of non-resident patents are coming from developed countries (European and US); hence such patents are more valuable resident patents in India.

Returning to the essay's main focus, we now discuss the effect of technological domains on the value of patents measured via its renewal length. In the broader technology group, we used instruments as the technology baseline for the regression. The reference category is randomly chosen, and one can take any other technological field instead. Electrical and chemistry patents are more likely to be renewed than instruments patents, whereas mechanical and ‘otherfield’ patents are less likely to be renewed. This result goes with the Moore (2005) study where she finds that electrical and electronics and communication and computer patents more likely to be maintained. The differences in the patent renewal are often associated with the marketability of invented product. However, in this study we have not been able to focus on the market factors due to the limitations of the data on the working of the patent.

For a detailed impact analysis of technological domains on the patent value, we subdivided the technology groups into 35 sub-categories as per 4-digit IPC classification 2008. Table 3.9 presents the results of GOLM fitted to the full dataset containing 21,562 patents. Since the regression estimates of the patent characteristics (Claims, Inventor size, Family Size, Technological Scope, Grant Lag, and Ownership) do not change, we only present the results corresponding to the technological sub-categories. Here, we used the pharmaceutical (a subcategory of chemistry) as the reference category for model fitting[7].

The insignificant results obtained for a large number of technological fields are not surprising because many scholars in the past found that a

[7] Our generalized ordered regression model automatically selects the reference category to the last technology group in the model. However, choosing any other technological field in the place of pharmaceutical will not alter the basic outcomes of the regression (Williams, 2016).

large number of patents issued each year has no value (Lessig, 1999; Gleick, 2000).

The coefficient of the electrical machinery apparatus is negative but gets larger across cutoff. Hence, electrical machinery apparatuses tend to be less valuable, with the greatest difference being that electrical machinery is less likely to place itself in a higher value category. Generally, the negative coefficient indicates that the explanatory variable's higher value increases the likelihood of being in the current or lower category. In contrast, the positive coefficient indicates that an increase in the explanatory variable is more likely to place in the higher category levels of the outcome variable (in this case, patent value) (Williams, 2006). The coefficient of telecommunications is consistently positive and increasing across the renewal levels, which means that patents in telecommunication technology are more valuable than pharmaceutical patents. The greater difference is that telecommunication will be more likely to place in higher value than pharmaceutical.

The highlights of the results presented in Table 3.9 are summarized as follows:

1. In the sub-category of electrical patents, electrical machinery apparatuses and computer technology are less likely to be renewed than pharmaceutical. Whereas audio-visual tech, digital communications, telecommunication, and basic communication patents are relatively more likely to be renewed; hence they have a higher value.

2. In the sub-category of “instrument” technology, analysis of biological materials and medical technology is less likely to have higher value, whereas “control” patents are more likely to have a higher value than pharmaceutical.

3. Organic fine chemistry and food chemistry of chemistry fields have a lower probability of having high-value patents while

basic material chemistry, biotechnology, environment tech, basic material chemistry, and materials, metallurgy patents are more likely to have a higher value as compared to pharmaceutical patents.

4. In the mechanical field, textile and paper, and mechanical elements are less likely to have high value, whereas engines, pump turbines and transports are more likely to have higher value relative to pharmaceutical.

5. In "otherfield", furniture and games, other consumer goods, and civil engineering are less likely to be renewed to the full term. The value of such patents is extremely low among all technological sub-categories.

Table 3. 9: GOLM analysis by technology sub-categories (reference category: pharmaceutical)

	Renewal level 1		Renewal level 2		Renewal level 3	
Variables	Coefficient	Std.Err.	Coefficient	Std.Err.	Coefficient	Std.Err.
Electrical machinery apparatus	-0.02	0.08	-0.136*	0.08	-0.162**	0.08
Audio-visual tech	0.233**	0.12	0.061	0.1	0.248***	0.09
Telecommunications	0.388***	0.09	0.253***	0.09	0.490***	0.08
Digital communication	0.225	0.17	0.263*	0.14	0.635***	0.13
Basic communication	0.007	0.19	0.334**	0.17	0.360***	0.14
Computer technology	0.088	0.1	-0.178**	0.09	-0.051	0.09
IT Methods for management	0.423	0.42	0.423	0.42	0.423	0.42
Semiconductors	0.166	0.16	0.166	0.16	0.166	0.16
Optics	0.008	0.14	0.008	0.14	0.008	0.14
Measurement	0.272**	0.11	0.147	0.11	0.065	0.1
Analysis of biological materials	-0.323*	0.17	-0.323*	0.17	-0.323*	0.17
Control	0.277*	0.15	0.277*	0.15	0.277*	0.15
Medical technology	-0.197***	0.09	-0.305***	0.09	-0.211**	0.09
Organic fine chemistry	0.049	0.08	-0.01	0.07	-0.122*	0.07
Biotechnology	0.253***	0.09	0.253***	0.09	0.253***	0.09
Macro-molecular polymer	-0.053	0.08	-0.053	0.08	-0.053	0.08
Food chemistry	-0.156	0.15	-0.005	0.13	0.227*	0.12
Basic material chemistry	0.125*	0.07	0.125*	0.07	0.125*	0.07
Materials, metallurgy	0.237***	0.07	0.237***	0.07	0.237***	0.07
Surface technology	0.059	0.11	0.059	0.11	0.059	0.11
Chemical engineering	0.106	0.07	0.106	0.07	0.106	0.07
Environmental tech.	0.298*	0.18	0.104	0.15	-0.212	0.14
Handling	-0.101	0.09	-0.101	0.09	-0.101	0.09
Machine tools	0.08	0.09	0.08	0.09	0.08	0.09
Engines pumps turbines	0.292**	0.12	0.125	0.1	-0.168	0.09
Textile and paper	-0.122	0.09	-0.230***	0.09	-0.303	0.09
Other special machines	-0.136	0.09	-0.136	0.09	-0.136	0.09
Thermal processes	0.041	0.11	0.041	0.11	0.041	0.11
Mechanical elements	0.072	0.12	-0.198**	0.1	-0.246	0.1
Transport	0.245**	0.11	-0.139	0.09	-0.488	0.1
Furniture, games	-0.565***	0.15	-0.565***	0.15	-0.565	0.15
Other consumer goods	-0.181*	0.11	-0.181*	0.11	-0.181	0.11
Civil engineering	-0.206**	0.11	-0.206**	0.11	-0.206	0.11
Constant	1.368***	0.09	-0.575***	0.08	-1.398	0.08
Pseudo R^2	0.0392					
LR chi square	2162.24***					
Number of observations	21,562	21,562	21,562	21,562	21,562	21,562

Note: Here, ***, **, and * denote $p < 0.01$, $p < 0.05$ and $p < 0.10$, respectively. Reference category is pharmaceutical.

The general observation here is that electrical and communication patents are more likely to be maintained than pharmaceutical patents. Pharmaceutical patents are more likely to be maintained than medical technology and less likely to Biotech patents. Moore (2005) found that biotech patents are more valuable than drug, agricultural, and organic compounds patents in the US. In India, the present study reveals that biotech patents are more likely to be maintained than patents belonging to simple devices. This can be less expensive in terms of R&D. We also find that the result of the subgroup derives from the earlier results of broader technology. Table 3.10 summarizes the information on valuable to not-so-valuable patents (reference technology pharmaceutical).

Table 3. 10: Sorted list of technologies as compared to the reference category (Pharmaceutical)

Technological field Sub category	Renewal level 1	Renewal level 2	Renewal level 3
Audio-visual tech	0.233**	0.061	0.248***
Telecommunications	0.388***	0.253***	0.490***
Digital communication	0.225	0.263*	0.635***
Basic communication	0.007	0.334**	0.360***
Measurement	0.272**	0.147	0.065
Control	0.277*	0.277*	0.277*
Biotechnology	0.253***	0.253***	0.253***
Food chemistry	-0.156	-0.005	0.227*
Basic material chemistry	0.125*	0.125*	0.125*
Materials, metallurgy	0.237***	0.237***	0.237***
Environmental tech.	0.298*	0.104	-0.212
Engines pumps turbines	0.292**	0.125	-0.168
Transport	0.233**	0.061	0.248***
Reference category: Pharmaceutical			
Electrical machinery apparatus	-0.02	-0.136*	-0.162**
Computer technology	0.088	-0.178**	-0.051
Analysis of biological materials	-0.323*	-0.323*	-0.323*
Medical technology	-0.197***	-0.305***	-0.211**
Organic fine chemistry	0.049	-0.01	-0.122*
Textile and paper	-0.122	-0.230***	-0.303
Mechanical elements	0.072	-0.198**	-0.246
Furniture, games	-0.565***	-0.565***	-0.565
Other consumer goods	-0.181*	-0.181*	-0.181
Civil engineering	-0.206**	-0.206**	-0.206

Note: Here, ***, **, and * denote $p < 0.01$, $p < 0.05$ and $p < 0.10$, respectively. Reference category is pharmaceutical.

3.7 Conclusion

Our objective in the chapter was to approach the problem from a developing country perspective that remained understudied in the literature. Hence, our methodological approach and results reinforce that patent's characteristics can be analyzed to capture if it is "valuable". In the patent characteristics, bigger inventor size, family size is positively associated with the high-value patents. In contrast, a technological scope is negatively associated with high-value patents (cutoff 3). However, it is found insignificant in cutoff 1 and 2. The theoretical literature says that the correlation between technological scope and value could be hypothesized to be negative, positive, or zero depending on the two effects' relative strength (Omland, 2011).

The impact of grant lag on the patent value is positive and significant; however, the grant lag's square is negative significant. We can understand this result from the average patent renewal pattern in India. We have seen that the average patent life in India is around 11 to 12 years. For example, if a patent is granted after eight years, that patent may likely renew for another three years. If the same patent is granted in the 11 or 12th years, it is less likely that the patentee will renew that patent for another couple of years. Thus, higher grant lag leads to higher renewal life, hence higher value of the patent. However, a doubling of the grant lag leads to lower patent value.

The results obtained using a generalized ordered logit model for five major technology groups suggest that electrical and chemistry are more valuable than instrument category patents (reference group). Chemistry patents fall under the discrete category, whereas electrical fall under the complex technology patent category. As argued in the literature, complex technology is inherently difficult to replicate, and therefore the value of a patent is 'in this respect' is lower. However, this study using a more disaggregated technology field reveals that not all complex technologies patents are less valuable. Similarly, not all discreet patents are valuable. For a better understanding of the discrete and complex technology value, we subdivided our technology class. In discrete category, the biotechnology, basic material chemistry patents (a subgroup of chemistry) are more likely to maintain full length.

Similarly, in the complex technology category (e.g., consumer electronic industry) audio-visual tech, telecommunications, digital communication, and basic communication higher value. The results also reveal that only a few technologies have significant value while a large number of technologies are either having a lesser value or no value at all. In the owner's status, foreign patents (non-resident patents) are more likely to have a higher value than domestic patents. Keeping the disaggregated technological result in view, IP law in India should consider industry specific patent law.

Chapter 4

Valuation of Patents in Emerging Economies: A Renewal Model-Based Study of Indian Patents

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4.1 Introduction

In the previous two essays, we have used patent level information to explore patent values for different technology, assignee, and ownership category. The present essay extends the discussion of patent valuation by estimating the monetary incentive of the patent system. Using the same determinants of patent value, we estimate the monetary value of expired patents (patent that completed 20 years of life or expired due to non-payment of renewal fee). The structure and inspiration of innovation are different in the developing economies, and therefore, the patent value in such countries may vary compared to the developed countries. This study intends to discuss patent valuation in India in the mainstream scholarship while highlighting the specific aspects of such valuation for an emerging economy.

The value of a patent is a multidimensional concept viewed from legal, economic, and financial perspectives. The legal dimension of patent value refers to the patent's sustainability when challenged (Bruke and Reitzig, 2007). The financial accounting perspective is about incorporating a patent in the company's financial statement. The accounting valuation of patents is defined under various accounting standards related to intangible assets such as Accounting Standard No. 38 (IAS 38), International Financial

Reporting Standards (IFRS), and the US accounting principle. Economic patent value refers to the reward that a patentee can generate from a patent by excluding the competitors, licensing the technology to the third parties, or a combination of both (Munari and Sobrero, 2011). Arora and Fosfuri (2003) defined patent rent as an incremental value above the profit captured without patent protection. In this chapter, we consider the economic perspective to estimate the patent value.

The identification of resident and non-resident patents in this study is based on the patent's assignee country. We also estimate patent values for different technology groups to visualize the country's technology market (e.g., Schankerman, 1998; Deng, 2007a). We have seen that there is less information about the academic and individuals' patents. Since the R&D expertise and patenting objective differs among institutions, individuals, and firms' categories, we further segregate patents into these categories. We separately estimate the return from the patent in monetary terms for each type.

This study contributes to the literature in the following ways. First, no study before this has used full-length renewal information of the patent to measure the patent's average life by technology, assignee, and ownership differences. Second, no study has quantified patent system incentives in India in monetary terms. Third, an earlier study used Monte Carlo simulation techniques (Bessen, 2008). However, this study uses evolutionary techniques of simulation (GAs), which gives more robust estimates of parameters. Thus, the obtained results using a diverse set of factors give an edge over previous studies. To check the robustness of the result, we conducted additional sensitivity analysis.

The remainder of the chapter is organized as follows. Section 4.2 starts with previous literature on patent value and valuation methodology. Section 4.3 explains the methodology, the patent valuation model, and parameters estimation techniques in detail. Section 4.4 elaborates the data and variables used for analysis. Section 4.5 summarizes descriptive statistics, and section 4.6 presents the main findings and discusses uncertainty analysis. We also compare our results with other available studies in this field in section 4.7. Section 4.8 concludes the results.

4.2 Previous Literature

4.2.1 Patent Value

Schankerman and Pakes (1986) use data on renewal payments to estimate the private value of patents considering patent life as an indicator of its value. Lanjouw et al. (1998) used patent data from West Germany for 1953-1988 and estimated patent value for four different technological areas (computer, textiles, combustion engines, and pharmaceuticals). The underlying rationale for using the patent renewal approach is that the patent holder will not renew its patent for an additional year if the cost of holding it exceeds the revenue generated.

The private value of the patent in China is measured by Gupeng and Xiangdong (2012) using renewal payment-based information. They compared the values of patents between locals and owners from the US, Japan, and European countries (in their study, foreign patents refer to the patents assigned to countries other than China). The study finds that the value of Chinese patents is much lower than the value of foreign patents. In the technology category, machinery patents have a high value as compared to pharmaceutical patents. Zhang et al. (2014) estimate patent rights' private value using Chinese patent renewal data on a similar line. They found that 30% of patents filed by Chinese firms are renewed over four years, while this ratio is much higher for the US, Japanese, and the E.U patents (between 40% and 60%). This indicates that patents' renewal age is shorter for the Chinese patents, underscoring the technology gap between China and developed countries. Liu et al. (2014) estimate the value of agricultural patents in China for patents filed between 1985 and 2005 and granted before January 2011. The results show that Chinese patent value measured by life span and renewal length has improved, although foreign patents are still maintained longer. Entity wise private firms are more likely to renew their patent than public entities. Furthermore, in the agricultural technology group, agricultural biotechnology and agricultural chemicals patents are higher than others.

In the Indian context, several studies utilize patent and R&D information to estimate various economic indicators (Kanwar and Hall, 2015; Ambrammal and Sharma, 2016). Kanwar and Hall (2015) estimate the market value of R&D in the context of manufacturing firms in India. Ambrammal and Sharma (2016) utilize patent count information to measure its impact on firm performance. However, there are no studies that explore the valuation aspect of Indian patents using renewal information. Thus, the present study attempts to bring patent value discussion in Indian academia by using Indian patents information from the economic perspective.

4.2.2 Patent Value Estimation

The estimation approach of the monetary value of patents is classified into three broader groups. The first approach relies on patent owners' observed behavior, for example, analyzing patent renewal decisions or assessing actual patent licensing (Bessen, 2008; Gupeng and Xiangdong, 2012). The second approach is based on the survey method in which investors are directly asked to estimate their patents' value (Scherer and Harhoff, 2000). The third approach is based on the valuation made by external investors, either by stock market valuation or by venture capital valuations (Hall et al. 2005; Hall and MacGarvie, 2006).

The interest of economists in the patent renewal information can be traced back to Nordhaus' thesis (1969). Later, Pakes and Schankerman (1984) used patent-based information to uncover the characteristics of the value of patent protection. They notated $r_i(t)$ as the annual flow of rent (the patent value) for the i-th patent at time $t\ (0 \leq t \leq 20)$. In the renewal model, each applicant is endowed with an initial return $r_i(0)$ from patent protection, which depreciates deterministically. A patent depreciates because of technology's irrelevance with time or because competitors can “invent around” it. However, the patent holder may learn about more applications of their technology in the future, and therefore, their expected return might increase over time. Pakes (1986) and Lanjouw (1998) used a model where returns from patents evolve stochastically. However, the results obtained through stochastic models are similar to those obtained using deterministic depreciation for the same data Bessen (2008). An essential feature of patent valuation using renewal data is its lognormal distribution. Studies by (Pakes, 1986; Lanjouw et al., 1998) compared the lognormal, Pareto, and Weibull distributions for modeling renewal data and found that the lognormal distribution provides the best fit.

Because patents are highly diverse, the patent value can differ significantly among technology fields and ownership status. Thus, assuming the deterministic model, (Bessen, 2008) studies estimate parameters ‘as close as possible’ to the actual data. Bessen (2008) uses cross-sectional US patent data to find that most litigated and highly cited patents are more valuable. He also finds that patents held by small enterprises have lower value in comparison to large corporations. Deng (2007b) suggests that the country's economic size and patent value are positively correlated. In recent times, the literature in this field has transcended Europe and the US boundary and explored other territories. Notably, Chinese scholars have adopted the renewal models for expired and non-expired patents (Gupeng and Xiangdong, 2012).

4.3 Methodology

The model proposed by (Pakes and Schankerman, 1984) is based on a patent's life in which the patentee decides to keep the patent in force to internalize the streaming returns. There is a compulsory renewal fee for every granted patent if the patentee wants to keep it enforced. The sequence of renewal fees increases monotonically with age and is denoted by c_{it}. A patentee who pays a renewal fee earns an implicit return $r_i(t)$, from the patent protection during the active life of the patent. We assume that $r_i(t)$ is known to the patentee at $t = 0$, the time of application / filing the patent. A more complicated model (Schankerman and Pakes, 1986) allows the patentee to be uncertain about return's sequence.

European nations have annual maintenance fees, whereas in US only three payments are required to keep the patent enforced until maturity. Like the European renewal system, the Indian patent office (IPO) requires patentees to pay annual renewal fees to keep their patents enforced. Therefore, Indian renewal data have a large degree of freedom, not the case in US data. Large degrees of freedom allow us to estimate model parameters with the yearly effect.

4.4 Renewal Model

We make two key assumptions about the profit flow of patents. First, the returns of patents, $r_i(t)$, depreciate at a fixed rate. Though stochastically varying depreciation rate-based model may appear to be more flexible, (Bessen, 2008) demonstrates that model based on the constant depreciation rate leading to similar results as the models using variable depreciation rate. That is,

$$r_i(t) = r_i(0)e^{-dt},$$

where d is a fixed (unknown) depreciation rate, and $r_i(0)$ is the initial return at the time of application / filing the patent. The annual renewal fee c_{it} is also assumed to depend only on time t and not the patent characteristics. Following (Bessen, 2008), we further modelled the present value of profits from t to $t + T$ (here, $T = 1$ annual renewal cycle) as,

$$r_i(0)z_t = \int_t^{t+1} r_i(\tau)e^{-s(\tau-t)}\,d\tau,$$

where,

$$z_t = e^{-dt}\left(\frac{1-e^{-(d+s)}}{d+s}\right),$$

The discount rate s is different from the technological depreciation or decay rate d. Following Bessen (2008), we assume that an expected return to patent value depreciates at a constant rate.

In this study, s is fixed at 0.1. The discount rate is fixed at 10% to make a comparison with previous studies.

The second key assumption is that the initial return is lognormally distributed. Let X_i denote the vector of characteristics for the i-th patent. Then,

$$\ln\big(r_i(0)\big) = \boldsymbol{\beta} \cdot X_i + \varepsilon_i, \tag{1}$$

where ε_i is independent and identically distributed (iid) normal variables with mean zero and (unknown) variance σ^2. To model the initial returns of a patent, this study uses four patent characteristics which include the size of the patent family (family size), number of inventors associated with that invention (inventor size), technological breadth (technology scope), and grant lag. Along with these four different factors that determine the patent value, we have included technology (chemical, electrical, mechanical, and instrument) dummies in the equation. We have also used the assignee categories (individuals, institutions, and firms' dummies). To see the value differences among resident and non-resident patents, we have used the ownership dummy.

The most crucial part of the renewal model is to formulate the decision criterion for deciding whether or not a patent should be renewed at time t.

Following Bessen (2008), the necessary and sufficient condition for a renewal of the i-th patent at time t is

$$\ln(r_i(0)) \geq \ln\left(\frac{c_{it}}{Z_t}\right).$$

Let T_i be the expiry age of the i-th patent. As per the IPO rules, the first decision has to be made at the end of the second year from the date of application (after issuance of the patent arrears of renewal fee is required to be paid), and the last renewal decision (if the patent is renewed until its maturity) is made at the end of the 19-the year. Based on the data we have, the i-th patent will fall into one of the following three scenarios at time $2 \leq t \leq 19$:

(a) The patent is never renewed: $[T_i = 2]$. The i-th patent is never renewed if and only if the value of the patent at the end of the second year is less than the renewal cost, i.e.,

$$\log(r_i(0)) \leq \log\left(\frac{c_{i2}}{z_2}\right).$$

Following the log-normal distribution, the probability of this event can be computed by

$$\begin{aligned} P[T_i = 2] &= P\left[\log(r_i(0)) \leq \log\left(\frac{c_{i2}}{z_2}\right)\right] \\ &= \Phi\left(\frac{\log\left(\frac{c_{i2}}{z_2}\right) - \boldsymbol{\beta} \cdot X_i}{\sigma}\right), \end{aligned} \tag{2}$$

where Φ is the standard normal cumulative distribution function (CDF).

(b) The i-th patent is renewed until maturity: $[T_i = 20]$. It is sufficient to say that this event can occur only if the i-th patent was renewed at $t = 19$, i.e.,

$$\log(r_i(0)) \geq \log\left(\frac{c_{i,19}}{z_{19}}\right),$$

with probability

$$P[T_i = 20] = P\left[\log(r_i(0)) \geq \log\left(\frac{c_{i,19}}{z_{19}}\right)\right]$$
$$= 1 - \Phi\left(\frac{\log\left(\frac{c_{i,19}}{z_{19}}\right) - \boldsymbol{\beta} \cdot X_i}{\sigma}\right) \quad (3)$$

(c) The i-th patent expires prematurely: $[3 \leq T_i \leq 19]$. In other words, the i-th patent expired at time $T_i = t$ and it was renewed at time $t - 1$, i.e.,

$$[T_i = t] = \left[\log(r_i(0)) \geq \log\left(\frac{c_{i,t-1}}{z_{t-1}}\right)\right] \cap \left[\log(r_i(0)) \leq \log\left(\frac{c_{it}}{z_t}\right)\right],$$

with probability

$$P[T_i = t] = P\left[\log\left(\frac{c_{i,t-1}}{z_{t-1}}\right) \leq \log(r_i(0)) \leq \log\left(\frac{c_{it}}{z_t}\right)\right]$$
$$= \Phi\left(\frac{\log\left(\frac{c_{it}}{z_t}\right) - \boldsymbol{\beta} \cdot X_i}{\sigma}\right)$$
$$- \Phi\left(\frac{\log\left(\frac{c_{i,t-1}}{z_{t-1}}\right) - \boldsymbol{\beta} \cdot X_i}{\sigma}\right). \quad (4)$$

These probabilities are not computable as the model parameters $\Omega = (\sigma, d, \boldsymbol{\beta})$ are unknown. Thus, we have to use the data on expiry age (T_i) and different characteristics (X_i) to estimate the model parameters, which are then used to simulate the initial patent value $r_i(0)$.

4.4.1 Parameter Estimation

Assuming $\boldsymbol{\beta}$ is a 14-dimensional vector of regression coefficients, we have to estimate 16 parameters. We follow the maximum likelihood approach for estimating the model parameters $\Omega = (\sigma, d, \boldsymbol{\beta})$. For the data on n patents, the likelihood based on the distribution of T_i, presented in Equations (2) - (4), is given by

$$L(T_1, T_2, \ldots, T_n\,; \Omega) = \prod_{i=1}^{n} P(T_i = t_i). \quad (5)$$

Unfortunately, none of the parameter estimates can be found in a closed analytical form. Thus, a numerical optimization approach has to be used for estimating the parameters.

We follow an evolutionary optimization technique called the Genetic Algorithm (GA) (Holland, 1975) for finding the maximum likelihood estimates (MLE) of $\Omega = (\sigma, d, \boldsymbol{\beta})$.

The search space for the parameter is defined by $d \in (0.1, 0.5)$, $\sigma > 0$, $\beta_{grant-lag} <$, $\beta_{technology-scope} > 0$, $\beta_{family-size} > 0$, and $\beta_{inventor-size} > 0$, whereas the other β coefficients were allowed to take any value in the real line[8]. The GA starts by selecting a random initial population (of the candidate Ω vectors) of size N_1 in the specified search space. Then, in the first generation, all individuals of this initial population were subjected to crossover and mutation steps. At the end, the fitness function (i.e., the likelihood) was computed and the best N_1 solution out of $3N_1$ candidates were retained for the second generation of the genetic evolution. In this chapter, we used $N_1 = 10{,}000$ and number of generations equal to 20 for estimating the parameters. Furthermore, we adopted the multi-start approach to reduce the initial population's dependency and find robust estimates of Ω.

The final estimates of Ω were taken as the median of the best 200 solutions from the last generation of the GA process. The standard errors of these 200 solutions were used to quantify the uncertainty and sensitivity of the parameter estimates.

[8] The detailed reasons and literature support for the direction of variables are given in section 4.2.

4.4.2 Simulation of the Patent Values

The chapter aims to estimate the net present value of patents using renewal information and various patent characteristics. Using the parameter estimates $(\hat{\sigma}, \hat{d}, \hat{\boldsymbol{\beta}})$ we estimate the bounds for each patent value conditional on corresponding renewal decisions made by the patentee. Using Monte Carlo simulation, we estimate the initial return $r_i(0)$ of the patent, thus $r_i(t)$ value is calculated using fixed depreciation rate as demonstrated in studies by (Bessen, 2008; Maurseth, 2005; Gupeng and Xiangdong, 2012).

The bounds on ε_i for the i-th patent, conditional on the observed renewal decision can be deduced separately for the three cases as listed in Section 3.1.

(a) The patent expires at the end of the second year (i.e., the patent is never renewed)

$$\varepsilon_i \leq \ln\left(\frac{c_{i2}}{Z_{2(\hat{d})}}\right) - \hat{\beta}X_i. \tag{6}$$

(b) Patent expires prematurely (i.e., at $t = 3,4, \dots ,19$),

$$\ln\left(\frac{c_{i,t-1}}{Z_{t-1(\hat{d})}}\right) - \hat{\beta}X_i \leq \varepsilon_i \leq \ln\left(\frac{c_{it}}{Z_{t(\hat{d})}}\right) - \hat{\beta}X_i. \tag{7}$$

(c) Patent matures at 20th year from the date of filling

$$\ln\left(\frac{c_{i,19}}{Z_{19(\hat{d})}}\right) - \hat{\beta}X_i \leq \varepsilon_i. \tag{8}$$

For every observation of the Monte Carlo iteration, we select ε_i as a random draw from the log-normal distribution of Equation (1) determined by $\hat{\boldsymbol{\beta}}$, $\hat{\sigma}$ and $\hat{d}$. The Monte Carlo simulations were repeated a large number of times(10^6) to ensure that we had a sufficient number of observations for estimating each patent value. The estimates of $r_i(t) = r_i(0)e^{-\hat{d}t}$ can also be used to find the present value of all expired patents at time t,

$$V(T) = \sum_{t=1}^{T} r_i(t) - c_{it}(1+i)^{-t}, \quad (9)$$

Where, $r_i(t)$ and c_{it} denotes return and renewal cost of patent i at time t, respectively. Whereas s denotes the annual discount rate, which is fixed at 10%.

4.5 Data and Variables

4.5.1 Data

We consider patents that were applied or filed from January 1996 to December 2005 and were granted by IPO. Most of the patent field's details in the early 90's was not complete, and more importantly, not electronically available. On the other hand, more recently, filed/granted patents have not been considered, as many of them would still be enforced till-date and would require more sophisticated methodologies to account for the censored information. Patents filed during 1996 will expire in 20 years, that is, 2016, and patents filed in the year 2005 completes their 20 years in 2025 (maximum life of a patent is 20 years). The renewal period in this study ranges from January 1998 to October 2018. This study utilizes all patents assigned (granted) to firms', individuals, and institutions, accounting for 18864 including 4279 residential and 14585 non-residential patents during the sampling period. All data were extracted from PatSeer database and the Indian patent advanced search system (inPASS) of Indian Patent Office. The 'PatsSeer is a private database company which provides detailed information of patent. Gupeng and Xiangdong (2012) suggested that the expired patent-based studies are more useful for accumulated but terminated resources up to the investigation date. Therefore, in this study, we have taken only patents for which complete information was available.

This study uses the IPC developed by the WIPO to construct a technology field. Technology fields are combinations of IPC classes that are designed to protect inventions of the same kind. On the basis of Schmoch (2008), technologies are categorized into five major groups of chemical, electrical, mechanical, instruments, and ‘other’ fields, including furniture, games, other consumer goods, and civil engineering. The technologies are classified on a four-digit IPC level (see Table 4.1 for technology level).

Table 4. 1: IPC Classification-2008

Section	**Class**	**Sub class**	**Group**	**Sub group**
A	**61**	**K**	31	/545

Source: WIPO- IPC Technology concordance-2008

4.6 Regression Variables

The patent document provides details about technical, legal, and business-specific aspects. These characteristics are likely to have a bearing on patent value. Hence, we quantify patent-specific aspects to find their association with patent value. The following patent characteristics are used in this study.

Number of claims: the number of claims is considered the single most telling indicator of patent strength. It is one of the important parts of a patent specification that fence the boundary of the patent. Precisely, patent claims define exactly what is claimed by the invention and, therefore, what is filed for protection. Patent valuation studies have frequently used this indicator to determine the patent value (Bessen, 2008; Okada et al., 2016).

Technology scope: The scope of the patent is often associated with the economic value of the patents. Gilbert and Shapiro (1990), and Lerner (1994) observe that the technological breadth of a patent is related to the firm’s valuation. The broad patents are more valuable when many possible substitutes in the same product class are available. We have calculated the technology scope by examining the 4-digit technology class of each patent.

Patent family size: The set of patents filed in several other countries that are close or related to each other by one or several other priority filings is referred to as family size. (Lanjouw et al., 1998) used family size and found that the number of jurisdictions in which the patent has been sought is associated with patent value.

Grant lag: It is defined as the time elapsed between the filing date of application and the grant date. For the inventions with short commercial life, delay in patent grant could be detrimental for the invention's commercial utilization. Harhoff and Wagner (2009) and Régibeau and Rockett (2010) found an inverse relationship between patent and grant lag period value.

Number of inventors: Among others, Guellec and Pottelsberghe (2000) and Gupeng and Xiangdong (2012) have used the inventors' information to determine the patent's economic value. Further, we segregate patents into assignee categories (individuals, institutions, and firms'). Based on the previous international studies, the other two most likely impacting factors considered in this study are ownership (resident and non-resident) differences (Pakes, 1986; Deng, 2007a) and technical field differences (Grönqvist, 2009; Pakes, 1986; Deng, 2007a).

To further explain whether variables in this study are correlated with each other or not, we generate the correlation table. The correlation matrix is presented in Table 4.2, which shows no high correlations among the variables.

Table 4. 2: Correlation matrix of regression variables

	Renewal	**Claims**	**Inventor**	**Family size**	**Tec scope**	**Grant lag**
Renewal	1.00					
Claims	0.00	1.00				
Inventor	0.04	0.04	1.00			
Family size	0.07	0.10	-0.01	1.00		
Tec scope	-0.01	0.19	0.09	0.34	1.00	
Grant lag	0.42	-0.08	0.03	-0.04	-0.16	1.00

Source: Authors' calculation

4.7 Descriptive Statistics

The sample consists of 18864 patents granted to firms. These patents are dis-aggregated into five technology groups, ownership status (resident and non-resident), and assignee category (individuals, institutions, and firms'). Table 4.3 presents the summary statistics of the independent regression variables for the data. Among the assignee category, firms' patent length is higher, followed by institutions and individuals. The institutions' patents have a larger inventor size, followed by firms' and individuals' patents. The renewal is higher in the technology group's electrical field, followed by instruments, chemistry, and mechanical.

Table 4. 3: Summary statistics

	Variable	Renewal	Claims	Inventor	Family size	Tec scope	Grant lag
Individuals	Obs.	1609	1,609	1609	1609	1609	1609
	Mean	11.36	11.88	1.56	10.91	4.34	6.28
Institutions	Obs.	2,019	2,019	2,019	2,019	2,019	2,019
	Mean	12.68	9.09	3.33	6.21	2.57	7.47
Firms	Obs.	15236	15236	15236	15236	15236	15236
	Mean	12.19	13.30	2.49	13.89	6.87	6.61
Electrical	Obs.	3757	3757	3757	3757	3757	3757
	Mean	12.53	14.82	2.34	12.82	6.10	6.94
Instrument	Obs.	1652	1652	1652	1652	1652	1652
	Mean	12.23	13.90	2.31	12.98	5.37	6.70
Chemistry	Obs.	8112	8112	8112	8112	8112	8112
	Mean	12.09	12.22	2.91	13.09	7.18	6.46
Mechanical	Obs.	4542	4542	4542	4542	4542	4542
	Mean	12.09	11.35	2.09	12.10	5.11	6.82
Otherfield	Obs.	801	801	801	801	801	801
	Mean	11.73	13.47	1.91	13.81	4.60	6.70
Non-resident	Obs.	14,585	14,585	14,585	14,585	14,585	14,585
	Mean	12.35	13.94	2.44	14.59	7.40	6.68
Resident	Obs.	4,279	4,279	4,279	4,279	4,279	4,279
	Mean	11.57	8.60	2.72	6.76	2.11	6.63
All	Obs.	18,864	18,864	18,864	18,864	18,864	18,864
	Mean	12.17	12.73	2.50	12.82	6.20	6.67

Source: Authors' calculation based on information collected from the IPO.

The mean technological scope is higher in the chemistry field, followed by electrical, instruments, and mechanical. The average number of people involved in a patent is highest in the electrical and chemistry areas, whereas instrument and mechanical have slightly smaller inventor size.

Table 4.4 depicts the survival rate of resident patents at a different age. The renewal fee in India is relatively small as compared to many developed nations. Contrary to the common understanding, many patents (19.63%) are not renewed even with a meager renewal fee. A large proportion of patents drops out between 7 to 15 years of age. The early expiry of the patent in India could be appropriated to short technology life cycle and patents' low quality. In some areas, technologies are fast-changing, and therefore patents associated with those technologies become irrelevant for owners.

Among the technology category, instrument patents show higher jumps, followed by mechanical and electrical patents. Deng (2007a) finds that the average patent life is longer in Germany and the U.K compare to other countries such as Belgium and Austria. However, in Germany, only 70 percent of patents survive up to 10 years, and about 50 percent of patents lapsed by age 14. The median length of patent life in Austria and Belgium is 11 years. The average renewal period of Chinese patents ranging from 3.29 to 5.94 years, which is shorter than US, Japanese, and EU firms (4.31 to 9.06 years) (Zhang et al., 2014). However, in India average patent length is between 11 to 12 years, which is higher than Chinese patents and at par with many developed countries.

Table 4. 4: Technology-wise patent expiration at different age (in percentage)

	Total patent	3rd to 6th year	%age expired	7th to 10th year	%age expired	11th to 15th year	%age expired	16th to 19th year	%age expired
Electrical	3758	97	2.58	1064	28.31	1798	47.84	798	21.23
Instruments	8112	305	3.76	2521	31.08	3899	48.06	1387	17.10
Chemistry	1652	75	4.54	464	28.09	797	48.24	316	19.13
Mechanical	4542	201	4.43	1351	29.74	2204	48.52	786	17.31
'Otherfield'	801	50	6.24	257	32.08	372	46.44	122	15.23
Resident	4279	321	7.50	1374	32.11	2046	47.81	538	12.57
Non-resident	14585	407	2.79	4283	29.37	7024	48.16	2871	19.68
Institution	2019	42	2.08	475	23.53	1124	55.67	378	18.72
Individuals	1609	163	10.13	506	31.45	705	43.82	235	14.61
Firms	15236	523	3.43	4676	30.69	7241	47.53	2796	18.35

Source: Authors' calculation based on the information collected from IPO

4.8 Results and Discussion

4.8.1 Factors Influencing Patent Value

The estimated regression coefficients reported in this study account for the behavior of various characteristics (see Table 4.5). Please refer to equation (1) for the settings of the underlying regression model. All parameter estimates are significant at a 1% level of significance except 'otherfield'. These results confirm general findings of patent value indicators and their association with the patent value. A negative grant lag co-efficient indicates that a larger gap between the application date and grant date lessens the patent value. Delay in one year in the granting process reduces the value by 256 times. Many studies in the past on patent valuation have mentioned the negative association between grant lag and patent value (Harhoff and Wagner 2009; Régibeau and Rockett, 2010). The reason could be appropriated because the shorter commercial life of a patent with a high grant lag cannot generate many benefits to the inventors. The patented technology with longer commercial life will not be affected by long grant lag. However, during this "patent pending period" technology can be produced, sold, and advertised by copier until the patent is issued.

Therefore, a higher grant lag eventually reduces the possibility of a higher profit margin for the inventors (Hegde and Luo, 2018). The other side of the coin is that higher grant lag in some cases opens a big opportunity for the inventors when they can sue imitators and take over the market share of the infringing product. Since the imitator has already invested huge money on product development, they will have no option except to buy the original inventors' license. Such litigation disputes are rare in India, and therefore longer grant lag inversely affects the patent value instead of generating any gain to the inventors.

As the hypothesized number of claims, family size, technology scope, and inventor size positively affect patent value. One unit increase in the claim increases the value by 326 times. Similarly, family size increases 123 times, inventor size 89 times, and technology scope 74 times.

Table 4. 5: Maximum likelihood estimates of $\boldsymbol{\Omega} = (\boldsymbol{\beta}, \boldsymbol{\sigma}, \boldsymbol{d})$ obtained via Genetic Algorithm

Independent variable	Estimate $\boldsymbol{\beta}$
Claims	326.96***
	(13.59)
Family size	123.09***
	(12.50)
Inventor size	89.28***
	(8.77)
Grant lag	-256.77***
	(2.78)
Tech scope	74.60***
	(13.18)
Chemistry	184.83***
	(65.35)
Mechanical	447.30***
	(77.10)
Electrical	376.48***
	(70.89)
Otherfield	106.98
	(80.66)
Firms	179.41***
	(37.31)
Institutions	1062.37***
	(98.51)
Ownership	292.03***
	(43.02)
$\boldsymbol{\sigma}$	1311.71***
	(7.55)
$\boldsymbol{d}$	0.50***
	(0.00)
Constant	-516.41***
	(44.75)

Note: All values in parenthesis are standard error. # denotes dummy variable. p-values for all estimates are less than 10^{-6}, and hence significant at 1% level.

We find that electrical patents are 376 times more valuable and mechanical patents 447 times more valuable than instruments patents among the technology category. However, chemistry and ‘otherfield’ patents are found insignificant. This implies that chemistry and ‘otherfield’ patent compared to instrument patents have a lower value. This shows that an average patent value in the electrical and mechanical technology group is high, whereas in the case of ‘otherfield’, and chemical value is low compared to the base group. In India, the law did not allow product patents for the pharmaceutical sector during 1970-2005; hence, our sample consists of only process patents. Thus, the results are not surprising because worldwide process patents have lesser value than product patents.

We find the depreciation rate $d = 0.49$ which suggests that the expected value of patented technology in India depreciates at a much higher rate than such a technology in China (i.e., 24.28 (Gupeng and Xiangdong, 2012). Patented technology in India depreciates at a much higher rate than any other studies reported using the renewal framework. We found that technology depreciation rates cannot be fixed in 0.1 to 0.25 ranges as found in other studies while estimating. Our optimization results improved when we increased the upper boundaries of the depreciation rate. Fast depletion or short technology time cycle could be the reason for the higher depreciation rate in India.

4.8.2 Initial Returns by Different Technology Field and Ownership Group

We now discuss the trend and pattern in the predicted $r_i(0)$ values. Table 4.6 reports the mean and median values of initial returns for different technology fields on 2010 base prices.

On the line of previous research, we find that the value distribution of Indian patents is highly skewed. The patent expired between 3-6 years initial return is valued $2425 ($0.002 million). The initial return of patent expires between 7 to 10 years is $40273.13 ($0.040 million) (Table 4.7). Similarly, the patent expires between 11 to 15 and 16 to 20 years initial is reported $0.719 million and $9.931 million. This result confirms the hypothesis that initial return $R_i(0)$ of patent expired at the early stage have a lower value compared to patent renewed to full length. Hence, due to patents' heterogeneous nature, the simple patent count may lead to a biased result.

Table 4. 6: value of initial return across the expiration category of patent

Patent expired years	3 to 6	7 to 10	11 to 15	16 to 20
Mean of $r_i(0)$	0.002	0.040	0.719	9.931

Note: Authors' calculation, all values are in a million dollars (2010 price)

Tables 4.7 and 4.8 reports the distribution of initial returns by technology, assignee, and ownership category. The initial return of the patent value across the technology group is highly skewed; therefore, we support the argument that patent is not a good measure for innovation output. The highest mean value we observed for electrical patents followed by instruments and mechanical. This outcome contrasts with the most global studies in which pharmaceutical/chemistry innovation consistently ends up being profoundly representative of the protection system's value and reasonableness. A similar pattern has been observed for China by Gupeng and Xiangdong (2012).

Table 4. 7: Distribution of initial returns by technology categories [Mean of $r_i(0)$]

Quantile	Electrical	Instruments	Chemistry	Mechanical	'Otherfield'
1%	0.02	0.02	0.02	0.02	0.01
5%	0.02	0.02	0.02	0.02	0.01
10%	0.02	0.02	0.02	0.02	0.01
25%	0.07	0.07	0.07	0.07	0.06
50%	0.52	0.38	0.36	0.36	0.32
75%	1.35	1.08	0.96	0.96	0.86
90%	7.71	7.06	7.04	7.23	4.69
95%	7.71	7.06	7.04	7.23	4.69
99%	7.71	7.06	7.04	7.23	4.69
Mean	1.54	1.25	1.20	1.23	0.90
Std.Dev	2.51	2.26	2.25	2.32	1.50

Note: Technology categories are from WIPO-technology classification (2008). All monetary values are in units of million US. dollars in the year 2010 value.

The initial distribution of returns for different assignee categories reveals that patent value differs across the assignee and ownership categories. Similar to the technology patent distribution, assignee and ownership category patents are skewed. The mean value of institutions' patents is more significant than firms' and individuals' patents. This implies that academic patents are more productive compared to firms and individual patents.

Further, patent value estimation in India suggests that the patent value of local Indian owners (resident) is generally lower than the patent values of foreign owners (non-resident). This reflects the different strategies of resident patentees compared to a non-resident patentee in India. Local patentees are more active in patenting according to frequent local policy demands than owners from other advanced countries.

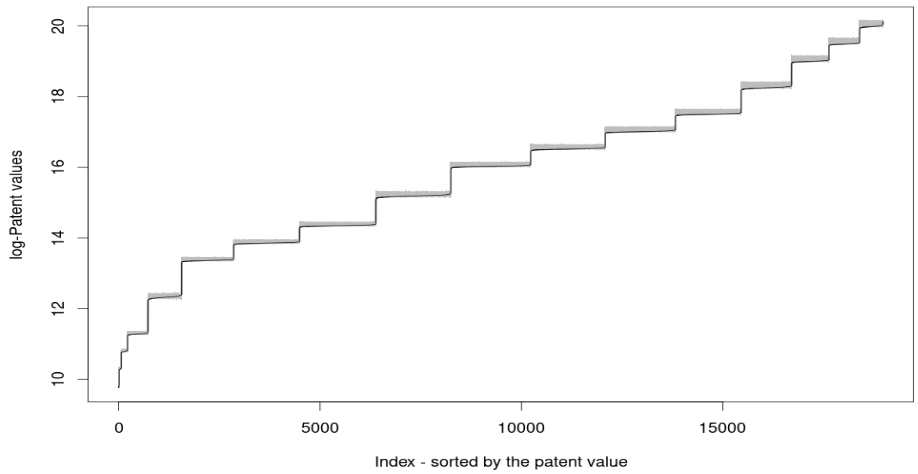
Table 4. 8: Distribution of initial returns by assignee categories and ownership status [Mean of $r_i\,(0)$]

Quantile	Individuals	Institution	Firms	Resident	Non-resident
1%	0.00	0.04	0.02	0.01	0.02
5%	0.00	0.04	0.02	0.01	0.02
10%	0.00	0.04	0.02	0.01	0.02
25%	0.04	0.15	0.07	0.06	0.07
50%	0.16	0.55	0.37	0.33	0.40
75%	0.63	1.13	1.00	0.85	1.09
90%	3.70	7.40	7.32	3.45	7.43
95%	3.70	7.40	7.32	3.45	7.43
99%	3.70	7.40	7.32	3.45	7.43
Mean	0.72	1.41	1.26	0.76	1.33
Std.Dev	1.21	2.34	2.34	1.12	2.39

Note: All monetary values are in units of million US. dollars in the year 2010 value.

Figure 4.1 shows the upward trend of the initial return for the complete sample. Patents that are never renewed have more or less similar value. The value of the patent shows upward with the increase in renewal age. The value differences among the patents can be observed in the trend line.

Figure 4. 1: Distribution of estimated initial return $r_i(0)$] of the full sample with age.



4.8.3 Estimation of Net Present Value

The net present value of a patent is estimated by discounting net returns at a 10 percent discount rate to compare with earlier studies. Table 4.10 reports the distribution of net present value (NPV) of patents at the constant 2010 constant price. As per the ownership category, non-resident patents have a larger NPV (4.60 million dollars) compared to resident patents (3.04 million dollars). Among assignee categories, institutions patents have a greater mean NPV, followed by firms' and individuals' patents. For easy comparison with developed countries studies, we have converted NPV to 2010 dollar. At 25 percent, the Finnish patent's overall value is reported to 326 euros (value expressed in the year 2000 Euro). On the other hand, our study on Indian patents observes 0.12 million dollars, i.e., 1,20,000 US dollars (value expressed in 2010 US. dollar) value of all patents at 25 percent quantile (see Table 4.9).

The estimated value of expired patents for different technology groups and ownership status, conditional on ε_i from equation Much lower value of resident patents may imply a strongly different point of view of local patent owners, with less powerful invention on potential market competition and more active willingness for innovative performance according to frequent local policy demands than owners from other advanced countries.

Table 4. 9: Distribution of paten discounted value of patent right by ownership status

Quantile	**Individuals**	**Institution**	**Firms**	**non-resident**	**Resident**
1%	0.01	0.07	0.04	0.05	0.02
5%	0.01	0.07	0.04	0.05	0.02
10%	0.01	0.07	0.04	0.05	0.02
25%	0.09	0.31	0.13	0.14	0.12
50%	0.33	1.07	0.73	0.80	0.64
75%	1.26	2.26	1.99	2.18	1.66
90%	7.42	14.80	14.60	14.90	6.90
95%	7.42	14.80	14.60	14.90	6.90
99%	7.42	14.80	14.60	14.90	6.90
Mean	1.44	2.79	2.51	2.64	1.50
Std.Dev	2.42	4.68	4.69	4.76	2.23

Note: Table 10 reports the distribution of Indian patents for residents and non-resident. All monetary values are in units of million US dollars in the year 2010 value

Table 4.10 presents the quantile distribution of patent value among different technology. The mean value of NPV is smaller for the 'otherfield' followed by chemistry though the difference is moderate. We have observed that electrical patents' mean value is highest among all technology fields, followed by instruments technology patents. The largest half of the value belongs to the upper quantile. It implies the distribution of the patent value is highly skewed, i.e., only a small number of patents have a higher value, whereas a large number of the patent have a minimal value.

Table 4. 10: Distribution of the discounted lifetime value of patent right

Quantile	Electrical	Instruments	Chemistry	Mechanical	'Otherfield'
1%	0.05	0.04	0.04	0.04	0.02
5%	0.05	0.04	0.04	0.04	0.02
10%	0.05	0.04	0.04	0.04	0.02
25%	0.15	0.14	0.13	0.13	0.12
50%	1.00	0.77	0.71	0.71	0.61
75%	2.59	2.15	1.92	1.92	1.66
90%	15.40	14.10	14.10	14.50	9.03
95%	15.40	14.10	14.10	14.50	9.03
99%	15.40	14.10	14.10	14.50	9.03
Mean	3.05	2.50	2.40	2.47	1.74
Std.Dev	5.04	4.52	4.50	4.63	2.90

Note: Table 10 reports the simulated value distribution of Indian patents, for each technology field group. All monetary values are in units of million US dollars in year 2010 value.

The results obtained in this study give the lower bound of the private value of a granted patent in India. The lower bound private value of patent could be appropriated for several reasons. First, this study has only used patents assigned to India by IPO. Second, we have accounted only for renewal costs, not an application, drafting, and attorney costs, as does Putnam (1996). Therefore, the estimated value of the patent does not reflect the total patent protection. Third, the cost of enforcement has not been included here as Lanjouw (1998). Hence, the estimated private value is again a lower bound of the real value. Fourth, we assume that renewal for each patent is independent of others, and hence the strategic value of a patent is ignored. Fifth, as Pakes (1986) discusses in patent renewals' stochastic model, we do not allow for learning. In a similar study, Granqvist (2009) finds that Finnish patents' value distribution is skewed.

4.8.4 Uncertainty Analysis

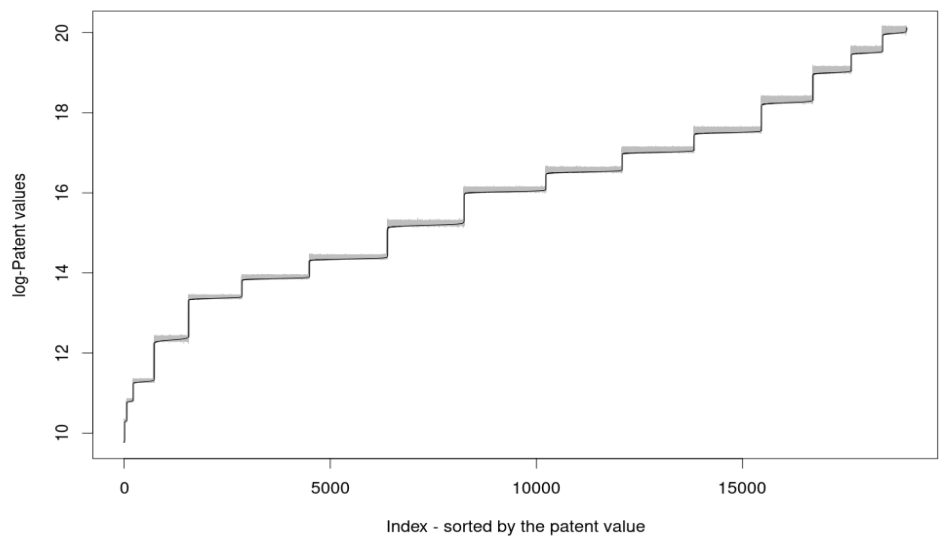
Thus far, we have first estimated the parameters $\Omega = (\sigma, \mathrm{d}, \boldsymbol{\beta})$ by taking the median value of the best 200 candidates from the Genetic Algorithm, and then used $\hat{\sigma}, \hat{\mathrm{d}}$ and $\hat{\boldsymbol{\beta}}$ to determine $\log(\mathrm{r_i}(0))$ for the i-th patent via Monte Carlo simulations. This approach does not account for the uncertainty in the parameter estimation process. As a result, we propose a slight modification in the estimation of $r_i(0)$.

The main idea is to use all 200 good Ω_k's (obtained from the final generation of GA) for predicting 200 realizations of $r_i(0)$ and then find the average (or median) of $r_i(0)$ as the predicted return for the i-th patent. That is,

$$\log\left(\hat{r}_i(0)\right) = \frac{1}{200}\sum_{k=1}^{200} \log\left(\hat{r}_i\left(0 \mid \widehat{\Omega}_k\right)\right).$$

This approach not only leads to a more robust estimate of $r_i(0)$, but also yield the uncertainty estimate of the patent value prediction. Figure 4.2 presents 200 realizations of $r_i(0)$ for all patents considered in this chapter. The patent value prediction for the median parameter estimates is also overlaid for reference. It appears that the predicted patent values over 200 realizations of $\widehat{\Omega}_k$ are very similar. It is perhaps not a surprise that the uncertainty is higher if the predicted patent value is either too high or too small. It is reassuring to see that the predicted patent values are not very sensitive to the estimated parameters and hence consistent with the conventional approach of estimating patent values. It is important to emphasize however that this proposed approach will give more comprehensive interval estimates.

Figure 4. 2: Sensitivity index line: Solid black line shows initial returns and the grey line represents predicted value over 200 realizations



4.9 Comparative Analysis

This study enables us to compare our patent value with the estimates in the existing literature around the globe (see Table 4.11). A few remarks about Indian patents are as follows: First, even at a minimum renewal fee, many patents cease or lapse at an early age. This implies that the patentee decides about the renewal life in its initial few years. Several studies conducted on US data reported similar results.

The present study reports a higher mean value for both technology and ownership categories. The mean net present value of foreign organizations in the US (Bessen, 2008) is 2.905 million on the $1992 price. Whereas, in India net present value of the non-resident patents is reported as 1.33 million dollars (base price 2010). Unlike the Indian chemical and pharmaceutical sector, US chemical sector performs way better. Indian chemical patent values are relatively lower than other sector patents due to processing patenting.

Table 4. 11: Patent value comparison by different studies

Study	Sample years	Sample country	Patent group	Patent value Mean ($M)
Barney (2002)	1986	US	All	$0.061
Serrano (2005)	1983–2002	US	Small business patentees	$0.047
Putnam (1996)	1974	US	Also filed abroad	$0.188
			All (imputed)	$0.078
Gupeng and Xiangdong (2012)	1985-2007	China	US patents in CNIPA	$0.04 to $ 2.00
			China domestic patents	$0.005 to $0.022
Bessen (2008)	1991	US	All US patentees	$0.078
	1985–1991	US	US public firms, manufacturing	$0.113
This study	**1996-2005**	**IN**	**Residential patents**	**$0.76**
			Non-resident patents	**$1.33**

Note: All monetary values are in a million US dollars.

4.10 Conclusion

A patent's value can be revealed based on its owner's assessment of patent cost and benefits. Many studies in the past hypothesized that a renewal fee creates a recurring investment. Therefore, it is expensive for the patent holder to keep a patent in force until its statutory life limit, particularly when the renewal fee is increasing in nature (Baudry and Dumont, 2006). However, the renewal model's criticism is that it measures the patent value from the patentees' point of view. Further, such valuation excludes other incidental expenses such as attorney costs, internal company costs, and therefore the value of patents is likely to be underestimated (Pitkethly, 1997).

Our empirical analysis suggests several implications about patent valuation practices. The results provide an interesting finding of the Indian patents' competitiveness across the technology. We also compare with other existing literature on patent valuation (US and China). In line with other studies, we observe similar patent and inventor characteristics (family size, technological scope, inventor size, and grant lag) on the patent's initial return (Granqvist, 2009). However, in the technology field, we find chemistry and pharmaceutical less valuable compared to electrical, instruments, and mechanical patents. The average survival rate of Indian patents (12.17 excluding patent never renewed) is greater than Chinese patents (4.36) and at par with many developed countries. It implies that the quality of R&D in India or any developing nation for that matter is not sufficiently large. Therefore, the outcome of the R&D that is patent does not generate a significant return for the firms.

The other important findings are about the average monetary value of the patent in different technology. We find that electrical, mechanical, and instruments patents are more valuable than those in India's chemical and pharmaceutical sectors. To some extent, this particular result contradicts the common understanding of patent valuation conducted in developed economies. The result implies that some technologies are more valuable in terms of domestic market demand. In India, before 2005, amendments to product patents were not allowed. Therefore, the value of process patents is lesser in comparison to other technology. (Gupeng and Xiangdong, 2012) also found similar results for Chinese patents where electrical engineering and mechanical engineering patents value higher than those in the chemical and pharmaceutical sector. Moreover, this study finds that mean NPV is higher for institutions patents ($2.79 million), followed by firms' ($2.51 million) and individuals ($1.44 million) category patents.

Thus, this result is important from the policy standpoint to understand the differential R&D preferences and market nature. Other findings of this study reflect that the distribution of patent value is highly asymmetric across technology and ownership group. Large numbers of patents are less valuable, and only a few patents hold high value. The study also finds that the mean patent value increases with an additional renewal year and other patent characteristics.

Chapter 5

Capturing the Future Value of Patent through Renewal Model for different Assignee, Ownership, and Technology Category in India

5.1 Introduction

Previous chapters established the heterogeneous nature of patents' value that differ significantly among technological fields, and ownership categories. In Chapter 4, we estimated monetary value of the expired patents that is extend to enforced patents in the current essay. Although, expired patents can be used as the best indicator of the value of patents with varied term length, valuation of enforced patents is relevant for updated technology market.

Most studies estimate patent value of the expired patents or patents whose term is over, but they overlook the patents that are currently in effect. Enforced patents are more relevant to understand the recent technological developments. Some studies discuss both expired and unexpired patents, such as the work of Maurseth (2005), Svensson (2007), Nakata and Zhang (2012), and Xie and Giles (2011). However, these studies do not estimate the monetary value of patent but focus on possible patent length determinants such as patent citation, nature of commercialization of patent, number and type of applicants, and patenting source country. Nevertheless, these studies are an important reference for the valuation studies to choose the corresponding influencing factors.

The present study focuses on the Indian patents (resident and non-resident) filed at IPO by developing and build on patent renewal model used by Bessen (2008). This study estimates patent value for both expired and unexpired in India by technology, ownership group, assignee category. We include expired along with enforced patents to increase the sample size as the small number of enforced patents may cause bias in the estimation (Davidson and MacKinnon, 2004; Cameron and Trivedi, 2005). Unlike previous studies on patent valuation, this essay considers all three possibilities, i.e., a patent completes full term, a patent expires (not renewed) between 2 to 19 years, and a patent is enforced.

The rest of the essay is organized as follows: Section 5.2 discusses the important literature, and section 5.3 explains data. Section 5.4 discusses the renewal model. Section 5.5 presents the estimated results for parameters. Subsection 5.5 also presents the estimated value of initial returns and net present value tables. Lastly, section 5.6 sums up the results.

5.2 The Literature on Patent Valuation

Andersen and Co. (1992) published a report on the valuation of intangible assets that categorized valuation methods into cost value, market value, and economic value methods. The categorization of the patent valuation method is not sufficiently comprehensive because even the most sophisticated methods cannot account for all the factors. Therefore, it needs to be understood that any valuation method is just the starting point or help towards better decision making.

The mainstream econometric works look at patent value from the patentee’s perspective using renewal data to estimate the patent worth. The patentee's viewpoint about their patent's potential is closest among all other economic agents involved with the technology later. However, some inherent biases stick to the renewal data-based model. Usually, the renewal data-based model estimates patent value in aggregate and retrospectively (Pakes and Schankerman, 1984). The renewal data-based model only considers the renewal fee and excludes incidental expenses that might bias results (Pikthely, 1997). To what extent these biases can be eliminated is not very clear. However, methodological advancement has brought significant changes in the valuation process (Gupeng and Xiangdong, 2012).

Schankerman and Pakes (1986) move from the deterministic model of patent valuation to the option-based model. In this work, in addition to the consideration if the returns from a patent exceeded the renewal cost, the authors included the option of paying the renewal fee. The study uses the renewal data from the UK, France, and Germany patents to estimate the model parameters. The study calculates the distribution of the value of patents using a Markov process while assuming that the initial returns have a lognormal distribution.

Schankerman and Pakes (1986) begins with the general observation that patents are real options, which means that the patent confers rights, no obligation to make further investment, renewal for an additional year, or to commercialize its knowledge. Several studies are focusing on the patent maintenance fee or whether paying renewal fees or deciding to let it lapse indicates the patent value (Cornelli and Schankerman, 1999). In this case, the patentee will have the option of whether to pay the renewal fee and keep it enforceable or discontinue the maintenance fee and let the patent lapsed. The decision to purchase or not purchase this option, in conjunction with the option's cost (renewal fees), reveals the patent value at the time of the option’s purchase (Scotchmer, 1999).

After reviewing major research papers in the field, we have observed here that there is a gap in the valuation method that can be filled if the right approach is adopted. There are some questions regarding patent valuation that are still not been answered in the earlier studies. For example, the valuation of enforced patents is still out of focus. Most of the studies estimate value for aggregate patent or patent cohort; however, estimating individuals patent value using retrospective and future information may serve the biggest purpose in the valuation field. The objective of this study is to estimate the individual patent’s value using more advanced techniques. This study also estimates enforced patent value, which might help organizations to evaluate their innovative capital in the beginning. It also helps budding entrepreneurs and start-ups to negotiate the deal based on their true IP value. This study will determine the patent's present forward value by predicting the likelihood that a patent will be maintained until its maximum expiration date.

5.3 Data

This study collects granted patent data applied between 1996 to 2005 at IPO for all IPC technological categories. It includes both expired (lapsed or completed 20 years of life) and unexpired (enforced) patent information. Further, patent data is categorized into resident and non-resident to estimate separate values for both categories. We have used IPC 4-digit technological classification to assign technology categories following WIPO 2008 technological classification documents. After processing and cleaning the data, we reach 27084 observations. The study assumes that patents are heterogeneous. Therefore, a patent filed by firms and individuals may not have similar value characteristics. Thus, we do further categorization of patents into individuals, institutions, and firms. The age of the patent is calculated to begin in the years of application. Table 5.1 presents the details of the data employed.

Table 5. 1: Data description

Total number of patents	27084
Application year	1995-2005
Granted	1997-2018
Type of technologies	Electrical, Chemistry, Instrument, Mechanical, and Otherfield
Assignee category	Individual owned patents, Institution owned patents, Firms owned patents
Censored patents	8191
Estimated Kaplan-Meier age	11.34 years

Detailed information on patent value characteristics is obtained from the PatSeer. However, the renewal information is collected from the IPO website by searching for each patent. The patent value characteristic includes several family sizes (patent filed in several jurisdictions), claims, grant lag (time elapsed between filing and grant date), inventor size, and technology scope (a patent belongs to several sub technological class) (Bessen, 2008; Gupeng and Xiangdong, 2012). Table 5.2 shows the description of patent characteristics used for the estimation of parameters.

Table 5. 2: Description of patent characteristics for both enforced and expired patents

	Expired patents		**Enforced patents**	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Renewal year	12.21	3.38	14.99	1.61
Number of Claims	12.75	9.95	13.95	10.76
Inventor size	2.50	1.66	2.68	1.74
Family Size	12.85	10.32	12.97	10.03
Technology Scope	6.21	5.78	7.17	6.11
Grant lag#	6.67	2.41	6.24	2.10

Note: #Year

5.4 Methodology

Here, we will be discussing the renewal model under the assumption that we have two types of patent renewal data (a) fully observed till expiry or maturity and (b) partially observed - still in-force/active on the date of data collection.

5.4.1 Renewal Model for unexpired patents

We make two key assumptions about the profit flow of patents. First, the returns of patents, $r_i(t)$, depreciate at a fixed rate. Though stochastically varying depreciation rate-based model may appear to be more flexible, Bessen (2008) demonstrates that model based on the constant depreciation rate leading to similar results as the models using variable depreciation rate. That is,

$$r_i(t) = r_i(0)e^{-dt},$$

where d is a fixed (unknown) depreciation rate, and $r_i(0)$ is the initial return at the time of application / filing the patent. The annual renewal fee c_{it} is also assumed to depend only on time t and not the patent characteristics. Following Bessen (2008), we further modelled the present value of profits from t to $t + T$ (here, $T = 1$ annual renewal cycle) as,

$$r_i(0)z_t = \int_t^{t+1} r_i(\tau)e^{-s(\tau-t)}\, d\tau,$$

where,

$$z_t = e^{-dt}\left(\frac{1 - e^{-(d+s)}}{d + s}\right),$$

The discount rate s is different from the technological depreciation or decay rate d. Following (Bessen, 2008), we assume that an expected return to patent value depreciates at a constant rate.

In this study, s is fixed at 0.1[9].

The second key assumption is that the initial return is lognormally distributed. Let X_i denote the vector of characteristics for the i-th patent. Then,

$$\ln\big(r_i(0)\big) = \boldsymbol{\beta} \cdot X_i + \varepsilon_i, \qquad (1)$$

where ε_i is independent and identically distributed (iid) normal variables with mean zero and (unknown) variance σ^2. To model the initial returns of a patent, this study uses five patent characteristics, which include a number of claims, size of the patent family (family size), number of inventors associated with that invention (inventor size), technological breadth (technology scope) and grant lag. Along with these four different factors that determine the patent value, we have included the technology field (chemical, electrical, mechanical, and instrument), assignee category

[9] Discount rate is fixed at 10% to make comparison with previous studies.

(individuals, institutions, and firms), and ownership category (resident and non-resident) dummies in the equation. These variables have been used in essay 3 and the justification is given there.

The most crucial part of the renewal model is to formulate the decision criterion for deciding whether or not a patent should be renewed at time t. Following Bessen (2008), the necessary and sufficient condition for a renewal of the i-th patent at time t is

$$\ln\left(r_i(0)\right) \geq \ln\left(\frac{c_{it}}{Z_t}\right).$$

Let T_i be the expiry age of the i-th patent. As per the IPO rules, the first decision has to be made at the end of the second year (after filing the patent), and the last renewal decision (if the patent is renewed until its maturity) is made at the end of the 19-th year.

We have tabulated the life of a patent data as T_i, which takes values between 0 and 20. The values can arise in four different scenarios:

(d) $[T_i = 0]$ The patent is never renewed. The i-th patent is never renewed if and only if the value of the patent at the end of the second year is less than the renewal cost, i.e.,

$$\log\left(r_i(0)\right) \leq \log\left(\frac{c_{i2}}{z_2}\right).$$

Following the log-normal distribution, the probability of this event can be computed by

$$P[T_i = 0] = P\left[\log\left(r_i(0)\right) \leq \log\left(\frac{c_{i2}}{z_2}\right)\right]$$
$$= \Phi\left(\frac{\log\left(\frac{c_{i2}}{z_2}\right) - \boldsymbol{\beta} \cdot X_i}{\sigma}\right), \qquad (2)$$

where Φ is the standard normal cumulative distribution function (CDF).

(e) $[\mathrm{T_i} = 20]$ The i-th patent is renewed until maturity. It is sufficient to say that this event can occur only if the i-th patent was renewed at $\mathrm{t} = 19$, i.e.,

$$\log\left(\mathrm{r_i}(0)\right) \geq \log\left(\frac{\mathrm{c_{i,19}}}{\mathrm{z_{19}}}\right),$$

with probability

$$\begin{aligned}\mathrm{P}[\mathrm{T_i} = 20] = {} & \mathrm{P}\left[\log\left(\mathrm{r_i}(0)\right) \geq \log\left(\frac{\mathrm{c_{i,19}}}{\mathrm{z_{19}}}\right)\right] \\ = {} & 1 - \Phi\left(\frac{\log\left(\frac{\mathrm{c_{i,19}}}{\mathrm{z_{19}}}\right) - \boldsymbol{\beta} \cdot \mathrm{X_i}}{\sigma}\right) \quad (3)\end{aligned}$$

(f) $[3 \leq \mathrm{T_i} \leq 19]$ We have complete data on the i-th patent, and it expires prematurely. In other words, the i-th patent was renewed at $T_i = \mathrm{t} - 1$, but expired at $\mathrm{T_i} = \mathrm{t}$, i.e.,

$$[\mathrm{T_i} = \mathrm{t}] = \left[\log\left(\mathrm{r_i}(0)\right) \geq \log\left(\frac{\mathrm{c_{i,t-1}}}{\mathrm{z_{t-1}}}\right)\right] \cap \left[\log\left(\mathrm{r_i}(0)\right) \leq \log\left(\frac{\mathrm{c_{it}}}{\mathrm{z_t}}\right)\right],$$

with probability

$$\begin{aligned}\mathrm{P}[\mathrm{T_i} = \mathrm{t}] = {} & \mathrm{P}\left[\log\left(\frac{\mathrm{c_{i,t-1}}}{\mathrm{z_{t-1}}}\right) \leq \log\left(\mathrm{r_i}(0)\right) \leq \log\left(\frac{\mathrm{c_{it}}}{\mathrm{z_t}}\right)\right] \\ = {} & \Phi\left(\frac{\log\left(\frac{\mathrm{c_{it}}}{\mathrm{z_t}}\right) - \boldsymbol{\beta} \cdot \mathrm{X_i}}{\sigma}\right) \\ & - \Phi\left(\frac{\log\left(\frac{\mathrm{c_{i,t-1}}}{\mathrm{z_{t-1}}}\right) - \boldsymbol{\beta} \cdot \mathrm{X_i}}{\sigma}\right). \quad (4)\end{aligned}$$

(g) $[13 \leq \mathrm{T_i} \leq 19]$ We have several patents that were filed and granted between 1999 and 2005. Many of these patents were still active (in-force till the date of data collection, i.e., December 2018) and have not completed 20-year span (since the filing date) to know whether they will expire prematurely or survive until maturity. Thus, we can only say that the i-th patent is renewed at: $[\mathrm{T_i} = \mathrm{t}]$ (as per the data collection date), i.e.,

$$\log\left(\mathrm{r_i}(0)\right) \geq \log\left(\frac{\mathrm{c_{i,t}}}{\mathrm{z_t}}\right),$$

with probability

$$\begin{aligned} \mathrm{P}[\mathrm{T_i} = \mathrm{t}] = {} & \mathrm{P}\left[\log\left(\mathrm{r_i}(0)\right) \geq \log\left(\frac{\mathrm{c_{i,t}}}{\mathrm{z_t}}\right)\right] \\ & = 1 - \Phi\left(\frac{\log\left(\frac{\mathrm{c_{i,t}}}{\mathrm{z_t}}\right) - \boldsymbol{\beta}\cdot \mathrm{X_i}}{\sigma}\right) \quad (5) \end{aligned}$$

That is, for $3 \leq t \leq 12$, $\mathrm{P}[\mathrm{T_i} = \mathrm{t}]$ is given by Equation (4), whereas for $13 \leq t \leq 19$,

$$\begin{aligned} \mathrm{P}[\mathrm{T_i} = \mathrm{t}] = {} & \left[1 - \Phi\left(\frac{\log\left(\frac{\mathrm{c_{i,t}}}{\mathrm{z_t}}\right) - \boldsymbol{\beta}\cdot \mathrm{X_i}}{\sigma}\right)\right]^{(Inforce=YES)} \\ & * \left[\Phi\left(\frac{\log\left(\frac{\mathrm{c_{it}}}{\mathrm{z_t}}\right) - \boldsymbol{\beta}\cdot \mathrm{X_i}}{\sigma}\right)\right. \\ & \left. - \Phi\left(\frac{\log\left(\frac{\mathrm{c_{i,t-1}}}{\mathrm{z_{t-1}}}\right) - \boldsymbol{\beta}\cdot \mathrm{X_i}}{\sigma}\right)\right]^{(Inforce=NO)} \end{aligned}$$

These probabilities are not computable as the model parameters $\Omega = (\sigma, \mathrm{d}, \boldsymbol{\beta})$ are unknown. Thus, we use the data on expiry age $(\mathrm{T_i})$ and different characteristics $(\mathrm{X_i})$ to estimate the model parameters, which are then used to simulate the initial patent value $\mathrm{r_i}(0)$.

5.4.2 Parameter Estimation

Assuming $\boldsymbol{\beta}$ is an 18-dimensional vector of regression coefficients, we estimate 15 coefficients (one category each from technology group, assignee group, and the ownership group is omitted to avoid dummy trap). We follow the maximum likelihood approach for estimating the model parameters $\Omega = (\sigma, d, \boldsymbol{\beta})$. For the data on n patents, the likelihood based on the distribution of T_i, presented in Equations (2) - (4), is given by

$$L(T_1, T_2, \ldots, T_n\,; \Omega) = \prod_{i=1}^{n} P(T_i = t_i). \tag{5}$$

Unfortunately, none of the parameter estimates can be found in a closed analytical form. Thus, a numerical optimization approach has to be used for estimating the parameters.

We follow an evolutionary optimization technique called the Genetic Algorithm (GA) (Holland, 1975) for finding the maximum likelihood estimates (MLE) of $\Omega = (\sigma, d, \boldsymbol{\beta})$.

The search space for the parameter is defined by $d \in (0.1, 0.5)$, $\sigma > 0$, $\beta_{\text{grant-lag}} < 0$, $\beta_{\text{technology-scope}} > 0, \beta_{\text{family-size}} > 0,$ and $\beta_{\text{inventor-size}} > 0$, $\beta_{\text{claims-size}} > 0$, whereas the other β coefficients were allowed to take any value in the real line[10]. The GA starts by selecting a random initial population (of the candidate Ω vectors) of size N_1 in the specified search space. Then, in the first generation, all individuals of this initial population were subjected to crossover and mutation steps. At the end, the fitness function (i.e., the likelihood) was computed and the best N_1 solution out of $3N_1$ candidates were retained for the second generation of the genetic evolution. In this chapter, we used $N_1 = 10{,}000$ and number of generations equal to 20 for estimating the parameters. Furthermore, we

[10] The detailed reasons and literature support for the direction of variables are given in section 4.2.

adopted the multi-start approach to reduce the initial population's dependency and find robust estimates of Ω.

The final estimates of Ω were taken as the median of the best 200 solutions from the last generation of the GA process (see annexure II). The standard errors of these 200 solutions were used to quantify the uncertainty and sensitivity of the parameter estimates.

5.4.3 Simulation of the Patent Values

Using the parameter estimates $(\hat{\sigma}, \hat{d}, \hat{\boldsymbol{\beta}})$, we estimate the bounds for each patent value conditional on corresponding renewal decisions made by the patentee. Using Monte Carlo simulations, we estimate the initial return $r_i(0)$ of the patent, thus $r_i(t)$ value is calculated using fixed depreciation rate as demonstrated in studies by (Bessen, 2008; Maurseth, 2005; Gupeng and Xiangdong 2012).

The bounds on ε_i for the i-th patent, conditional on the observed renewal decision can be deduced separately for the three cases as listed in Section 3.1.

(d) The patent expires at the end of the second year (i.e., patent is never renewed)

$$\varepsilon_i \leq \ln\left(\frac{c_{i2}}{Z_{2(\hat{d})}}\right) - \hat{\beta}X_i. \tag{6}$$

(e) Patent expires prematurely (i.e., at $t = 3,4, \dots ,19$),

$$\ln\left(\frac{c_{i,t-1}}{Z_{t-1(\hat{d})}}\right) - \hat{\beta}X_i \leq \varepsilon_i \leq \ln\left(\frac{c_{it}}{Z_{t(\hat{d})}}\right) - \hat{\beta}X_i. \tag{7}$$

(f) Patent matures at 20th year from the date of filling

$$\ln\left(\frac{c_{i,19}}{Z_{19(\hat{d})}}\right) - \hat{\beta}X_i \leq \varepsilon_i. \tag{8}$$

(g) Patent still in-force at $t \in \{13, 14, \dots, 19\}$

$$\ln\left(\frac{c_{i,t}}{Z_{t(\hat{d})}}\right) - \hat{\beta}X_i \leq \varepsilon_i. \tag{9}$$

For every observation of the Monte Carlo iteration, we select ε_i as a random draw from the log-normal distribution of Equation (1) determined by $\hat{\boldsymbol{\beta}}$, $\hat{\sigma}$ and $\hat{d}$. The Monte Carlo simulations were repeated many times(10^6) to ensure that we had sufficient number of observations for estimating each patent value. The estimates of $r_i(t) = r_i(0)e^{-\hat{d}t}$ can also be used to find the present value of all expired patents at time t,

$$V(T) = \sum_{t=1}^{T} r_i(t) - c_{it}(1+i)^{-t}, \tag{9}$$

Where, $r_i(t)$ and c_{it} denotes return and renewal cost of patent i at time t, respectively. Whereas s denotes the annual discount rate of 10%.

5.5 Results

5.5.1 Descriptive Statistics

First, we present the patent renewal distribution by technology, ownership, and assignee category (Table 5.3). The correlation matrix, along with the descriptive statics, is presented in Table 5.4. The patent expiration pattern reveals that a smaller number of patents expires at the beginning across the group. The maximum number of patents lapse during 11th to 15th year. The patent obsolete on average in 11th year of patent life in India. The largest share of patent belongs to chemistry (43.24%) followed by mechanical (24.16%), electrical (19.99%), instruments (8.36%), and ‘otherfield’ (4.25%).

Table 5. 3: Distribution of patent lapse at different stages of renewal life

Group	Total	3rd to 6th	7th to 10th	11th to 15th	16th to 19th	Patent share
Individual owned	1605	9.907	31.402	43.863	14.829	8.50
Institution owned	2025	2.074	23.457	55.457	19.012	10.72
Firms owned	15263	3.374	30.433	47.271	18.922	80.79
Electrical	3776	2.569	28.178	47.617	21.637	19.99
Instrument	1580	3.987	27.278	48.734	20.000	8.36
Chemistry	8170	3.733	30.857	47.711	17.699	43.24
Mechanical	4564	4.404	29.601	48.291	17.704	24.16
Otherfield	803	6.227	32.005	46.326	15.442	4.25
Non-resident	14638	2.760	29.136	47.855	20.249	77.48
Resident	4255	7.333	31.939	47.873	12.855	22.52

Note: Author's calculation based on information collected from IPO

The correlation matrix presented here show no sign of multicollinearity. The VIF (variance inflated method) is used to calculate the correlation matrix. The VIF score for all exogenous variables is below 10.

Table 5. 4: Correlation matrix

Variable	VIF	1/VIF
Chemistry	6.78	0.147396
Mechanical	5.21	0.192103
Electrical	5	0.19992
Instruments	2.82	0.354977
Firms	2.4	0.417504
Individuals	1.9	0.525457
Ownership	1.71	0.586377
Technology scope	1.34	0.743958
Family size	1.16	0.861527
Inventor size	1.1	0.906387
Number of claims	1.1	0.912179
Grant lag	1.05	0.952402
Mean	2.63	

We have further applied the exploratory data analysis to identify the patterns of important variables across the patent categories. There are several statistical techniques available to identify this pattern. One of these techniques is the "box plot," which is used to summarize and compare groups of data visually. The box plot in the form of a summary of a given dataset which includes, the median, the interquartile range.

The first set of figures presents patent characteristics across the assignee and ownership category. Figure 5.1 and 5.2 display the distribution of a number of claims by ownership (resident and non-resident) and assignee group (firms. individuals, and institutions). The highest median claims were observed for non-resident patents across the assignee and technology group. If we delimit the information, we find that institution patents (in the non-resident category) and firms (in the resident category) have the highest claims among assignee categories. Whereas in the technology category, electrical patents have the highest claims in both resident and non-resident categories.

Figure 5. 1: Patent claims by resident and non-resident patent across assignee categories

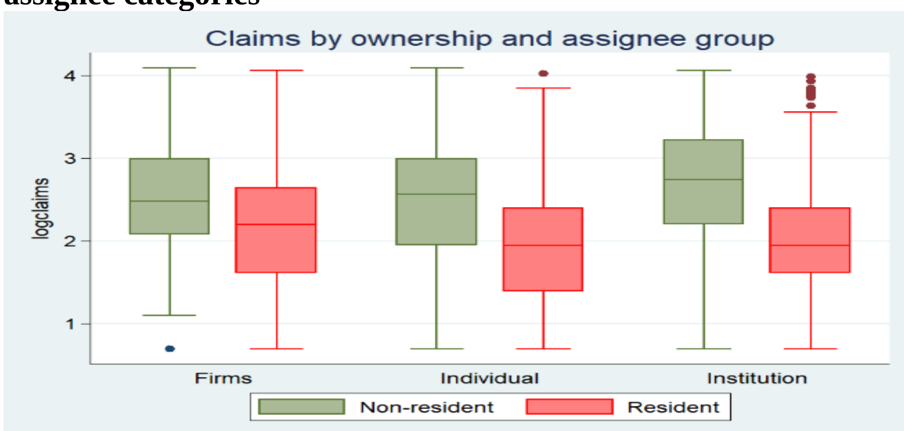


Figure 5. 2: Patent claims by resident and non-resident patent across technology categories

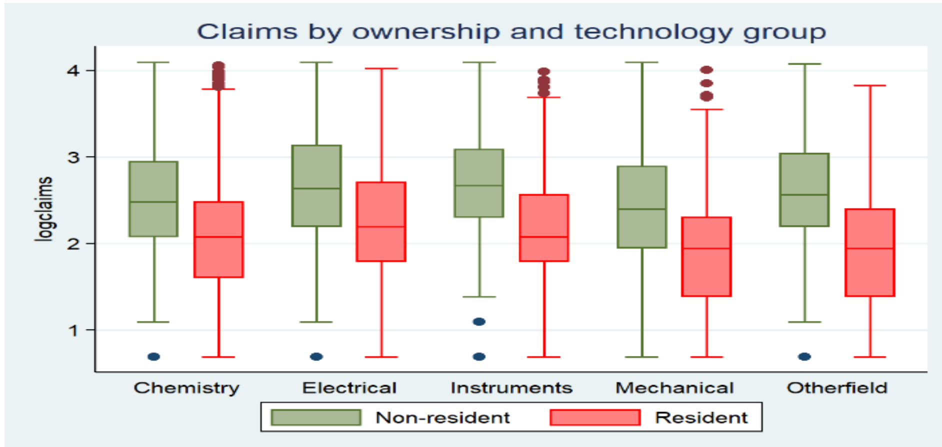


Figure 5.3 and 5.4 display patent family size by resident and non-resident and assignee categories. Each box-plot is divided into four quantiles. Inside the box present interquartile range. Median family size of non-resident patents highest across the assignee and technology categories. The result displays several interesting patterns. We see the number of family size is highest for institution patents followed by firms and institutions. In the technology category highest median is observed for electrical in both resident and non-resident category of patents.

Figure 5. 3: Family size by resident and non-resident and assignee categories

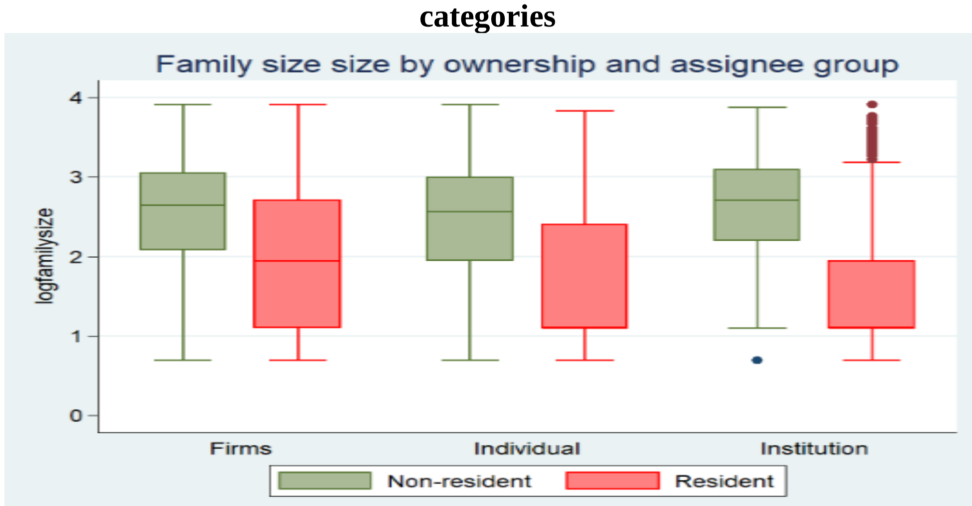
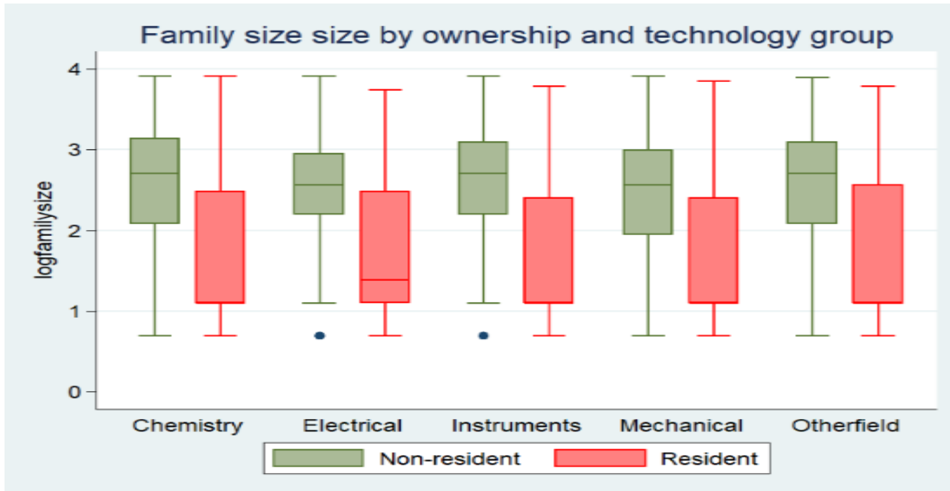


Figure 5. 4: Family size by resident and non-resident and technology categories



Figures 5.5 and 5.6 present grant lags by assignee and technology group, respectively. We found the highest institution patents take a longer time to grant (in both the category: resident and non-resident). In the technology category, median grant lag is almost. However, the distribution of grant lag varies across the assignee group. In the technology category highest median is observed for electrical patents.

Further, grant lag is highly skewed to the right for chemistry instruments and otherfield (in the non-resident patents). In the resident category, chemistry, mechanical and other field patents are right-skewed. The right-skewed represent the quick grant, whereas the left-skewed shows that the majority of patent face grant delay.

Figure 5. 5: Grant lag by resident and non-resident and assignee group

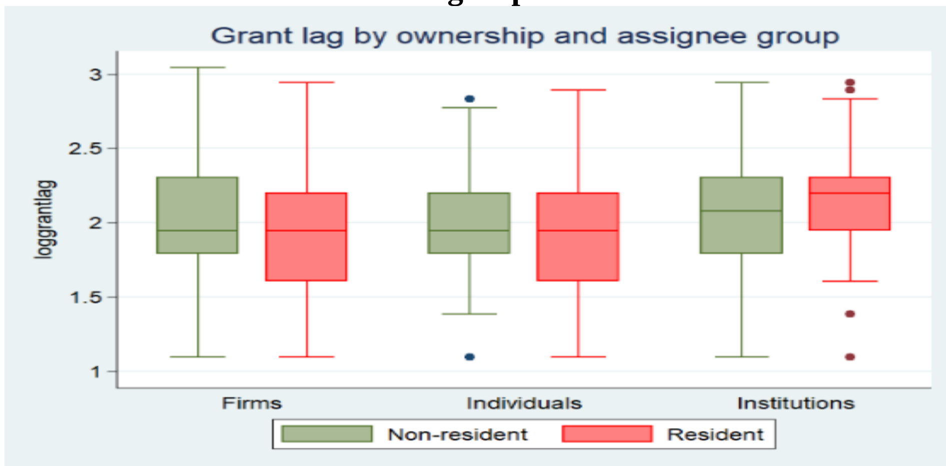


Figure 5. 6: Grant lag by resident and non-resident and technology group

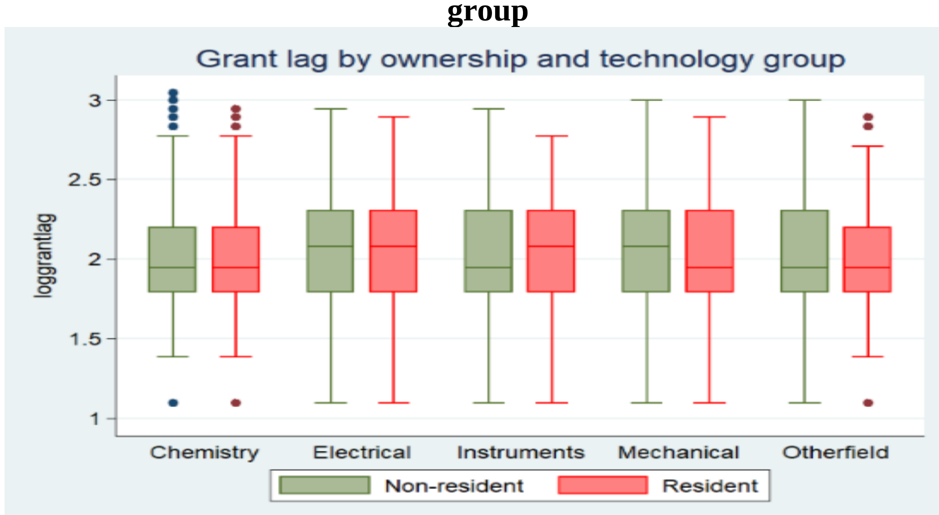


Figure 5.7 and 5.8 depicts inventor size for assignee and technology group, respectively. We find the distribution of inventor size is high across the ownership and technology group. Only institution patents in the assignee group (in both resident and non-resident patents) and chemistry of resident patents have left-skewed inventor size. This implies that the majority of the patents concentrated in the lower inventor size area.

Figure 5. 7: Inventor size by resident and non-resident and assignee group

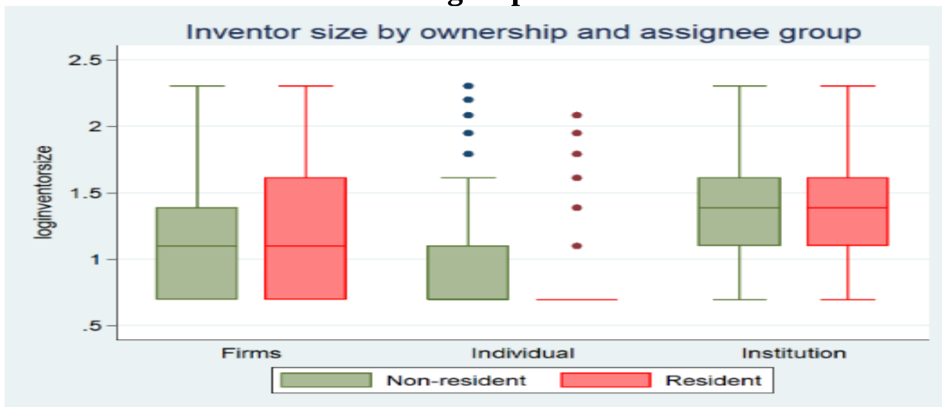
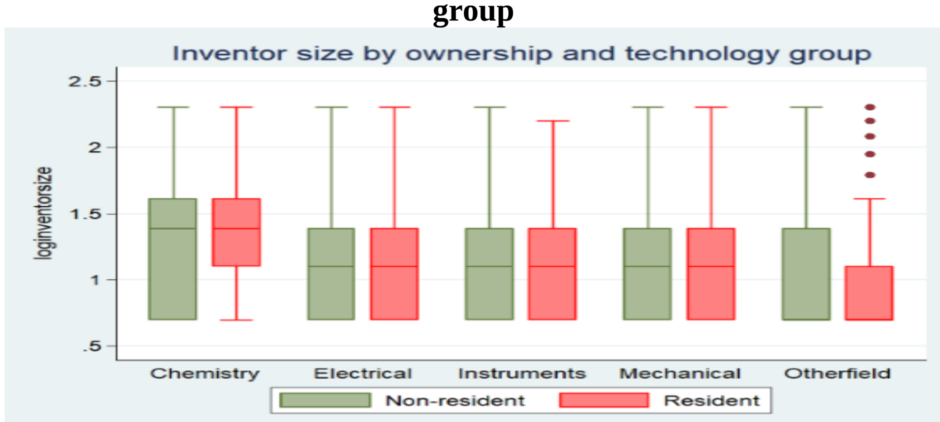


Figure 5. 8: Inventor size by resident and non-resident and technology group



The patent's renewal life across the assignee and technology group for both resident and non-resident patents is presented below in Figures 5.9 and 5.10. Firms' patents in the non-resident category are left-skewed. Distribution skewed to the left suggests that most patents survive longer and right-skewed patents concentrated in the lower survival length. The highest median is observed for institution patents. In the technology category, higher survival is observed for electrical and instruments followed by chemistry and mechanical.

Figure 5. 9: Renewal years by ownership and assignee group

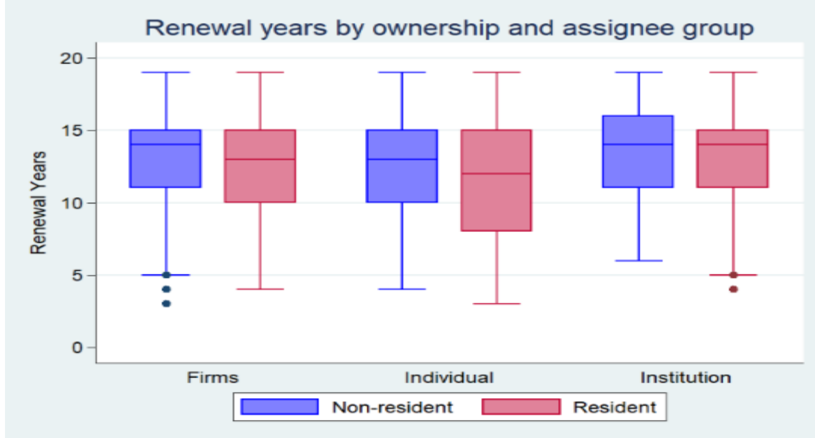
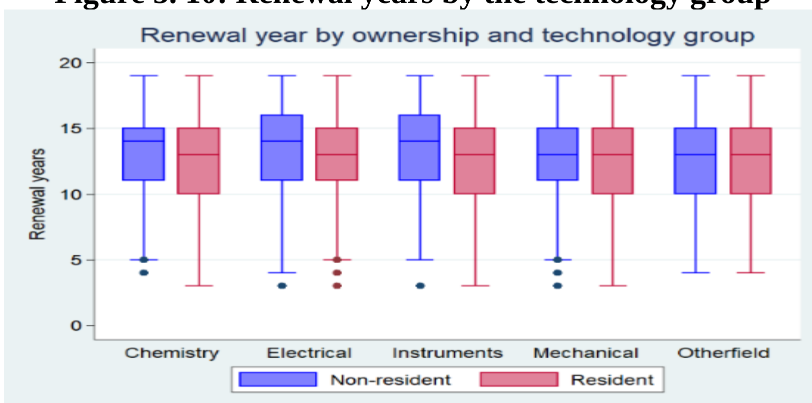


Figure 5. 10: Renewal years by the technology group



5.5.2 Parameter Estimation

First, we estimate the parameter mean βs, standard deviation σ of the initial distribution, and the depreciation rate $d,$ following the maximum-likelihood (MLE) approach. Further, the estimated parameter is used to simulate the initial return value (Table 5.5). The result is presented for both enforced and expired patents separately (Tables 5.6 and 5.7). Last, we estimate the net present value for the above-mentioned categories.

a. Depreciation Rate

The decay or depreciation rate refers to the pace at which the initial revenues, $r_i(0)$ diminish every year, which will always be less than one. Thus, the decay rate explains the characteristic of the innovation and industry and market structure characteristics. Here we assumed the depreciation rate is exogenous and equal across patents, $d_{it} = d_t$.

The decay rate on return is estimated 0.48 per year in India. Earlier studies on the patent value in Europe and the U.S estimated parameters of obsolescence around 3.1% and 4.1% (Lanjouw, 1998). Thus, compared to an earlier study in developed countries, India's depreciation rate is much higher. Bessen (2008) study report around 14% depreciation rates for U.S patents. However, China's depreciation rate is found to vary between 34% and 24%, which suggests that the expected value of patented technology depreciates at a much faster rate in China than U.S and Europe (Gupeng and Xiangdong, 2012). Thus, here we conclude that India's patent filed between 1995 to 2005 depreciated at a faster rate. India's patent value distribution across the innovation field shows a higher initial return (contrasted with China's study), more noteworthy dispersion, and a quicker obsolescence.

b. Parameter Estimation for Initial Return, $\boldsymbol{r_i(0)}$

The initial distribution, $r_i(0)$, is a function of various factors such as assignee category, invention complexity (measured by technology scope, number of inventors, and grant lag), filing strategy (number of claims and family size), and technological filed. We summarize our estimation result in Table 5.5. Column 1 shows the combined results (enforced and expired patents), and column 2 represents only expired patent results.

Number of Claims

This investigation reports a positive and significant effect of the number of claims on the patent's underlying return. An extra claim expands the underlying return by 12.42 times. The claims are significant because they characterize the strength of the patent by fencing the innovation. Prior examinations utilized the number of claims as an informative variable to assess the patent worth found a more modest effect on patent value (0.9%)

in the European setting (Gambardella et al., 2008). This outcome means that broader claims are hard to circumvent by a competitor and block the access to incremental inventions based on the original technology. Thus, the breadth of claims is a significant determinant of patent worth.

Technology Scope

Since quite a while ago, the writing on patent valuation distinguished the significance of patent scope as a determinant of patent protection's efficacy (Scotchmer, 1991; 1996). The present study follows Learner (1996) approach to generate a measure of technology scope computed as the number of different four-digit IPC classification enlisted in the granted patent documents. The regression results detailed in Table 5.5 for the technology scope discovered to be positive and significant. This implies that a patent with broader technology scope is more likely to have a higher return. A prior investigation in the European and US setting found the distinctive after effect of technology scope (TS) on patent worth. For instance, Lerner (1994) noticed the positive effect of TS on patent worth whereas, Harhoff et al. (2003) study reports a negative impact on the patent value. The disparity between two outcomes might be because of the distinction in the idea of the technology field, for instance, Lerner (1994) study is based on biotechnology patents though Harhoff et al. (2003) incorporate all innovative fields. The current investigation result is according to Lerner (1994) and Gronqvist (2009), which locate that broader patents are more important than smaller ones.

Family Size

Family size measures the number of jurisdictions in which a patent is filed through PCT or separate filing. The estimated parameter of family size shows positive explanatory power for the value of the patent. Putnum (1996) argued that information on family size reveals the patented technology's international outreach, hence well suited to indicate patent rights' value. Later, Lanjouw (1998) finds a positive impact of family size on the patent's survival length. The current examination in the Indian setting underpins the prior outcomes acquired for the US and European information.

Inventor Size

The present study measures the number of inventors involved in the development of a project as inventor size. Inventor size reveals the importance of innovation. Zeebroeck (2007), who estimated the determinants of patent life, suggests that the number of inventors positively impacts patent value. There is an economic reason behind this interpretation: a larger team of inventors involves a larger set of skills and expertise. Hence, this specific quality may lead to developing a high-quality patent. Guellec and Potterie (2000) study reveals that the collaboration of two countries' inventors or joint application of different nationalities increases patent value.

Grant Lag

The grant lag is on average 6.65 years, but some patents are granted after two years, whereas some patents have to wait more than 10 years for the grant. We find the negative impact of grant lag on the initial returns of the patent. Grant lag is often seen as an uncertain period for the applicant because they are unsure whether a patent will be accepted. A patent grant may delay due to many reasons such as frivolous claims, complex drafting style, applicants refilling amended applications in response to initial rejections of various claims (Quillen and Webster, 2001). Harhoff and Wagner (2009) find that more controversial claims lead to slower grants and that well-documented applications are approved faster. Régibeau and Rockett (2010) conclude that important patents are approved more quickly, i.e., inverse relationship between the value of a patent and the length of the grant lag period

Initial Return by the Technology Group

The underlying return for various technology classes uncovers significant information about industrial structure in the country. In contrast to the base category, all technology filed is positive and significant in the enforced renewal model. The coefficient of 'otherfield' is most elevated, followed by mechanical, chemistry, and electrical. This suggests that 'otherfiled' are bound to have higher-worth contrasted with instrument patent in the improved model. Nonetheless, in the traditional model of terminated patent, 'otherfield' patent is discovered to be insignificant. At the later stage with more enforced patent information sector with a weak industrial background (consumer market-based sector) improved their renewal life.

Initial Return by Assignee Category

Compared to individual-owned patents, institutions and patents are both positive and significant among the assignee category. We further disaggregated institution patents into foreign and residential categories to the value differences. We find that non-resident institution patents are more valuable compared to resident patents in the institution category. A similar result holds for firms' patents where non-resident patent value has a higher value than resident patents. The lower coefficient of a firm's patent can be explained by the competitive market's nature and the patent race that significantly influences its quality.

Initial Return by Ownership Category

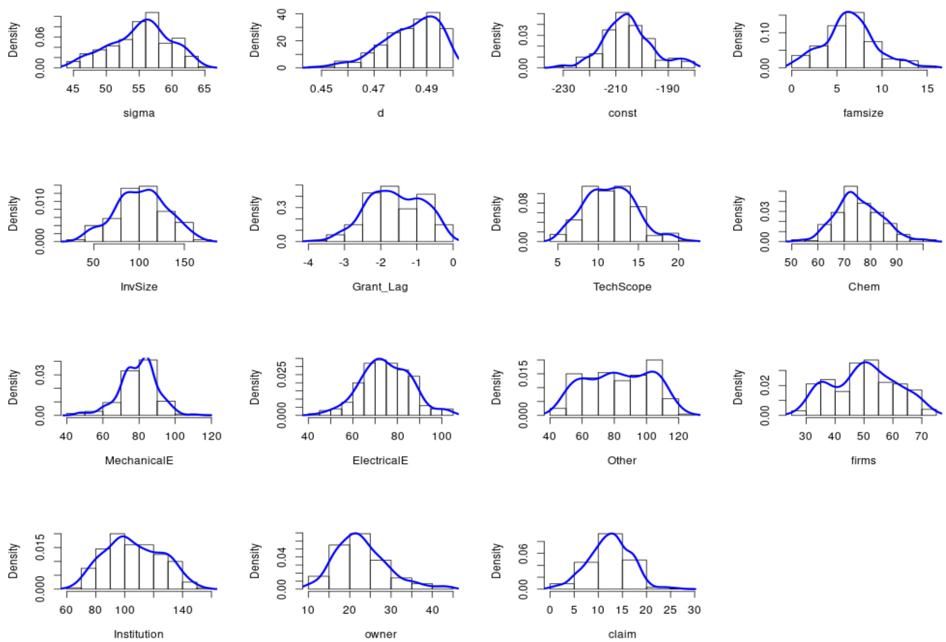
The non-resident patent in India contributes 78 percent of the total granted patent by the IPO. In terms of ownership differences, foreign-owned patent value is higher than the resident patents patent in both models. These parameters may appear to be unreasonably large. However, they measure the impact on the initial return to holding a patent. Figure 5.11 shows the distribution of the parameters. The distribution of parameters explains the feasible range (upper, lower range, and median) of each parameter separately.

Table 5. 5: Estimates of the patent renewal model, by technology Field, ownership, and assignee category

Parameters	**Coefficient**
Claim	12.42*** (4.29)
Family Size	6.45*** (2.87)
Inventor Size	102.30*** (28.17)
Grant Lag	-1.61*** (0.76)
Technology Scope	11.50*** (3.16)
Chemistry	75.47*** (8.53)
Mechanical	79.49*** (10.14)
Electrical	74.90*** (11.04)
Otherfield	82.78*** (20.11)
Firms	50.04*** (11.05)
Institution	106.29*** (19.23)
Ownership	22.83*** (6.29)
Sigma	55.21*** (4.50)
d	0.48*** (0.01)
Constant	-205.41*** (9.49)

Note: All values in parenthesis are standard error. # denotes dummy variable. p-values for all estimates are less than 10^{-6}, and hence significant at 1% level.

Figure 5. 11: Distribution of parameter estimation



5.5.3 Distribution of Initial Return

This study provides an empirical investigation of patent rights' private value by technology, ownership, and assignee category. Tables 5.6 and 5.7 present the distribution of initial return by ownership, and assignee category for both expired and enforced patents, respectively. We get clear evidence that the median (50% quantile) values for the sample patent data among the typical source assignee category are much lower than the mean value. This suggests that the distribution of patent value is extremely right-skewed. The standard deviation reported in Table 5.6 shows a higher dispersion in the enforced category patents compared to expired patents.

One important observation we made here is that the mean value of the enforced patent's initial return is 18.10% more valuable than the expired patent across the assignee. The top 1% of patents accounts for 14.68%, 9.44%, and 11.03% of the total value of patent rights in individuals, institutions, and firms, respectively in the expired category, and 3.23%, 2.57, and 3.17% in the enforced category[11]. The coefficient of variation ranges from 2.49 in individuals, 2.13 in firms to 2.01 in the institution category of expired patents. However, the coefficient of variation is found comparatively low in the enforced patent sample. Difference across assignee category in mean are negatively correlated with those in standard deviation. Higher mean and median value of initial return have lower dispersion.

Table 5. 6: Distribution of initial return disaggregated by ownership category for expired patents

Quantile	Assignee category (expired patents)			Assignee category (enforced patents)		
	Individuals	**Institutions**	**Firms**	**Individuals**	**Institutions**	**Firms**
1%	0.00	0.00	0.00	4.09	4.13	4.07
5%	0.00	0.01	0.01	4.15	4.18	4.13
10%	0.01	0.03	0.02	4.18	4.26	4.15
25%	0.03	0.07	0.06	5.51	5.58	5.49
50%	0.15	0.49	0.33	7.22	7.39	7.19
75%	0.83	1.36	1.28	12.53	16.64	12.53
90%	3.24	6.49	6.32	16.88	22.09	16.84
95%	8.05	11.13	11.11	22.09	29.08	22.09
99%	21.28	18.98	21.28	29.30	29.52	29.30
Mean	1.45	2.01	1.93	9.08	11.50	9.25
Std. dev.	3.61	4.05	4.11	5.95	7.19	6.17
C.V	2.49	2.01	2.13	0.66	0.63	0.67
Obs.	1605	2025	15263	538	762	6891

Note: All monetary values are in units of million U.S. dollars in the year 2010 value.

The distribution of initial return among ownership classification of enforced and expired patents follows skewed distribution as we notice in the earlier assignee category results. The top 1% of expired patents in the non-resident category accounts for 10.40% of the total value, and resident

[11] The fraction of total value in the top percentile is given by .01 $V_{.99}/V_m$, where $V_{.99}$ is the value for the top percentile and V_m is the mean value (Schankerman, 1998).

patent accounts for 13.93% of the total value. Similarly, enforced patent category, 1% of patent accounts 3.15% (resident) and 2.94% (non-resident) of the total value. in the expired patent sample, the top 5% of patent accounts for 54.36% of the total value in non-resident and 42.90% in the resident category. This equation changes as we move to the enforced patent category where 5% of patents account for 75.39% and 75.54% of the total value in non-resident and resident patents.

Table 5. 7: Distribution of initial return disaggregated by assignee and ownership category for enforced patents

	Ownership category (expired patents)		Ownership category (enforced patents)	
Quantile	**Non-resident**	**Resident**	**Non-resident**	**Resident**
1%	0.00	0.00	4.09	4.09
5%	0.01	0.00	4.13	4.13
10%	0.02	0.01	4.15	4.18
25%	0.06	0.04	5.49	5.51
50%	0.37	0.30	7.24	7.28
75%	1.33	0.88	12.53	12.60
90%	6.56	3.08	16.84	22.09
95%	11.59	8.07	22.09	22.30
99%	21.32	18.81	29.30	29.52
Mean	2.05	1.35	9.29	10.02
Std. dev.	4.24	3.28	6.17	6.76
CV	2.07	2.43	0.66	0.67
Obs.	14638	4255	6595	1596

Note: All monetary values are in units of million U.S. dollars in year 2010 value.

Table 5.8 presents the value distribution (initial return) for each technology group. Value includes the initial return occurring from the date of application until the optimal expiration date. The most prominent feature of the value distributions is the sharp dispersion in each technology field. Most patent have very little value: the mean value of the patent right in the expired patent category (2010 U.S dollar) is $2.14 million electrical, $1.89 million instruments, $1.82 million chemistry, $1.87 million mechanical, and $1.68 million ‘otherfield’. We discussed earlier that the patentee's renewal decision is a direct source of information of the value of the patent right, which emerges from the study where differences in the renewal pattern across the technology group lead to a significant difference in the value of the patent. Top 1% of the total patent holds 9.53%, 10.06, 11.68, 11.37, and 11.23 of total value in electrical, instrument, chemistry, mechanical, and 'otherfield'.

The requirement of patent protection varies by technological group, and so the renewal pattern. For example, chemistry, pharmacy, and biotechnology fall in the discrete industry category where patents are used to earn extra profit. In contrast, the complex product industries-semiconductor industry, telecommunications, consumer electronics- firms are involved in the cross-licensing and trading negotiations and prevent litigation (Hall and Ziedonis, 2001). In a complex industrial field, innovation is tricky and dependent on information from a multitude of sources. In these sectors, patents are mostly used as a bargaining chip—the fundamental differences in these technologies produce different patent value.

Table 5. 8: Distribution of initial return disaggregated by technology field of expired patents

Quantile	Electrical	Instruments	Chemistry	Mechanical	Otherfield
1%	0.00	0.00	0.00	0.00	0.00
5%	0.01	0.01	0.01	0.01	0.00
10%	0.02	0.02	0.02	0.02	0.01
25%	0.06	0.06	0.05	0.05	0.04
50%	0.46	0.37	0.32	0.33	0.28
75%	1.36	1.33	1.27	1.27	0.91
90%	6.76	6.34	6.08	6.30	5.58
95%	11.68	10.45	10.67	11.09	11.50
99%	21.30	19.02	21.26	21.28	18.87
Mean	2.14	1.89	1.82	1.87	1.68
Std.Dev.	4.31	3.85	3.98	4.07	3.89
CV	2.01	2.04	2.19	2.18	2.32
Obs.	3776	1580	8170	4564	803

Note: All monetary values are in units of million U.S. dollars in the year 2010 value.

Further, we estimate the initial return of the enforced patent. Table 5.9 presents the quantile distribution of initial return for the five different major technology categories. The initial return's highest mean value is observed for the mechanical patents followed by instruments, electrical, and 'otherfield'. However, the chemistry patents' initial return is the lowest among all technology groups. Top 5% of the enforced category patents hold 75% of the total value across India's technology group. In China, on average, 77.6% of the value is captured by the top 5% of the patent (e.g., Gupeng and Xiangdong, 2012). However, in the U.S, chemical patents are found to have the highest value (Bessen, 2008). The skewed nature of patent value reveals fewer blockbuster patents across the technology field.

Table 5. 9: Distribution of initial return disaggregated by technology field of enforced patents

Quantile	Electrical	Instruments	Chemistry	Mechanical	Otherfield
1%	4.09	3.94	2.54	4.11	4.09
5%	4.13	4.05	2.56	4.15	4.13
10%	4.15	4.09	2.58	4.18	4.15
25%	5.49	5.38	3.41	5.51	5.49
50%	5.60	6.23	4.50	7.28	5.60
75%	12.51	12.51	7.78	12.53	12.49
90%	16.84	16.77	13.56	16.88	16.90
95%	22.09	22.09	13.73	22.30	22.09
99%	29.30	29.30	18.15	29.30	29.30
Mean	9.01	9.23	6.04	9.56	8.99
Std.Dev.	6.28	6.04	3.96	6.25	6.12
CV	0.70	0.65	0.66	0.65	0.68
Obs.	2067	706	3285	1827	306

Note: All monetary values are in units of million U.S. dollars in year 2010 value.

5.5.4 Distribution of private value of the patent

The private value of a patent estimated using renewal decision measures how much a patent owner earns if they renew for an additional year. Research indicates that 70 to 80 percent company’s market capitalization comes from intangible assets such as patents, trademarks, copyrights, and other business knowledge and know-how. The mean net present value is presented in Table 5.10. The highest mean value is observed for the institution patents followed by firms and individuals in enforced and expired patent categories. Top 1% of enforced patent accounts 3.24%, 2.55%, and 3.18% of the total net present value in individuals, institutions, and firms, respectively. The quantiles are estimated quite precisely in pharmaceuticals and chemicals but less so in the mechanical and electronic technology fields, especially in the upper 5% of the tail. Still, the mean value differs sharply across the assignee field of enforced and expired patents.

Table 5. 10: Distribution of the private value of patent by assignee category

	Expired patent			Enforced patent		
Quantile	**Individuals**	**Institutions**	**Firms**	**Individuals**	**Institutions**	**Firms**
1%	0.00	0.00	0.00	4.18	4.20	4.16
5%	0.00	0.01	0.01	4.24	4.26	4.21
10%	0.01	0.03	0.02	4.27	4.36	4.25
25%	0.04	0.07	0.06	5.67	5.72	5.64
50%	0.15	0.51	0.34	7.46	7.63	7.42
75%	0.86	1.41	1.32	12.90	17.20	12.90
90%	3.34	6.70	6.51	17.40	22.80	17.40
95%	7.99	11.50	11.50	22.90	30.00	22.90
99%	21.10	19.50	21.10	30.30	30.40	30.30
Mean	1.48	2.05	1.97	9.35	11.90	9.52
Std.Dev.	3.66	4.11	4.17	6.14	7.43	6.38
CV	2.47	2.00	2.12	0.66	0.62	0.67
Obs.	1605	2025	15263	538	762	6891

Note: All monetary values are in units of million U.S. dollars in the year 2010 value.

In terms of ownership category (see Table 5.11), Patent value estimation in India suggests that the patent value of local Indian owners is generally lower than the patent values of foreign owners in the expired patent category. However, in the enforced category, resident patent value improved slightly. This indicates that more recent patents in India have improved the quality. Further investigation is required with more recent patents. The difference between expired patents and enforced are even wider. Non-resident enforced patents value is 4.5 times bigger, and resident 7.4 times greater than the expired patents.

Table 5. 11: Distribution of patent value by ownership category

Quantile	Ownership category (expired patents) Non-resident	Resident	Ownership category (enforced patents) Non-resident	Resident
1%	0.00	0.00	4.16	4.17
5%	0.01	0.00	4.22	4.23
10%	0.02	0.01	4.25	4.27
25%	0.06	0.04	5.65	5.66
50%	0.38	0.30	7.46	7.51
75%	1.37	0.91	12.90	13.00
90%	6.77	3.18	17.40	22.70
95%	11.90	8.01	22.90	23.00
99%	21.20	19.30	30.30	30.30
Mean	2.10	1.38	9.58	10.30
Std. dev.	4.32	3.33	6.38	6.98
CV	2.06	2.41	0.67	0.68
Obs.	14638	6595	6595	6595

Note: All monetary values are in units of million U.S. dollars in the year 2010 value.

The mean net present value sharply differs across the technology fields (see Table 5.12): $2.18 million in electrical, $1.93 million in instruments, $1.86 million in chemistry, $1.91 million for mechanical, and $1.71 million in ‘otherfield’. Top 5% of expired patent holds for 56%, 55%, 52%, 54%, and 60% of the total value in electrical, instruments, chemistry, mechanical, and ‘otherfield’ patents.

Table 5. 12: Distribution of private value of patent by technology group (expired patents)

Quantile	Electrical	Instruments	Chemistry	Mechanical	Otherfield
1%	0.00	0.00	0.00	0.00	0.00
5%	0.01	0.01	0.01	0.01	0.00
10%	0.02	0.02	0.02	0.02	0.01
25%	0.06	0.06	0.05	0.05	0.04
50%	0.47	0.38	0.33	0.34	0.29
75%	1.41	1.37	1.31	1.30	0.94
90%	6.98	6.53	6.27	6.48	5.73
95%	12.00	10.80	11.00	11.40	11.80
99%	21.10	19.60	21.10	21.10	19.40
Mean	2.18	1.93	1.86	1.91	1.71
Std.Dev.	4.37	3.91	4.05	4.14	3.94
CV	2.00	2.03	2.18	2.17	2.30
Obs.	3776	1580	8170	4564	803

Note: All monetary values are in units of million U.S. dollars in the year 2010 value.

Furthermore, we estimated the net present value for the enforced patents (see Table 5.13). Enforced patents compared to expired patents are more valuable. For example, the mean value of electrical patents is $9.28 million, which 4.25 times higher than expired patents similarly, instruments patents 4.29 times, chemistry 5.37 times, mechanical 5.15 times, and ‘otherfield’ 5.41 times more valuable. Among the technological category, the highest mean value is observed for chemistry ($10.00 million), followed by mechanical ($9.84 million), instruments ($9.50 million), and electrical ($9.28 million).

Table 5. 13: Distribution of patent value by technology group (enforced patents)

Quantile	Electrical	Instruments	Chemistry	Mechanical	Otherfield
1%	4.18	4.01	4.18	4.20	4.17
5%	4.22	4.11	4.23	4.23	4.21
10%	4.24	4.18	4.26	4.27	4.24
25%	5.63	5.54	5.67	5.67	5.64
50%	5.75	6.41	7.52	7.52	5.75
75%	12.90	12.90	13.00	12.90	12.90
90%	17.40	17.30	22.60	17.40	17.40
95%	22.90	22.80	22.90	22.90	22.80
99%	30.30	30.30	30.30	30.30	30.30
Mean	9.28	9.50	10.00	9.84	9.26
Std.Dev.	6.49	6.25	6.59	6.46	6.32
CV	0.70	0.66	0.66	0.66	0.68
Obs.	2067	706	3285	1827	306

Note: All monetary values are in units of million U.S. dollars in the year 2010 value.

5.5.5 Conclusion

The empirical findings in this essay demonstrate that patent protection creates valuable property rights. This investigation assessed the forward estimation of patent rights alongside expired rights. There are two suppositions: first, the distribution for the initial return of patent is log-normal, and second, the depreciation is steady over the long haul. The renewal model depends on the possibility of a patent holder's renewing choice to save its patent for an extra year. The renewal choice depends on economic criterion where renewal cost is contrasted with contemporaneous incomes, which build withholding the patent. The models estimate the distribution function parameters of initial revenue and the rate of decay of these revenues. The parameters are further used to generate the distribution of the private value of the patent. The experimental examination incorporated patent recorded from 1996 to 2005 and issued prior to 31st December 2018 at IPO.

The exact findings that rise out of this investigation can be summed up as follows: First, the distribution of private estimation of the patent right is slanted across the technological field. There is a concentration of patent rights with next to no or minimal value, yet the tail of dispersion contains essential patents. Second, the depreciation rate in the underlying return is very high. Future examinations can assess distinctive decay rates for various innovation classifications to comprehend the varying nature of innovation.

Third, resident patents' value is generally lower than the patent values of non-resident patents, i.e., resident patents are 1.5 times lower valuable than foreign patents in the expired category. A more modest estimation of residential patents in India reflects the different strategies of local patent owners. Locally inventors innovate according to frequent local policy demands, compared with owners from other leading technologically advanced countries. However, in the enforced category patent, the value of resident patents improves slightly, i.e., the resident patent is 1.07 times more valuable to the non-resident patent. We find that the average renewal age of foreign patents in the enforced category is 14 years, while resident patents average is 15.14 years.

Fourth, there are also important differences in patent values among different technological fields based on the patent records in India's market. The initial return is higher for electrical patents in both categories. The finding that patent rights are surprisingly less valuable in chemistry, where there is no product patent allowed in India during the study period, highlights the important point that R&D incentives are majorly shaped by patent law and other institutional constraints that affect the appropriability environment. However, net present value (discounted life time value) in the enforced category patents is higher for chemistry patents. Net present value in a life time of patents is higher if a patent survives longer. We find that the average renewal age in the enforced category patents higher for the chemistry patents (15.08) followed by mechanical (14.03), and instruments (14.94).

Fifth, among assignee category institution patents across the enforced and expired patents have a higher value than firms' and individuals' patents. There are numerous positions where universities team up with industries for advancing in a particular area, which gives a great deal of exposure to its faculties and students and helps them acquire a position in these industries. To a certain extent, the collaborative effort may generate a higher value of the patent. Further, unlike industrial researchers and inventors who by and large are recruited to create and assign rights in their innovations to their employer with no residual rights to extra pay, university scientist is in different position. These additional factors may culminate to have higher value of institution patents.

The enforced patent outcome will help the researchers to draw the optimal patent length for the recently granted patents. The analysis of patent portfolios using renewal information for different companies may help investors forecast their future profitability. Recognizing and estimating these institutional factors' significance on R&D incentives is a significant research challenge that will require near investigations of patent renewal information from the patent system in different countries. The strategy and observational outcomes recommend that it is both practical and imperative to incorporate patent quality measures when estimating inventive output based on patent factors, at least in countries with renewal rates. Further, a study on patent valuation may include a number of patent-level information with market, industry, and country characteristics to predict initial return value. As we have included only a constant depreciation rate, a future study can estimate technology-wise depreciation since it is an important factor in determining the inventors' learning activity.

Chapter 6

Summary and Conclusion

The thesis investigates the patent value (in quantitative and qualitative terms) for the patent applied between 1995 to 2005 at IPO. This thesis consists of four essays. These four essays though independent yet are closely linked with patent value as a common thread. First, we estimate the determinants of patent value (survival length) in the Indian context. We examine the impact of patent indicators on the survival life of the patent. Since R&D volumes and patenting efforts vary across the assignee category, controlling these variables gives ample information about the patent's quality. Second, we identify the valuable technology at a disaggregated technological level. The third essay estimates the value of expired patents in monetary terms. Finally, we estimate the forward value of unexpired patents. We capture patent values using different measures based on renewal data that necessitate the use of different methodologies. Such an approach allows us to gain insights into the India's innovation quality. Further, the patent's embedded information reveals its general features and value. The present chapter is organized as follows:

Section 6.1 summarizes the dissertation. 6.2 delineates the results of each essay. Section 6.3 presents the synthesis of the results. Section 6.4 draws policy implications. Section 6.5 elaborates upon the contributions of the study. 6.6 delineates limitations of the dissertation and outlines directions for the future research.

6.1 Summary of the Thesis

The valuation of IP plays an essential role in the technology market. For instance, IP, including patents, are being traded more regularly between companies. Keeping the patents' significance as a central deducing force of this work, we endeavour to estimate patents' value in the Indian setting from the inventors' perspective. Various notions of value are found in the literature with a different perspective (legal, economic, strategic, accounting, and taxation) depending on the valuing agency's specific context and objective. The patent's value can be perceived as the value of the underlying technology that a patent protects. Patent rights' value may also refer to the incremental value above any profit that can be captured without patent protection (Arora et al., 2008).

One of the difficulties we face while estimating the monetary value is the asymmetric information on the patent's marketability (Lemley and Myhrvold, 2007), and dependence on highly idiosyncratic details (Cohen et al., 2000). The innovation process is uncertain, and hence, value coming from the innovation (the result of R&D) is unstable.

The patent valuation studies are arranged into two classes, i.e., qualitative, and quantitative. The former appraises the strength of invention through *patents due diligence* which is an in-depth investigation of patent's characteristics to determine the firms' most valuable innovations. The qualitative studies identify the factors that contribute towards the valuable patents. The quantitative methods estimate a single patent's value (patent portfolio) in monetary terms. Over time, scholars have developed various methods to estimate patent value. They have used litigation, renewal decision, and citation information as a proxy of value indicators in the absence of any direct measure of patent value. Further, as most patent systems levy renewal fees, the patentee's renewal decision is also tied to patent rights' value (Sullivan, 1994). The patent renewal data provides information on the private value of patent rights. The renewal fee is charged annually from the patentee by the respective patent office to keep a patent enforced for an additional year. The failure to renew cancels the exclusive rights of the patentee. Thus, an assignee/patent holder will pay the renewal fee for an additional year when the returns from holding the patents exceed the renewal cost. In this thesis, we use renewal information to estimate the private value of patents in India.

The initial two essays follow *patent due diligence*. The *patent due diligence* explores the status and strength of patent (or patent portfolio) for companies, institutions, and individuals. Such evaluation is relevant for businesses during IP exchanges, consolidations, acquisitions, or financing choices. To decide the estimation of patent rights, it is important to have an exhaustive understanding and evaluation of patent qualities, for example, patent claims, family size, innovation scope, inventor size, and grant lag. Moreover, *due diligence* strategy joined with the ranking method categorizes patents whereby such ranks are associated with different value classes for a comparative analysis. The importance of patents is not the same for all technology classes. Thus, this study controls the value of patents for a different technology class, ownership status (resident and non-resident), and assignee category (individual, institution, and firms). All the approaches mentioned so far incorporate more or less defined value determinants in their model to highlight the possible source of variation. Some patent characteristics are used as ex-ante determinants of patent value; others are included as controls with no specific expectations.

The quantitative methodologies for patent valuation in the third and fourth articles utilize patent characteristics to gauge the monetary value of patents controlling for technology, ownership, and assignee heterogeneity. This is the first study in the Indian context that explored the private value patent in monetary terms. In addition, the estimation of enforced patent’s value has been carried out only by Gupeng and Xiangdong (2012) for the Chinese patents. The patent's renewal life is a common thread used in all the essays to indicate the patent value, following Schankerman and Pakes (1986). The returns calculated in this study reveal the internalization of the profits by inventors while renewing the patent compare to non-renewal. The initial revenues may depend on various factors, and the underlying technology class is one among them. Besides, revenue also depends on the industry type. Accordingly, this study captures the three aspects of a patent: ownership, technology field, and assignee category.

Regarding the patent, three important questions have not been discussed in the Indian context. First, does an increase in the patent filing also reflect the quality of the patent? Second, do patents owned by resident and non-resident have any difference in value? Third and the last question about patent valuation is that which technology in India produce quality patent? Keeping the above question in mind, we have formulated the following four objectives that are investigated in the four essays, separately.

9) To estimate the determinants of survival length of a patent filed at IPO for technology, ownership, and assignee category.

10) To identify valuable technology at the disaggregated technology level.

11) To estimate the monetary value of expired patents using the renewal model framework.

12) To estimate the forward value of non-expired (enforced) patents in India.

We have used IPO data to estimate the patent value from 1995 to 2005. Patents are divided into five major technology fields (electrical, mechanical, instruments, chemistry, and otherfield) on the basis IPC 4-digit classification. We expanded the five major technology fields for disaggregated levels into 32 categories following IPC classification developed by the WIPO technology cohort. We further collected patent level information such as a number of claims, renewal life of the patent, technology scope, inventor size, family size (geographical coverage), grant lag (time elapsed between patent application and grant) from the IPO. We visited each patent's documents separately to get the renewal information. We further assigned patents into three categories based on the ownership of the patent-individual, institution, and firms. The third category of the patent we have is the resident and non-resident patent.

We apply appropriate econometrics techniques for both the approaches (qualitative and quantitative). We apply the Cox proportional hazard model (Cox-PH) and Accelerated Failure Time Model (AFT) to estimate the determinants of survival length. We apply the ordered logit model (OLM) and generalized ordered logit model (GOLM) to identify the valuable technology. The third objective of this thesis is to estimate the monetary value of the expired patent. For this purpose, we model decision criteria for deciding whether or not a patent should be renewed at time t. We follow an evolutionary optimization technique called the Genetic Algorithm (GA) (Holland, 1975) for finding the maximum likelihood estimates (MLE) of $\Omega = (\sigma, \mathrm{d}, \boldsymbol{\beta})$. The fourth objective of this study is to estimate the forward value of the patent. We follow the renewal model used in the expired patent study with some modification in the probability function. The probability function of the enforced patent includes whether it will expire prematurely or survive until maturity.

India's patenting activities has increased significantly over time; for example, in 1995-96 the total domestic patents filed were 1606, and non-resident filing was 5430 at Indian Patent Office (IPO). In 2018-19, the patent applications are 50,659, which is 5.9% higher than 2017-18. (IPO Annual Report, 2018-19). However, the increasing patenting activity does not capture the quality of the invention, which is the focus of this doctoral dissertation. Table 6.1 summarizes the objective, duration, data and sample details for each essay.

Table 6. 1: Objective, time period, and number of observations

Objective	Time-period	No. of observations	Reason for different sample size
1. To investigate the determinants of patent survival.	1995 to 2005	40132	This study includes the complete sample
2. To identify valuable technology at a disaggregated level.	1995 to 2002	21562	Since we have to categorize patent’s life in ascending order, we remove the patent expired after 2019. Because of limited information on the future renewal
3. Estimate private value of the expired patent.	1995-2005	18864	We removed the enforced patent from the sample.
4. Estimate the value of the enforced patent.	1995-2005	27100	It includes both enforced and expired patents minus patents that are never renewed and outliers.

6.2 Empirical Results

Essay 1: Determinants of Patent Survival in Emerging Economies: Evidence from Resident and Non-Resident Patents in India

The synthesis of determinants of patent survival studied in essay 1 reveals that the patent attributes influence the survival length across the assignee categories. We find strong evidence that non-resident patents compared to resident patent survive longer across the assignee category. This reflects the gap of both innovation capability and innovation quality between India and the developed countries as most non-resident patents originate from US, Europe, and other developed countries. Further, the impact of patent attributes on the survival length varies with the assignee categories. For example, larger claims affect survival length positively in the individual and firm’s category. However, it negatively influences the institution category patents. Such contrasts might be clarified by either the composition of patents or within-group quality differences. Patent family size as an indicator of international patent scope positively impacts the patent's overall survival length. This makes sense because of the huge costs involved when a patent is filed in multiple jurisdictions.

This study finds that technological scope is positively associated with the patent's renewal life across the model except for institution patents. The average technology scope among the assignee category is the lowest for the institution patent category. This result reveals that the technology breadth of institution patents is lower than firms and individual patents. Similarly, the grant lag is positive and significant across the models. Further, our investigation finds that the inventor metrics are critical across the models aside from individual categories. This implies that patents invented in collaboration are more valuable.

Essay 2: Identification of "Valuable" Technologies via Patent Statistics in India: An Analysis Based on Renewal Information

In essay 2, there are likewise contrasts in the value of patents from different technology fields. This article gives experimental assessments of the patent system's significance as a source of monetary profit from the inventive activity. The literature on IPR and patent policy determine if the patent system is an effective incentive mechanism for spurring innovation; a few groups question the actual presence of a patent system. The observational proof in this essay gives data on the value of patent protection and how that worth may fluctuate among disaggregated technology groups. Whether a patent is probably going to be kept up by its owner is indicative of the long-term value of the patent. Here we used patent renewal data to identify ex-ante valuable patents among disaggregated technology fields. We have further presented the valuable technology groups in an ascending order as directed by the arrow (see Table 6.2).

The results obtained using a generalized ordered logit model for five major technology groups suggest that electrical and chemistry are more valuable than instrument category patents (reference group). Chemistry patents fall under the discrete category, whereas electrical fall under the complex technology patent category. As argued in the literature, complex technology is inherently difficult to replicate, and therefore the value of a patent is ‘in this respect’ is lower (Roycroft and Kash, 1999; Kingston 2001). However, this study using a more disaggregated technology field reveals that not all complex technologies patents are less valuable. Similarly, not all discreet patents are valuable. For a better understanding of the discrete and complex technology value, we subdivided our technology class. In discrete category, the biotechnology, basic material chemistry patents (a subgroup of chemistry) are more likely to maintain full length.

Similarly, in the complex technology category (e.g., consumer electronic industry) audio-visual tech, telecommunications, digital communication, and basic communication higher value. The results also reveal that only a few technologies have significant value while a large number of technologies are either having a lesser value or no value at all.

Table 6. 2: Sorted list of technology groups as compared to the reference category (Pharmaceutical)

Technological field Sub category	Renewal level 1	Renewal level 2	Renewal level 3
Audio-visual tech	0.233**	0.061	0.248***
Telecommunications	0.388***	0.253***	0.490***
Digital communication	0.225	0.263*	0.635***
Basic communication	0.007	0.334**	0.360***
Measurement	0.272**	0.147	0.065
Control	0.277*	0.277*	0.277*
Biotechnology	0.253***	0.253***	0.253***
Food chemistry	-0.156	-0.005	0.227*
Basic material chemistry	0.125*	0.125*	0.125*
Materials, metallurgy	0.237***	0.237***	0.237***
Environmental tech.	0.298*	0.104	-0.212
Engines pumps turbines	0.292**	0.125	-0.168
Transport	0.233**	0.061	0.248***
Reference category: Pharmaceutical			
Electrical machinery apparatus	-0.02	-0.136*	-0.162**
Computer technology	0.088	-0.178**	-0.051
Analysis of biological materials	-0.323*	-0.323*	-0.323*
Medical technology	-0.197***	-0.305***	-0.211**
Organic fine chemistry	0.049	-0.01	-0.122*
Textile and paper	-0.122	-0.230***	-0.303
Mechanical elements	0.072	-0.198**	-0.246
Furniture, games	-0.565***	-0.565***	-0.565
Other consumer goods	-0.181*	-0.181*	-0.181
Civil engineering	-0.206**	-0.206**	-0.206

Note: Here, ***, **, and * denote $p < 0.01$, $p < 0.05$ and $p < 0.10$, respectively. Reference category is pharmaceutical.

Essay 3: Valuation of Patents in Emerging Economies: A Renewal Model-Based Study of Indian Patents

In essay 3, we have estimated the monetary value of expired patents. The renewal fee in India is meagre compared to many developed nations. Our results show that many patents (19.63%) are never renewed—many patent lapses between 7 to 15 years of life. In India standard patent length is 11.68 years, which is higher than Chinese patents and at par with many developed nations. We discover the depreciation rate d=0.49, which suggests that India's protected innovation deteriorates at a higher rate than such innovation in China (24.28%), as indicated by Gupeng and

Xiangdong (2012). Fast depletion or short technology time cycle could be the reason for the higher depreciation rate in India.

On the line of previous research, we find that the value distribution of Indian patents is highly skewed. The patent that expires between 3-6 years has initial return of $2425 ($0.002 million). The initial return of patent expiring between 7 to 10 years is $40273.13 ($0.040 million). Similarly, the patent expiring between 11 to 15 and 16 to 20 years has initial return of $0.719 million and $9.931 million, respectively. This result confirms the hypothesis that initial return of patent expiring at the early stage have a lower value compared to patent renewed to full length.

We also examine how the private value of patents differs among technologies. For example, electrical patents hold the highest mean value, followed by instruments and mechanical patents. Somewhat, this result is different from the developed economies (Bessen, 2008), highlighting the market differences among the countries. The dollar estimates for resident patents is marginally smaller than estimates for non-resident patents. The much lower value of resident patents may imply a strongly different point of view of local patent owners. Domestic inventors frequently invent according to the local policy demands, compared with owners from other advanced countries.

A few remarks about Indian patents are as follows: First, even at a minimum renewal fee, many patents cease or lapse at an early age. This implies that the patentee decides about the renewal life in its initial few years. Several studies conducted on US data reported similar results. The mean net present value of foreign organizations in the US (Bessen, 2008) is 2.905 million on the $1992 price. Whereas, in India net present value of the non-resident patents is reported as 1.33 million dollars (base price 2010). Unlike the Indian chemical and pharmaceutical sector, US chemical sector performs way better. Indian chemical patent values are relatively lower than other sector patents due to process patenting.

We also find a significant difference in the value of patents across the categories of institutions, firms, and individuals. Institution patents value in India surprisingly is higher than firms' and individual patents. This study's outcome reveals that institutions are involved in patenting only when they see the potential of innovation. However, firms patent many for strategic reasons. Further, a higher quantity of patent filing includes more low-quality patents. We find that the distribution of Indian patents' value is skewed; therefore, patent counts are not a good measure for innovation output. The study also finds that the mean patent value increases with an additional renewal year and other patent characteristics.

Essay 4: The Value of Unexpired Patents in India: Assignee, Ownership and Technology Field Differences

In essay 4, we find that the enforced patents' private value is higher across the assignee and ownership categories compared to expired patents. One important observation we made here is that the mean value of the enforced patent's initial return is 18.10% more valuable than the expired patent across the assignee. The top 1% of patents accounts for 14.68%, 9.44%, and 11.03% of the total value of patent rights in the individual, institution, and firms, respectively in the expired category, and 3.23%, 2.57, and 3.17% in the enforced category. The coefficient of variation ranges from 2.49 in individual, 2.13 in firms to 2.01 in the institution category of expired patents. However, the coefficient of variation is found comparatively low in the enforced patent sample.

The value computed in the essay includes the initial return occurring from the date of application until the optimal expiration date. The most prominent feature of the value distribution is the sharp dispersion in each technology field. Most patents have very little value: the mean value of the patent right in the expired patent category (2010 US dollar) is $2.14 million (electrical), $1.89 million (instruments), $1.82 million (chemistry), $1.87 million (mechanical), and $1.68 million ('otherfield'). We discussed earlier that the patentee's renewal decision is a direct source of information of the value of the patent right, which emerges from the study where differences in the renewal pattern across the technology groups lead to a significant difference in the value of the patent. Top 1% of the total patent holds 9.53%, 10.06, 11.68, 11.37, and 11.23 of the total value in the electrical, instrument, chemistry, mechanical, and ‘otherfield’.

The requirement of patent protection varies by technological group, and so the renewal pattern. For example, chemistry, pharmacy, and biotechnology fall in the discrete industry category where patents are used to earn extra profit. In contrast, the complex product industries-semiconductor industry, telecommunications, consumer electronics- firms are involved in the cross-licensing and trading negotiations and prevent litigation (Hall and Ziedonis, 2001). In a complex industrial field, innovation is tricky and dependent on information from a multitude of sources. In these sectors, patents are mostly likely to be used as a bargaining chip—the fundamental difference in these technologies produce different patent value results.

Among assignee category, institution patents across the enforced and expired patents have a higher value than firms’ and individual patents. There are numerous positions where universities team up with industries for advancing in a particular area, which gives a great deal of exposure to its faculties and students and helps them acquire a position in these industries, leading to a lot of acknowledgment respective universities. To a certain extent, the collaborative effort may generate a higher value for the patent. Further, unlike industrial researchers and inventors who by and large are recruited to create and assign rights in their innovations to their employer with no residual rights, university scientist is in a different position. These additional factors may culminate to have a higher value of institution patents. The argument of the higher value of institution patents was extended by Tahmooresnejad and Beaudry (2018). They observe whether receiving funding from the government contributes to high-value patents as measured by their owners' patent renewal decisions. Their observation suggests that Canada's academic nano-technology patents discover a positive relationship between institution patents renewal rate of patents after 4 years.

The enforced patent outcome will help the researchers to draw the optimal patent length for the recently granted patents. The quick analysis of patent portfolios using renewal information for different companies may help investors forecast their future profitability. Recognizing and estimating these institutional factors' significance on R&D incentives is a significant research challenge that will require near investigations of patent renewal information from the patent system in different countries. The strategy and observational outcomes recommend that it is both practical and imperative to incorporate patent quality measures when estimating inventive output based on patent factors, at least in countries with renewal rates.

6.3 Synthesis of Findings

This thesis builds on the argument that embedded information in the patent documents help reflect upon the company's quality of the patent portfolio. If we further extend the methodology, we can get patents' forward value following the patentee's renewal decision. In any case, the value acquired using econometric techniques may not be reflect the exact value but can give the idea concerning the technology development and future choices of intangibles.

In this section, we discuss the synthesis of results gained from essays 1 to 4. The survival analysis finds that too many claims deaccelerate the hazard rate and influence patent survival probability across the technology fields. In essays 3 and 4, higher claims significantly influence the initial returns; however, the number of claims found insignificant when applied generalized ordered logit model. This is unlike to what Moore (2005) found for USPTO patents.

Additionally, geographical scope (patent family size) and inventor size influence the estimation of the patent. The technology scope is positively significant. The vast majority of the outcomes uphold the positive effect of technological breadth on the renewal decision. This thesis shows that a patent with several distinct 4-digit IPC classes enjoys a higher value of the patented technology.

The grant lag defines the time elapsed between application and grant. It measures the efficiency of the patent system of the country and the complexities of the innovation. The basic understanding of higher grant lag uncovers that a patent office has since quite a while ago accumulated work or the patent is not elegantly composed. Therefore, it takes effort to analyze such a patent. Sometimes the legality of the patent delays the granting process. In this thesis, we have found two unique outcomes for the grant lag. The qualitative essays locate a significant effect of the grant lag on the patent's renewal length; however, the results are opposite while estimating patents' monetary value. The renewal length of the patent is emphatically connected with the grant lag. This implies the patent granted late will endure longer, but it negatively affects the patent's initial return.

In assessing the private value of Indian patents, we assume that a patent is renewed as long as the patent's return surpasses the yearly renewal expense. The monetary value assessed in this thesis relates most closely to Bessen (2008), who appraises the effect of owner and patent characteristics on the patent's private worth. In the Indian context, the result of the investigation for expired patents uncovers the highest mean of initial return for electrical patents ($2.46 million), trailed by instruments ($2.09 million), chemistry ($2.06 million), and 'otherfield' ($1.93 million). Bessen (2008) finds that patents claimed by an individual, small entity, and non-benefit organization are less important than patents possessed by large entities. In the Indian setting, we find that patents possessed by institutions

(2.32) have the highest mean value, followed by firms ($2.18 million) and individuals ($1.66 million).

On the other hand, the patent forward value shows the highest mean value for mechanical patents, followed by instruments, electrical, and ‘otherfield.’ Surprisingly, the mean value of chemistry patents is the lowest among all. Earlier, we have mentioned that the chemistry patents include process patents, and therefore, the value observed here is low compared to other technological fields.

Further, examining important innovation utilizing patent support information to recognize important ex-ante patents at disaggregated innovation level uncovers that a few technologies are valuable in the Indian setting. Compare to pharmaceuticals, biotechnology has a higher value, whereas patents from medical technology have a lower value. The patents of environmental technologies are more valuable than pharmaceutical, whereas computer technology and electrical apparatus have a lower value. Although electrical patents have a higher value in the aggregate category, when we estimated the value at a disaggregated level, we find that only a few technologies in the electrical drive the value. Thus, identifying valuable patents at disaggregated levels reveals that patents generate value only in few technologies.

6.4 Policy Implications

As IPRs play an undeniably significant role in corporate strategy, the precise valuation of IP remains a major impediment to their emergence as a tradable asset class. There is a need to have reliable patent valuation methods to invigorate IP transactions to help IP-based funds and most essentially create confidence in the IP valuation methods. The qualitative and quantitative methods used in this dissertation act as useful tools for measuring the patent value and efficiency of the patent system, helping companies, individuals, and policymakers determine their intangible assets worth. The methods can also be applied to analyze the efficient utilization of overall resources allocated to different universities and institutions. Further, private companies can measure the value of their intangible assets (patents) in the early stage of the grant to make an informed decision about the future R&D investment.

Our findings have implications for the R&D managers and policymakers. The recognizable indicia of value, importance, or probability of renewal give the knowledge to help the patent law reforms. For example, the value of patents concentrated in few technological fields suggests that the law needs to be tailored to address these specificities. Further, to weed-out low-quality patents from the system, the patent office needs to make certain changes. For example, the Indian patent office should strategically increase the renewal fee for commercially utilized patents. One of the important observations of this dissertation is that India's average patent life is around 12 years. Since most of the patentee’s learning and commercial benefits occur during the initial years, the maintenance fee schedule needs to be revised while accounting for such aspects. Higher support charges toward the initial stage over the long run may encourage more rapid transfer of the technologies to the public domain. Strategic revision of the fee schedule will also help in weeding-out the low-quality patents from the system. The skewed value distribution reveals the patent's heterogeneous nature thus for research purposes, one should include quality indicators instead of the simple patent count. These findings gain relevance in view of the recent measures introduced to capture innovation through different indices across countries and across states in India by the government.

The results suggest that the individual assignees’ patents have a lower value than institutions and firms' patents. Thus, if the patent is seen as a good incentive mechanism for innovation, policy intervention could improve patent revenues' internalization, at least for individuals and small firms. For instance, individual patentees (small entities) or institutions need to accumulate more data before figuring out how to utilize patents. The intervention of policymakers and the government can make this challenging task easy by initiating a platform for innovators who fail to commercialize their inventions due to lack of finances. Further, as we find a wider patent is more valuable, R&D team needs to pay special attention to the writing of the claims. The collaboration outcome is also positive and significant on the patent value, and therefore, companies should invest time and money in the collaborative projects.

6.5 Contribution of the Study

This thesis is a continuation of some interesting work on patents in the Indian context. A prior paper by Pakes (1986) laid the background for the present work utilizing aggregate data. Having a disaggregated informational collection across sectors makes it conceivable to address some new inquiries and test some new hypotheses. This study contributes to the existing literature (especially in the developing country context) by estimating the patent value for different technology fields. Besides, this study estimates the value of resident and non-resident patents in India.

The value estimation for the different technology fields reveals India's trajectory of innovation by resident and non-resident. Further, this study contributes at the methodological level where we apply the parametric model (AFT), generalized ordered logit model, and maximum likelihood estimation (MLE) to estimate the study's different objectives. Further, to estimate the monetary value of patent use, we simulated the patentee's renewal decision for each patent. This study builds on strong logic that the patent is renewed only when realized return from the patent is greater than the renewal cost.

6.6 Limitations and Future Research

There are a few limitations of this examination that need consideration in future work. First, the monetary value of the patents assessed in this thesis utilizes a fixed depreciation rate. Further, applying a dynamic model where depreciation rate changes with time and technology field we may explain the technology life cycle. Second, this study considers detailed patent-level information. However, it misses some vital information from the patent, such as forward citation and proportionality of Indian inventors. We recommend using detailed information on the patent claims instead of straightforward claims count. Third, this study does not include firm-level information such as R&D intensity, firm size, and profitability that can be undertaken in future research.

APPENDIX 1

Patent renewal information technology-wise

Technology	Patent	Renewal years	Never renewed
Electrical machinery, apparatus, energy	1860	10.47	335
Audio-visual technology	1285	11.14	176
Telecommunications	1828	11.98	202
Digital communication	889	10.91	96
Basic communication processes	335	11.79	45
Computer technology	1845	10.49	263
IT methods for management	40	11.65	2
Semiconductors	293	10.7	42
Optics	399	10.12	64
Measurement	897	11.03	135
Analysis of biological materials	328	9.08	54
Control	337	11.5	44
Medical technology	1536	9.62	293
Organic fine chemistry	4037	10.37	592
Biotechnology	1229	10.84	152
Pharmaceuticals	3542	10.2	504
Macromolecular chemistry, polymers	1209	10.76	195
Food chemistry	706	10.69	97
Basic materials chemistry	2172	11.17	299
Materials, metallurgy	1777	11.57	219
Surface technology, coating	676	10.91	104
Micro-structure and nano-technology	18	10.27	2
Chemical engineering	1965	11.01	293
Environmental technology	446	10.15	67
Handling	1026	10.26	208
Machine tools	1081	11.05	154
Engines, pumps, turbines	1319	10.48	157
Textile and paper machines	1488	10.16	245
Other special machines	1143	10.81	199
Thermal processes and apparatus	584	10.66	95
Mechanical elements	1006	10.29	158
Transport	1199	10.26	154
Furniture, games	303	8.68	74
Other consumer goods	625	9.76	117
Civil engineering	708	10	129
Total	40131	10.59	5965

Note: Author’s calculation based on IPO information

APPENDIX 2

Four-digit IPC technology class

Technology	**IPC**
Electrical machinery, apparatus, energy	F21#, H01B, H01C, H01F, H01G, H01H, H01J, H01K, H01M, H01R, H01T, H02#, H05B, H05C, H05F, H99Z
Audio-visual technology	G09F, G09G, G11B, H04N-003, H04N-005, H04N-009, H04N013, H04N-015, H04N-017, H04R, H04S, H05K
Telecommunications	G08C, H01P, H01Q, H04B, H04H, H04J, H04K, H04M, H04N001, H04N-007, H04N-011, H04Q
Digital communication	H04L
Basic communication processes	H03#
Computer technology	(G06# not G06Q), G11C, G10L
IT methods for management	G06Q
Semiconductors	H01L
Optics	G02#, G03B, G03C, G03D, G03F, G03G, G03H, H01S
Measurement	G01B, G01C, G01D, G01F, G01G, G01H, G01J, G01K, G01L, G01M, (G01N not G01N-033), G01P, G01R, G01S; G01V, G01W, G04#, G12B, G99Z
Analysis of biological materials	G01N-033
Control	G05B, G05D, G05F, G07#, G08B, G08G, G09B, G09C, G09D
Medical technology	A61B, A61C, A61D, A61F, A61G, A61H, A61J, A61L, A61M, A61N, H05G
Organic fine chemistry	(C07B, C07C, C07D, C07F, C07H, C07J, C40B) not A61K, A61K-008, A61Q
Biotechnology	(C07G, C07K, C12M, C12N, C12P, C12Q, C12R, C12S) not A61K
Pharmaceuticals	A61K not A61K-008
Macromolecular chemistry, polymers	C08B, C08C, C08F, C08G, C08H, C08K, C08L
Food chemistry	A01H, A21D, A23B, A23C, A23D, A23F, A23G, A23J, A23K, A23L, C12C, C12F, C12G, C12H, C12J, C13D, C13F, C13J, C13K
Basic materials chemistry	A01N, A01P, C05#, C06#, C09B, C09C, C09F, C09G, C09H, C09K, C09D, C09J, C10B, C10C, C10F, C10G, C10H, C10J, C10K, C10L, C10M, C10N, C11B, C11C, C11D, C99Z
Materials, metallurgy	C01#, C03C, C04#, C21#, C22#, B22#
Surface technology, coating	B05C, B05D, B32#, C23#, C25#, C30#
Micro-structure and nano-technology	B81#, B82#
Chemical engineering	B01B, B01D-000#, B01D-01##, B01D-02##, B01D-03##, B01D041, B01D-043, B01D-057, B01D-059, B01D-06##, B01D-07##, B01F, B01J, B01L, B02C, B03#, B04#, B05B, B06B, B07#, B08#, D06B, D06C, D06L, F25J, F26#, C14C, H05H
Environmental technology	A62D, B01D-045, B01D-046, B01D-047, B01D-049, B01D-050, B01D-051, B01D-052, B01D-053, B09#, B65F, C02#, F01N, F23G, F23J, G01T, E01F-008, A62C
Handling	B25J, B65B, B65C, B65D, B65G, B65H, B66#, B67#
Machine tools	B21#, B23#, B24#, B26D, B26F, B27#, B30#, B25B, B25C, B25D, B25F, B25G, B25H, B26B
Engines, pumps, turbines	F01B, F01C, F01D, F01K, F01L, F01M, F01P, F02#, F03#, F04#, F23R, G21#, F99Z

Textile and paper machines	A41H, A43D, A46D, C14B, D01#, D02#, D03#, D04B, D04C, D04G, D04H, D05#, D06G, D06H, D06J, D06M, D06P, D06Q, D99Z, B31#, D21#, B41#
Other special machines	A01B, A01C, A01D, A01F, A01G, A01J, A01K, A01L, A01M, A21B, A21C, A22#, A23N, A23P, B02B, C12L, C13C, C13G, C13H, B28#, B29#, C03B, C08J, B99Z, F41#, F42#
Thermal processes and apparatus	F22#, F23B, F23C, F23D, F23H, F23K, F23L, F23M, F23N, F23Q, F24#, F25B, F25C, F27#, F28#
Mechanical elements	F15#, F16#, F17#, G05G
Transport	B60#, B61#, B62#, B63B, B63C, B63G, B63H, B63J, B64#
Furniture, games	A47#, A63#
Other consumer goods	A24#, A41B, A41C, A41D, A41F, A41G, A42#, A43B, A43C, A44#, A45#, A46B, A62B, B42#, B43#, D04D, D07#, G10B, G10C, G10D, G10F, G10G, G10H, G10K, B44#, B68#, D06F, D06N, F25D, A99Z
Civil engineering	E02#, E01B, E01C, E01D, E01F-001, E01F-003, E01F-005, E01F-007, E01F-009, E01F-01#, E01H, E03#, E04#, E05#, E06#, E21#, E99Z

Note: This table is available in Excel format on: www.wipo.int/ipstats/en/statistics/patents
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