Intellectual Property Rights and Innovation in Developing Countries: Evidence from India

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Abstract

In 1994, India signed the TRIPs Agreement, which obligated the country to dramatically strengthen its protection and enforcement of intellectual property rights (IPR). This paper uses panel data on Indian firms from 1989 to 2005 to ascertain whether the IPR reforms were successful in increasing innovation by firms in India. We characterize industries according to their technological dependence on innovation, and find strong evidence that Indian firms in more innovation-intensive industries increased their R&D expenditure after TRIPs. The estimated within-firm increase in annual R&D spending after TRIPs is on average 20 percentage points higher in an industry with a one standard deviation higher value of innovation intensity. This differential growth estimate is robust to accounting for contemporaneous trade and industrial policies, and growth in R&D spending by foreign-owned firms. We also find that patenting by India in the U.S. increased after TRIPs, and to a greater extent in more innovation intensive industries.

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1 Introduction

International trade involves an increasingly diverse array of products in which ideas and knowledge play an important role. These products range from high-technology goods such as new medicines and computer processors, to creative material like films, music and books, as well as traditionally low-technology goods that are now associated with a higher proportion of invention and design, such as brand-named apparel and new varieties of plants.

Before the Uruguay Round of trade negotiations that occurred between 1986 and 1994, there was no specific agreement on intellectual property rights (IPR) in the framework of the GATT multilateral trading system. Countries differed greatly in the extent of protection and enforcement of IPR, with developing countries being typically associated with much lower standards for IPR protection than developed countries. The resulting ability of local firms in these weak-IPR countries to market products that were still under patent protection elsewhere in the world meant that the high costs of innovation were mostly borne by the strong-IPR nations in the developed world. However, developing countries argued that weak IPRs protected the poor in their countries from the high prices associated with stronger patent regimes. With increasing trade and economic integration between countries, such differences in IP laws became a source of tension in international economic relations. The TRIPs Agreement, formulated in 1994, is an attempt to narrow the gaps in the way IPR are protected around the world.

India, along with several other developing countries, signed the TRIPs Agreement in 1994, and became obligated to amend its domestic IPR laws within ten years. The signing of TRIPs remained deeply controversial in India for much of the 1990s, even as the country's patent regime began to be gradually modified to comply with the stronger IPR requirements stipulated in the agreement. On January 1, 2005, India became fully TRIPs-compliant by bringing into effect its most important requirement of enforcing product patents in all fields of technology. Given the large number of theoretically valid conjectures on both sides of the TRIPs debate, empirical evidence on its actual consequences in India would shed some important light on the relevance of stronger IPR protection for developing countries. In this paper, we use detailed firm-level panel data from India for 1989 to 2005 to examine whether the signing of the TRIPs Agreement changed the incentives faced by firms operating in India and led to increased innovation and technology transfer in the country.

Although the TRIPs Agreement is connected to a series of international trade negotiations, enforcement of IPR has been a subject of academic and policy debate for many years even without this context of trade and globalization. IPRs generate monopoly positions that reduce current consumer welfare in return for providing greater payoffs for innovation, which then raises future consumer welfare. The variation in the strength and scope of IP laws across nations is largely a function of how policy-makers in different countries have traditionally weighed the short-term costs against the longer-term benefits of IPR protection.

The debate over IPR protection becomes even more complicated and controversial in an international framework. Sharp divisions in opinions about the international harmonization of IPR standards follow from the fact that developing countries possess neither the rights to most current intellectual property, nor the institutional support to alleviate some of the shorter-term costs of strong patent protection. Critics of the TRIPs Agreement argue that the move towards stronger IPR may hurt poorer countries, because they would involve the transfer of rents to multinational corporate patent holders based in the world's most developed countries. Moreover, such critics contend that in the post-TRIPs environment, smaller domestic firms in developing countries will be unable to pay the necessary fixed costs that would allow them to conduct research and development at a scale where they could compete with these giant multinational firms. This, in turn, could have longer-term implications for industry structure and composition in developing nations.

On the other hand, proponents of the TRIPs Agreement have argued that stronger IP laws could increase incentives to conduct R&D by domestic firms in developing countries, making these firms more likely to become owners of the rights to future innovations. A developing country could also benefit from the TRIPs Agreement because strengthening IP laws increases the likelihood for technology transfer between developed and developing countries.

Our firm-level data on expenditure on R&D and technology in India allow us to test these conjectures in the context of the strengthening of IPR induced by the TRIPs Agreement. Trends in R&D spending and patenting activity by Indians do suggest a marked rise in domestic innovative activity during the last decade: R&D spending by publicly listed firms in India has risen sharply since the early 1990s,[1] while U.S. patent applications by Indians grew more than 14-fold between 1995-2004 (Abramson, 2007).

However, prior to attributing these trends entirely to the changing IPR-regime, it is necessary to consider two facts: first, TRIPs was expected to introduce sweeping economy-wide changes in patent administration and protection in India. Therefore, isolating the effects of TRIPs on the incentives to innovate in India requires a careful analysis of the relevance of innovation across different industries. Second, TRIPs was signed amidst other changes such as trade and industrial liberalization, which could potentially deliver their own independent effects on innovation.

To deal with these concerns, we develop a methodology that allows us to make a causal connection between spending on innovation by Indian firms and the strengthening of IPR. We argue that industries vary in terms of their technological dependence on innovation,

[1]See summary statistics on the number of firms and mean firm R&D spending in Table 2.

and that the strengthening of IPR would induce the largest incentives effects on those industries which are most inherently "innovation intensive". Furthermore, this technological dependence can be best uncovered by focusing on environments that already have high standards of IPR protection and enforcement. Following this argument, we use data on R&D and patenting activity of firms in the US to construct two measures that capture an industry's innovation intensity: the R&D-to-sales ratio and the patents-to-sales ratios. We then test if changes in innovative activities in India in the post-TRIPs period correspond to these measures.

We find that R&D expenditure in Indian firms increased relatively more in the industries in which our measures of innovation intensity are higher. In particular, we find that the the estimated within-firm increase in annual R&D spending after TRIPs is on average 20 percentage points higher in an industry with a one standard deviation (SD) higher value of our primary measure of innovation intensity. The results are robust to multiple specifications that include allowing for alternate measures of innovation-intensity, changes in trade tariffs, industrial deregulation, different trends in R&D spending by foreign-owned firms and the staggered nature of the TRIPs-induced policy changes over several years. They are also robust to allowing the effects of tariff reduction and industrial liberalization to vary across high and low innovation intensity industries.

In addition, we also find evidence of increased international patenting activity by Indians in industries that are more dependent on innovation. Our results indicate that a 1 SD increase in our primary measure of innovation-intensity leads to a 7.4 percentage points higher post-1994 growth rate in patents granted to Indian inventors in the United States. For two control groups of countries that were much less dramatically affected by the TRIPs Agreement - the U.S. and Western Europe - the corresponding increases in the growth rate of successful U.S. patent applications are only 3.8 and 1.9 respectively. Together, these patterns suggest that changes in IPR regimes led to more innovation by Indian firms.

The rest of the paper proceeds as follows: in the following section, we describe the background of the Indian IPR regime, in which the TRIPs Agreement came into effect in 2005. In Section 3, we describe our empirical strategy and the regression specification. Following this, section 4 discusses the two main data sources used in this paper, and then Section 5 discusses some basic trends in innovative activity during the sample period. In Section 6 we present our regression results. Finally, Section 7 concludes.

2 Background and Motivation

Due to deep political disputes over the role of patent protection in the country's developing economy, India was unable to enact its first independently-drafted patent laws for over two decades after its independence from British rule. India's controversial 1970 Patents Act was modeled on Great Britain's Patents Act of 1949 but the Indian Act incorporated major departures intended to lessen the social costs imposed by largely foreign-owned patents. The Patents Act of 1970 specifically prohibited *product* patents on "substances intended for use, or capable of being used as food or as medicine or drug" or "relating to substances prepared or produced by chemical processes (including alloys, optical glass, semi-conductors and inter-metallic compounds)", while allowing the *processes* for the making of such substances to be patentable for a short period of between 5 to 7 years. The terms of all other types of patents (for e.g., mechanical devices) was 14 years from the date of the patent. In shaping its first indigenous patents regime, India made a deliberate choice to stimulate domestic manufacturing and reduce the prices of products deemed "essential", such as food and medicines.

During the first three years of the Uruguay round of trade negotiations, India led the opposition to the inclusion of patent and intellectual property rights in a GATT accord. India and other developing countries viewed the GATT framework as a tool by which wealthy nations would impose strong IPRs as the cost of much needed access for the developing world to western markets. By 1989, India had reversed its anti-TRIPS stance and agreed to serious negotiations over patent protection, while arguing for special provisions to be made within the framework of TRIPs for developing countries. Upon its signing the Uruguay Agreement along with 116 other countries in 1994, India became a member of the WTO from January 1, 1995 and became obligated to amend its domestic IP laws. India was given ten years to implement its new laws.

The transformation of India's patent laws has thus far involved a three-stage process corresponding to the three acts amending the Patents Act of 1970. First, the Patents Amendments Act of 1999 resulted in the creation of a "mailbox" in India which allowed inventors to file patent applications for products invented after 1995. These applications were to be considered for patent protection at the end of India's ten-year transition period when product patents were to be brought into full effect. Second, the Patents Act of 2002 further amended the 1970 Act by providing the TRIPs-required twenty-year patent term, a reversal of the burden of proof for process patent infringement and modifications to compulsory licensing requirements. Lastly, India finally put product patent protection into full effect as of January 1, 2005.

Opponents of the TRIPs Agreement have often argued that the small market sizes of developing countries such as India would not provide adequate incentives for changing either the level or direction of total R&D expenditure, even under strong IPR regimes such as those in developed nations. At the same time, most of the patents on existing products would be held by giant firms in the world's most developed nations. According to such critics, in such a setting, the primary effect of increased IPR protection as stipulated by TRIPs would be increased prices in the short-run for patented products and a transfer of rents from developing countries to these foreign patent holders (Lanjouw (1997), McCalman (2001)).

Additionally, many researchers have questioned whether the patent system is an important mechanism for promoting innovation. The evidence on this question is mixed. Jaffe (2000) documents several studies that calls the value of stronger patents into question and notes that in the U.S., a substantial increase in R&D *preceded* the legal reforms that made U.S. IPR stronger. Kortum and Lerner (1998) conclude that strengthened IPR are unlikely to have been the primary cause of the spurt in U.S. patenting activity that began in the mid-1980's. Schankerman's (1998) empirical estimates of the value of patent protection and survey data by Cohen et al (1998) suggest that patents are relatively weak, imperfect instruments of appropriation, such that substantial increases in their strength might be insufficient to induce additional innovation. Sakakibara and Branstetter (2001) examine responses to the Japanese patent reforms of 1988 and find that even though reforms significantly expanded the scope of patent rights, there is no clear evidence of an in increase in either R&D spending or innovative output. In the context of India. Lanjouw and Cockburn (2000) use survey data from India, the results of interviews with industry and government and measures of R&D activity to determine trends in the allocation of research to products specific to developing country markets and find some limited evidence of an increase in the mid-to-late 1980s which leveled off after the 1990's. On the other hand, Mansfield (1986) sampled 100 firms in 12 US manufacturing industries on their views about whether patents are important in innovation and found that in pharmaceuticals and chemicals, where fixed costs are high and imitation is easy, the strength of patents played a decisive role in the decision to invest in R&D. Similarly, Evenson and Kumar (2001) and Chen and Puttitanum (2005) find positive effects of stronger IPR on domestic innovation.

The supporters of TRIPs argue that the post–TRIPs era could result in big differences in R&D expenditure because of a variety of reasons. The first of these is simply the standard direct effect of stronger IPR on the incentives to conduct R&D, that could exist because the market size in India is, in fact, large enough to attract such investment. For example, investment in innovative activities by domestic firms could increase if domestic firms are more likely to invest in products that have a specific relevance to India (such as cures for tropical diseases) or if domestic firms have sufficiently low selling and marketing costs in India, that would make their investment in R&D worthwhile.

Other pro-TRIPs parties argue that even if the market size in India alone is not large enough, because several trade-related privileges of the WTO were tied to the efficient implementation of the TRIPs Agreement for developing countries, a second mechanism through which we could observe an increase in R&D spending is that the WTO provided firms with access to larger markets, thus allowing firms to cover the high fixed costs of R&D. A large theoretical and empirical literature ties exporting status to increased spending on technology. For example, Yeaple (2005) shows that increased export opportunities make adoption of new technologies profitable for more firms. Using detailed firm-level data on spending on technology adoption, Bustos (2005) finds evidence of an increase in technology spending and skill intensity after trade and capital account liberalization in Argentina .

Third, the TRIPs and WTO were also responsible for attracting the entry of multinational and other foreign firms into India in large numbers and for improving trading relations between India and many developed countries.[2]This entry by R&D-intensive foreign firms and increased interaction with such firms through increased trade could lead to several sources of technological spillovers in the domestic economy, over and above any direct effects to invest in innovative activities by domestic firms. Such spillovers could take the form of externalities, whereby Indian firms upgrade their technology in order to absorb some of the benefits of a more knowledge-intensive atmosphere or technology could be explicitly transferred between foreign firms and their domestic affiliates or other domestic firms. For example, Branstetter et al (2006) examine how technology transfer within US multinational firms changed in response to a series of IPR reforms undertaken by 16 countries over the 1982-1999 period and find that royalty payments for technology transferred to affiliates increase at the time of reforms, as do affiliate R&D expenditures and total levels of foreign patent applications.

3 Empirical Strategy

3.1 The Basic Strategy

Comparing innovative activity by firms in India before and after India signed the TRIPs Agreement would lead to a biased estimate of the impact of patent reforms if other determinants of innovation were also changing systematically over time. We propose a solution to this problem that involves characterizing industries according to differences in their reliance on IPR protection and on innovation, and then comparing changes in innovative activity across industries based on this characterization. The basic idea here is that with the intro-

[2]A positive relationship of this nature between the strength of a country's IPR and the volume and composition of FDI is empirically established in a survey by Lee and Mansfield (1998) of about 100 US firms in six manufacturing industries. A link between IPR and trade is established by Maskus and Penubarti (1995) who estimate reduced-form equations for 1984 bilateral trade in manufacturing sectors for 22 exporting countries and 71 importing countries. They find that within the group of large developing countries, the strength of national patent laws exerted a significantly positive effect on bilateral manufacturing imports in many product categories with qualitatively similar although statistically weaker results for the group of smaller developing countries. Interestingly, Maskus and Penubarti find that the pharmaceuticals industry is particularly sensitive to patent rights for protecting innovation rents.

duction of a stronger IPR regime in India, some industries would be expected to increase their R&D expenditure more than other industries. A major part of this differential response is likely to be defined by "exogenous" or technological features of the industry that relate to how important it is to innovate in this industry.

We use data on R&D spending and innovation in the U.S. between 1990 and 1994 to try to capture the degree to which a given industry in India was "treated" by the TRIPs-induced IPR policy shock. Under the assumption that IPR protection and enforcement in the U.S. was "perfect' during this period, we assert that cross-industry differences in R&D spending and in rates of innovation in the U.S. reflect underlying technological characteristics that vary across industries and determine the incentives to innovate. Our strategy is similar to that in Rajan and Zingales (1998), wherein the authors use the extent to which an industry in the US uses external finance to construct a more general measure of an industry's financial dependence for a large sample of countries.

In our context, a natural industry-level measure of innovation-dependence is the R&D intensity - or the ratio of R&D expenditure to sales- of that industry in the U.S. Such a measure is based on the idea that in an environment of very strong IPR, U.S. firms endogenously solve for the profit-maximizing level of R&D expenditure, so that the ratio of R&D spending to sales reveals the importance of R&D spending in that industry.

Because not all innovation is patented and our policy change relates directly to the patentability of inventions, we also introduce a second measure that is directly connected to patenting activity across industries. This measure is the "patenting intensity" of an industry, which is calculated as the ratio of total patents granted to sales. Since patents can be thought of as the output of R&D spending, the two measures are closely related. However, in industries where methods other than patenting are traditionally used to protect innovation - such as marketing and branding - or where R&D spending largely reflects upgrading of existing facilities rather than investment in patentable inventions, the patent to sales ratio may be low even when the R&D to sales ratio is high.

Section 4.2 describes how we calculate these two measures from data on R&D and patenting by firms in the US. But given these measures of an industry's dependence on innovation and IPR, our estimation strategy is clear: if the TRIPs-induced IPR reforms increased the incentives to innovate for firms in India, then the post-TRIPs growth in spending on innovation should be higher in industries for which the values of these measures are higher.

Much of our empirical analysis depends on the validity of using firm-level data from the US as a proxy for "innovation-dependence" in India. The legitimacy of this strategy is best evaluated by considering the key components of the two measures of innovation-dependence that we derive from US data. In interpreting cross-industry differences in the ratio of R&D

to sales and patent-to-sales as measures of the relative importance of innovation across industries in India, we are basing our argument on a primarily supply-driven story. In other words, in our story, an industry's R&D-to-sales ratio and its patent-to-sales ratio capture industry-specific technological features that are fully uncovered only in environments with effective and strong IPR laws.

However, it is very probable that demand-side factors also play a role in determining both the proportion of total sales that a firm chooses to dedicate to R&D and patenting efforts. In this case, to the extent that the relative patterns of demand vary substantially across industries in the US and in India, we introduce potential measurement error into our measures.

We can respond to this criticism in several ways. First, it has been argued that because the economic size of developing country markets are small relative to the large fixed costs of R&D in most industries, developing country markets are unlikely to determine the size and direction of R&D.[3] Nevertheless, a large literature indicates that local strengthening of R&D should increase incentives to conduct R&D by firms operating in the region (Mansfield,1986). Together, these arguments imply that if TRIPs did provide a boost to the incentives to conduct R&D in India, we should expect much of this R&D to be driven by the needs of the more profitable markets in the developed world.

Second, according to a simple convergence story, we would expect India's patterns of domestic consumption and production to approximate those of more developed economies over time. Therefore, to the extent that firms can anticipate this convergence, we expect that they would sink more of their fixed costs of R&D into industries where they expect future growth to be high. To the extent that US markets serve as a more general proxy for developed economies, our use of US data seems appropriate from this point of view.

Finally, given the clear trends of increased R&D in post-TRIPs India for industries commonly known to be heavily dependent on innovation – such as the pharmaceuticals and other chemicals industries – it seems likely that TRIPs did, in fact, have an effect on R&D activities undertaken by local firms in India. Therefore, we believe that a somewhat noisy measure of innovation-dependence creates a bias *against* finding a more general effect of TRIPs on the incentives to conduct R&D in India.

3.2 Regression Specification

Our key regressions examine the effect of TRIPs by comparing changes in innovative activity across industries expected to be affected differentially by a strengthening of IPR. Let Y_j be a measure of the importance of R&D to industry j. If patent reforms cause more innovative activity in domestic firms, then we expect the impact of these reforms to be

[3] Chaudhuri et al. (2005), Dutta (2008), Lanjouw (1997).

increasing in Y_j. This can be tested by estimating a linear regression of the differences-in-differences type specification:

$$x_{ijt} = \alpha Y_j + \beta Post_t + \gamma Post_t * Y_j + \epsilon_{ijt} \tag{1}$$

Here, x_{ijt} is a firm-level outcome of interest and $Post_t$ is a dummy indicating if the observation is from a year following the IPR change. The coefficient of interest is γ, which measures how the change in outcome varies according to the industry-level IPR importance measure Y_j. For instance, if x_{ijt} measured firm R&D expenditure, then a positive estimate of γ would mean that the increase in firm R&D following TRIPs was greater in industries with higher Y_j. Under the identifying assumption that other factors affecting innovation were uncorrelated with $Post_t * Y_j$, this would indicate a causal influence of patent reforms on R&D.

In our main estimations, we use a more general version of equation 1, one that allows for common year effects and either industry or firm fixed effects. The year dummies control for shocks to x_{ijt} which are common to firms across all industries. Industry fixed effects control for all time-invariant differences across industries. Because we use an unbalanced panel of firms, these estimates reflect both within-firm changes as well as the within-industry changes arising from the entry and exit of firms from the panel. Estimates of the coefficient on $Post_t * Y_j$ from regressions with firm FEs are driven by the within-firm changes across pre and post TRIPs years, since the coefficient on the interaction term is identified off firms observed for at least one period each before and after the IPR reform. In our robustness analysis, we also try specifications that including 2-digit industry-specific linear time trends in addition to the interaction term.

In interpreting our results, it is important to keep in mind the staggered and uncertain nature of the formal process of IPR change in India, and the high likelihood that the changes in patent law were anticipated by Indian firms. No one year in particular can be claimed to be an IPR policy "shock" year, and our approach is to simply designate the first formal indication of a change in patent law as the first "Post" (or "shock") year, while allowing for subsequent policy "shocks". Our main specification focuses on India's signing of the TRIPs agreement in 1994, which is represented by the "Post" dummy indicating all post-1994 years, $Yr94$. But to the extent that Indian firms responded before 1994 in anticipation of the agreement, the coefficient on $Yr94_t * Y_j$ underestimates the response to IPR changes.

Some regressions include two other "Post" dummies- a dummy equal to one for years 2000 and later, which corresponds to the passing of the Patents (Amendment) Act of 1999, and a similar dummy corresponding to the 2002 Patents Amendment Act. We stress that these dummy variables are meant to be the formal markers of a lengthy reform process, and should not taken for unanticipated policy shocks. It is likely- and this is what the additional

"Post" dummies would pick up- that the R&D response to these reforms was a gradual but consistent divergence across industries.[4]

4 Data

4.1 Indian Firm Level Data

Our primary source of firm-level data on R&D expenditure and foreign royalty payments is Prowess, a comprehensive database of Indian firms that is maintained by the Center for Monitoring the Indian Economy (CMIE). Prowess contains detailed information on over 5000 firms, including all companies traded on India's major stock exchanges and several other firms, such as the central public sector enterprizes, for the period 1989-2006.

The database covers most organized industrial activities, banking, organized finance and other services sectors in India. The firms in Prowess account for 75 per cent of all corporate taxes and over 95 per cent of excise duty collected by the Government of India. Prowess provides detailed information on each company's production, sales and expenditure as well as financial information such as share prices, dividends and other gains.

Because smaller Indian firms are generally not publicly-traded, the firms in the Prowess database are mostly "medium" or "large" in size by Indian standards, constituting a small fraction of the total number of Indian firms, but a very large share of the total revenue. According to the Indian Annual Survey of Industries (ASI), India had more than 100,000 registered manufacturing plants in 2000. The Prowess database contained 5250 companies in the same year, many of which were multi-plant. But the Prowess companies had a total revenue of Rs. 9 trillion, which was nearly 90% of the combined revenue of all registered manufacturing units.[5]

Table 2 summarizes the Prowess data over two periods, 1989-1994 and 1995-2005. During the first period, a total of 3016 unique companies existed (for at least one year each) in the Prowess data set, with average annual sales, in year 2000 prices, of Rupees 1.5 billion, or about 38 million USD.[6] These firms, on average, spent Rs. 1.5 million annually on R&D and Rs. 3.1 million on foreign royalties, while earning Rs. 5 million in exports. During the second period, the total number of unique Prowess firms increased to 5252 firms, with

[4] Moreover, unlike some differences-in-differences studies, we cannot be certain a priori that the adjustment to the new policy regime would be over before 2005, our last year of data. Therefore, we cannot examine if the differential growth in R&D spending ceased, as one might expect if it were a response to the IPR changes, some years after the end of the reforms.

[5] These figures are based on the authors' own calculations using the 2000-01 Annual Survey of Industries and Prowess data.

[6] In 2000, the Rupee-Dollar exchange was 45 Rupees to a Dollar. We have deflated all monetary values in our Prowess data to constant year 2000 prices using the Indian Wholesale Price Index.

mean sales, in year 2000 prices, at Rs. 1.8 billion, R&D spending at Rs. 5 million, and foreign royalty payments at Rs 3.8 million. Thus, annual R&D spending during 1995-2005 was more than three times of that during 1989-1994, while there was a 38% increase in the number of firms reporting positive R&D spending between the two periods.

4.2 U.S. Firm and Patent Data: Measures of Innovation-Dependence

For our measure of the "intensity" of R&D in U.S. industries, *RnDIntensity*, we used Compustat, a large US firm-level data set.[7] The variable *RnDIntensity* is calculated using the ratio of total R&D spending and revenue during 1990-94 at the 4-digit industry level. All the firms in the 1990-94 Compustat universe, including those with zero reported R&D expenditure, were included in this calculation.

The second related measure of innovation-dependence was created by matching industry level data on sales from Compustat to data on US patents. The data on patents is from the NBER Patent Data File which comprises detailed information on all patents granted in the U.S. between 1963 and 1999. The measure of innovation-dependence derived from the patent data is *PatIntensity*, the ratio of the total number of patents granted between 1990-1994 and the total sales of the industry calculated at the 4-digit industry level.

Table 3 lists industries in descending order of average *RnDIntensity* for 2-digit NIC groups. The average value of *RnDIntensity* ranges between 0.076 (for radio, television and communication equipment) and 0.0002 (for mining of metal ores). Other highly R&D-intensive industries include office and computing machinery, medical and precision instruments, and chemicals and chemical products. One fact to be noted here is that *RnDIntensity* is calculated at the 4-digit industry level and there is some degree of heterogeneity in the values of *RnDIntensity* within the same two-digit industry group. For example, the average value of *RnDIntensity* for chemicals and chemical products is 0.039, which places it fourth on the list of two-digit industries in Table 3, but its constituent sub-category of pharmaceuticals products has the highest value of *RnDIntensity* across all 4-digit industries at 0.09.

Table 4 lists the same industries in descending order of average *PatIntensity* for 2-digit NIC groups. The variable *PatIntensity*is the ratio of the number of patents granted to an industry divided by its total sales (in million USD). The two-digit average for this measure varies between 0.098 (for radio, television and communication equipment) and 0.0007 (for mining of coal and lignite).

Because *PatIntensity* and *RnDIntensity* are highly correlated (the correlation coefficient at the 4-digit level is 0.64), the rankings of industries in Tables 3 and 4 are very similar. The mining and tobacco industries have both low rates of R&D and low rates of patenting

[7]Compustat is the data set of all firms traded in the U.S. stock market.

while communication equipment, chemicals, computing and other machinery place high on both the R&D-intensity and patent-intensity lists. However, a comparison of the two tables demonstrates some minor differences between the two measures. For example, the chemicals industry is ranked second according to the patent-based measure but fourth according to the R&D-based measure, highlighting the relative significance of patenting in the chemicals industries.

5 Preliminary Analysis

5.1 Summary Statistics by R&d Intensity

Table 5 previews our regression analysis by comparing summary statistics across the pre and post-TRIPS periods and across "high" and "low" *RnDIntensity* industries- that is, those above and below the median values of *RnDIntensity*. As the table shows, annual firm sales, though highly dispersed, is on average *higher* in the "low" *RnDIntensity* industries in both periods. So are the median values of firm sales, although to a smaller extent. Mean and median firm sales increase in both groups after 1994, and going by the medians, this increase is of comparable magnitudes in the two groups. So is the increase in the number of firms between 1989-94 and 1995-2005.

In contrast to these sales statistics, firms in "high" *RnDIntensity* are *more* likely to be spending on R&D, and more significantly, the post-1994 increase in mean R&D spending and the likelihood of R&D spending is clearly higher in the "high" *RnDIntensity* group. The mean R&D spending in a "low" group firm increases by about 155%, while that in a "high" *RnDIntensity* firm increases by 250%. In the post-1994 period, 37% of the "high" group firms report non-zero R&D spending, in contrast to just 22% of the "low" group firms.

5.2 Trends in R&D, Sales, Firm Entry, Trade and Patenting

The first panel of Figure 1 contains a graphical exposition of our main result. It shows the levels of average industry R&D spending of the 13 2-digit industries that are above the median values of *RnDIntensity* and that of the 13 industries that are below this median. As displayed in the graph, the R&D expenditure of the "high" industries is growing steadily throughout the early 1990's, rises sharply around 1996 but experiences a temporary drop for the next 3 years and then starts to increase again at an unprecedented rate around the year 2000. The R&D expenditure of the "low" industries displays no such trend and levels off around the same time. The average industry R&D spending in "high" industries is higher both in terms of the levels of R&D and the rate of growth.

In the second panel of Figure 1, we plot the trajectories of average industry sales during the same period for the two categories of industries. In the "high" industries, both the level and the rate of growth of average industry sales is lower than that for the "low" industries throughout the sample period. Moreover, particularly for the "high" industries, there appears to be no significant differences in the growth rate of industry sales between the pre-TRIPs and the post-TRIPs periods. While sales is clearly an imperfect proxy for exogenous demand conditions, to the extent that it can serve as such a proxy, the sales graphs of the two categories of industries indicates that increases in R&D spending are not entirely driven by underlying changes in demand.

Figure 2, which plots R&D to sales ratios, highlights this relationship between R&D and sales in the two categories of industries. While for the "low" industries, this relationship is essentially flat or even decreasing in the post-TRIPs period, for the "high" industries, this relationship has a noticeable upward trajectory from 2000. Interestingly, the average value of the variable $RnDIntensity$ for the "high" industries is 0.036. This implies that in the US, the average R&D to sales ratio for the 13 "high" industries between 1990 and 1994 was approximately 3.5%. Figure 2 shows that even at its highest, the average R&D to sales ratio for the corresponding industries in India is well below this mark and does not rise above 1%.

Figure 3 plots the growth in the number of firms with low and high values of $RnDIntensity$. It is important to note here that the relationship between the number of firms and R&D spending is fairly complicated. While greater potential for growth in traditionally more R&D-intensive and IP-heavy industries may have increased entry into such industries in the post-TRIPs era, the increasing importance of the high fixed costs of R&D in such industries may have served as a barrier to such entry. In addition, the entry of firms may itself influence R&D by introducing greater competition. The first panel of Figure 3 shows that while the absolute number of firms in the average high industry is larger than that in the average low industry, there is not much difference in the growth in firms between the "high" and "low" industries throughout the sample period.

In the second panel of Figure 3, we plot the growth in the number of foreign firms. It could be argued that foreign firms represent superior competition and induce greater R&D spending through this channel. It is clear from the graph that both in the pre-TRIPs and post-TRIPs periods, the number of foreign firms in India was greater for the "high" industries. The graph also shows that between 1989 and 2001, the number of foreign firms increases at a slightly faster rate in the "high" industries as compared to the "low" industries. However, there is an equally steep fall in that number in the later years such that the average number of foreign firms in a "high" industry is lower in 2005 than it was in 1995 . For the "low" industries, the number of foreign firms increases for most of the sample period, albeit at a slower rate, and there are more foreign firms in the average "low" industry in 2005 as compared to 1995.

Figures 4 and 5 address the potential relationship between trade and R&D spending by considering the trends in trade policy during the sample period. The 1990's saw many changes in trade policy, particularly the reduction of export tariffs faced by Indian producers abroad and in import tariffs faced by foreign sellers in India. The reduction in export tariffs may represent increased access to larger markets for domestic producers, potentially encouraging domestic R&D spending. The reduction in import tariffs may represent increased competition in product markets in India, which could also potentially increase domestic R&D spending. In the first panel of Figure 4, we see the export tariffs for the "high" versus "low" industries while in the second panel, we see the value of exports in the two sets of industries. It is clear from the first panel that while export tariffs decreased in both the "high" and "low" industries, export policies did not significantly favor one group of industries over another. The second panel of Figure 4 shows that the pattern of changes in exports resembles that of the cuts in tariffs, making export tariffs a good proxy for changes in policy.

Similarly, Figure 5 captures trends in import tariffs and the value of imports. The first panel shows that the sample period saw steady decreases in import tariffs for both groups of industries, and the second panel shows that imports responded to these tariff cuts by rising steadily throughout the period. Importantly, the changes in import tariffs do not appear to be correlated with the type of industry in terms of its dependence on R&D.

Increases in R&D spending should eventually show up in measures of the output of R&D, such as patents. Figure 6 considers the trends in successful patent applications granted between 1989 and 1999. The industries are once again broken up into "high" and "low" groups, and the three panels represent the average number of patents granted in each of these two industry groups to firms in India, the U.S. and three Western European countries respectively. In contrast with India, the U.S. and the three Western European countries already had strong IP protection in place before TRIPs and were, therefore, relatively unaffected by it. The graph shows a sharp increase in the number of patents granted to Indian firms in the "high" industries. Patents granted to the "low" industries also increases, but this increase is not as pronounced as that found in the "high" group. For both U.S. and the three Western European countries, patents granted in the "high" industries increases relative to that in the "low" group in the post-TRIPs period, but the increase appears to be less dramatic than the corresponding increase for India.

6 Results

6.1 Main Results: Differential Response to IPR Changes

Our main regressions estimate equation 1, where we use firm-level data for 1989-2005, with the logarithm of the annual R&D spending as the outcome variable X_{ijt}. As our main explanatory variable, we use the interaction between a post-TRIPs dummy variable ($Yr94$) and the R&D to sales ratio calculated at the four-digit industry level from US Compustat data for 1990-94 (*RnDIntensity*). As described in a previous section, because the US represents an environment of strong IP protection, the R&D to sales ratio in the US proxies for the underlying technological dependence of an industry on R&D. In some specifications, we use the patents to sales (*PatIntensity*) ratio as the measure of the importance of innovation to an industry.

The regressions include a full set of year dummies (which absorb the coefficient on $Shock_t$) and industry or firm fixed effects (which absorb the coefficient on Y_j). The purpose of the interaction term $Yr94 * Y_j$ is to measure how the proportional increase in R&D spending between 1989-94 and 1995-2005, varied by Y_j, the "innovation intensity" of an industry.

Tables 6 presents our key results on R&D spending: the proportionate increase in expenditure on R&D after 1994 was systematically higher in industries that had higher R&D to sales ratios (or patents to sales ratios) in the United States. Column (1) presents OLS results from regressing the logarithm of R&D on 16 year dummies and 121 industry dummies, and an interaction of $Yr94$ with $RnDIntensity$. The estimated coefficient on the interaction term has a value of 4.67, and it is significant at the 5% level. This estimate implies that the average change in annual firm R&D spending, before and after 1994, was roughly 9 percentage points higher in an industry with a one standard deviation higher value of *RnDIntensity*.[8]

The industry FE estimates in column (1) reflect within-industry changes, since the interaction of $Yr94$ with $RnDIntensity$ picks up not only the within-firm changes in R&D spending after 1994, but also the effects of any post-1994 firm entry on average firm R&D in an industry. Here it may be significant that the early 1990s in India saw major changes in industrial policy that are claimed to have had large effects on the entry and expansion of firms (Aghion et al., 2007). This is evident in Figure 3, which shows a marked increase in the number of Prowess firms in the early 1990s, in *both* high and low $RnDIntensity$ industries. If young firms- even those that intend to innovate- start off at low levels of R&D spending, then in the short run firm entry by itself would *lower* average firm R&D spending in an industry. In our context, the high rate of post-1994 firm entry, which appears to be

[8] $RnDIntensity$ has a standard deviation of 0.02.

similar across high and low *RnDIntensity* industries, could have reduced the estimated post-1994 divergence in R&D spending across industries. In addition, R&D spending could be influenced by a number of firm-specific factors, many of them unobservable, which are not accounted for in the above specification.

This suggests that measures of within-firm changes would be more reliable indicators of the impact of patent reforms. So in column (2), we replace the industry dummies with firm fixed effects. Now the coefficient on the interaction of $Yr94$ with $RnDIntensity$ is identified off firms observed at least once in both pre-1994 and post-1994 periods. The estimated coefficient on the interaction term is markedly larger -18.9- and it is significant at the 1% level. This number implies that the within-firm increase in annual R&D spending in the post-TRIPs period was on average about 37 percentage points higher in an industry with a one standard deviation higher value of *RnDIntensity*. Additionally, the fact that the estimated coefficient with firm fixed effects estimate is larger that that with industry fixed effects indicates that the post-1994 entry of firms and firm-specific unobservables that influence R&D spending dampened the post-1994 divergence in average firm R&D expenditure. In the rest of this paper, the reported results will correspond to firm fixed effects, and we note now that like the first two regressions, our industry FE estimates are in general smaller but of the same sign as the corresponding firm FE estimates.

Next, in column (3) of Table 6, we interact $RnDIntensity$ with two additional "Post" dummies representing the subsequent IPR policy changes, $Yr99$ and $Yr02$ (respectively, dummy variables for the years 2000-2005 and 2003-2005). Thus, in this specification, each successive period dummy picks up a cumulative effect over the previous one. While the coefficient on the interaction of $Yr99$ with $RnDIntensity$ is not statistically significant, that on $Yr02 * RnDIntensity$ is positive and significant at 1% level. This implies that the cross-industry divergence in R&D spending, which began around 1994, widen further after 2002, the year in which an additional Patents Amendment Act was passed. The coefficient on $Yr94 * RnDIntensity$ implies that the increase in annual firm R&D spending in an industry with a 1 standard deviation higher value of *RnDIntensity* between the pre-TRIPs period and its immediate aftermath (i.e. 1995-2002) was about 34 percentage points. The coefficient on $Yr02 * RnDIntensity$ implies that subsequent phases of IP reform (in this case, the 2002 Patent Amendenment) led to an additional increase of about 10 percentage points in R&D spending. This pattern is thus consistent with the step-wise nature of the formal patent law reform process.

Columns (4) and (5) use *PatIntensity*, instead of *RnDIntensity*, to characterize the extent to which innovation matters in an industry. The results are similar to and reinforce previous results: industries with higher values of *PatIntensity* saw a larger increase in R&D spending after 1994 and 2002. In column (4), in a regression analogous to that presented in column (2), the coefficient on $Yr94*PatIntensity$ is equal to 7.7 and is significant at the 5% level. This number indicates that the post-1994 increase in annual firm R&D spending was on average about 27 percentage points higher in an industry with a 1 standard deviation higher value of *PatIntensity*.[9] In column (5), as in column (3), the coefficients on both $Yr94 * PatIntensity$ and $Yr02 * PatIntensity$ are positive and statistically significant.

6.2 Robustness Checks

A potential concern with our econometric specification is that differences-in-differences estimators using multiple years of before and after data on a policy change can underestimate the standard errors on the treatment effect, if errors are serially correlated (Bertrand et al., 2004). A common approach to addressing this problem is to allow for arbitrary correlations within appropriate groups. Our results are robust to different clustering schemes, and in particular, all our regression results that use annual data report robust standard errors that allow for arbitrary correlation within 4-digit industries.[10] We have also tried another suggested solution (Bertrand et al., 2004), which is to ignore the time-series by collapsing the data to two periods, one before and one after the policy change. We present these results in columns (1)-(4) of Table 7, with each column corresponding to one of the annual data regressions shown in columns (2)-(5) of Table 6.

For example, column (1) in Table 7 corresponds to the second column of Table 6: the annual data have been collapsed to two periods, 1989-1994 and 1995-2005, by taking within-firm means in each period, and the logarithm of firm R&D in these periods is regressed on two period dummies, firm fixed effects and an interaction of $RnDIntensity$ with the dummy for the post-1994 period. The second regression in Table 7 corresponds to that shown in column (3) of Table 6, since here the data have been collapsed to four periods- 1989-1994, 1995-1999, 2000-2002 and 2003-2005, and $RnDIntensity$ is interacted with all three post-1994 period dummies. The next two columns repeat the exercise with $PatIntensity$.

These estimations on collapsed data yield a pattern of positive and significant interaction affects that are similar to those in the previous table, indicating that our main results are robust to serial correlation. The coefficients on the interactions of either $RnDIntensity$ or $PatIntensity$ with the post-1994 period dummy are positive and significant, as are their interactions with the post-2002 dummy. Their values are lower than those estimated in Table 6. For example, a 1 standard deviation increase in $RnDIntensity$, is now estimated to affect R&D growth by 27 percent points (Column 1).[11]

In estimating $RnDIntensity$ and $PatIntensity$ by averaging U.S. firm data for 1990-94,

[9] The variable *PatIntensity* has a standard deviation of 0.035 across 4-digit industries.

[10] In general, this clustering scheme increases our estimated standard errors compared to no clustering or other clustering schemes.

[11] This could be related to the non-linearity of the log function.

we hope to have captured the stable measures of the dependence of an industry on R&D and patenting. But it is possible that these averages also pick up the effects of shocks or recent trends in R&D activities. For example, high $RnDIntensity$ as measured for 1990-94 could reflect early 1990s advancements in basic technology that stimulated commercial R&D. If the same trend were also affecting R&D spending in India, we would misinterpret it as the response to patent reforms. To check against this possibility, we developed alternate $RnDIntensity$ and $PatIntensity$ measures by averaging Compustat's U.S. firms data for older periods, going as far back as 1975-80. We found that irrespective of the lag on the $RnDIntensity$ and $PatIntensity$ measures, our core results stayed the same.

In the last two columns Table 7, we re-estimate our basic regressions, with $RnDIntensity$ and $PatIntensity$ measured using firm-level data from the US for 1975-80. In both regressions, the estimate of the coefficient on the interaction of the lagged innovation intensity measure with the shock dummy is positive and significant. The estimated magnitudes of the interaction effects are identical to those in the corresponding columns ((2) and (4)) of Table 6. A 1 standard deviation increase in $RnDIntensity$ constructed with 1975-80 data is estimated to increase post-1994 R&D growth rate by 36 percent points, and the corresponding differential effect of 1975-80 $PatIntensity$ is 24 percent points.[12] Thus, it is clear that our original measures of $RnDIntensity$ and $PatIntensity$ using data from 1990-94 represented the stable, long-term dependence of an industry on innovation.

As seen in Tables 6 and 6, both measures of the innovation intensity of an industry- the R&D/Sales and the Patents/Sales ratios- give the same basic results. This is also true of the regressions estimated in the rest of the paper, and for the sake of economy, we report results only from the specifications which use *RnDIntensity* as the measure of the importance of innovation in an industry.

6.3 Other Policy Developments

In addition to the more general aspects of TRIPs that affected the entire economy, the IPR reforms in 1994 included an additional provision for chemicals, drugs, agrochemicals and food processing industries. This was the mandatory introduction of product patenting in these industries. Column (1) of Table 8 investigates whether these additional reforms had any independent effects by adding to our basic specification interactions of $Chem$-a dummy for chemicals, drugs, agrochemicals and food processing- with the $Yr94$ dummy. This inclusion does not affect the coefficients on $RnDIntensity*Yr94$ and $RnDIntensity*Yr02$. This shows that our results reflect broader IPR reforms and are not driven by chemicals or drugs industries alone. The coefficient on $Chem*Yr94$ itself is not significant; perhaps

[12]The lagged *RnDIntensity* and *PatIntensity* measures have standard deviations of 0.01 and 0.04, respectively.

because the chemicals and drugs industry group also has the highest value of U.S. R&D intensity, our analysis cannot tease apart any potential additional effects of product patent laws in these industries from those of the more general package of IP reforms.

The rest of Table 8 deals with the potentially confounding effects of major trade and industrial policy reforms in India. A balance of payments crisis in the early 1990s in India led to a period of wide-spread economic liberalization. Owing to this dramatic economy-wide change, one concern with our interpretation of the results in Table 6 is that the differential patterns in R&D growth could be related to other policy changes. In particular, many industries were deregulated by removing "licensing" requirements on the entry and expansion of firms, foreign direct investment restrictions were lowered, and trade barriers were lowered for a large set of products. It is possible that by increasing the intensity of competition between firms, these policy changes altered domestic incentives to invest in R&D .

In 1991, India began to slash tariff and non-tariff barriers to imports in most industries. The magnitude and exact timing of the tariff change varied markedly across industries, and while there is evidence that these changes are not strongly correlated with baseline industry characteristics such as productivity, size and capital intensity (Topalova, 2007), we would want to confirm that our results are robust to changing tariff rates. This is necessary because of the growing evidence that industrial productivity in developing countries rises in response to trade liberalization (Tybout, 2000).

An additional source of complication is the fact that the TRIPs agreement was formed in conjunction with the World Trade Organization (WTO). The WTO involved a commitment by developed nations to lower trade barriers to developing countries, if these countries complied with the obligations to strengthen IPR, in the manner stipulated by TRIPs. Because the prospect of access to larger markets can induce firms to invest more in innovation, this lowering of trade barriers arouses concern that our results could have been influenced by differential changes in access to foreign markets.

Another major policy change was "delicensing", or entry liberalization. The Industries (Development and Regulation) Act of 1951 required registered manufacturing units to obtain, through an onerous process, licenses to establish new factories, expand capacity, change product lines or plant location (Aghion et al, forthcoming; Chari, 2008). In 1985, the Indian government began the process of removing these controls by delicensing about a third of industries. Most of the remaining industries were delicensed in 1991, and there is evidence that these industries saw increased firm entry and productivity in states with pro-employer labor regulation (Aghion et al, forthcoming). Although fewer than 10% of industries were delicensed between 1994 and 2000, deregulation might have a delayed impact on innovation, and industries delicensed in 1991 might have seen an increase in R&D

spending in the late 1990s.

There is also the possibility that the observed R&D patterns reflect *heterogenous* industry-specific response to trade and industrial policy reforms. Suppose the R&D intensity of an industry is correlated with other industry characteristics that predict the degree to which an industry responds to increased competition or new market opportunities. Then even if the extent of tariff reductions or delicensing were uniform across industries, the response to these changes would vary by *RnDIntensity*, and this would be mistaken for a differential response to patent reform. In other words, $RnDIntensity * Yr94*$ could be correlated with the unobserved, heterogeneous effects of tariff reductions or delicensing.

The regressions presented in columns (2)-(6) of Table 8 address these concerns by adding appropriate controls to the regressions shown earlier in Table 6. We control for changes in export barriers by including as a regressor annual industry-level import barriers in India's export destinations. To take into account domestic import liberalization, we use annual industry-level data on import tariffs in India as a control. We control for delicensing by including a dummy that is equal to one for an industry in the years following the removal of license controls on that industry. To deal with the possibility of heterogeneous effects of tariff reductions or delicensing, we also estimate regressions that allow these policy developments to have had a differential response across high and low *RnDIntensity* industries. We do so by including *interactions* of *RnDIntensity* with tariff and delicensing measures in the set of controls.

First, in column (2) we add an interaction of a dummy for majority foreign ownership with the post-1994 dummy to the set of regressors. This is to check against the possibility that the observed differential in R&D growth is driven by R&D intensification in foreign owned firms following FDI liberalization.[13] The result shows that foreign owned firms increased R&D more than domestic firms- the coefficient on $Foreign * Yr94$ indicates that the post-1994 R&D growth was more than 100 percent points higher in foreign owned firms. However, this does not affect the coefficients on our main explanatory variables, the interactions of *RnDIntensity* with the shock dummies. The finding that foreign-owned firms stepped up R&D more than other firms is not surprising - for example, foreign-owned firms might respond more because they have better access to financing or to a superior initial R&D base. Importantly, this finding does not contradict the hypothesis that local strengethening on IP laws increased R&D spending in India. The essential point to be noted here is that neither foreign nor domestic firms may have willing to step up their R&D efforts in India without the promise of the stronger IPR.

Next, column (3) of Table 8 takes into account the effects of trade policy by including

[13]Note that because of the firm fixed effects, any entry of foreign firms *after* 1994 could not be driving our results.

annual industry-level import tariffs in India (*InTariff*) and a weighted mean of industry-specific tariffs in India's export destinations (*ExTariff*). In calculating the latter, for each 4-digit industry, year-wise import tariffs[14] in foreign countries were weighted by that destinations's share in Indian exports for that industry in 1989. The core regression results are unaffected by these additions, which is perhaps not surprising, given that changes in domestic and foreign import tariffs in the 1990s were roughly similar across high and low *RnDIntensity* industries. The coefficients on *InTariff* and *ExTariff* are statistically not significant.

Column (4) adds a dummy for post-delicensing years to the set of explanatory variables; this too does not affect the size and significance of the coefficients on the interaction of *RnDIntensity* with the shock dummies. The coefficient on the delicensing dummy is not significant, which suggests that firms in delicensed industries did not have significantly higher R&D spending in post-delicensing years.

The regression presented in column (5) addresses the possibility of heterogeneous effects of tariff reductions and delicensing by including interactions of *RnDIntensity* with tariff and delicensing measures in the set of controls. The results are interesting: first, the estimated coefficient on *RnDIntensity**InTariff* is negative and significant, indicating that lower import tariffs raised R&D spending relatively more in higher *RnDIntensity* industries. The estimates imply that for a 1 percent decline in the import tariff, the growth in R&D spending is 0.5 percentage points higher in an industry with a 1 standard deviation higher value of *RnDIntensity.* This suggests that import competition encourages firms to innovate, and more so in more innovation dependent industries. The second notable result in column (5) is that the estimated coefficient on $RnDIntensity{*}Delicensed$ is positive and significant, implying that some of the divergence in R&D spending in the 1990s was the outcome of entry and expansion. The estimates show that compared to an industry that was not delicensed, the post-delicensing growth in R&D spending was nearly 35 percentage points higher in an industry with 1 standard deviation higher value of *RnDIntensity.* This indicates that firms in innovation-intensive industries respond to the threat of entry by stepping up R&D efforts.

Column (5) also shows that including interactions of *RnDIntensity*with tariff and delicensing measures in the set of controls lowers the estimated values of the coefficients on the interactions *RnDIntensity* with $Yr94$ and $Yr02$, although they remain statistically significant as before. This suggests that not accounting for potentially heterogenous impacts of trade and industrial policy changes gave us an overestimate of the effect of IPR reforms on R&D spending. In this more cautious estimate, which we prefer to that in Table 6, the effect of a 1 SD increase in *RnDIntensity* on post-1994 R&D growth is closer to 20 percentage

[14] Adjusted for non-tariff restrictions through tariff equivalents.

points.

Lastly, column (6) does a specification check by including 2-digit industry specific time trends to the set of control variables. The concern being addressed here is that the coefficients on the interactions of *RnDIntensity* with the post-1994 dummy could be picking up differential R&D trends (potentially generated by underlying demand conditions) across broad industry groups in the 1990s. Comparing the estimates to those in column (5), it is apparent that key coefficients are unaffected, so that our estimate of post-1994 differential R&D spending growth is robust to allowing different linear time trends in different industry groups.

6.4 Survey-based Measure of IPR Importance

So far, we have relied on indirectly inferring the importance of patenting and innovation by observing R&D and patenting in U.S. firms. The Yale Survey on *Industrial Research and Development* (Levin et al., 1987) asked U.S. R&D executives from over 1500 businesses to describe and rate various mechanisms, including patents, for appropriating returns from R&D. Cockburn and Griliches (1987) used these data to construct industry-level measures of the effectiveness of patenting in appropriating the returns from R&D. To the extent that these measures reflect industry-specific technological features of the R&D process that are common across countries, they should also predict cross-industry variation in the response of Indian firms to IPR strengthening. Just like with *RnDIntensity* and *PatIntensity*, R&D growth should be higher in industries whose managers gave higher average ratings to patents as a means of appropriating R&D returns in the Yale Survey.

Using the Yale survey measures in place of *RnDIntensity* or *PatIntensity* involves tradeoffs, because although the survey tried to directly elicit the overall importance of IPR to R&D, the managers' responses, like other perception-based ratings, might not be comparable across industries. Moreover, the survey was fielded across a limited number of industries, and the industry identifier used in the survey is based not on a standard industrial classification but on a "line of business" classification. After recomputing these measures at the 4-digit NIC level using the industry group descriptions given in Cockburn and Griliches (1987), we were able to calculate survey response values for only 69 of the 120 4-digit NIC industries that feature in our regressions.[15]

Table 9 presents results from regressing R&D spending on $Yr94$ interacted with the Yale Survey measures of the importance of patenting to R&D that Cockburn and Griliches (1987) construct. The variable PPP is based on responses to "do process/product patents prevent

[15]The industry averages of the measures derived from the Yale Survey are presented in Table C2 in Cockburn and Griliches (1987). They matched the Yale survey respondents to a self-devised industry scheme, based on the U.S. SIC, which is close to but in general coarser than the 4-digit NIC scheme.

competitors from duplicating inventions?". If stronger IPR encouraged domestic R&D in India, then we expect the post-1994 increase in R&D spending to be increasing in PPP. This does appear to be the case, and the results presented in Table 9 are weaker than but consistent with previous results. In column (1), where the specification corresponds to that in columns (2) and (4) of Table 6, the estimated coefficient on $PPP * Yr94$ is positive and close to 10% level of significance, while in column (2), where PPP is also interacted with $Yr99$ and $Yr02$, the coefficient on $PPP * Yr99$ is positive and significant at the 5% level. In column (3), we add an interaction of $Yr94$ with NPP, a measure of the effective of *non-patent* measures to protect inventions, and find that controlling for the effectiveness of patenting (as measured by PPP), the post-1994 growth in R&D was falling in NPP. Next, columns (4) and (5) verify that like our results on $RnDIntensity * Yr94$ and $PatIntensity * Yr94$, the $PPP * Yr94$ result is robust to a specification in which the firm level data have been collapsed to two periods- before and after 1994.[16]

6.5 Domestic Market Size Effect

Patents help in appropriating the returns from private R&D by assigning a monopoly right to the inventor. Thus, the larger the market that could potentially be captured by this monopoly, the greater the incentive to work towards a patentable innovation.[17]To the extent that investment in R&D by local firms in India is geared towards developing patentable innovations for the local market, stronger IP *in India* could matter more in industries where the size of the local market is larger. Moreover, since India is a low-income country, its demand structure is likely to be different from that of the U.S., and it is possible that two industries with the same R&D intensity in the U.S. have very different domestic market sizes in India. To the extent that US-based measures of $RnDIntensity$ reflect demand-side factors that are specific to the US and not applicable to India, accounting for initial differences in market sizes in the two countries may reduce measurement error.

We test this in Table 10, where we add interactions of $RnDIntensity * Shock$ with $Dmarket$ to our basic specification. $Dmarket$, which serves as a proxy for the size of the potential domestic market represented by each industry, is India's industrial output less net exports in each 4-digit industry in 1990.[18] Column (1) uses one shock dummy, $Yr94$, while column (2) also includes $Yr99$ and $Yr02$ dummies, and column (3) the full set of control variables that were featured in last column of Table 8. We find that in all the specifications,

[16]We get similar results by using alternative measures of patent importance, similar to PPP, that are presented in Cockburn and Griliches (1987).

[17]Market size is a determinant of equilibrium R&D intensity in most theoretical models of R&D investment, such as Kortum (1993).

[18]Source: Industrial output is from the Annual Survey of Industries, and import-export data is from COMTRADE.

the estimated coefficient on the interaction of $RnDIntensity * Yr94$ with $DMarket$ is positive and significant at the 1% level, which indicates that the impact of $RnDIntensity$ on the post-1994 growth in R&D spending was significantly higher in industries with higher domestic consumption in 1990. For example, the estimates from column (1) imply that the coefficient on $RnDIntensity * Yr94$ increases from about 5 to 11 as the domestic market size increases from the 25th to the 75th percentile of its distribution across industries. This result is consistent with the idea that the larger the size of the initial market in India, the more relevant would U.S. $RnDIntensity$ be in predicting the post-1994 R&D growth in India.

6.6 Patenting by Indian Innovators

The increased R&D spending by firms in India documented in the preceding sections could be directed towards major, patentable innovations or towards minor upgrades of technology.[19] The former kind of R&D spending is more likely to create greater long-term economic gains for the local economy. Therefore, more light can be shed on the economic effects of TRIPs in India by analyzing the extent to which the patterns of R&D spending correlate with patterns of patenting by firms in India.

In this section, we use information from the NBER Patent Database on all successful U.S. patent applications between 1989 and 1999 to examine if the post-TRIPs era saw an increase in the total number of successful patents by India. In particular, we test whether patenting by Indian inventors rose relative to developed countries where TRIPs involved relatively minor changes to IP laws, and if this increase was greater in more innovation-dependent industries.[20]

To make this analysis comparable to our examination of R&D spending, we would like to measure patents by NIC industry groups. However, U.S. patents are categorized into U.S. "patent classes", which are distinct from industry groups, and there is no standard mapping between these classes and 4-digit ISIC or NIC industry groups. Moreover, the data on patenting by Compustat firms show that firms in the same 4-digit NIC group hold patents across several U.S. patent classes, suggesting that a mapping from patent classes to broader 2-digit NIC groups would be more realistic.

We first used the NBER patent data to calculate, for each patent class, the number of patents granted annually between 1989-1999 to inventors from India, the United States and three Western European countries- Britain, France and Germany. In contrast with India, the comparison group- the U.S. and the Western European countries - had strong

[19]For example, Branstetter et al (2006) argue that affiliates of foreign MNC's in developing countries increase their R&D spending at the time of IP reforms partly because they are getting ready to absorb their parent firm's technology.

[20]The NBER Patent Data are described in Hall et al. (2001).

IPR protection in place before TRIPs and did not see a change in IPR laws around this time.

Next, in order to obtain a mapping from patent class to NIC groups, we used our data on patenting by Compustat firms to measure, for each patent class, the shares of patents taken out by U.S. firms belonging to different 2-digit NIC groups.[21] Assuming that patenting by US, Indian or European firms in the same industry has a similar profile across patent classes, we used this mapping to translate our class-wise estimates of the number of patents into 2-digit industry-wise estimates.[22]

We also used the NBER data to estimate two measures of the quality of patenting, the mean "originality" and number of citations received by patents in an industry*country group*year cell (Hall et al., 2001). A patent's "originality" measure is one minus the index of concentration, across patent classes, of the citations made by the patent. Thus, if a patent cites previous patents that belong to a narrow set of technologies the originality score will be low, whereas citing patents in a wide range of fields would render a high score. Citations received measures the total number of citations by other patents that the patent received between 1975-99.

It should be noted that in an average year, U.S. patents granted to Indian inventors are only about 10% of the number of patents granted by India to Indians (Abramson, 2007). Moreover, not all Indian inventors who are granted a U.S. patent work for an Indian entity.[23] However, as long as this erroneous attribution does not vary systematically across industry groups, using U.S. patent inventor data should not bias our measurement of how patenting growth varied across industries in India.

Table 11 first summarizes the NBER patent data by country groups and two periods-pre and post 1994. In both the periods, Indian inventors are granted far fewer patents that those from the United States or Britain, France and Germany. But unlike these countries, patenting by Indians doubles in the second period. In both periods, the mean originality index of Indian patents is similar to that of U.S. and European patents. Patents by Indians, however, receive fewer citations than U.S. patents.

In Table 12, we examine if U.S. patents by Indians rose after 1994, relative to those by U.S. and European inventors, and whether this was more pronounced in higher $RnDIntensity$

[21]The median U.S patent class saw patents granted to Compustat firms from 7 distinct 2-digit NIC groups. However, on average, about 40% of the patents in a class went to firms from the same 2-digit NIC group.

[22]A similar methodology is used in computing the "Yale Technology Concordance", a mapping from patent classes to industrial definitions based on industry of manufacture and sector of use (Evenson and Johnson, 1997).

[23]Unlike the the NBER patent data, the United States Patent and Trademark Office database contains information on both patent assignees as well as the individual inventors named on patents. These data indicate that on average, only about 50% of patents granted to inventors with Indian citizenship have an Indian organization as the assignee.

industries. Columns (1) and (2) presents results from regressions of the logarithm of the number of U.S. patents granted on a dummy for the post-TRIPs period, and its interactions with our measures of innovation-dependence.[24] Patents are measured for country-industry-year cells, with the inventor's country clubbed into three groups (U.S., India and Britain-France-Germany), and industries categorized into 35 2-digit NIC groups. All the regressions include industry-country group fixed effects, and a full set of year dummies.

The regression shown in column (1) clubs U.S. and European inventors together- both US and $Europe$ dummies are omitted from the set of explanatory variables. Column (3) allows patenting by U.S. and European inventors to grow at different rates- that is, only the US dummies are omitted. This implies that in column (1) the coefficients on the $India$ dummy measure how patenting by Indians differed from the mean of U.S. and European inventors' patenting, whereas in column (2) the coefficients on the $India$ dummy measure how patenting by Indians differed from that by U.S. inventors.

In both columns, the coefficients on $India * Yr94$ and $RnDIntensity * India * Yr94$ are positive and statistically significant, and in column (2), the coefficient on $RnDIntensity * India * Yr94$ is higher than that on $RnDIntensity * Europe * Yr94$. This indicates that compared to both U.S. and European inventors, the number of U.S. patents granted to Indian inventors increased between 1989-94 and 1995-99, and that this increase was relatively higher in industries with higher values of $RnDIntensity$. The estimates in column(2) imply that as the $RnDIntensity$ of an industry increases by 1 SD, the post-TRIPs growth in the number of U.S. patents awarded in that industry increases by 3.8% for U.S. inventors, 1.9% for Western European inventors, and 7.4% for Indian inventors. Thus, changes in patenting by Indian in the U.S. during 1989-1999 are consistent with the observed patterns in R&D spending by Indian firms.

Another dimension of the quality of R&D is the quality of the innovation that it produces. Columns (3) and (4) test this by regressing our quality measures- respectively, the originality index and the number of citations received in other patent applications- on the same set of explanatory variables as in column (2). We find that analogous to the patterns in the volume of patenting, compared to both U.S. and European inventors, the average originality index of patents granted to Indian inventors increased between 1989-94 and 1995-99, and that this increase was relatively higher in industries with higher values of $RnDIntensity$. For citations, the $RnDIntensity * India * Yr94$ is positive but not significant. However, citations are generally received with a lag (Hall et al., 2001), so perhaps 1999 is too early for an increase in mean citations to post-1994 Indian patents to show up. On the whole, the patenting results indicate that the post-1994 increase in R&D expenditure

[24]We use logarithms because the number of U.S patents to Indians is a tiny fraction of all U.S. patents, which suggests comparing proportional, rather than absolute increases in the number of patents, across Indians and non-Indians.

in India is not driven by minor technological upgrading alone.

6.7 Foreign Royalty Payments

Did the patent regime change affect technology purchases by firms in India? With secure IPR, there is a lower risk of theft of licensed technology and consequently, we may observe more licensing and sales of technology between firms in this environment. We test this by regressing our measure of foreign technology purchase- their foreign royalty payments- on the interaction variable $RnDIntensity * Yr94$ and year and firm fixed effects. The regressions specifications are similar to those featured in Tables 6 and 8.

The results, presented in Table 13, are ambiguous and sensitive to the the inclusion of controls. In columns (1) and (2), which do not include controls for tariffs and delicensing, the coefficients on $RnDIntensity * Yr94$ and $RnDIntensity * Yr02$ are negative, although statistically not significant. But in column (3), where the controls include dummies for tariffs, delicensing and their interactions with $RnDIntensity$, the coefficients on $RnDIntensity * Yr94$ and $RnDIntensity * Yr99$ are *positive* and significant.

Ideally, we would have liked to measure post-1994 changes in the demand for foreign technology, rather than the equilibrium spending on foreign technology. Since stronger IPR could increase not just demand for foreign technology but also its supply, its net effect on foreign royalty spending can in theory be negative. It could be that our results on foreign technology purchase are inconclusive because the changes in supply need not have varied systematically by $RnDIntensity$.

7 Conclusion

The issue of strengthening intellectual property rights in developing countries has led to a multi-faceted and acrimonious debate. Given the large number of poor people in such countries, the risk of higher prices in a stronger IPR regime and the low levels of indigenous innovation in developing countries, the issues involved in this debate have ranged from concerns about market access for the poor to the implications of stronger IPRs for the international distribution of wealth.

This has certainly been the case for India which, after several years of resistance and in spite of severe opposition from large segments of the Indian population, finally agreed in 1994 to a ten-year deadline to completely overhaul its existing weak IPR-regime.

In this paper, we address the issue of whether the TRIPs Agreement of 1994 led to changes that increased the level of and the capacity for innovation for domestic firms in India. In order to do this, we develop a methodology that relates industries to their intrinsic, technological dependence on innovation and R&D and attempt to correlate the trends in innovative efforts made by Indian firms in the post-TRIPs era to this dependence.

We find strong evidence that the post-TRIPs era is associated with increased expenditure on R&D and U.S. patent applications by domestic firms in India. We also find some evidence that the period is associated with greater and more original patenting by Indians in the United States. We interpret the results to mean that the anticipated onset of stronger IPRs were responsible for generating greater incentives to invest in innovative activities by domestic firms and for facilitating the transfer of technology between firms.

A definitive cost-benefit analysis of India's TRIPs experience cannot be made without a better understanding of the economic value of these early innovative efforts undertaken by Indian firms and the effect of stronger IPRs on domestic prices, product quality and market access in India. However, we conclude that the immediate short-term effects of the TRIPs Agreement in India show promising trends about the ability of stronger IPR's to create incentives for greater R&D and transfer of technology.

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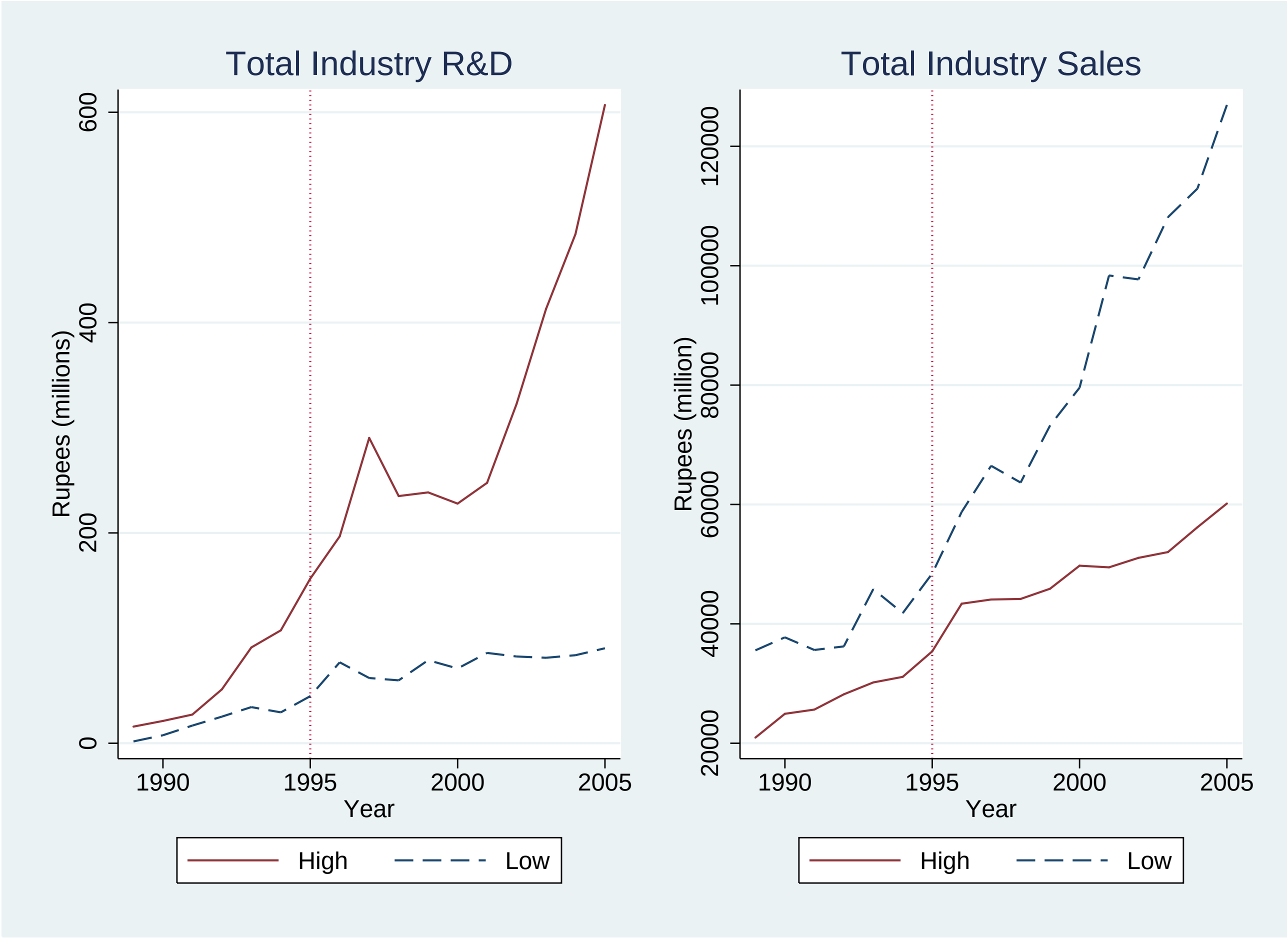

Figure 1: R&D and Sales Trends in Indian Firms- Comparing High and Low *RndIntensity* Industries

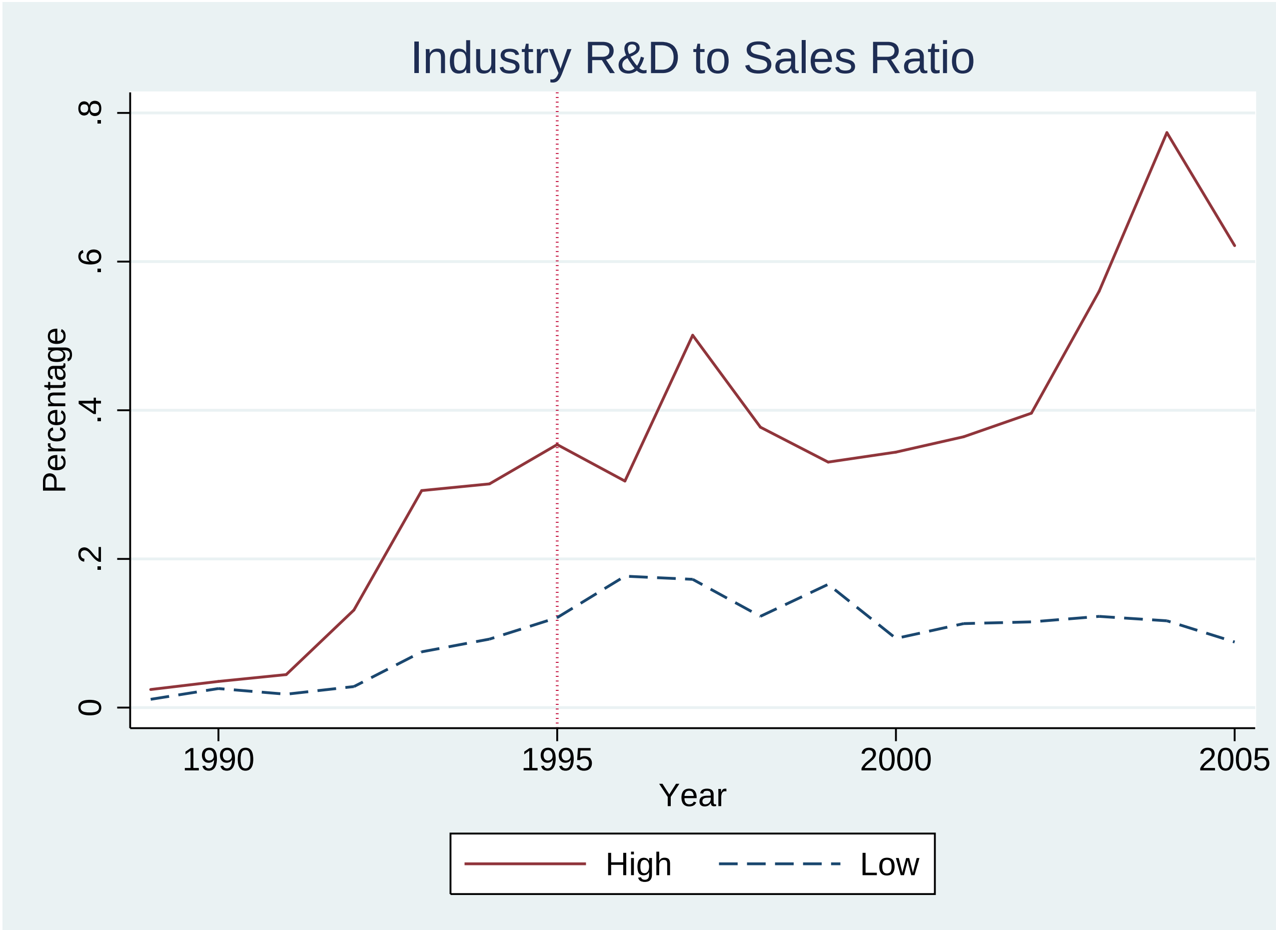

Figure 2: Trends in the R&D to Sales Ratio in Indian Firms- Comparing High and Low *RndIntensity* Industries

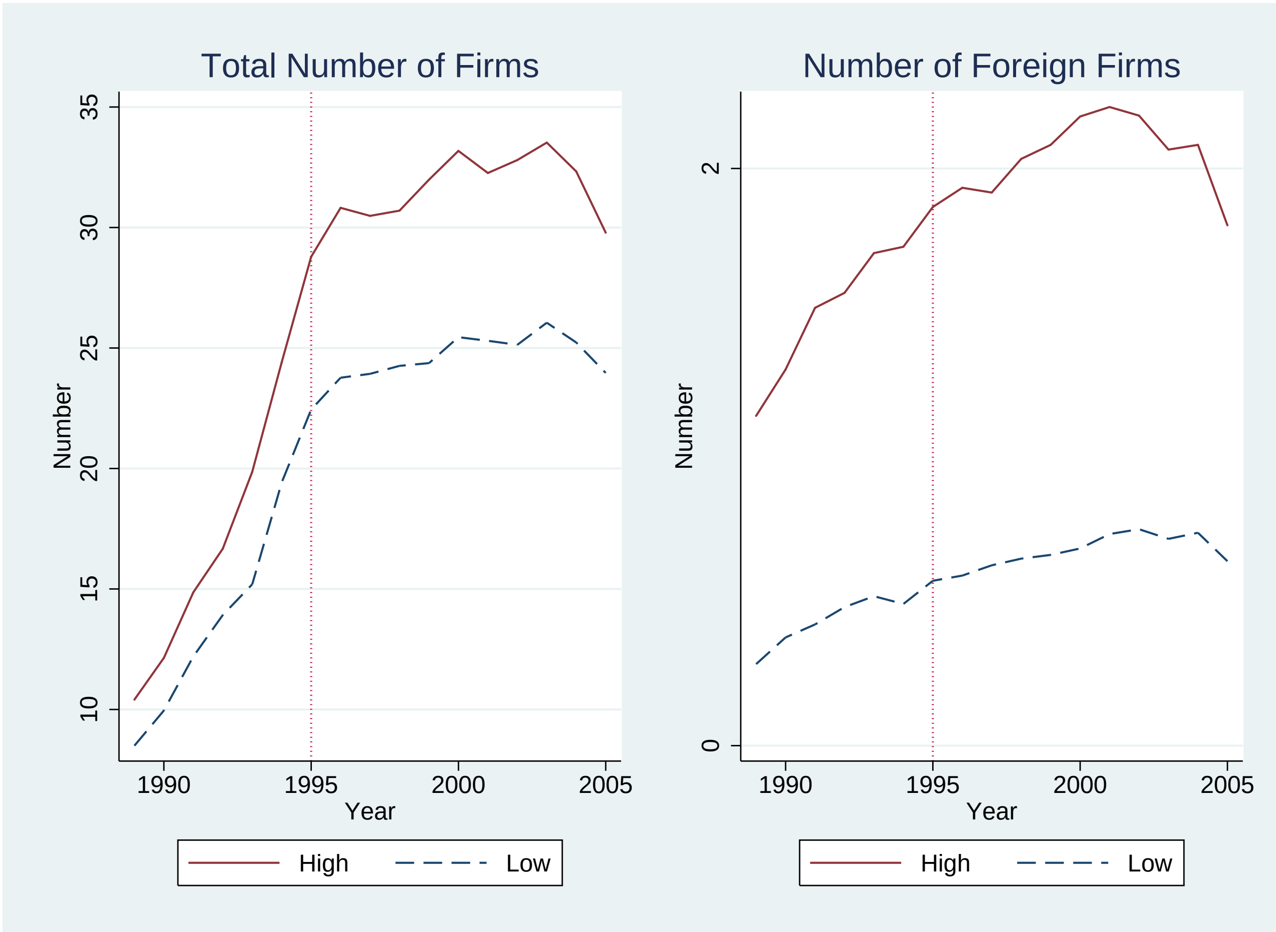

Figure 3: Firm Entry in High and Low *RndIntensity* Industries

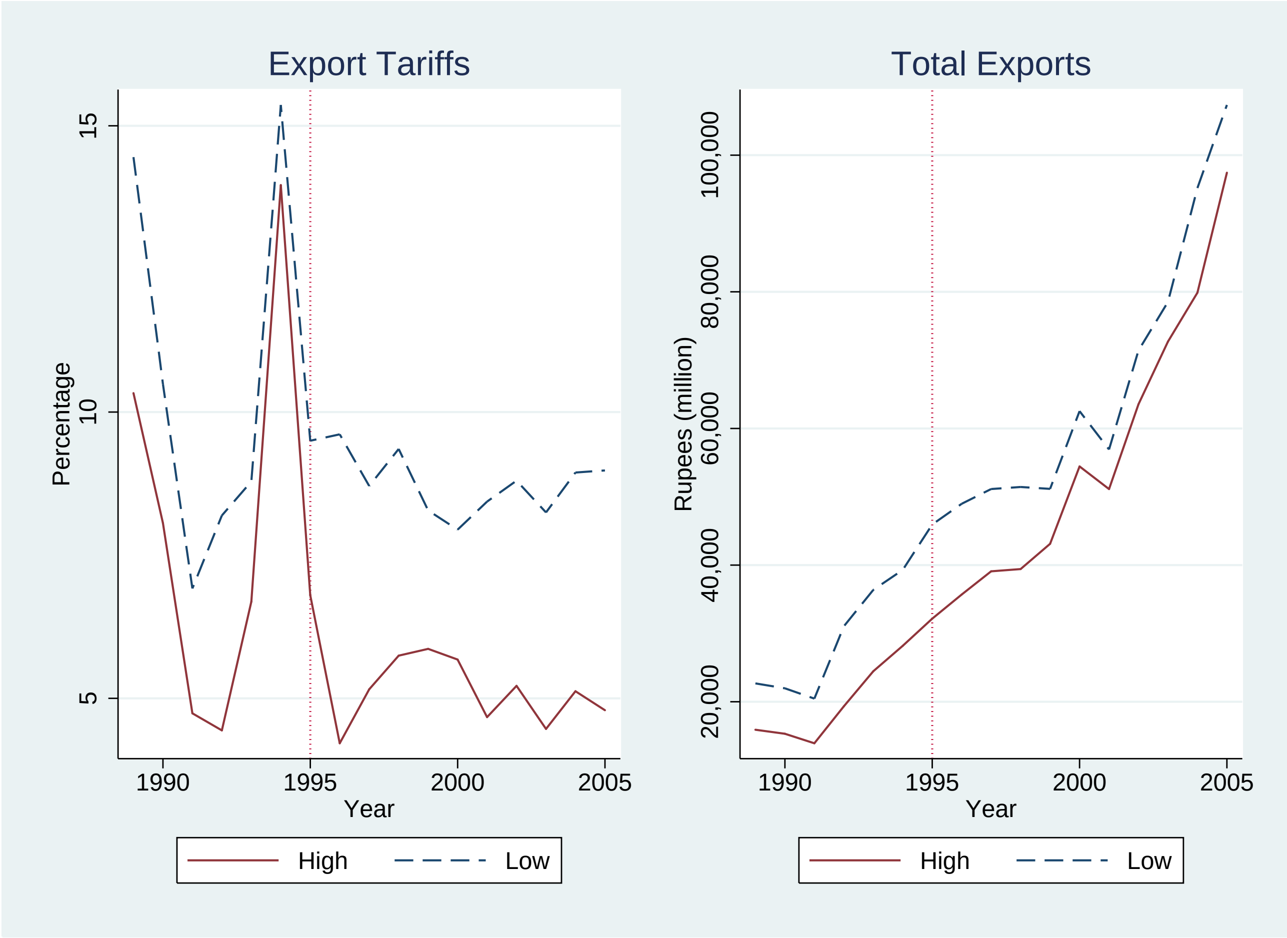

Figure 4: Foreign Tariffs and Exports By Indian Firms- Comparing High and Low *RndIntensity* Industries

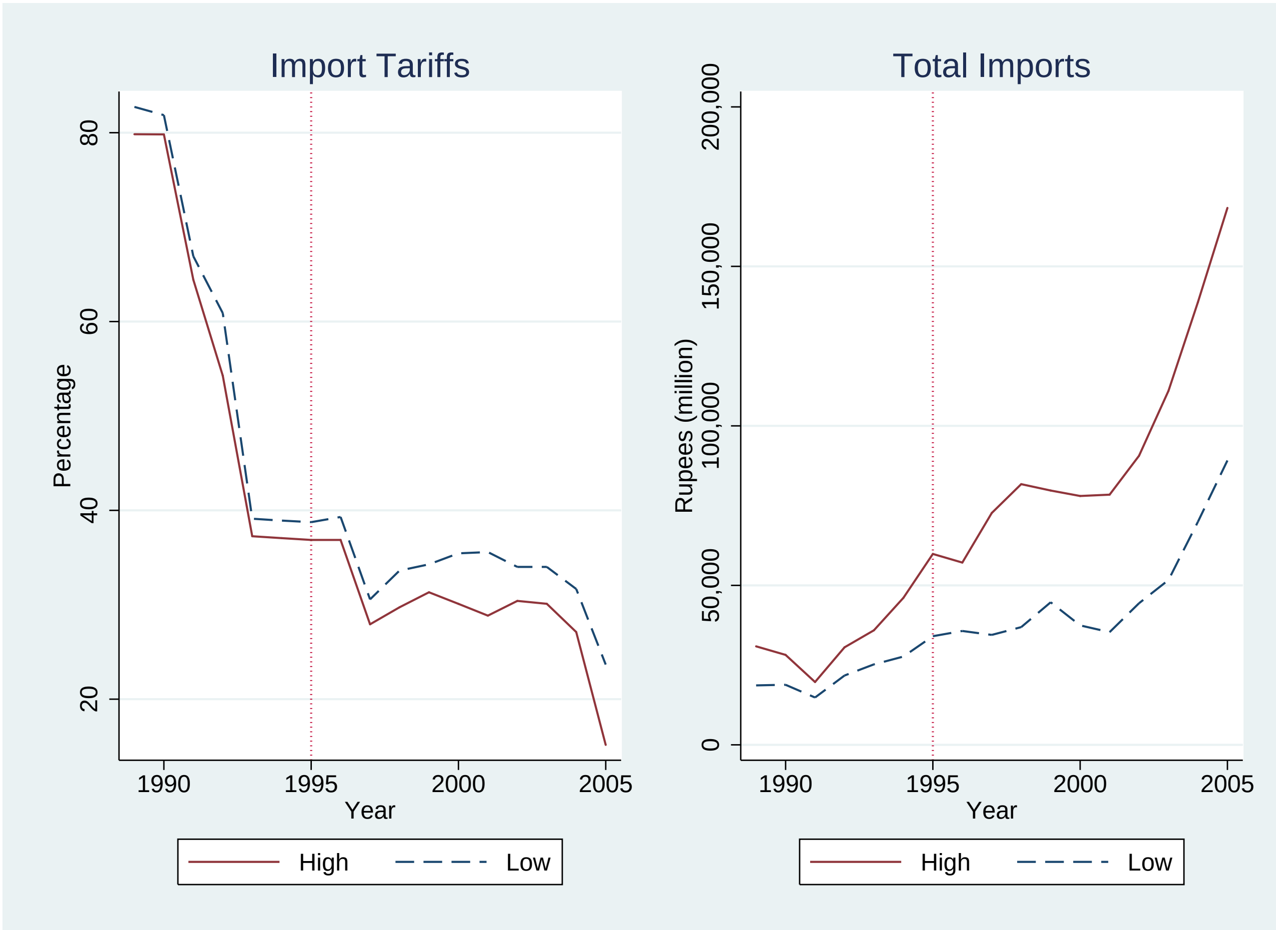

Figure 5: Indian Import Tariffs and Imports- Comparing High and Low *RndIntensity* Industries

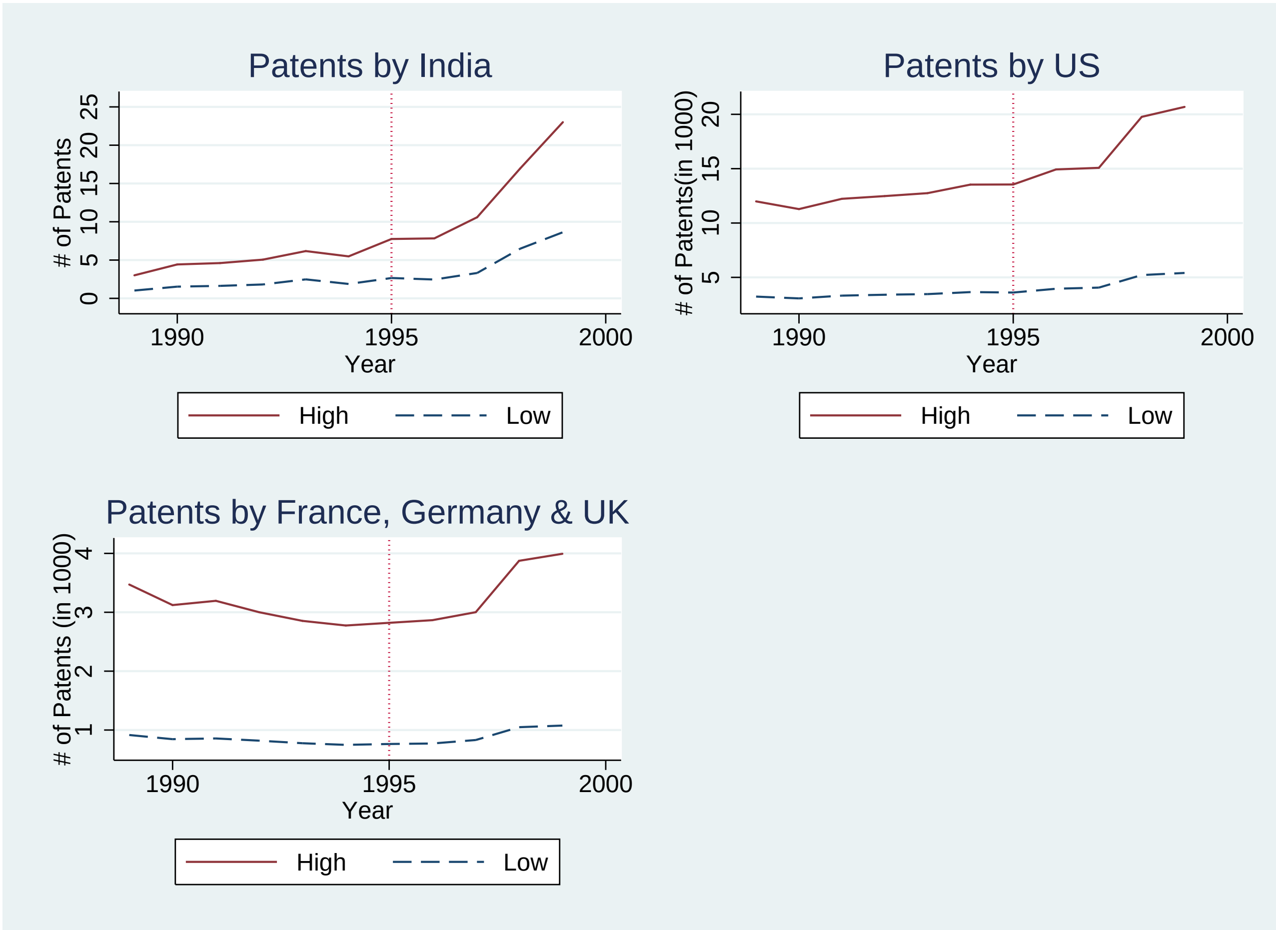

Figure 6: Patenting in the United States by India, the U.S. and Western Europe- Comparing High and Low *RndIntensity* Industries

Table 1: Variable Definitions

Variable	Description
Revenue	Prowess firm sales (in million INRs)
R&D	Prowess firm R&D expenditure (in million INRs)
Royalties	Prowess firm foreign currency expenditure on technology royalties (in million INRs)
Foreign	Dummy indicating foreign ownership of Prowess firm
RnDIntensity	US industry R&D spending to sales ratio in 1990-94 (at4-digit NIC level) Source: COMPUSTAT
PatIntensity	US industry # patents to sales ratio in 1990-94 (at4-digit NIC level) Source: COMPUSTAT and NBER Patent Database
Chem	Dummy indicating chemicals, pharmaceuticals, agrochemicals or food industry
Ex Tariff	Index of import tariffs in India's trading partners, measured by 4-digit industry-year & weighted by the partners' 1989 shares in India's exports
In Tariff	India's import tariff, measured by 4-digit industry-year Source: COMTRADE
Delicensed	Dummy indicating an industry's delicensing (equal to one in all post-delicensing years)
Yr94	Dummy equal to 1 for years > 1994
Yr99	Dummy equal to 1 for years > 1999
Yr02	Dummy equal to 1 for years > 2002

Table 2: Summary Statistics

Prowess companies, 1989-1994	
Number of companies	3016
Mean sales	1460.7
	[9264.0]
Mean Export Earning	4.9
	[31.2]
Mean R&D Spending	1.5
	[15.3]
Mean Foreign Royalty Spending	3.1
	[20.4]
% companies doing R&D	21.3
Prowess companies, 1995-2005	
Number of companies	5252
Mean sales	1803.9
	[16191.4]
Mean Export Earning	16.4
	[104.8]
Mean R&D Spending	5.1
	[44.2]
Mean Foreign Royalty Spending	3.8
	[58.7]
% companies doing R&D	29.5
Median RnDIntensity	0.011
Mean RnDIntensity	.018
	[0.019]
Median PatIntensity	0.018
Mean PatIntensity	0.028
	[0.035]

Notes: Standard deviations in brackets. Sales, export earnings, R&D and royalty spending of Prowess firms are in million Indian Rupees, deflated to 2000 prices. In 2000, 1 USD was equal to approximately 45 rupees. The statistics on the US industry-level measures from Compustat data- RnDIntensity and PatIntensity- were calculated for 279 4-digit NIC industry groups. R&D spending and sales of US firms are in million USD.

Table 3: Industries in Descending Order of Industry R&D to Sales Ratio in the U.S. (RnDIntensity)

NIC Code	Industry	RnDIntensity
32	Radio, television & communication equipment	0.076
30	Office, accounting & computing machinery	0.067
33	Medical, precision & optical instruments	0.043
24	Chemicals & chemical products (incl. drugs)	0.039
23	Coke, refined petroleum products & nuclear fuel	0.037
31	Electrical Machinery	0.028
25	Rubber & plastic products	0.027
29	Machinery & equipment	0.023
35	Transport equipment (incl. ships, aircraft & spacecraft)	0.022
34	Motor vehicles	0.019
36	Misc. manufacturing	0.016
21	Paper & paper products	0.014
19	Leather, luggage & footwear	0.013
17	Textiles	0.012
27	Basic metals	0.010
18	Apparel	0.009
28	Fabricated metal products	0.008
22	Publishing, printing & reproduction of recorded media	0.007
11	Extraction of crude petroleum & natural gas	0.007
20	Wood & products of wood & cork	0.006
26	Other non-metallic mineral products	0.005
15	Food products & beverages	0.005
14	Other mining	0.004
16	Tobacco	0.003
10	Mining of coal & lignite	0.001
13	Mining of metal ores	0.0002

RnDIntensity was calculated at the 4-digit NIC level, & this tables presents its means at the 2-digit NIC level.

Table 4: Industries in Descending Order of Industry Patents to Sales Ratio in the U.S. (PatIntensity)

NIC Code	Industry	PatIntensity
32	Radio, television & communication equipment	0.0980
24	Chemicals & chemical products (incl. drugs)	0.0856
30	Office, accounting & computing machinery	0.0808
33	Medical, precision & optical instruments	0.0704
29	Machinery & equipment	0.0406
31	Electrical Machinery	0.0368
36	Misc. manufacturing	0.0350
35	Transport equipment (incl. ships, aircraft & spacecraft)	0.0336
25	Rubber & plastic products	0.0314
11	Extraction of crude petroleum & natural gas	0.0309
19	Leather, luggage & footwear	0.0233
28	Fabricated metal products	0.0216
34	Motor vehicles	0.0203
23	Coke, refined petroleum products & nuclear fuel	0.0167
17	Textiles	0.0126
26	Other non-metallic mineral products	0.0126
27	Basic metals	0.0117
21	Paper & paper products	0.0112
18	Apparel	0.0107
20	Wood & products of wood & cork	0.0101
14	Other mining	0.0077
22	Publishing, printing & reproduction of recorded media	0.0029
15	Food products & beverages	0.0025
16	Tobacco	0.0022
13	Mining of metal ores	0.001
10	Mining of coal & lignite	0.0007

PatIntensity was calculated at the 4-digit NIC level, & this tables presents its means at the 2-digit NIC level.

Table 5: Summary Statistics- By RnDIntensity, Before and After 1994

	Low RnDIntensity Industries	High RnDIntensity Industries
Pre-1994 summary		
Number of firms	1383	1599
Mean Annual Sales	1981.9	1037.1
	[13260.9]	[3065.3]
Median Annual Sales	304.9	232.8
Mean Annual R&D	.9	2.2
	[13.2]	[17.1]
% of firms with non-zero R&D	14.6	27.4
Post-1994 summary		
Number of firms	2369	2768
Mean Sales	2630.4	1157.9
	[23614.5]	[4400.9]
Median Sales	326.6	257.5
Mean R&D	2.3	7.7
	[25.5]	[56.1]
% of firms with non-zero R&D	21.5	36.7

Notes: Standard deviations in brackets. Sales and R&D are in million Rs. and constant year 2000 prices. Within each sub-period, we first averaged firm sales and R&D spending across years, and then split the firms into two roughly equal-sized groups, based on the median value of RnDIntensity across firms. This median was 0.016 in both sub-periods. Then, we calculated the mean and standard deviation of average annual firm sales and R&D in every sub-period*group cell.

Table 6: IPR changes and R&D spending by Indian firms

	log(R&D)				
	(1)	(2)	(3)	(4)	(5)
RnDIntensity*Yr94	4.666	18.873	17.414		
	(2.371)**	(3.923)***	(3.459)***		
RnDIntensity*Yr99			-.440		
			(1.527)		
RnDIntensity*Yr02			5.346		
			(1.085)***		
PatIntensity*Yr94				7.739	7.022
				(3.858)**	(3.517)**
PatIntensity*Yr99					.081
					(1.113)
PatIntensity*Yr02					2.094
					(1.063)**
Year Dummies	Y	Y	Y	Y	Y
Industry FE	Y				
Firm FE		Y	Y	Y	Y
Obs.	48848	48848	48848	48848	48848

Notes: Robust standard errors adjusted for clustering at 4-digit industry in parenthesis. *** indicates 1% , ** 5% and * 10% significance level. The dependent variable is the logarithm of the firm's annual R&D spending plus one.

Table 7: Robustness Checks- Annual Data Collapsed to Two/Four Periods; 1975-80 Measures of RnDIntensity & PatIntensity

	log(R&D)					
	(1)	(2)	(3)	(4)	(5)	(6)
RnDIntensity*P2	13.078	7.350				
	(2.737)***	(2.263)***				
RnDIntensity*P3		-2.163				
		(1.685)				
RnDIntensity*P4		6.377				
		(1.859)***				
PatIntensity*P2			5.694	2.375		
			(1.741)***	(1.426)*		
PatIntensity*P3				-.632		
				(1.098)		
PatIntensity*P4				2.210		
				(1.205)*		
Firm FE	Y	Y	Y	Y		
Period Dummies	Y	Y	Y	Y		
Collapsed Data	Y	Y	Y	Y		
Obs.	7732	15282	7732	15282		
RnDIntensity*Yr94					36.467	
					(12.626)***	
PatIntensity*Yr94						6.078
						(1.919)***
Firm FE					Y	Y
Year Dummies					Y	Y
Collapsed Data					No	No
1975-80 Measures					Y	Y
Obs.					46952	46952

Robust standard errors in parenthesis. *** indicates 1% , ** 5% and * 10% significance level. In columns (1) and (3), the annual firm level data have been collapsed to two periods per firm - 1989-1994 and 1995-2005. In columns (2) and (4), the data have been collapsed to four periods per firm - 1989-1994, 1995-1999, 2000-2001 and 2002-2005. P2 is a dummy equal to 1 in 1994-2005, P3 is a dummy equal to 1 in 1999-2005, and P4 is a dummy equal to 1 in 2001-2005. In columns (5) and (6), RnDIntensity and PatIntensity are calculated using US Compustat and NBER Patent Data from 1975-80, and standard errors are adjusted for clustering at 4-digit NIC industry level.

Table 8: Robustness checks- tariffs, delicensing, foreign ownership and industry-specific time trends

	log(R&D)					
	(1)	(2)	(3)	(4)	(5)	(6)
RnDIntensy*Yr94	17.152	15.859	16.110	16.150	10.469	8.793
	(3.529)***	(3.532)***	(3.354)***	(3.283)***	(3.105)***	(2.873)***
RnDIntensy*Yr99	-.441	-.450	-.051	.008	-.461	-1.282
	(1.526)	(1.541)	(1.417)	(1.430)	(1.680)	(2.216)
RnDIntensy*Yr02	5.348	5.345	5.464	5.457	4.071	3.395
	(1.085)***	(1.083)***	(1.090)***	(1.093)***	(1.382)***	(1.704)**
Chem*Yr94	.056	.079	.086	.084	.086	.077
	(.290)	(.280)	(.273)	(.273)	(.288)	(.215)
Foreign*Yr94		1.263	1.255	1.256	1.239	1.039
		(.364)***	(.367)***	(.367)***	(.364)***	(.358)***
InTariff			.005	.005	.011	.010
			(.004)	(.003)	(.004)***	(.003)***
RnDIntensity* InTariff					-.287	-.380
					(.119)**	(.120)***
ExTariff			-.004	-.004	-.004	-.0003
			(.006)	(.006)	(.007)	(.006)
RnDIntensity* ExTariff					-.048	.014
					(.410)	(.374)
Delicensed				.044	-.103	-.140
				(.277)	(.295)	(.284)
RnDIntensity* Delicensed					17.930	15.358
					(9.969)*	(9.819)
Year Dummies	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Industry Trends						Y
Obs.	48848	48848	48848	48848	48848	48848

Notes: Robust standard errors adjusted for clustering at 4-digit industry in parenthesis. *** indicates 1% , ** 5% and * 10% significance level. The dependent variable is the logarithm of the firm's annual R&D spending plus one. Control variables in columns (6) include separate linear time trends for all 2-digit NIC industries.

Table 9: Robustness check- Patent importance measures from the Yale Survey of Industrial Research and Development

	log(R&D)				
	(1)	(2)	(3)	(4)	(5)
PPP*Yr94	.164 (.126)	.120 (.119)	.122 (.122)	.116 (.058)**	.077 (.062)
PPP*Yr99		.062 (.031)**			
PPP*Yr02		.043 (.034)			
NPP*Yr94			-.541 (.472)		-.484 (.312)
Year Dummies	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y
Data collapsed to two periods				Y	Y
Obs.	31240	31240	31240	5069	5069

Notes: Robust standard errors in parenthesis. *** indicates 1% , ** 5% and * 10% significance level. In columns (1)-(3), the standard errors are adjusted for clustering within 69 4-digit industry groups. The dependent variable is the logarithm of the firm's annual R&D spending plus one. *PPP* measures the response to "do process/product patents prevent competitors from duplicating inventions?", while *NPP* is the response to average effectiveness of **non-patent** protection methods, both averaged within industries. *PPP* and *NPP* are from Table $C2$ in Cockburn and Griliches (1987), which is based on the Yale Survey of *Industrial Research and Development*, and range in value from 1 to 10 (approximately).

Table 10: The Effect of Domestic Market Size

	log(R&D)		
	(1)	(2)	(3)
RnDIntensity*Yr94	4.649	5.302	-9.096
	(6.183)	(6.109)	(7.453)
RnDIntensity*Yr99		-3.167	-6.238
		(3.436)	(4.668)
RnDIntensity*Yr94		2.829	2.760
		(3.232)	(4.290)
RnDIntensity*DMarket*Yr94	.0001	.0001	.0002
	(.00004)***	(.00004)**	(.00006)***
RnDIntensity*DMarket*Yr99		.00003	.00004
		(.00003)	(.00004)
RnDIntensity*DMarket*Yr02		.00002	-1.04e-06
		(.00002)	(.00004)
Foreign*Yr94			1.042
			(.357)***
InTariff			.009
			(.003)***
RnDIntensity*InTariff			-.385
			(.122)***
ExTariff			.002
			(.006)
RnDIntensity*ExTariff			-.211
			(.419)
Delicensed			-.179
			(.278)
RnDIntensity*Delicensed			22.538
			(10.521)**
Year Dummies	Y	Y	Y
Firm FE	Y	Y	Y
Industry-Time Trends			Y
Obs.	48848	48848	48848

Notes: Robust standard errors adjusted for clustering at 4-digit industry in parenthesis. *** indicates 1% , ** 5% and * 10% significance level. Control variables include Chem*Yr94 & the interaction of DMarket with the year dummies. DMarket is the 4-digit NIC industry revenue + imports - exports in India in 1990. Source: Annual Survey of Industries and Comtrade.

Table 11: US Patents Granted Between 1989-1999

		Country of First Inventor		
		Britain+France + Germany	India	USA
1989-94	Total Patents	568239	1003	2297509
	Mean Originality Measure	0.31	0.32	0.37
	Mean Citations Received	3.94	4.53	6.40
1995-99	Total Patents	512106	2292	2575415
	Mean Originality Measure	0.33	0.32	0.39
	Mean Citations Received	0.98	0.82	1.63

Source: NBER US Patent Database. A patent's originality measure is one minus the index of concentration, across patent classes, of the citations made by the patent. Thus, if a patent cites previous patents that belong to a narrow set of technologies the originality score will be low, whereas citing patents in a wide range of fields would render a high score. Citations Received measures the total number of citations by other patents that the patent received between 1975-99.

Table 12: Patenting in the U.S. by Indian Innovators

	Total # Patents		Mean Originality	Mean # Citations
	(1)	(2)	(3)	(4)
RnDIntensity*Yr94	1.470	1.990	-.054	.493
	(.569)***	(.733)***	(.087)	(.583)
India*Yr94	.756	.653	.714	.950
	(.066)***	(.062)***	(.097)***	(.111)***
RnDIntensity*India*Yr94	2.239	1.718	4.936	1.934
	(1.052)**	(.962)*	(1.829)***	(2.156)
Europe*Yr94		-.205	-.030	.022
		(.021)***	(.021)	(.044)
RnDIntensity*Europe*Yr94		-1.040	-.144	.027
		(.415)**	(.335)	(.667)
Year Dummies	Y	Y	Y	Y
Country*Industry FE	Y	Y	Y	Y
Obs.	1881	1881	1785	1769

Notes: Robust standard errors clustered by industry in parenthesis. *** indicates 1% , ** 5% and * 10% significance level. In columns (1)-(2), the dependent variable is the logarithm of the total number of US patents granted (plus one) in an industry*country group*year cell. In columns(3) and (4), respectively, the dependent variable is the (log) mean "Originality Index" of patents in a industry*country group*year cell, and the mean number of citations received by the patents in a cell. The number of observations is lower in column (3) and (4) because these means are not defined when a industry*country group*year cell contains zero patents.

Industry is the 2-digit NIC category of the patent, year refers to the patent grant year, and country group refers to the first inventor's country, which have been grouped into 3 categories - India, US and Europe (Britain, France and Germany). Source of data on US patents, citations and originality index: NBER Data on US patents granted between 1989-1999.

Table 13: IPR reforms and foreign royalty payments

	log(Royalties)		
	(1)	(2)	(3)
RnDIntensity*Yr94	-1.495	-1.121	5.239
	(5.164)	(4.473)	(2.196)**
RnDIntensity*Yr99		.980	3.572
		(2.088)	(1.933)*
RnDIntensity*Yr02		-2.484	-1.213
		(1.291)*	(1.852)
Year Dummies	Y	Y	Y
Firm FE	Y	Y	Y
Additional Controls			Y
Industry time trends			Y
Obs.	48848	48848	48848

Notes: Robust standard errors adjusted for clustering by 4-digit industry groups in parenthesis. *** indicates 1% , ** 5% and * 10% significance level. The dependent variable is the logarithm of the firm's annual foreign currency spending on royalties and licenses. Additional control variables in column (3) are Foreign*Yr94, ExTariff, InTariff, Delicensed and their interaction with RnDIntensity.