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Does environmental regulation indirectly induce upstream innovation? New evidence from India☆

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ABSTRACT

Exploiting a quasi-natural experiment, which involves the imposition of a ban by Germany in 1994 on an input ('Azo-dyes') used by the Indian leather and textile industries, we estimate the indirect impact of the environmental regulation on innovation activities of upstream (dye-producing) firms in India and examine how it varies by different firm characteristics: size and ownership. We find robust evidence of a significant increase (11–61%) in innovation expenditure for the dye-makers in response to the 'Azo-dyes' ban. Additionally, we find: (i) increase in technology transfer to the tune of 1.2–2.5 times more than that of internal R&D; (ii) increase in innovation expenditure with firm size; (iii) domestic firms investing more in technology transfer as compared to R&D, whereas foreign firms only undertaking the latter and (iv) decrease in investments towards innovation by downstream firms, thereby pointing towards a possible substitution effect in aggregate innovation by upstream firms. Our results are consistent with a variety of estimation methods and robustness checks.

1. Introduction

The relationship between environmental regulation and innovation has received considerable attention over the last two decades, especially after Michael Porter (Porter, 1991; Porter and Van der Linde, 1995) challenged the conventional wisdom about the impact of environmental regulation by arguing that well-defined regulation can actually increase competitiveness and innovation. Since then, there has been a plethora of studies investigating the role of regulation, especially environmental regulation, on business performance of firms and innovative activities (by looking either at innovation input or Research and Development (R&D) expenditure and/or innovation output or patents). However, till now there is no consensus on what is called the 'Porter's Hypothesis', as researchers continue to find conflicting evidence (Palmer et al., 1995; Jaffe and Palmer, 1997; Gray and Shadbegian, 1998; Berman and Bui, 2001; Greaker, 2006; Popp, 2006). New studies have also emerged in terms of examining the indirect impact of environmental regulation on technical change (Miller, 2015; Calel and Dechezleprêtre, 2016). We extend the literature by investigating whether environmental regulation affects upstream innovation. Using a quasi-natural experiment, in terms of imposition of a foreign regulation, targeted primarily towards the downstream sector, we estimate the innovation effects of the regulation on upstream firms. Our results show that the imposition of the foreign regulation led to a significant increase of innovation expenditure of upstream firms between 11 and 61%.

Global standards, especially non-tariff barriers have proliferated during the last two decades (as tariff barriers have started to decline). As this has happened, developing economies have contested that these shifts might potentially create trade barriers.

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UNCTAD (2005) quotes a 2002 study by International Trade Commission (ITC), documenting that 40% of exports from less developed countries are subject to non-tariff barriers, including standards. Chaturvedi and Nagpal (2002) also point out that the global proliferation of environmental and health related standards, along with a rise in trade in environmentally sensitive goods creates new challenges for firms in the developing world. This abundance of global standards started a debate on how and under what conditions can supplier firms in developing countries, especially firms in polluting industries such as leather and textile goods, dyes and chemicals (who are also large employers) comply with these stringent environmental regulations imposed by global buyers without necessarily compromising their competitiveness (Tewari and Pillai, 2005).

Our study exploits one such binding foreign regulation that originated because of a petition by some consumer advocacy groups due to health and environmental concerns. The regulation is popularly known as 'Azo-dyes' ban. It came from Germany in July 1994, and was primarily targeted on the goods produced by the leather and textile industries. The regulation banned the use of 'Azo-dyes', a colorant, in the production of leather and textile goods. During the early 1990s, Germany and USA were the two largest consumers of Indian-made textiles with the two nations importing more than 70% of all Indian textiles (Iyer, 1992). In 1994, textiles alone made up 76% of all consumer good exports (IKB Deutsche Industriebank, 1994). On the other hand, the textile industry, specifically in India, accounts for some 70% of the consumption of dyestuffs produced by the chemical sector.[1] Therefore the 1994 German banning of 'Azo-dyes', one of the oldest and most widely used chemicals in the production of leather and textile goods, also became a *de-facto* indirect ban for the producers of this particular input in India, i.e., for the dye-maker firms of the Indian chemical industry.[2] Tewari and Pillai (2005) point out that the ban on the widely used chemical, effectively (though unintendedly) turned the input industry, in this case, the dye producers, into *de-facto* diffusers of environmental compliance. In 1997, the Ministry of Environment and Forests (MoEF), Govt. of India extended this foreign regulation for firms selling in the domestic market; an issue we will come to in our analysis later.

Facing a zero demand for one of their most important products, firms in the dye-making sector of the broader chemical industry opposed the ban to begin with. But, due to widespread demand for newer and safer dyes, especially, among the leather and textile firms in India, they started experimenting with development of new substitutes and offered technical assistance to downstream (leather and textile) firms to adapt and adopt them. The primary reason for these responses on innovation activity can be attributed to the fact that the leather and textile firms were the biggest buyers for the products of the Indian chemical industry in the domestic market. Using these primitives in our setting, we investigate whether this German 'Azo-dyes' regulation in 1994 induced upstream dye-producing chemical firms in India to invest more in innovative activities to produce a safer alternative. In addition, we explore if there is any role of firm heterogeneity.

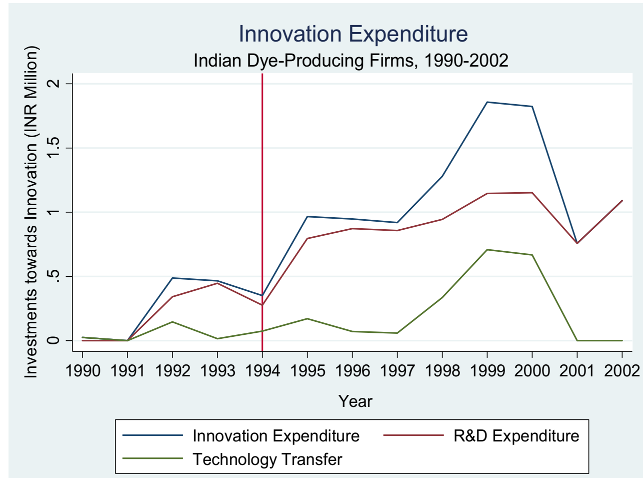

Fig. 1. Innovation Expenditure, Indian Dye-producing Chemical Firms, 1990–2002.
Notes: Lines represent the average expenditure of a "Dye-producing" firm in India towards innovation.
Source: CMIE Prowess

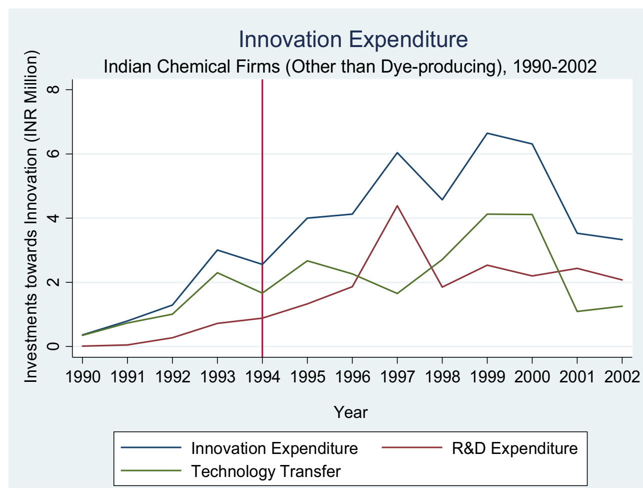

Fig. 2. Innovation Expenditure, Indian Chemical (other than Dye-producing) Firms, 1990–2002.
Notes: Lines represent the average expenditure of a "Chemical (other than Dye-producing)" firm in India towards innovation.
Source: CMIE Prowess

Fig. 1 plots the total innovation expenditure (sum of R&D expenditure and Technology Transfer) and its components (separately) of the Indian dye-producing chemical firms from 1990 to 2002. It shows a very sharp rise in the aggregate innovation expenditure of these firms right after 1994. The figure also point out that this rise in the investments towards innovation expenditure is primarily driven by the increase in R&D expenditure of these firms. In addition, Fig. 1 displays another significant increase in the innovation expenditure of the dye-makers in the post-1997 period. And, this jump in the aggregate innovation expenditure is a result of sudden increase in another component of the aggregate innovation expenditure, which is royalty payment for technical knowhow or technology transfer. Fig. 2 plots the same trends for other chemical firms (producing chemical compounds other than dyes) to understand whether such a trend (sharp rise after 1994 and 1997) is common to all sectors or is specific to the dye-makers. It does not

[1] (Source: https://www.dnb.co.in/Chemical/overview.asp)
[2] Overall, the Indian chemical industry is among one of the established traditional sectors of the country that play an integral role in the country's economic development. This sector forms a part of the basic goods industry and is a critical input for industrial and agricultural development. As on March 31, 2008, the size of the Indian chemical industry was estimated at around USD 35 Billion and 3% of India's GDP. The Indian chemical sector accounts for 13–14% of total exports and 8–9% of total imports of India. In terms of volume of production, it is the twelfth-largest in the world and the third-largest in Asia. The dyestuff sector is one of the important segments of the Indian chemical industry and has forward and backward linkages with a variety of sectors. (Source: https://www.dnb.co.in/Chemical/overview.asp)

show similar effects in other firms like the steep jumps we see for dye-producing chemical firms after 1994 and 1997.[3]

Taking a cue from Figs. 1 and 2, we use a novel unbalanced panel dataset from India containing direct measures on innovation expenditure, divided into R&D expenditure and technology transfer to causally examine the effect of German 'Azo-dyes' ban on innovation activities of upstream dye-makers in India for the years 1990–2002 using a difference-in-differences framework. In other words, our identification strategy employs the firms from the dye-producing sub-sector of the broader chemical industry as the treated group and firms from all other chemical (firms producing compounds other than dyes) sectors as the control group. In doing so, what we estimate is the difference in the innovation expenditure between the firms belonging to the dye-producing chemical cohort (treated group, as the regulation directly hits them) and other chemical firms (exogenous to the shock, but has similar characteristics like the ones in the treated group). However, we start our empirical investigation by looking at whether this might be a result of the substitution effect in innovation from the downstream to the upstream sector by estimating the innovation responses of the downstream or leather and textile firms.

We find negative effect of the 'Azo-dyes' ban on the innovation expenditure of the downstream or leather and textile firms. On the other hand, our empirical investigations reveal strong evidence of an increase in the innovation expenditure of the dye-producing chemical firms relative to other chemical firms due to the foreign regulation. This indicates a possible substitution effect of innovative activities from downstream to upstream sector as a result of the 'Azo-dyes' ban. To quantify the effect, the relative increase in innovation expenditure of the dye-makers in response to the 1994 'Azo-dyes' ban varies between 11 and 61%. Our benchmark finding is significantly robust across other policy changes, such as simultaneous macroeconomic and trade reforms, industry level controls and various firm characteristics. Next, we segregate the innovation expenditure, into R&D and technology transfer, to understand the differential impact of the foreign regulation. Our estimates show that the increase in innovation expenditure is driven by increase in investments for both R&D and royalty payments for technical knowhow or technology transfer; with the increase in the latter 1.2–2.5 times more than that of the former. Lastly, we explore whether there is any variation in effect by dividing firms according to their size and ownership. Results show that the rate of increase in innovation expenditure for the dye-makers decreases with the decrease in size. Domestic firms invest in both R&D and technology transfer, while foreign firms only engage in internal R&D.

Our findings primarily contribute to the literature on environmental policy/regulation and innovation. The issues involved here debates around the classical Porter's Hypothesis (Porter 1991; Porter and Van der Linde, 1995), which argues that contrary to perception, regulation can have a positive impact on firm level innovation (Ambec and Barla, 2002). While the Porter's Hypothesis has only been substantiated with mixed evidence (Jaffe and Palmer, 1997; Lanoie et al., 2011; Ambec et al., 2013), there are hardly any studies that looks at whether environmental regulation indirectly induces upstream innovation either in a developed or developing economy. Ghosh and Sanyal (2013) considers the issue of upstream innovation, but in response to product market competition. While we do not test the Porter's Hypothesis directly, in examining the innovation effects of the upstream sector, we essentially extend the Porter's Hypothesis to the case of upstream firms. In doing so, we offer new evidence on the relationship between indirect inducement of innovation in the upstream sector as a result of an environmental regulation targeted primarily to the downstream sector and find support for theoretical predictions of Greaker (2006) in case of upstream innovation. We believe this to be an important contribution to the existing literature.

Our study also contributes to the literature on green innovation and value-chain. Nesta et al. (2014) find that renewable energy policies are more effective in fostering green innovation in countries with liberalized energy markets. This is supported by empirical evidence from Italy on the role of policies, like emission trading scheme and on environmental innovation and transmission of innovation from manufacturing to services (Borghesi et al., 2015; Cainelli and Mazzanti, 2013). This is also indicated in the Bruntland Report of 1987 (Stefan and Paul, 2008), the subsequent Earth Summits in Rio de Janeiro (1992) and Johannesburg (2002), as well as the European target for a green economy between 2010 and 2050, all pushing the world towards a green economy through high-quality R&D intensive products promoting green sustainable development.[4] Herein it is also important to mention that we also relate to studies that examine the direct (Gans, 2012) and indirect (Perunovic and Vidic-Perunovic, 2012; Miller, 2015) impacts of environmental regulation on technical change.

In addition, there is an emerging discussion on international diffusion of regulations and the California effect–which highlights a convergence in regulatory norms globally–thereby impacting productivity of firms in developing economies (Perkins and Neumayer 2012; Levi-Faur, 2005). Our study relates to this literature by examining how the German ban was a leading indicator of a future domestic Indian ban on 'Azo-dyes'. Lastly, it is also worthwhile to note that while the effects of environment-related barriers on developing country firms has been documented in terms of qualitative case studies (Chakraborty, 2001; Mehta, 2005; Chakraborty, 2009), empirical evidence in terms of the effects of environmental regulation(s) or non-tariff barriers (NTBs) on innovation (and the associated role of firm heterogeneity) has been inadequate. Our novel data and identification strategy allows us to fill this void in the literature.

The rest of the paper proceeds as follows. Section 2 provides a background of our setting in addition to reviewing the literature. Section 3 describes the data with some descriptive analysis. We discuss the direct and indirect impact of the foreign regulation on firm level innovation expenditure in Section 4. Section 5 concludes with policy and managerial implications.

2. Institutional background and literature review

2.1. The German 'Azo-dyes' ban

Consumers in the Organization for Economic Cooperation and Development (OECD) countries consider environmental threats seriously and demand industries to act accordingly. They effectively use their purchasing power to influence governments and legislatures to introduce new regulations so as to facilitate the diffusion of eco-friendly products. These regulations often carry a technical standard or label affecting not only the products themselves but also the production process. These standards, such as product certification standards or labelling requirements commonly encompass a well-defined protocol based on a laboratory test procedure, which

[3] We note that innovation expenditure for other chemical firms (excluding dye-makers) also increased after 1994, but it is not the same as the dye-makers for two reasons: (i) the increase for other chemical firms was not as steep as compared to the dye-makers; and (ii) both R&D and technology transfer, especially technological transfer, had a fare more secular trend in the pre-1994 period when compared to dye-producing chemical firms. Also, there was no increase immediately after 1997 when the domestic ban was imposed.

[4] See EEA Report No 8/2013 at: http://www.eea.europa.eu/signals/signals-2014/articles/transition-towards-a-green-economy/download.pdf.

ascertains specific criteria that have a direct bearing on the quality of a product. The ban on 'Azo-dyes' is one such regulation. 'Azo-dyes' is a coloring substance used in the dying process.[5] They are a group of synthetic dyes made from benzidine, toluidine and similar organic chemicals and at their peak around the 1980s, they accounted for close to 70% of all organic dyes produced in the world. Some 'Azo-dyes' however, through chemical breakdown form substances called aromatic amines (aryl amines) and these have been proven to be or are suspected of being carcinogenic.

Germany, following the going 'green' agenda of the OECD economies through the 1980s and 1990s, banned 'Azo-dyes' by an amendment to the Consumer Goods Ordinance on July 15, 1994.[6] The German Parliament passed a legislation completely banning the use of 'Azo-dyes' in consumer products, since they had the potential of coming into close and prolonged contact with the skin inducing carcinogenicity. The amendment of ξ16 of the "German Consumer Goods Regulation" states that the food and consumer goods as defined in ξ5 article 1 number 6 of the law may not be produced, imported, or sold after a certain period if they contain 'Azo-dyes', since they can generate one of the forbidden Azo-radicals listed in amendment 1 number 7 of this regulation. We use this amendment, in what is informally known as the 'Azo-dyes' ban, as the quasi-natural experiment in our paper. The law applied to domestic products as well as foreign ones. It is worthwhile to note that as Germany (once the world center of 'Azo-dyes' production) became the first country to ban their use (OECD, 2006) few other European countries followed suit in the next few years like The Netherlands, Austria and Norway, effectively spreading the 'Azo-dyes' ban across Europe.[7] In 1999, the European Union (E.U.) mandated the ban across all its member states by circulating a draft directive. The ban on 'Azo-dyes' was an acceptable measure within the General Agreement on Trade and Tariff (GATT) since, according to Article XX, it is implemented to protect human health. Furthermore, the ban also did not discriminate against the origin of products as we already highlight earlier.[8]

A report by OECD in 2006 notes that the effects of the European legislation on 'Azo-dyes' is perhaps most acutely felt in India, which has considerable dye-making capacity and a large leather and textile industry dependent on those dyes. Around 25–70% of the items (depending on what is the end-product) treated with 'Azo-dyes' in the Indian leather and textile industries are exported to the E.U. with Germany as one of its main markets (Tewari and Pillai, 2005).[9]

To start with, the dye-producing chemical firms protested the ban. However, the "stick" for getting the dye-producing firms to comply came entirely from the demand side: a potential loss of sales and reputation from its downstream customers. At the same time, a substantial network of support, coordinated by the concerned industrial bodies (such as, the leather and textile industrial associations) through a collaborative forum tried to make it easier for leather and textile firms to work with the dye-makers to be able to switch to the available alternatives. The large, mainly multinational dye-makers who had resources and international reach to access substitutes, took the lead in developing safer alternatives (Tewari and Pillai, 2005). This unleashed vigorous innovation by the local dye-producers as well, as they worked with their customers (the leather and textile firms), to try to achieve affordable alternatives (Pillai, 2000). Once the alternative dyes were produced, it was the dye-makers, who due to their own interests, marketed them as widely as possible. Thus, rather than the state monitoring the use of the banned chemicals, it was the dye-producing firms who marketed locally developed substitutes. To get leather and textile firms to adopt their new products, the dye-makers offered credit and technical assistance, and worked with them closely (Pillai, 2000). The dye-makers that had initially protested the ban became the biggest promoters of the substitute chemicals. So, in effect, the German regulation resulted in the dye-producing chemical firms becoming chief "enforcers" of the bans. Thereafter they also turned out to be the main disseminators of the alternative dyes and preservatives (Tewari and Pillai, 2005).

2.2. Literature review

This section discusses the literature that is most closely related to our work, namely, the studies on environmental policy and innovation. Historically, the conventional wisdom regarding environmental policy or protection is that it comes at an additional cost to firms given that pollution is an externality and focusing on it may erode firm competitiveness. Porter (1991) and Porter and van der Linde (1995) contested this traditional paradigm (by relying primarily on case studies) to argue that more stringent and properly designed environmental regulations can "trigger innovation [broadly defined] that pay partially or in some instances more than fully offset the costs of complying with them" (Porter and Van der Linde, 1995, p.98).[10] Notwithstanding the aggregate importance ascribed to the hypothesis (which came to be known as "Porter's Hypothesis"), the literature in the last two decades offer very different and contradictory conclusions, both theoretically and empirically, regarding the manner, in which environmental regulation(s) affect innovation and competitiveness.[11] Ambec et al. (2013) find out that the main reason for such conflicting accounts is that the Porter's Hypothesis does not say that all regulations will lead to innovation, but only well-designed regulations do. This is, in general, consistent with performance-based and/or market-based environmental regulations. The regulation on 'Azo-dyes' is one such. In this case, the market(s), where the consumer products

[5] See: http://www.straw.com/sig/dyehist.html as also Moser and Voena (2012) & Murmann (2003) for an influential discussion on the production of 'Azo-dyes' and the German chemical industry.

[6] "Zweite Verordung zur Aenderung der Bedarfsgegenstandeverordung", Bundesgesetzblatt – Teil 1, nr. 46 of 28 July 1994, pp. 1670–1671.

[7] By 1996, the Netherlands had already passed legislation banning the import and sale of goods containing 'Azo-dyes'. By 1998, Sweden, France and Denmark were on their way to doing the same (see, Fengzhong, 1999).

[8] Following this legislation, a draft notification proposing imposition of prohibition on the handling of 'Azo-dyes' was published by the Ministry of Environment and Forests (MoEF), Govt. of India in March 1997. It completely banned the import and production of this chemical. This study examines the impact of the more exogenous German regulation and its effect on innovation of upstream dye-producing Indian chemical firms while controlling for the effect of the 1997 MoEF regulation.

[9] India is one of the main exporters of leather and textile products in the global market and both these industries employ a very high proportion of the domestic labour force. The textile industry, one of the largest employers in India, second only to agriculture, accounts for about 16% of India's total exports and 3.04% of the global trade in textiles (Ministry of Textiles, Govt. of India, 2008). The total Indian leather exports is US$ 2.4 billion, third only to China and Italy, and it ranks eighth in export earnings within the country, holding a share of around 5.16% of the world trade. It is also a major employer, providing employment to about 2.5 million people (Council of Leather Exports, 2008). In addition, Germany represents a large share of the export market for Indian leather and textile goods. For example, textiles alone made up around 76% of all consumer good exports from India to Germany (IKB Deutsche Industriebank, 1994). This created a strategic space for the chemical firms to be indirectly involved given that leather and textile firms were one of the primary customers of the upstream dye-producing chemical firms.

[10] However, Porter was not the first to question mainstream economic views about the cost of environmental regulation. Arguments that pollution controls can spur the reduction of waste by businesses date back to the 1800s (Desrochers and Haight, 2012). By the 1980s, some researchers had already begun to examine whether environmental regulation(s) could boost technological innovation without harming competitiveness (Ashford, 1993).

[11] The Porter's Hypothesis has generated arguments both for and against substantiated by theoretical and empirical evidence (see Ambec and Barla (2002) for an early theoretical discussion and Jaffe and Palmer (1997) for an early empirical examination).

treated with 'Azo-dyes' were sold, demanded its replacement with other higher-quality substitutes. Identifying one such exogenous regulation, which can be exploited to test the innovation effects, is the first contribution of the study. Our paper makes an important contribution to this debate around Porter's Hypothesis using the facility of a well designed exogenous foreign environmental regulation and examining its effects on innovation of the targeted downstream and upstream industry.

The theoretical mechanisms that have been offered through which the Porter Hypothesis manifests have been behavioral (Aghion et al., 1997; Ambec et al., 2013) where a rationally bounded manager taking decisions on behalf of a profit-maximizing firm is argued to be present-biased, postponing investments on costly innovation now for which benefits occur later. This strand of literature argues that an external environmental regulation reduces the information asymmetry that is inherent in such principal-agent settings. A second theoretical strand offers a market failure explanation as to why firms underinvest in innovation. It argues that sometimes regulation can be used as a strategic tool for protection of the domestic industry (Simpson and Bradford, 1996) or in creating a market for apples in a setting where lemons are being sold by firms aided by an external regulatory endorsement (Ambec et al., 2013). A final market failure based explanation also comes from the notion that due to the public nature of knowledge, there is potentially a chance that firms will necessarily underinvest in R&D in the absence of regulation (Mohr, 2002; Popp, 2005).[12] It is worth noting that all these arguments hardly incorporate the role of downstream-upstream nature of an industry and herein the heterogeneous effects of regulation on innovation. By examining the impact of our focal regulation primarily on upstream innovation we aim to advance this literature, where to the best of our knowledge there exists very little assessments with only couple of exceptions indirectly examining the issue (Greaker, 2006; Ghosh and Sanyal, 2013).

It is also useful to note here that the most common empirical literature on environmental policy and innovation is to test the 'weak' version of the Porter Hypothesis: properly designed environmental regulation may spur innovation.[13] In one of the very first studies concerning Porter's Hypothesis, Jaffe and Palmer (1997) estimates the relationship between pollution abatement costs (a proxy for the stringency of environmental regulation) and total R&D expenditures (or the number of successful patent applications). They find a positive and significant link between R&D and pollution abatement costs, but none with the number of patents. Many other studies examining the hypothesis find broadly similar conclusions (Lanjouw and Mody, 1996; Brunnermeier and Cohen, 2003; Popp, 2006; Kneller and Manderson, 2010; Dechezleprêtre et al., 2011; Asano and Matsushima, 2014; Dechezleprêtre and Glachant, 2014; Pelkmans and Renda, 2014; Dechezleprêtre et al., 2015; Calel and Dechezleprêtre, 2016). In contrast, Nelson et al. (1993) and Gray and Shadbegian (1998) emphasizes a negative relationship between environmental regulations and investments in capital. Therefore, empirically it is less clear whether there is an increase or decrease in the investments towards innovation following an environmental regulation. It is also critical here to note that for the most part, extant literature on environmental policy and innovation focuses on the effect of environmental policy on technical change of the downstream firms or the firms to which the regulation is primarily directed. Though, our foremost objective is to investigate the role of 'Azo-dyes' on the innovation activities of the upstream (or dye-making) firms, we also look at the innovation effect on the downstream (or leather and textile) firms. We find that the 1994 German ban on 'Azo-dyes' significantly reduces the innovative activities of the downstream firms, thereby contradicting Porter Hypothesis. This suggests that there could be a substitution effect in terms of innovation from the downstream to the upstream sector. We believe that this is a novel finding that requires further validation in future empirical and theoretical work.

Finally, the above discussion brings us to the third and most important contribution of this study. Reviewing the existing literature on environmental policy and regulation reveals to us that there is an important gap in prior work on the role of Porter's Hypothesis in the context of its effect on upstream firms. Greaker (2006) develops a theoretical model to argue that a stringent environmental policy can increase entry into the upstream sector providing new abatement equipment, and making the supply curve for pollution abatement equipment shift downwards. He argues that the competitiveness (increase in export market share) of the downstream polluting industry may improve through more innovation at the upstream sector. Empirically, to the best of our knowledge the only other study that exists in this context is by Ghosh and Sanyal (2013), who uses the US electricity deregulation in the 1990's to study the innovation response of upstream technology suppliers when their downstream technology buyers experience a transition from regulation to product market competition. They find that electric technology innovation by upstream innovators has experienced a 19.3% decline due to deregulation. Therefore, ours is the first paper that empirically tests the innovation responses of the upstream firms given the imposition of a stringent environmental regulation, in our case the ban on 'Azo-dyes'. Our results offer robust evidence of significant increase in the innovation expenditure of the dye-makers relative to other chemical firms (producing compounds other than dyes) because of the 'Azo-dyes' ban in 1994. With this, we provide empirical support to Greaker (2006), offer a potential complement to Ghosh and Sanyal (2013) and extend the Porter Hypothesis to show the possibility of a substitution effect across downstream-upstream sectors in examining the relationship between innovation and regulation.

Needless to say, given our context, our study associatedly makes some other subsidiary contributions. This is especially in terms of the heterogenous effect of the regulation on innovation across various quartiles of firm sizes and by domestic or multinational firms. By doing so, we first connect our paper to the burgeoning literature on trade, innovation and heterogeneous firm effects (Acharya and Keller 2009; Bustos, 2011 offer some recent evidence). Second, our finding that domestic upstream firms engage more in technology transfer (compared to R&D expenditure), while foreign upstream firms engage in R&D finds an audience with past seminal work on technology transfer between northern and southern countries (Krugman 1979; Glass and Saggi, 1998). Our findings also resonates with the literature that investigates the extension of green practices across the supply chain (Vachon and Klassen, 2006; Olson, 2013). Finally, given our developing economy context, we also provide a new empirical setting in which to examine the extended Porter's Hypothesis as it relates to its upstream-downstream implications.

To summarize, our study asks two baseline questions. First, what is the direct effect of the exogenous foreign environmental regu-

[12] Beyond behavioral and market-failure based arguments some studies have also offered organizational reasons as to why regulation would be required to enhance innovative activity by firms. Ambec and Barla (2002) explores this notion by highlighting that if managers have "private information about the real costs of technologies which enhances productivity and environmental performance, they can potentially use this information opportunistically by exaggerating these costs, thereby extracting rent from the firm" (Ambec et al., 2013). These studies argue that in these cases governmental regulation reduces the rent spillage to managers helping in resetting the relationship between environmental regulation and innovation.

[13] In practice, innovation is generally measured through R&D expenses (input) or through the number of registered patents (the product of R&D activity). However, as Porter and van der Linde (1995, p.98) emphasize, innovation is more than just technological change and can take various forms including "a product's or service's design, the segments it serves, how it is produced, how it is marketed and how it is supported." (Ambec et al., 2013)

Table 1
Descriptive Statistics.

	Mean	Median	Std. dev	Min	Max
Dependent Variables					
Innovation Expenditure	1.52	0	14.72	0	600.6
R&D Expenditure	0.38	0	3.74	0	113.3
Technology Transfer	1.14	0	13.67	0	600.6
Firm level determinants – Explanatory Variables					
Capital Employed	837.32	163.1	2388.24	2	30757.1
Import of Capital Goods	43.40	3.9	132.88	0.1	1801.8
Export Share	0.07	0.002	0.25	0	0.94
Sales	253.65	40.2	1142.48	0	22098.7
Productivity	0.03	0	0.25	0	3.17
Assets	1090.75	225.65	2962.02	5.2	38092.7
GVA	126.63	0	623.16	0	14724.5
Ownership	0.93	1	0.25	0	1
Age	10.02	6	16.50	0	115
Industry level determinants – Explanatory Variables					
Skill Share	0.31	0.33	0.03	0.27	0.34
Input Tariffs	157.92	178.01	34.57	85.63	202.02

Notes: 'Innovation Expenditure', 'R&D Expenditure' and 'Technology Trasnfer' is measured at the firm level in Million INR. 'Innovation Expenditure' is defined as the sum of 'R&D Expenditure' and 'Technology Trasnfer'. 'Technology Trasnfer' is defined as the royalty payment towards technical knowhow. 'Capital Employed' is the total amount of capital employed by a firm. 'Import of Capital Goods' is the amount of capital imported by a firm. 'Export Share' is the ratio of exports to total sales of a firm. 'Sales' is the total amount of sales (exports + domestic sales) of a firm. 'Productivity' is the total factor productivity measured by Levinsohn and Petrin (2003) methodology at the firm level. 'Assets' is the total amount of assets of a firm. 'GVA' is the gross value-added of a firm. It is defined as the total sales minus total raw material expenditure. 'Ownership' is a binary variable. It takes a value 1 if it is a domestic firm and zero otherwise. 'Age' is the age of a firm. 'Skill intensity' is the ratio of non-production workers to total employees of an industry at 3-digit level (NIC 2004). 'Input Tariff' is input tariffs of an industry at 3-digit level (NIC 2004).

lation on the innovative activity of downstream firms? Second, is there any subsequent effect of the exogenous foreign environmental regulation on the innovative activities of upstream firms? If so, are these effects heterogenous across firm sizes and ownership? In answering these questions, we identify an exogenous shock, in terms of environmental regulation, apply a sharp treatment-control group approach and causally contribute to the literature on Porter's Hypothesis, especially when extended to its implications for upstream innovation.

3. Data and preliminary analysis

3.1. Firm level data

We examine the proposed effect of the 'Azo-dyes' ban on the comparative innovation expenditure of upstream and downstream firms using firm level data from PROWESS database, previously used by Fisman and Khanna (2004), Goldberg et al. (2010), Helmers et al. (2015) among others and published by the Centre for Monitoring Indian Economy (CMIE). We outline the features of this dataset in detail in this section.

The PROWESS database contains information on approximately 27,400 publicly listed companies, all within the organized sector, of which almost 9000 are in the manufacturing sector. It contains information primarily from the income statements and the balance sheets of firms. It reports direct measures on a vast array of firm level characteristics including sales, disaggregated trade (exports and imports) components, R&D expenditure, payment on technical knowhow or technology transfer, production factors employed, gross value-added, assets, ownership and others which we use for our empirical analysis. In addition, the database covers large firms, firms listed on the major stock exchanges (including all the publicly traded firms) and many small firms. Data for larger firms is worked out from the balance sheets, while CMIE periodically surveys the smaller firms.

PROWESS presents several features that make it particularly appealing for the purposes of our study, and puts it at an advantage compared to other available sources, such as the Indian Annual Survey of Industries (ASI), for instance. First, unlike other sources, the PROWESS data is in effect a panel of firms, enabling us to study their behaviour over time; specifically, the (unbalanced) sample covers up to 9000 firms, across 310 (5-digit National Industrial Classification (NIC) 2008) manufacturing industries that belong to 22 (2-digit NIC 2008) aggregated industries,[14] over the period of 1990–2002.[15] For our analysis, we focus only on the 'Chemical' industries, which is 20 at the 2-digit level of NIC 2008. Further, we use NIC at the 5-digit level to identify the exact 'dye-producing' chemical firms, or our treated group of firms; a dye-producing firm belongs to "20114 (5-digit NIC 2008) – Manufacture of dyes and pigments from any source in basic form or as concentrate." We use other chemical firms, except dye-producing firms, as the control group.

Second, the unique feature of the data set, upon which our study is mainly based, is that it disaggregates innovation expenditure into internal technology development or R&D expenditures and technology transfer or royalty payment for technical knowhow. We use the sum of the R&D expenditures and technology transfer as the total innovation expenditure by a firm as our outcome of interest. This feature enables us to study the effect of the 'Azo-dyes' regulation, over a relatively large period, ranging from the total innovation expenditure to internal technology development (R&D) and foreign acquisition of technology (technology transfer), and with that we trace down the underlying channel through which shifts occur in the aggregate innovation expenditure of upstream firms.

Last, PROWESS has a relatively wide coverage. It accounts for more than 70% of the economic activity in the organized industrial sector, and 75% (95%) of corporate (excise duty) taxes collected by the Indian Government (Goldberg et al., 2010). However, the database does not cover the unorganized sector. All variables are measured in Millions of Indian Rupees (INR), deflated to 2005 using the industry-specific Wholesale Price Index,[16] and are outlined in the Appendix A. An unbalanced panel over the period 1990–2002 is

[14] In terms of composition, approximately 12% of the firms in the dataset are registered under the Chemical industries, followed by Food Products (11.5%), Textiles (10.99%) and Basic Metals (10.88%).

[15] While our data covers the period of 1990–2006, we limit the main analysis to 2002 in order to avoid the potential biases caused by other innovation-inducing reforms, such as patent laws in 2002 and 2005.

[16] We thank Hunt Allcott for sharing this data with us, used in Allcott et al. (2016).

Table 2
Summary Statistics: Innovation Expenditure of Dye-producing Chemical firms – Pre and Post 1994 'Azo-dyes' Ban.

	Dye-producing Firms	
	Pre-Ban 1990–1994	Post-Ban1995–2002
Innovation Expenditure	2.71	5.47***
R&D Expenditure	0.65	2.57***
Technology Transfer	2.05	3.00**

Notes: The numbers represent average for a firm belonging to the Dye-producing sector. A dye-producing firm belongs to "**20114** (5-digit NIC 2008) – **Manufacture of dyes and pigments from any source in basic form or as concentrate**". All monetary-based variables (Innovation Expenditure, R&D Expenditure and Technology Transfer) are measured in Millions of Indian Rupees (INR). The numbers are deflated by 2005 industry-specific Wholesale Price Index (WPI). The significance of the difference between the numbers, for two different period, is based on a simple t-test of difference in means. **, *** denotes 5% and 1% level of significance.

used for estimation purposes. Table 1 presents descriptive statistics for all variables.

3.2. Preliminary analysis

Table 2 provides the average values of investments towards aggregate innovation (R&D expenditure plus technology transfer), R&D expenditure and technology transfer in pre- and post-regulation period for the dye-producing upstream chemical firms. For our purpose, we denote 1990–1994 as the pre-regulation period and 1995–2002 the post-regulation period. The numbers point to a significant increase in the aggregate innovation expenditure in the post-regulation period. Both the components of aggregate innovation expenditure registered a steep increase in the post-regulation period; however, the increase is particularly higher in case of R&D expenditure. Before the regulation, dependence of an average dye-producing chemical firm on technology transfer or foreign acquisition of technology was much higher compared to internal R&D, whereas, in the post-regulation period, the difference in the average expenditure on R&D and technology transfer decreases very sharply; R&D expenditure of an average dye-producing chemical firm increased by a factor of 4, whereas payments for technology transfer jumped by 150%. We test the significance of the differences between the average values of these two different periods based on a simple t-test of difference of means and all the t-tests are significant. However, these results are merely suggestive and we would need to control for other simultaneous events and firm and industry level characteristics (both observed and unobserved) to make some causal inferences. To address these concerns, we describe our empirical strategy in the following section.

4. The indirect effects of regulation on upstream innovation

4.1. Empirical strategy

Following the existing literature on the effect of environmental policy on firm level innovation (Berrone et al., 2013; Dechezleprêtre and Glachant, 2014; Dechezleprêtre et al., 2015; Calel and Dechezleprêtre, 2016), and in general firm level innovation (Bustos, 2011; Ghosh and Sanyal, 2013), we evaluate the effect of the 'Azo-dyes' ban imposed by Germany in 1994 on the relative innovation expenditure by the dye-producing upstream chemical firms using a specification that relates to the literature in economics of R&D (Griliches, 1979; Branstetter, 2001; Mairesse and Mohnen, 2002) as follows:

$$\ln(x_{ijt}) = \beta\left(Post_t * Dye_{ij}\right) + Post_t + \gamma X_{ijt} + firmcontrols_{it} + \theta_j + \eta_t + \varepsilon_{ijt} \quad (1)$$

where, x_{ijt}, is the aggregate innovation expenditure of a firm i belonging to sector j at time t. The innovation expenditure of a dye-producing chemical firm, our treatment group, is the sum of R&D expenses and royalty payment towards technical knowhow. $Post_t$ is a dummy variable measuring the environmental regulation; it takes a value of 1 for the years following the 'Azo-dyes' ban, i.e., from 1995 to 2002. Dye_{ij} is a dummy variable, which takes a value 1 if a firm i belongs to the 'dye-producing' sector j.[17] A firm i is a dye-producer, if it belongs to "20114 (5-digit NIC 2008) – Manufacture of dyes and pigments from any source in basic form or as concentrate". Since, our main variable of interest, $Post_t$, is a year dummy, it will be difficult to distinguish between 'treatment' and 'time' effects, unless we use a control group in the estimation. To untangle the true effect of the regulation dummy, $Post_t$, we need to use a group which is exogenous to the shock or the treatment, while ensuring that its behavioral pattern more-or-less follows the same path as that of the treated one. For this purpose, we use all other chemical sector firms, excluding those who are dye-producing as the control group in our estimations.

We recognize that these may not be the perfect 'treatment' and 'control' groups that we could use. The first best would have been to identify the exact 'Azo-dyes' producing firms and treat it as the 'treatment' group, whereas 'other dyes' producing firms as the 'control group since they did not produce the banned chemical, and therefore are unaffected by the regulation. But, our dataset only allows us to identify the product of a firm at the NIC 5-digit level, which identifies the product of a dye-producing firm as "Dyes". Given the importance of 'Azo-dyes' in the 1990s, it would not be entirely wrong to assume that one of the products for most of the dye-producing firms is 'Azo-dyes'. However, it would still not solve the problem of the perfect control group of it being completely exogenous as there is free mobility of workers across different sub-sectors of the overall dye-producing industry in India. Therefore, given the circumstances, this is the best that we could come up with, since all the other chemical sectors are impacted by some of the Indian macroeconomic reforms (e.g., by simultaneous tariff and FDI liberalization that happened in the 1990s) in the same way as chemical sector. Using any other sector, say services, would be more exogenous to the shock relative to the other chemical sectors (apart from dye-producing), but the behavioral pattern of any sector belonging to services is completely different (e.g., it is not a tradable sector) and this may bias the results completely.[18]

Our main coefficient of interest is β. β measures the effect of the 'Azo-dyes' regulation ($Post_t \times Dye_{ij}$) on firm level innovation expenditure given that a firm belongs to the dye-producing sector relative to other sectors, which potentially has the same characteristics as the treated sectors but are exogenous to the regulation. In other words, it measures the relative effect of the 1994 'Azo-dyes' ban on the innovation expenditure of the dye-producing firms. The interaction of Dye_{ij} with $Post_t$ provides a clear and exogenous measure to investigate the effect of the 'Azo-dyes' ban from Germany. It also represents a difference-in-differences approach to measure the effect of 'Azo-dyes' ban on the innovation expenditure of Indian

[17] We use the National Industrial Classification (NIC) 2008. The manufacturing sector runs from 10 to 32 at the two-digit level. The 'dye-producing' sector is embedded within the Chemical sector, which is 20 (at two-digit level) of NIC 2008. We carefully identify the 'dye-producing' sector at the 5-digit NIC 2008. There are around 100 dye-producing chemical firms at the 5-digit NIC level.

[18] In unreported results, available with the authors, a robustness check was conducted by defining a broader treatment group with all chemical firms and the control group as all other manufacturing firms, excluding chemical, leather and textile firms. Results with this alternative treatment and control approach are consistent with our reported baseline findings. We thank anonymous reviewers for suggesting us to implement a sharper treatment-control approach to increase the causal strength of our analysis.

dye-producing firms. This interaction term would capture the differential effect of the 'Azo-dyes' ban on firms according to their affiliation to the dye-producing sector. Or, in other words, since we expect the aggregate innovation expenditure of dye-producing firms to rise, therefore it is the change in innovation expenditure due to the 'Azo-dyes' ban, net of general change post-1994, and net of possible permanent difference across other chemical sector firms.

X_{ijt} is a vector of control variables at both the firm and industry level, such as import of capital goods, capital employed, export share, firm level productivity estimates and skill share, input tariffs at the industry level, which can potentially affect the innovation expenditure of a firm. Therefore, not controlling for such variables, our results may run into omitted variable bias. $Firmcontrols_{it}$ is a vector of variables that includes firm size, size squared, age, age squared and an indicator for domestic or foreign ownership. We use total assets of a firm as the size indicator. Since, our main variable of interest is at the industry level, we follow Moulton (1990) and include industry fixed effects (θ_j) at the 5-digit NIC in Eq. (1); η_t are year fixed effects which controls for any time-specific shocks that affect all firms equally. We cluster our standard errors at the 5-digit NIC level.[19]

While estimating Eq. (1), we also carefully control for other simultaneous events or trade policies which could potentially affect our outcome of interest and confound our analysis. The most substantive one in the Indian context is the trade liberalization process, that started because of the macroeconomic shock in 1991. Following, Topalova and Khandelwal (2011) and Ahsan and Mitra (2014), we use input tariffs as an indicator of trade reform to control for the possibility of trade liberalization significantly affecting technology upgrading of firms (Bustos, 2011).

Next, two other important events took place during the same time frame which may also affect the results: (a) India became a member of World Trade Organization (WTO) in the year 1995; and (b) because of the membership of WTO in 1995, India experienced substantial depreciation in bilateral exchange rate, which could also affect the results. We control for these confounding effects by: (i) interacting industry fixed effects and time-trend and (ii) also by interacting industry and time fixed effects, since accession to WTO and depreciation in exchange rates will have differential effects on different industrial sectors over time. The interaction of industry fixed effects and time trend will also categorically control for the possible effects of the matching domestic regulation by the Ministry of Environment and Forests (MoEF) of Govt. of India. In March 1997, the Govt. of India also proposed a domestic prohibition on the handling of 'Azo-dyes'. In addition, the interaction of the industry fixed effects and year trends will account for unobserved changing consumer preferences for the safer-improved product, pre-policy. The time fixed effects and time trends to some extent will also account for impact of other foreign bans that were announced after the German ban and which might be impacting the focal sector in India. The presence of industry level fixed effects (θ_i) will specifically control for the network effects across other chemical sectors with dye-producing sector, information received by firms belonging to the dye-producing industries about the bans, the assistance/suggestions from industry level stakeholders and government sponsored institutions that might have helped in their upgradation of innovation capabilities. Controlling for all these other effects will help us to produce unbiased and exact estimates of the effect of the 'Azo-dyes' regulation indirectly on the Indian dye-producing firms in the chemical or upstream sector.

4.2. Results

4.2.1. The effects on the downstream sector

Before we investigate the effects of the 1994 German 'Azo-dyes' regulation on the innovation patterns of the Indian dye-producing chemical firms (upstream sector), it is imperative to understand the effect on the innovation patterns in the downstream leather and textile sectors, the sectors on which the ban was originally targeted. In other words, we would like to start our analysis with a falsification exercise and examine if there is any direct evidence of substitution effect regarding innovation from the downstream to upstream sector. In particular, we estimate the counterfactual, which is the direct effect of the 1994 'Azo-dyes' regulation on firm level innovation expenditure of the downstream, i.e., the leather and textile firms. The thought experiment here is to test if the 1994 'Azo-dyes' ban indeed had no or negative impact on the innovative activity of the downstream sector on which it was primarily targeted, which in turn led to an increase in innovative activity for the upstream sector. For this purpose, we estimate Eq. (1) using the same methodology outlined above, but with two major differences. First, the sectoral dummy or Dye_{ij} is substituted by lt_{ij}. It takes a value 1 if firm i belongs to sector j = leather or textile; second, the control group that we use in the estimation is the entire manufacturing sector excluding the dye-producing firms of the chemical sector.

Results are outlined in Table 3. Overall, the results clearly point out that there is indeed no positive effect of $Post_t \times lt_{ij}$ on the innovation expenditure for an average leather and textile firm. In fact, the 'Azo-dyes' ban led to significant drop in the innovative activities of the downstream sector relative to other manufacturing sectors (less dye-producing firms) in the post-1994 period. In columns (1) to (4), we use aggregate innovation expenditure (sum of R&D expenditure and technology transfer) of a leather and textile firm as the outcome of interest. Columns (1) and (2) use interactions of industry fixed effects with time trend and year fixed effects, respectively to control for other simultaneous policy changes that may affect the innovation patterns of the leather and textile firms. We use import of capital goods and capital employed by a firm in column (3) to control for the association between capital intensity and innovative activities. Our main finding, relative decrease in the innovation expenditure of a downstream firm, continues to hold. Theoretical studies in industrial organization literature highlights that competition can have downward effect on innovation (Aghion et al., 2005). We use input tariffs at 3-digit NIC in column (4) as an indicator for trade liberalization or product market competition. The coefficient of $Post_t \times lt_{ij}$ remains negative and significant; inclusion of different kinds of controls at both firm and industry level does little to change our benchmark findings. We decompose the aggregate innovation expenditure into R&D expenditure and royalty payment for technical knowhow or technology transfer in columns (5) and (6), respectively. The results do not change. Both R&D expenditure and payment for technical knowhow took a downturn as a response to the 'Azo-dyes' ban, with the effect for R&D expenditure significantly higher. These results indicate the possibility of a substitution effect of innovation from the leather and textile to the upstream dye-producing firms of the chemical sector which we investigate next.

4.2.2. Benchmark results: the effects on upstream sector

In this section, we focus on our main outcome of interest – the innovation expenditure of the upstream firms. In particular, we now examine the effect of the 1994 'Azo-dyes' regulation ($Post_t \times Dye_{ij}$) on the firm level innovation expenditure of the dye-

[19] We also cluster our standard errors at the firm level, the results remain the same. In addition, in unreported results available with authors on request, findings remain consistent if we use alternative levels of industry fixed effects at 2 or 3 digit NIC level.

Table 3
Impact of 1994 German 'Azo-dyes' Ban on Innovation of Leather and Textile Firms (Downstream Sector).

	Innovation Expenditure				R&D Expenditure	Technology Transfer
	(1)	(2)	(3)	(4)	(5)	(6)
$Post_t \times lt_{ij}$	−0.168***	−0.187***	−0.171***	−0.108*	−0.153***	−0.059*
	(0.052)	(0.008)	(0.052)	(0.061)	(0.043)	(0.032)
lt_{ij} × (Cap Employed)			0.016			
			(0.018)			
lt_{ij} × (Imp of Cap Goods)			−0.219***			
			(0.065)			
lt_{ij} × (Input Tariffs)				0.063		
				(0.050)		
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes
R-Square	0.42	0.44	0.42	0.43	0.33	0.29
N	39931	39931	39662	37568	39931	39930
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE (5-digit)*Time Trend	Yes	No	Yes	Yes	Yes	Yes
Industry FE (4-digit)*Year FE	No	Yes	No	No	No	No

Notes: Columns (1) – (4) use natural logarithm of innovation expenditure of a firm plus 1 as the dependent variable. Innovation expenditure is defined as the sum of R&D expenses and payments towards technical knowhow of a firm. Columns (5) and (6) use R&D expenses and payments towards technical knowhow of a firm plus 1, respectively as the dependent variable. '$Post_t$' is a regulation dummy, which takes a value 1 when the year is greater than 1994. lt_{ij} is a firm level dummy variable, which takes a value 1, if the industrial sector belongs to leather and textile, the downstream sectors. 'Imp of Cap Goods' is the amount of capital goods imported by a leather and textile firm. 'Cap Employed' is the amount of capital employed by a leather and textile firm. 'Input Tariffs' is the industry level (3-digit) tariffs on intermediate inputs at National Industrial Classification (NIC) 2004. We use the entire manufacturing sector less the 'dye-producing' sector as the control group. A dye-producing firm belongs to "**20114** (5-digit NIC 2008) – **Manufacture of dyes and pigments from any source in basic form or as concentrate**". 'Firm Controls' include age of a firm, age squared, size of a firm and ownership dummy (foreign or domestic). We use assets as the indicator for size of a firm. Numbers in the parenthesis are robust clustered standard errors at the 5-digit industry level. Intercepts are not reported. All the regressions contain the pairwise and individual terms of the interactions. *,**,*** denotes 10%, 5% and 1% level of significance.

producing upstream chemical firms as compared to other chemical firms (not engaged in dye-producing), following Eq. (1). Table 4 reports our benchmark findings. Columns (1)–(11), except column 7, use natural logarithm of total innovation expenditure plus 1 (to take care of the zeros) as the dependent variable. We define innovation expenditure of a firm as the sum of R&D expenditure and royalty payment for technical knowhow. We start by simply regressing logarithm of total innovation expenditure of a dye-producing chemical firm on the interaction of $Post_t \times Dye_{ij}$ controlling for size of a firm (indicated by total assets), age, age squared, ownership dummy (domestic or foreign) and industry-year fixed effects. Our coefficient of interest is significant and positive. It point out that the 1994 'Azo-dyes' ban led to an increase in innovation expenditure of an average dye-producing firm by 21.5% as compared to any other firm belonging to the chemical sectors which were not dye-producing. We also find that firm size is positive and significantly associated with innovation expenditure, which point out that big firms are more engaged in innovation, a finding that is consistent with some prior work in the literature on economics of innovation (Scherer, 1967; Aghion et al., 2005; Cohen 2010). Column (2) additionally introduces interaction of industry fixed effects (at 5-digit NIC) with time trends. The interactions of industry fixed effects with time trends would control for all other simultaneous policies, which may have an impact on the innovation activities; introduction of these interaction effects does little to change our benchmark results. Our coefficient of interest continues to be positive and significant.

Next, in column (3), we control for scale effects by introducing a square term of total assets. Our benchmark result continues to hold with the squared term of total assets positively and significantly affecting innovation expenditure of a dye-producing firm. Columns (4) and (5) interact industry-year fixed effects at 3-digit and 4-digit, respectively to control for the unobserved macroeconomic and trade reform effects, since such effects are differentiated across industries. As the coefficient demonstrates, the effect of $Post_t \times Dye_{ij}$ on innovation expenditure of a dye-producing chemical firm is positive and significant. In other words, an average dye-producing chemical firm has higher innovation expenditure relative to other chemical firms (producing other chemical compounds) because of the 1994 'Azo-dyes' ban.

Column (6) controls for a matching domestic policy change. The MoEF, Govt. of India, extends the German 'Azo-dyes' regulation in the domestic market by banning the import and production of 'Azo-dyes' completely in 1997. This means, the leather and textile firms, which were selling goods treated with 'Azo-dyes' between 1994 and 1997 in the domestic market were not able to sell those in the post-1997 period.[20] To measure the additional effect of the domestic regulation, we use the same interaction term, $Post_t \times Dye_{ij}$, but with a small change: $Post_t$ is substituted with $Post_{97}$. $Post_{97}$ takes a value 1 if year is greater than 1997 instead of 1994. Our findings suggest that the 1997 MoEF regulation also led to further increase in innovative expenses of the dye-producing chemical firms as compared to other chemical firms. However, our primary coefficient of interest from the 1994 ban continues to be significant and larger in size indicating that in a horse race between the German ban of 1994 and the Indian domestic ban of 1997, the primary impact came from the 1994 ban even controlling for the presence of the domestic 1997 ban in the Indian market. In column (7), we deal with the problem of zeroes. For all the previous specifications, we use natural logarithm of the dependent variable plus one and estimated the model in percentage changes. We understand that dealing with zeroes in this way is an arbitrary method, which could possibly induce measurement error in the analysis, thereby biasing our estimates. We therefore use a Poisson Pseudo-Maximum Likelihood (PPML) estimation approach following Silva and Tenreyro (2006).[21] While PPML estimates the coefficients in percentage changes, PPML can

[20] This would create further demand for newly substitutable chemical(s) by the domestic-oriented firms and in turn will increase the innovation expenditure by the dye-producing firms.

[21] On the recommendation of a referee, we plot the density of the aggregate innovation expenditure, which is our outcome of interest; approximately 15% of the values are zero. While this might merit the use of zero inflated poisson models, poisson distribution is used in general when the dependent variable is based on count data. Nonetheless, we conduct a robustness test using the method and in unreported results available with the authors, the results were consistent with our baseline findings.

Table 4
Benchmark Results – Impact of 1994 German 'Azo-dyes' Ban on Innovation Expenditure of Dye-producing Chemical firms (Upstream Sector).

	Innovation Expenditure										
								Propensity Score Matching (PSM)			
						1997 MoEF Regulation	PPML	Average Treatment Effect (ATE)	Average Treatment Effect of the Treated (ATT)	Endogenous Regulation	One Year Before & After the Regulation
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
$Post_t \times Dye_{ij}$	0.195***	0.142***	0.109***	0.177***	0.165***	0.103***	0.476***	0.253**	0.184***	0.142***	0.136***
	(0.049)	(0.042)	(0.035)	(0.039)	(0.047)	(0.039)	(0.116)	(0.103)	(0.060)	(0.042)	(0.035)
Size (Assets)	0.371***	0.371***	−0.475***	0.370***	0.372***	0.371***	1.093***			0.371***	0.435***
	(0.025)	(0.025)	(0.091)	(0.026)	(0.026)	(0.025)	(0.018)			(0.025)	(0.028)
[Size (Assets)]^2			0.069****								
			(0.007)								
$Post_{97} \times Dye_{ij}$						0.097***					
						(0.027)					
$Post_{t-3} \times Dye_{ij}$										−0.126*	
										(0.072)	
$Post_{t-2} \times Dye_{ij}$										−0.095	
										(0.105)	
$Post_{t+1} \times Dye_{ij}$										0.331*	
										(0.200)	
$Post_{t+2} \times Dye_{ij}$										0.262	
										(0.211)	
$Post_{t+3} \times Dye_{ij}$										0.241*	
										(0.139)	
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-Square	0.37	0.37	0.44	0.38	0.38	0.37	n/a	n/a	n/a	0.37	0.40
N	6251	6251	6251	6251	6251	6251	3224	5420	5420	6251	1430
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Industry FE (5-digit)*Time Trend	No	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes
Industry FE (3-digit)*Year FE	No	No	No	Yes	No	No	No	No	No	No	No
Industry FE (4-digit)*Year FE	No	No	No	No	Yes	No	No	No	No	No	No

Notes: Columns (1) – (11) use natural logarithm of innovation expenditure of a firm as the dependent variable. Innovation expenditure is defined as the sum of R&D expenses and payments towards technical knowhow (Technology Transfer) of a firm. '$Post_t$' is a regulation dummy, which takes a value 1 when the year is greater than 1994. 'Dye_{ij}' is a firm level dummy variable, which takes a value 1 if a firm belongs to "**20114** (5-digit NIC 2008) – **Manufacture of dyes and pigments from any source in basic form or as concentrate**". '$Post_{97}$' is a regulation dummy, which takes a value 1 when the year is greater than 1997. '$Post_{t-3}$' and '$Post_{t-2}$' takes a value 1 if the year is equal to or less than three and two years from the year of the regulation, respectively. '$Post_{t+1}$', '$Post_{t+2}$' and '$Post_{t+3}$' takes a value 1 if the year is equal to or greater than one, two and three years following the regulation. We use the other sub-sectors of "**Chemical**" industry as the control group. 'Firm Controls' include age, age squared and ownership dummy (either domestic or foreign owned). Numbers in the parenthesis are robust clustered standard errors at the 5-digit industry level. Intercepts are not reported. All the regressions contain the pairwise and individual terms of the interactions. *,**,*** denotes 10%, 5% and 1% level of significance.

handle zeros giving consistent point estimates for a broad class of models. PPML has this additional attribute that the dependent variable does not have to follow a Poisson distribution or has to be integer-valued (i.e., it can be continuous). We estimate the standard errors using Eicker-White robust covariance matric estimator. As the point estimate demonstrates, using this alternative method of estimation does not alter our primary finding: the 1994 German 'Azo-dyes' regulation induces significant positive increase in innovation for the dye-makers or the upstream firms.

An important problem of causal inference is how to estimate the treatment effects in observational studies, in which a group of units is exposed to a well-defined experiment, but (unlike an experiment) no systematic methods of experimental design are used to maintain a control group. It is well recognized that the estimate of a causal effect obtained by comparing a treatment group with a nonexperimental comparison group could be biased because of problems such as self-selection or some systematic judgement by the researcher in selecting units to be assigned to the treatment. Columns (8) and (9) uses propensity score-matching methods to correct for potential sample selection bias due to observable differences between the treatment and control groups. We estimate both the average treatment effect (ATE) and average treatment effect on the treated (ATT) to understand the effect of the 'Azo-dyes' ban on the relative innovation expenditure of the dye-producing firms. A simple exposition of the ATE can be written as follows:

$$ATE = E\left(Y_{1i}|T_i = 1, 0\right) - E(Y_{0i}|T_i = 1, 0)$$

where, $E(.)$ represents the expectation in the population. T_i denotes the treatment (in our case, it is the 'Azo-dyes' ban) with the value of 1 for the treated group and the value of 0 for the control group. In other words, the ATE can be defined as the average effect that would be observed if everyone in the treated and the control groups received treatment, compared with if no one in both groups received treatment (Li, 2012). The ATE measures the difference in mean (average) outcomes between the units assigned to the treatment and control group, respectively. Since, ATE averages across gains from units, we use ATT, which is the average gain from treatment for those who are actually treated. We estimate the following equation to calculate the gain from treatment:

$$\tau_{ATT} = E[Y_{1\mathrm{i}} - Y_{0\mathrm{i}}|T_i = 1]$$

where, τ_{ATT} denotes the gain received by the firms belonging to the dye-producing sector. The expected gain is assumed to be in response to the randomly selected unit (firms) from the population. This is called the ATT. $Y_{1\mathrm{i}}$ is the outcome of the treatment and $Y_{0\mathrm{i}}$ is without the treatment. However, in case of ATT, we employ the nearest neighbor matching method, which is as follows:

$$ATT = \frac{1}{N^T}\sum_{i \in T}\left[Y_i^T - \sum_{i \in C(i)} w_{ij} Y_j^C\right]$$

where, N^T is the number of treated units; $C(i)$ is a set of controls matched to treated unit i; $w_{ij} = \frac{1}{N_i^C}$ if $j \in C(i)$ or 0 otherwise; N_i^C is the number of controls matched to treated unit i. Our β, in both the cases, is positive, significant and higher in absolute value and remain consistent with our baseline findings of a positive effect of the 1994 German ban on the average upstream dye-producing chemical firm.

Our estimation strategy treats the timing of the 'Azo-dyes' ban as exogenous, at least with respect to the activities of the upstream Indian dye-producing chemical firms. It may be that other changes that are coincident with the 'Azo-dyes' ban drive both the changes in the regulation and the measured changes in firm behavior towards innovation. For example, there might be pressure by the multinationals, exerted indirectly via the German government or consumer advocacy group, that may cause Germany to impose the regulation when firms have a need to increase innovation expenditure. While, we cannot completely rule out these alternative explanations, we can examine their plausibility more carefully. In order to understand, whether this is indeed the case, column (10) runs a placebo test with detailed estimates of the timing of changes in innovation expenditure. In particular, it uses an ex-ante ex-post approach to prove that the 1994 'Azo-dyes' regulation is not endogenous. In other words, it examines if there were any anticipatory effects of the ban. It could be possible that consumer sentiment was growing against the use of 'Azo-dyes' before the imposition of the ban. This could have given some idea to firms about the ban. Also, it could be that some of the exporters, who are members of some importers organization, knew about the 1994 regulation from before; therefore, they may have adjusted their firm's behavior as per the modalities of the regulation, which in turn renders a positive impact on the innovation expenditure in the post-regulation period. We argue that this is not the case. We follow Branstetter et al. (2006) and adopt the following methodology. The $Post_{t-3}$ dummy is equal to one for all years that predate the 'Azo-dyes' ban by three or more years and is equal to zero in other years, and the $Post_{t+3}$ dummy is equal to one for all years at least three years after the 'Azo-dyes' ban and zero during other years. The other regulation dummies are equal to one in specific years and zero during other years. There is no dummy for the year immediately preceding the ban (i.e., year t − 1); the coefficient on the ban dummy estimates relative to that year.

The results indicate that the coefficients on the dummies for years prior to the 'Azo-dyes' ban are negative and fails to show any evidence of a clear upward trend prior to the ban when estimated relative to the preceding year. For example, the coefficient on the $Post_{t-3}$ show that the innovation expenditure of a dye-producing firm is less prior to the ban relative to the concurrent effect of the ban, which is $Post_t \times Dye_{ij}$.

On the other hand, the coefficient of the interaction term of regulation and sectoral dummy continues to be positive and significant; whereas, the coefficient for the years after the ban are large, positive and significant. Thus, the timing of changes is consistent with a shift in activities that follows soon after the enactment of the ban; a fairly rapid reaction is reasonable, otherwise the dye-producing firms will witness a significant decrease in their sales revenue, because of drop in demand for one of their core products. Our sample of Indian dye-producing chemical firms include those that possess a portfolio of technologies employed around the world and that are familiar with strong regulated environments. While endogenous firms might require some time to adjust to a binding regulation with which they have little previous experience, it is plausible that the multinationals or foreign firms could respond quickly, redeploying their existing technologies to take advantage of new opportunities created by the binding regulation; this is what we explore later by dividing firms according to their ownership.

Lastly, we consider the immediate effect of the 'Azo-dyes' ban by reducing the period of the study from 1990–2002 to 1993–1995. The reason to do this is to control for the fact that there may be similar kind of regulation(s) in the post-1994 period in other E.U. countries that may have also affected Indian dye-producing firms. Reducing the period to one-year before and after the regulation does little to change our benchmark result; 'Azo-dyes' ban significantly increased the innovation expenditure of the dye-producing firms relative to all other chemical firms. Overall, our estimates show that the effect of the 'Azo-dyes' ban on the relative increase in the innovation expenditure by an average dye-producing chemical firm varies between 11% and 61%.

Our results are robust to using alternative methods and time periods. We extend Porter's Hypothesis to the upstream sector through a possible substitution mechanism from the downstream sector and highlights an important channel through which regulation can also induce innovation. But, one still cannot completely rule out the hypothesis that, in the same year (1994) and maybe in other countries (as other regulations/policy changes within the country will be controlled by either time trends or year fixed effects), other regulations have affected Indian chemical firms producing compounds other than dyes. Such a test is not included in the study and results cannot exclude that possibility. While we admit this as a limitation, to the best of our knowledge, we have not come across any major policy change (apart from the ones that we already control for, such as the MoEF domestic Indian regulation in 1997) during the same period, which can possibly confound our estimates.

4.2.3. Additional controls

After establishing the benchmark result, we turn to test for some additional controls and further potential channels. All specifications in this sub-section follow Eq. (1), with interactions of industry fixed effects (5-digit NIC) and a time trend; given our previous results, we focus strictly on $Post_t \times Dye_{ij}$. Results are presented in Table 5. Our starting point is the potential connection between trade, particularly import of capital goods, and innovation at the firm level. Higher import of capital or intermediate goods can significantly induce firms to invest in technology upgrading (Bas and Berthou, 2016). We do not find any such evidence as in column (1). In column (2), we use capital employed, an indicator for capital intensity of a firm. Our benchmark result, the coefficient estimate on $Post_t \times Dye_{ij}$, continues to be positive and significant. Column (3) introduces export share of a dye-producing firm. We use export share to control for the idea that exposure to international trade might also affect innovation expenditure. In other words, the dye-producing firms must also be exporting the banned dye and a drop in international sales of that product (due to the ban) could also induce firms to innovate new substitutable inputs and this in turn could affect innovation expenditure. Our coefficients show that this is not the case; 'Azo-dyes' ban continues to significantly increase innovation expenditure of dye-producing chemical firms relative to other chemical firms when we control for export share.

Next, we refer to the literature on trade liberalization and productivity, which suggests that firm productivity increases in liberalized industries (e.g., Topalova and Khandelwal, 2011). To the extent that innovation is associated with productivity, the effect we observe may be a result of that. This may be especially prominent in the Indian economy; Hsieh and Klenow (2009) estimates that the 90th to the 10th percentiles of firms' total factor productivity (TFP) in India is 5.0. To address that, we control directly for productivity, by following Ahsan (2013) and Topalova and Khandelwal (2011) and used the Levinsohn and Petrin (2003) methodology to control for firm level TFP. This approach controls for the potential simultaneity in the production function by using a firm's raw material inputs as a proxy for the unobservable productivity shocks.[22] Results are presented in Column (4); as can be seen, $Post_t \times Dye_{ij}$ remains stable in sign, significance, and magnitude, providing additional support that the underlying mechanism works through a different channel than productivity. Column (5) puts all these four attributes together to examine if controlling for all these factors disturbs our benchmark result. Our coefficient of interest suggests that this is not the case.

In columns (6) and (7), we use industry level determinants. We use two important attributes, which could potentially affect innovation expenditure. First, is the potential connection between skilled labour and innovation. We measure the former through the 3-digit industry level ratio of non-production workers to all employees, obtained from Ghosh (2014) (1990–2000),[23] and the ASI (2001–2002) – this being the standard skill intensity measure used in the literature. To test this, in column (6) we add the skill intensity variable; the main result continues to hold with the additional result that skill intensity is positively associated with innovation expenditure. Lastly, in column (7), we control for India's trade liberalization exercise following Topalova and Khandelwal (2011), Ahsan and Mitra (2014). Bustos (2011) who all show that drop in tariffs or trade costs induces firms to upgrade itself technologically significantly and innovate more. In 1990s, India experienced a sufficiently long and significant process of trade liberalization in the form of drop in tariffs (both input and output). Seminal work by Rivera-Batiz and Romer (1991) and Grossman and Helpman (1991), propose that trade liberalization creates tougher market competition and this in turn may affect a firm's incentive to innovate. We test this channel by using input tariffs at the 3-digit industry level from Ahsan and Mitra (2014). Our coefficients show that even though drop in tariffs significantly induced firms to invest in innovation, the primary result controlling for the tariff drops remains positive and significant. Overall, our results provide robust and causal evidence to show that the 1994 German 'Azo-dyes' regulation, which is primarily targeted towards the downstream leather and textile firms, significantly affects the innovation or R&D expenditure patterns of the upstream dye-producing chemical firms.

4.2.4. Disaggregating innovation into R&D expenditure and technology transfer

This section disaggregates the aggregate innovation expenditure into R&D expenditure and royalty payment for technical knowhow (technology transfer) to understand the exact source of increase in aggregate innovation expenditure. Results appear in Table 6. The coefficients from the estimation of 'Azo-dyes' ban separately on R&D expenditure (columns (1)–(5)) and technology transfer (columns (6)–(10)) clearly show us that the increase in the aggregate innovation expenditure because of the 1994 'Azo-dyes' regulation, is due to investments laid out by a dye-producing upstream chemical firm towards both R&D expenditure and technology transfer. However, the effect on technology transfer is higher by a factor of around 1.2–2.5. The results are robust to the interaction of industry-year fixed effects, vector of different firm-industry controls (discussed above) that accounts for other possible confounding trade, macroeconomic and policy changes in India.

Additionally, similar to our exercise above, we run a horse race in columns (5) and (10) between the foreign and domestic (the notification issued by MoEF, Govt. of India in 1997) regulation to see whether there is any possible heterogeneity in the effect between these two different kinds of ban. Our coefficients show that this is indeed the case: R&D expenditure increased because of both the 1994 foreign and 1997 domestic regulation, with the effect significantly higher (double) for the foreign regulation. On the other hand, the effect on technology transfer is two and half times higher because of the 1997 MoEF (domestic) regulation compared to the foreign regulation.

4.2.5. Size heterogeneity

Did all the upstream dye-producing chemical firms in India respond homogenously to the 1994 German 'Azo-dyes' ban? To

[22] For firm i, in industry j, at time t, if ω_{ijt} is an unobservable productivity shock that might be correlated with the firm's choice of variable inputs, yet demand function for intermediate inputs is monotonic in the firm's productivity, then Levinsohn and Petrin (2003) show that raw materials expenditure can act as a proxy for the unobservable shocks, which in turn enables to estimate the corresponding production function and TFP levels. See Levinsohn and Petrin (2003) for further details and more of our TFP estimation are available on request.

[23] We thank Sangeeta Ghosh for sharing these data with us.

Table 5
Impact of 1994 German 'Azo-dyes' Ban on Innovation Expenditure of Dye-producing Chemical firms (Upstream Sector): Controlling for Other Possible Channels.

	Innovation Expenditure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$Post_t \times Dye_{ij}$	0.138***	0.133***	0.147***	0.129***	0.144***	0.124***	0.135***
	(0.041)	(0.047)	(0.051)	(0.041)	(0.054)	(0.040)	(0.031)
$Dye_{ij} \times$ (Imp of Cap Goods)	−0.193				0.567***		
	(0.120)				(0.104)		
$Dye_{ij} \times$ (Cap Employed)		−0.037*			−0.097***		
		(0.019)			(0.020)		
$Dye_{ij} \times$ (Export Share)			0.046		−0.55		
			(0.121)		(0.117)		
$Dye_{ij} \times$ (Productivity)				0.092	0.123		
				(0.116)	(0.136)		
$Dye_{ij} \times$ (Skill Intensity)						0.171***	
						(0.023)	
$Dye_{ij} \times$ (Input Tariffs)							−0.046***
							(0.004)
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-Square	0.38	0.39	0.40	0.38	0.41	0.37	0.37
N	6228	5875	5656	6251	5430	6251	6021
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE (5-digit)*Time Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Columns (1) – (7) use natural logarithm of innovation expenditure of a firm plus 1 as the dependent variable. Innovation expenditure is defined as the sum of R&D expenses and payments towards technical knowhow (Technology Transfer) of a firm. '$Post_t$' is a regulation dummy, which takes a value 1 when the year is greater than 1994. 'Dye_{ij}' is a firm level dummy variable, which takes a value 1 if a firm belongs to "**20114** (5-digit NIC 2008) – **Manufacture of dyes and pigments from any source in basic form or as concentrate**". 'Imp of Cap Goods' is the natural logarithm of import of capital goods by a firm. 'Cap Employed' is the natural logarithm of amount of capital employed by a firm. 'Export Share' is the ratio of export to sales of a firm. 'Productivity' is calculated using Levinsohn and Petrin (2003) methodology at the firm level. 'Skill Intensity' is defined as the ratio of non-production workers to total employees at the 3-digit NIC 2004. 'Input Tariffs' is tariffs on intermediate inputs at the 3-digit NIC 2004. We use the other sub-sectors of "**Chemical**" industry as the control group. 'Firm Controls' include age, age squared, ownership dummy (either domestic or foreign owned) and size. We size 'Assets' of a firm as the size indicator. Numbers in the parenthesis are robust clustered standard errors at the 5-digit industry level. Intercepts are not reported. All the regressions contain the pairwise and individual terms of the interactions. *,**,*** denotes 10%, 5% and 1% level of significance.

Table 6
Impact of 1994 German 'Azo-dyes' Ban on Innovation Expenditure of Dye-producing Chemical firms (Upstream Sector): Dividing into R&D Expenditure and Technology Transfer.

	R&D Expenditure					Technology Transfer				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$Post_t \times Dye_{ij}$	0.067***	0.062***	0.126***	0.078**	0.059***	0.127***	0.173***	0.137***	0.098***	0.050*
	(0.017)	(0.012)	(0.028)	(0.031)	(0.013)	(0.037)	(0.016)	(0.035)	(0.031)	(0.030)
$Dye_{ij} \times$ (Imp of Cap Goods)			0.240					−0.439***		
			(0.152)					(0.141)		
$Dye_{ij} \times$ (Cap Employed)			−0.023					0.004		
			(0.017)					(0.011)		
$Dye_{ij} \times$ (Input Tariffs)				−0.002					−0.060***	
				(0.005)					(0.006)	
$Post_{97} \times Dye_{ij}$					0.030**					0.138***
					(0.015)					(0.032)
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-Square	0.30	0.31	0.32	0.31	0.30	0.23	0.24	0.24	0.22	0.23
N	6251	6251	5875	6021	6251	6251	6251	5875	6021	6251
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE (5-digit)*Time Trend	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Industry FE (4-digit)* Year FE	No	Yes	No	No	No	No	Yes	No	No	No

Notes: Columns (1)–(5) use natural logarithm of R&D expenditure, whereas, columns (6)–(10) use natural logarithm of Technology Transfer (or Royalty Payments for Technical Knowhow) of a chemical firm plus 1 as the dependent variable, respectively. '$Post_t$' is a regulation dummy, which takes a value 1 when the year is greater than 1994. 'Dye_{ij}' is a firm level dummy variable, which takes a value 1 if a firm belongs to "**20114** (5-digit NIC 2008) – **Manufacture of dyes and pigments from any source in basic form or as concentrate**". 'Imp of Cap Goods' is the natural logarithm of import of capital goods by a firm. 'Cap Employed' is the natural logarithm of amount of capital employed by a firm. 'Input Tariffs' is tariffs on intermediate inputs at the 3-digit NIC 2004. We use the other sub-sectors of "**Chemical**" industry as the control group. 'Firm Controls' include age, age squared, ownership dummy (either domestic or foreign owned) and size. We use 'Assets' of a firm as the size indicator. Numbers in the parenthesis are robust clustered standard errors at the 5-digit industry level. Intercepts are not reported. All the regressions contain the pairwise and individual terms of the interactions. *,**,*** denotes 10%, 5% and 1% level of significance.

understand whether this is the case, this section explores the amount of heterogeneity involved in our benchmark findings conditioned by firm size. This is a critical issue still much debated in the literature on economics of innovation (Cohen and Klepper 1996; Cohen, 2010). To do so, we divide the entire sample of firms into four different quartiles, according to the total assets of a firm (using total assets as the size indicator of the firms). The different size categories of firms are indicated by a dummy variable. For example, if the total assets of a firm fall below the 25th percentile of the total assets of the industry, the firm belongs to the first quartile and the variable would indicate 1 for that firm, and zero otherwise. Likewise, if a firm's total assets fall between 25th percentile to 50th percentile, 50th percentile to 75th percentile and above 75th percentile, the firm belongs to the categories of second, third and fourth quartile, respectively. Next, we interact different quartile dummies with $Post_t \times Dye_{ij}$ to measure the effect of the 1994 'Azo-dyes' regulation on that quartile of firms.

We estimate the effect of the foreign regulation on the innovation expenditure of the different quartiles of firms using a similar specification as in Eq. (1):

$$\ln(x_{ijt}) = \beta^r \sum_{r=1}^{4} \left(Post_t \times Dye_{ij} \times Q_{it}^r \right) + \varphi^r \sum_{r=1}^{4} Q_{it}^r + \gamma \left(Post_t \times Dye_{ij} \right) + firmcontrols_{it} + \theta_j + \eta_t + \varepsilon_{ijt} \quad (2)$$

where r indexes each of the four different quartiles of the size distribution and Q_{it}^r are dummy variables taking the value of 1 when firm i belongs to quartile r. Firms could change their position (quartiles) over the period of operation and this may endogenize our estimates. To control for this, we run the above regressions by using the average rank of the firms over all the years of our dataset, 1990–2002. To test for robustness, we also use the rank of the firms in the base period of the analysis, i.e., 1990 but the results do not change. We continue to cluster the standard errors at the 5-digit industry level.

Results are reported in Table 7. Column (1) regress the natural logarithm of aggregate innovation expenditure on the interaction of the four different quartile dummies with both $Post_t \times Dye_{ij}$. The coefficients demonstrate that the effect of the regulations is indeed heterogeneous.[24] The increase in innovation expenditure as a response to the 1994 'Azo-dyes' regulation is significantly higher for upper-half of the size distribution as compared to the other or lower-half. In other words, foreign regulation primarily targeted towards the consumer goods of the downstream (leather and textile) firms led to significant increase in investments towards innovation by the big upstream dye-producing chemical firms. Simultaneously, it also led to decrease in innovation expenditure for the small firms. Column (2) uses R&D expenditure as the outcome of interest. Our coefficients follow the same pattern as before: increase in R&D expenditure is concentrated with the big firms only, whereas, small firms record a decrease. Column (3) exploits the other significant component of aggregate innovation expenditure, technology transfer, as the dependent variable. Results continue to show us the same trend as before. Our results confirm the findings of some prior work in the literature like Scherer (1967) and Aghion et al. (2005) – investments in innovation expenditure increases with size as a result of competition and this increases the inequality in innovation across the firm-size distribution. Moreover, it also confirms our previous finding about the effect of 'Azo-dyes' regulation: increase in investments towards technological catch-up is on average higher than investments in R&D expenditure. This motivated us to examine which type of firms, in terms of ownership, is engaged in R&D expenditure and which in technology transfer in the next section.

4.2.6. Ownership

Following the literature on Southern vs. Northern firms (Acemoglu et al., 2014; Asano and Matsushima, 2014; Jakobsson and Segerstrom, 2016), we divide our sample of firms according to their ownership: domestic and foreign. We present our findings in Table 8 to see whether aggregate and different kinds of innovative expenditure vary with the ownership of firms. Columns (1)–(3) tests the proposition for domestic firms, whereas columns (4)–(6), focus on foreign firms. In case of aggregate innovation expenditure, the coefficients show us that both kinds of firms are affected, but the extent of the effect is significantly higher for foreign firms. Next, we divide aggregate innovation into R&D expenditure and technology transfer for domestic and foreign firms in columns (2)–(3) and (5)–(6), respectively. The estimates show us that R&D expenditure did increase for both type of firms, whereas, technological transfer is concentrated only for domestic firms. However, the increase in R&D expenditure is higher by a factor of around three for foreign firms or multinationals relative to domestic firms. This finding shows that innovation activity in the big foreign firms might potentially be taking advantage of being multinational in nature. Tewari and Pillai (2005) also point out that the large and multinational companies, who had access to resources and substitutes took the lead in developing safer alternatives followed by the domestic or local firms. Our results in a way also provides support to the theoretical argument of the North-South model of innovation. That is, with incentives for innovation, it is usually done even in the South by the Northern firms, whereas, Southern firms engage in technology transfer. Our results also provide additional evidence of domestic firms getting involved in R&D expenditure, but investments on such is about one-half that of spending on technology transfer.

5. Conclusion

We investigate the role of a suddenly imposed plausibly exogenous foreign environmental regulation on upstream innovation. Our setting involves downstream leather and textile firms and the upstream dye-producing chemical firms, supplying dyes to the downstream firms within India. Using the incidence of a German ban on 'Azo-dyes' in 1994 as a quasi-natural experiment, we tease out the impact of the ban especially on the upstream dye-producing chemical firms. Our results indicate that the 1994 German 'Azo-dyes' ban led to an increase in innovation expenditure by an average dye-producing firm by at least 11% and at most 61%, as when compared to any other firm belonging to the chemical sector but who did not produce dyes. In addition, this effect can possibly be an outcome of substitution patterns, decrease in innovation for downstream firms (the direct effect of the ban is also investigated on the downstream firms since Germany was a key market for Indian leather and textile firms at that point in time) with simultaneous increase for the upstream firms after the 1994 ban, a finding which we demonstrate significantly in our analysis. Our findings are robust to a variety of estimation methods, implementation of alternative matching techniques like propensity score based methods, and controls at the firm and industry level. Other confounders like macroeconomic changes, domestic bans or a sharper time window fails to alter our baseline findings. In addition to the aggregate effect of the 1994 ban, we also demonstrate heterogeneous effects in terms of type of innovation expenditure, firm size and by ownership. First, technology transfer increase by around 1.2–2.5 times than R&D in response to the 'Azo-dyes' ban. Second, foreign dye-producing chemical firms seem to be focusing more on internal R&D, while domestic firms got engaged in technology transfer. Third, there exists a positive relationship between firm size and innovation expenditure.

Our findings contribute and extend the existing empirical and theoretical debate on the Porter's Hypothesis in the context of an upstream-downstream set-up of an industry for a developing economy. We also contribute to a burgeoning literature on the role of environmental policy and innovation (Palmer et al., 1995). The identification strategy based on a foreign environmental ban also illustrates the role of regulatory externalities across borders as is

[24] The probability that the coefficient for four different quartiles being equal is zero.

Table 7
Impact of 1994 German 'Azo-dyes' Ban on Innovation Expenditure of Dye-producing Chemical firms (Upstream Sector): Heterogeneity in Size.

	Innovation Expenditure (1)	R&D Expenditure (2)	Technology Transfer (3)
$Post_t \times Dye_{ij} \times$ 1st Quartile	−0.238**	−0.173***	−0.159**
	(0.084)	(0.054)	(0.079)
$Post_t \times Dye_{ij} \times$ 2nd Quartile	0.108*	−0.007	0.115***
	(0.063)	(0.065)	(0.046)
$Post_t \times Dye_{ij} \times$ 3rd Quartile	0.356***	0.185*	0.256***
	(0.067)	(0.098)	(0.049)
$Post_t \times Dye_{ij} \times$ 4th Quartile	0.525***	0.285**	0.464***
	(0.133)	(0.136)	(0.068)
Firm Controls	Yes	Yes	Yes
R-Square	0.39	0.33	0.26
N	6251	6251	6251
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Industry FE (5-digit)*Year Trend	Yes	Yes	Yes

Notes: Columns (1), (2) and (3) use natural logarithm of Total Innovation expenditure, R&D expenditure and Technology Transfer of a firm plus 1 as the dependent variable, respectively. Innovation expenditure is defined as the sum of R&D expenses and payments towards technical knowhow (Technology Transfer) of a firm. '$Post_t$' is a regulation dummy, which takes a value 1 when the year is greater than 1994. 'Dye_{ij}' is a firm level dummy variable, which takes a value 1 if a firm belongs to "**20114** (5-digit NIC 2008) – **Manufacture of dyes and pigments from any source in basic form or as concentrate**". We use the other sub-sectors of "**Chemical**" industry as the control group. Quartiles are defined according to the total assets of a firm. A firm belongs to 1st quartile if the total asset of that firm is below 25th percentile of the total assets of that industry to which the firm belongs and so on. 'Firm Controls' include age, age squared, ownership dummy (either domestic or foreign owned) and size. We size 'Assets' of a firm as the size indicator. Numbers in the parenthesis are robust clustered standard errors at the 5-digit industry level. Intercepts are not reported. All the regressions contain the pairwise and individual terms of the interactions. *,**,*** denotes 10%, 5% and 1% level of significance.

Table 8
Impact of 1994 German 'Azo-dyes' Ban on Innovation Expenditure of Dye-producing Chemical Firms (Upstream Sector): Ownership.

	Domestic Ownership			Foreign Ownership		
	Innovation Expenditure (1)	R&D Expenditure (2)	Technology Transfer (3)	Innovation Expenditure (4)	R&D Expenditure (5)	Technology Transfer (6)
$Post_t \times Dye_{ij}$	0.092***	0.067***	0.119***	0.531**	0.204**	0.206
	(0.035)	(0.013)	(0.043)	(0.271)	(0.100)	(0.2037)
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes
R-Square	0.34	0.25	0.22	0.58	0.52	0.35
N	5755	5755	5755	496	496	496
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE (5-digit)*Year Trend	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Columns (1) and (4), (2) and (5), (3) and (6) use natural logarithm of Innovation expenditure, R&D expenditure and Technology Transfer of a firm plus 1 as the dependent variable, respectively. Innovation expenditure is defined as the sum of R&D expenses and payments towards technical knowhow (Technology Transfer) of a firm. '$Post_t$' is a regulation dummy, which takes a value 1 when the year is greater than 1994. 'Dye_{ij}' is a firm level dummy variable, which takes a value 1 if a firm belongs to "**20114** (5-digit NIC 2008) – **Manufacture of dyes and pigments from any source in basic form or as concentrate**". We use the other sub-sectors of "**Chemical**" industry as the control group. 'Firm Controls' include age, age squared, ownership dummy (either domestic or foreign owned) and size. We size 'Assets' of a firm as the size indicator. Numbers in the parenthesis are robust clustered standard errors at the 5-digit industry level. Intercepts are not reported. All the regressions contain the pairwise and individual terms of the interactions. **,*** denotes 5% and 1% level of significance.

documented in past work on the California effect and highlights the possibility of international regulatory spillovers across borders (Levi-Faur, 2005; Perkins and Neumayer, 2012). In addition, our findings also relate to prior work around R&D spillovers and the role here of geography of innovation that examines the role of regional spillovers in enhancing increasing returns and ultimately economic growth (Audretsch and Feldman, 1996).

Our findings also have important policy implications. First, the heterogeneous outcomes of innovation expenditure between the upstream and downstream response to an environmental regulation is currently understudied and our findings could help policy makers in more optimally designing environmental regulation in the context of the Porter's Hypothesis. Second, our results can certainly make the policy makers understand the substantive role of foreign regulation from Northern economies, which can possibly substitute for institutional voids (Palepu and Khanna, 1998) that Southern economies face in formulating and implementing best in class regulation. This can aid in surmounting information asymmetries that might exist in the context of a developing economy industry and accelerate their catching up process in terms of the technological frontier. Third, policies related to ease of technology transfer might help the process of technology upgrading of firms from a developing economy, when faced with shocks coming from advanced markets. Our heterogeneous effects in terms of firm ownership and size on the innovation expenditure (Berrone et al., 2013) suggests that there is a robust role of markets for technology in augmenting or muting the differential ability of firms to upgrade given shifting environmental standards and policies around the world (Arora et al., 2001).

However, our analysis does have a few shortcomings and these could give future researchers a platform to investigate related issues building on our work. First, in trying to investigate the issue of productivity of innovation and not just innovation expenditure, we ran into data issues about patent filings of upstream dye-producing chemical firms. Data on patent filings, from the Indian Patent Office (IPO), by these upstream treatment group of firms are close to non-existent and potentially new data, especially from global patenting activity could further extend our findings with an innovation productivity lens. In addition, the nature of industrial science could also be studied using both pre-1994 and post-1994 data on scientific publications by the upstream Indian dye-producing chemical firms relative to all other chemical firms following some prior work that has demonstrated the important role of industrial science in creating new knowledge (Gittelman and Kogut, 2003). Third, future research could also focus on the generation of 'green' dyes versus 'non-green' dyes because of such regulation. Finally, one might also want to explore here if firms from other countries in the value chain (like China) posed a substitution or complementary effect when the German 'Azo-dyes' ban created nuanced incentives for upstream dye-producing Indian chemical firms. In addition, theoretical work could be built on our findings to tease out the structural implication of regulation for industries with an upstream-downstream setup and examine implications for their evolution. As is usually the case in research, much more therefore remains to be done.

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Appendix A. Data

Data

We use an annual panel of Indian chemical firms that covers around 1100+ firms, among which 100 belong to the dye-producing sector, across 46 industries (5-digit NIC 2008), over the period of 1990–2002. Data is used from the PROWESS database of the Centre for Monitoring Indian Economy (CMIE). All monetary-based variables measured in Millions of Indian Rupees (INR), deflated by 2005 industry-specific Wholesale Price Index (WPI). Please find below the definitions of all the variables used:

Innovation Expenditure: It is defined as the sum of R&D expenditure and Royalty Payments for Technical Knowhow of a firm.

R&D Expenditure: Expenses towards the Research and Development (R&D) expenditure of a firm.

Technology Transfer: Royalty Payments for Technical Knowhow by a firm.

Capital Employed: Total amount of capital employed by a firm in its production process.

Import of Capital Goods: Total amount of import of capital goods by a firm.

Export Share: It is defined as the ratio of total exports by a firm to its total sales.

Sales: Total amount of sales of a firm.

Productivity: It is estimated at the firm level using Levinsohn and Petrin (2003) methodology.

Skill Intensity: It is defined as the share of non-production workers to the total employees at 3-digit 2004 National Industrial Classification (NIC).

Input Tariffs: Input tariffs at 3-digit 2004 NIC.

Assets: Total assets of a firm.

GVA: Gross Value-Added = Total Sales – Total Raw Material Expenditure.

Ownership: It indicates whether a firm is domestic or foreign-owned.

Age: Age of a firm in years.

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