R&D Tax Credit and Product Quality vs. Scope*

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Abstract

Do firms with heterogeneous in-house R&D capacity respond discordantly in terms of product development to an industrial policy aimed at boosting R&D expenditure? We utilize an R&D tax credit policy introduced in 1998 by the Indian Govt. which was aimed at firms with in-house R&D units in certain groups of industries. Our results show that R&D tax credit policy increase R&D expenses for all firms, but the effect on product development is quite different across firms in terms of their ex-ante R&D expenses. Small firms spend their new R&D investments to expand product scope, while large firms invest in upgrading the quality of the products. These effects are largely driven by exporters and firms producing differentiated products. We rationalize our findings using a heterogeneous firm model in which a firm maximizes output along three dimensions: product scope, scale, and quality. Our results also show significant welfare gains as the aggregate price index dropped by 48%. To the best of our knowledge, ours is one of the first to show that R&D tax credit policy and its interaction with heterogeneous R&D capacity can have distinctly different effects on product development.

Keywords: R&D Tax Credit, Industrial Policy, In-house R&D Units, R&D Expenditure, Product Quality, Product Scope.
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1 Introduction

Governments increasingly adopt targeted industrial policy, such as R&D tax incentives, to catalyze in-house innovation within firms and strategic sectors. Although there is substantial evidence that R&D tax credits stimulate firm level innovation – R&D expenditures, patenting activity, entrepreneurship (Dechezleprêtre et al. (2023); Bloom et al. (2002); Rao (2016); Melnik (2024)) – much less is known about the form these innovation investments take in terms of product development. Specifically, it remains unclear whether firms predominantly invest these resources in expanding product variety (scope) or improving the quality of existing products. In addition, these strategic choices may also involve trade-offs; investments in product diversification could come at the expense of quality improvements. Understanding whether the type of R&D investments varies systematically with the size of the firm and if such trade-offs are essential to design R&D incentive policies that maximize both private and social returns to innovation.

We exploit a tax reform in India, proposed in the Union Budget of 1997–98, aimed to increase R&D tax credits for firms with in-house R&D units registered with the Ministry of Science & Technology, Govt. of India. The reform was initially introduced for drugs and pharmaceuticals, chemicals, electronic equipments, computers, telecommunication equipments in 1997–98 and later extended to helicopters and aircrafts in 2001 and automobiles and auto parts in 2004.[1] This R&D tax credit policy partitioned firms based on a clearly defined eligibility criterion creating a set of eligible and non-eligible firms that are directly and not directly impacted by the reform, enabling us to causally estimate the relative effects of the reform both within and between industries.

In this study, we examine how firms respond to this R&D tax credit by adjusting their investments along three margins: production scale, product scope, and product quality.

[1] For details, please see Section 2.

We extend the multi-product firm framework developed by Eckel & Neary (2010) and Eckel et al. (2015) to incorporate firm heterogeneity and investigate whether the responsiveness to R&D tax incentives differs systematically across these dimensions. We show, both theoretically and empirically, that larger firms, in terms of their production scale, respond to R&D tax incentives by upgrading product quality at the expense of product scope, in contrast to smaller firms that tend to expand scale and scope rather than quality.

To formalize this mechanism, we first develop a model in which multi-product firms choose the optimal scale and quality of each product, as well as the total number of products (scope), to maximize aggregate profits. Following a flexible manufacturing approach, firms possess a comparative advantage in producing a core product, defined as the variety with the lowest marginal cost, while marginal costs increase with distance from this core. Consumers derive utility from both the quantity and quality of products, creating an incentive for firms to invest in product quality.

However, quality improvements are costly, and firms invest until the marginal return equals the marginal cost. Importantly, our framework departs from models that assume independent demand across varieties by allowing firms to internalize intra-firm competition among their own products. This leads to strategic substitution across margins: When the number of products becomes sufficiently large, the cannibalization of demand across varieties reduces the marginal profitability of scope expansion. In such settings, particularly for large firms, it becomes optimal to invest more in the quality of existing products rather than expanding product scope.

The intuition for this strategic reallocation is rooted in the trade-off between demand-side cannibalization and cost-side diseconomies of scope. In multi-product settings, the addition of new varieties induces a *cannibalization effect*, whereby a firm's own products compete for market share, thus reducing the marginal gains from scope expansion. These demand-side linkages – absent in single-product firm models – have been highlighted in the work of Eckel & Neary (2010), Milgrom & Roberts (1990), and Eaton & Schmitt (1994). On the supply side, while flexible manufacturing enables scope expansion, firms are most efficient near their technological core, and productivity diminishes with distance from this core, creating an increasing cost structure. This implies that for sufficiently large firms, improving the quality of existing products becomes more profitable than diversifying into costlier, less efficient varieties. Thus, firm size and cost structure jointly determine the margin along which R&D incentives exert the greatest impact.

To support our theoretical predictions, we exploit a phased introduction of an R&D tax credit policy, aimed at firms with in-house R&D units, that was implemented by the Ministry of Science and Technology, Govt. of India, beginning in 1997–98. In addition, the Department of Scientific & Industrial Research (DSIR), the research arm of the Ministry of Science and Technology that administer the R&D generation process in India, further classified firms into three different categories based on their reported in-house R&D expenses: (a) firms with $<$ 10 million INR (small); (b) firms with 10–50 million INR (medium); and (c) firms with $>$ 50 million INR (large). We exploit this crucial classification in terms of the R&D expense distribution to estimate the differential effect of the R&D tax credit policy on R&D expenses, product entry, and product quality not only for eligible and ineligible firms, but also between different types of eligible firms.

The key point in exploiting this particular event of R&D tax credit policy for causal inference is that the policy design provides a plausible exogenous change in the dynamics between as well as within the industry level; in our case for firms with recognized in-house R&D units in those industries for which the policy was implemented (representing the 'treatment' group) relative to the rest of the firms (representing the 'control' group). Using a difference-in-difference approach and detailed firm-product level information combined with data from firms' balance sheets and income statements from PROWESS, we find two important results.

(i) a remarkably persistent and economically meaningful positive effect of the R&D tax credit policy on the R&D expenses of all types of eligible firms, with a significantly higher effect for large firms. In particular, large firms, i.e. firms with $>$ 50 million INR of in-house R&D expenses recorded a 650% growth in R&D expenses as compared to 148% for firms with 10–50 million INR of R&D expenses and 12% for firms with $<$ 10 million INR;

(ii) firms, depending on the size of their R&D expenses, invest their R&D resources differentially in response to the R&D tax credit policy. We find that large firms invest the R&D resources to significantly upgrade the quality of the range of products they produce – the quality index of their products as compared to the pre-policy quality index doubled. On the other hand, small and medium-sized firms expand their product range or variety. In other words, they invest their R&D resources in product innovation. These patterns are particularly pronounced for exporters and firms that produce differentiated products. To the best of our knowledge, our paper is among the first to show that firms with different sizes of R&D expenses behave disparately while investing their R&D resources. This is our key contribution.

We also show that R&D leads to an increase in sales for all firms. Large firms maximize their sales value by increasing prices (as quality goes up), while small and medium-sized firms increase the quantity of products sold (as the number of varieties increases). Large firms also increase the amount of capital employed in production, the use of skilled labour, and imported raw materials and capital goods in the process of upgrading quality. These resulted in higher gross value-added and exports while lowering domestic sales.

Our study also quantifies the welfare gains associated with the R&D tax credit policy by disaggregating the gains due to improvements in product quality and expansion in variety. Employing a two-tier utility framework and the price index decomposition method of Sheu (2014), we find that the aggregate price index declined by 48% between the pre- (1999) and the post-policy period (2005), indicating substantial welfare improvements. Interpreted through the lens of equivalent variation, this implies that consumers would require more than twice the expenditure in 1999 to achieve the utility level attained in 2005. By separately holding unit prices and variety (or quality) constant, we isolate the welfare contributions of each margin and find that both quality upgrading and variety expansion yield significant consumer gains. Decomposing this change reveals that quality upgrading accounts for about 43% increase in effective consumer spending, while expansion in scope generates an additional welfare gains by reducing the price index by 69%. These results underscore the effectiveness of R&D tax credits in generating sizable welfare improvements through firm level innovation.

Our paper makes a few important contributions. First, this paper contributes to the theoretical literature by developing a tractable multi-product firm model that analyzes firm level responses to R&D tax credits along both the quality and scope margins. Although existing studies have investigated the impact of R&D incentives, these are typically conducted using empirical methods (e.g., Dechezleprêtre et al., 2023; Bloom et al., 2019) or dynamic general equilibrium frameworks that abstract from within-firm product heterogeneity (e.g., Akçigit & Kerr, 2018; Atkeson & Burstein, 2019). In contrast, our model explicitly embeds flexible manufacturing and endogenous product quality into a multi-product framework inspired by Eckel et al. (2015) and Feenstra & Ma (2007), enabling a richer analysis of how firms optimally reallocate innovation effort across margins in response to policy incentives.

To the best of our knowledge, this is the first theoretical model to show that responses to R&D tax credits can be heterogeneous across firms depending on their size. Specifically, we show that large firms – due to their scale advantages and exposure to cannibalization effects – are more likely to upgrade the quality of existing products rather than expand product scope. In contrast, smaller firms, facing less internal competition and lower opportunity costs of expansion, are more likely to increase the number of product varieties they offer. This heterogeneous mechanism provides a theoretical rationale for observed differences in innovation responses across firm types, complementing and extending empirical findings in the literature.

Second, based on reduced form estimation, using novel firm-product level data with detailed information on product level sales and quantities, we quantify the interdependence between R&D tax credit policy and entry of new product varieties, and product quality. More generally, our work informs how government policy can have both direct and indirect effects of a specific program.

Our combined theoretical and empirical results have two important implications: (i) we deviate from the literature and are among the first to show that interaction between R&D tax credit policy and the size of the R&D expenses of firms can produce new gains from such policy interventions; and (ii) R&D tax policy can lead to quality upgrading of industries and increase its competitiveness at the global level through an increase in exports. This is our primary contribution.

These results relate to a small but growing literature that examines the causal effect of R&D tax incentives on different types of innovation, such as (i) patents (Ivus et al., 2021); (ii) quality-adjusted patents (Dechezleprêtre et al., 2023); (iii) innovative search or new technologies (Balsmeier et al., 2025); (iv) product innovation (Czarnitzki et al. (2011); Labeaga et al. (2021); Pless (2025); Liu et al. (2025)); and (v) process innovation (Cappelen et al., 2012).

Third, our results also contribute and complement the small, growing, and important empirical literature on how industrial policies can affect firm performance.[2] Recently, several studies used the Global Trade Alert (GTA) project to study the relationship between industrial policies and different economic outcomes in both (a) cross-country setting (Criscuolo et al. (2019); Juh´asz et al. (2023); Barwick et al. (2024); Parente et al. (2025); Yueling et al. (2025)); and (b) country-specific case studies (Cherif & Hasanov (2019); Choi & Levchenko (2024)). Our paper is close to Lane (2025), who examines the effect of industrial policies on the industrial development of South Korea's heavy and chemical industries during 1973–1979. He finds that those targeted policies promoted the expansion and comparative advantage of those industries. We complement this study to show that targeted industrial policies, in our case R&D tax credit, can also lead to both product variety expansion and upgrading of product quality, leading to new sources of gains from such policies. In addition, we also find that the export competitiveness of those industries improves significantly, supporting the findings of Lane (2025).

Lastly, we also contribute to the constantly growing literature on how R&D tax credit affects R&D expenses of firms in both developed (Czarnitzki et al. (2011); Cappelen et al. (2012); Guceri & Liu (2019); Dechezleprêtre et al. (2023)) and developing economies (Yang et al. (2012); Guo et al. (2016); Ivus et al. (2021)).

The rest of the paper is organized as follows. Section 2 briefly describes the R&D tax credit policy. We develop our theoretical model with empirical propositions in Section 3. Section 4 describes the data used to test the theoretical predictions, while Section 5 outlines our empirical strategy, including endogeneity checks. All our results are discussed in Section 6. We quantify the welfare gains from the policy in Section 6. Section 8 provides some concluding remarks.

[2]Industrial policies are defined as "state actions aimed at transforming the structure of economic activity, typically by altering relative prices across sectors or directing resources toward specific industries or activities like exporting and R&D." (Parente et al., 2025)

2 Institutional Background – The R&D Tax Credit Policy

In the Union budget of 1997–98, the Govt. of India introduced a fiscal incentive in the form of a tax-weighted deduction scheme for firms belonging to select industries that had in-house R&D units and were registered with the Department of Scientific and Industrial Research (DSIR), the nodal unit in the Ministry of Science & Technology, Govt. of India. These industries were: (1) drugs and pharmaceuticals, (2) chemicals, (3) electronic equipments, (4) computers, and (5) telecommunication equipments.[3] The scheme was further extended to helicopters and aircraft in 2001 and automobiles and auto parts in 2004. By 2009, this tax incentive was offered to all firms across all manufacturing industries, except a few listed in Schedule 11 of the Income Tax Act.[4]

Starting in 1998, firms in the five industries listed earlier were offered a weighted tax deduction of 125% for any approved revenue or capital expenditure undertaken in their R&D facility. The tax-weighted deduction for firms was increased to 150% in 2001. However, the rest of the industries were not affected by the reform and continued to be eligible for the regular limit of 100% tax deductions on R&D spending.[5] Therefore, using the criterion of whether a firm has an in-house R&D, we can differentiate these firms from those that do not have an in-house R&D facility, thus identifying a group of firms within an industry that were not directly impacted by the reform. This enables us to estimate the effect of the R&D tax credit incentive not only between but also within industries.

[3] The DSIR releases annual reports to confer an overview of the R&D generation process across industries in India to disseminate information to government bodies, R&D institutions or anyone who may want to initiate interaction with the in-house R&D units in various sectors. While the reports from 1998 onward mention the tax deduction scheme, no information is provided on why some industries were eligible for the scheme, while others were not. In order to check whether differential trends exist between eligible or ineligible industries or firm characteristics or eligible firms lobbied for such type of policies, we run pre-trends and endogeneity checks and find that our results are robust to any unobserved selection into the treatment group. More on this in Section 5.

[4] These were tobacco, alcohol, cosmetics, confectionery, chocolate, etc.

[5] For further details on the R&D tax credit policy, see Jain & Singh (2023).

Panel A of **Figure 2** plots the normalized R&D expenses for treated vs. control industries. The plot clearly shows that R&D expenses for firms in industries where the R&D tax credit was implemented increased significantly after the reform in 1998, relative to other industries, where there were minor differences across the two groups before 1998. Similarly, **Panel B** juxtaposes the normalized R&D expenses for firms with recognized in-house R&D facility versus those without such a facility. The finding here is similar to that seen in **Panel A**, confirming the increase in R&D expenditure after 1998.

The DSIR approval requires that firms with in-house R&D units engage in R&D activities related to a firm's line of business, such as the development of new technologies, design and engineering, process and/or product design improvements, development of new methods of analysis and testing, research for increased efficiency in the use of resources, such as capital equipment, materials, and energy, pollution control, effluent treatment, and recycling of waste products. In addition, these firms were required to present the previous three years of annual reports, information on past, present, and future research projects, details on the scientific personnel and equipment working in the R&D unit, and photographs of the R&D facility. Once approved, firms were required to report their R&D activities each year and apply for renewal every three years.

3 Model

We develop a multi-industry framework featuring heterogeneous firms that produce multiple differentiated products. In our model, consumer utility is derived along three dimensions: the scope (i.e., the number of product varieties), the scale (i.e., the quantity consumed), and the quality of the products offered. This approach extends standard models of heterogeneous firms (e.g., Melitz (2003)) by incorporating endogenous product scope and quality choices.

Firms choose their optimal product scope, scale of production, and quality levels to maximize profits, subject to market demand, cost structures, and policy incentives such as R&D tax credits. In particular, we allow R&D investment to affect the number of varieties a firm can offer, the scale of production, and the quality of each product, following mechanisms similar to those in Dhingra & Morrow (2019) and Hottman et al. (2016).

In equilibrium, firms endogenously select their innovation strategy. Our model predicts that the response to R&D tax incentives is heterogeneous across firms. Specifically, larger firms – measured by their scale or average scale – and firms operating in more differentiated industries are more likely to respond to R&D incentives by upgrading product quality. In contrast, smaller firms, particularly those with limited scale, are less inclined to upgrade quality and more inclined to expand their product scope.

This framework allows us to quantify the differential impact of R&D policy across firms of varying sizes and sectors and to identify which margin— scope or quality— matters for innovation.

3.1 Preferences and Demand

Each representative consumer maximizes a two-tier utility function that depends on the level of consumption $q(i)$ and quality $z(i)$, $i \in [1, N]$, where N is the number of differentiated goods produced in each industry k. The upper-tier utility is a Cobb-Douglas over sub-utility functions for each industry k, weighted by its expenditure share, α_k. The upper-tier utility function is given by:

$$U = \prod_k u(k)^{\alpha_k} \tag{1}$$

The lower-tier utility is given as:

$$u(k) = \left[a \int_0^N q(i)di - \frac{1}{2} b \Big[(1-e) \int_0^N q(i)^2 di + e \Big\{ \int_0^N q(i)di \Big\}^2 \Big] \right] + \beta \int_0^N q(i)z(i)di \quad (2)$$

For each industry k, the lower-tier utility function depends on the quantity of goods consumed, $q(i)$, and its interaction with quality, $z(i)$. The parameters a, b, and e are assumed to be non-negative and identical for all consumers: a denotes the consumer's maximum willingness to pay, and $b > 0$ governs the degree of diminishing marginal utility from consumption. The parameter e is the inverse of the measure of product differentiation. If $e = 0$, the products are highly differentiated; on the other hand, products are perfectly substitutable if $e = 1$.

Maximizing utility subject to budget constraints gives us the linear demand function for a representative consumer:

$$p(i) = [a^0 + \beta z(i)] - b[(1-e)q(i) + e \int_0^N q(i)di] \quad (3)$$

These individual demand functions can be aggregated over all consumers in a market. Suppose, there are L consumers. Imposing market clearing condition gives us that the total sales of each variety $x(i)$ must be equal to total demand $Lq(i)$. Substituting this gives us the inverse market demand function faced by firms:

$$p(i) = [a^0 + \beta z(i)] - \frac{b}{L}[(1-e)x(i) + eY] \quad (4)$$

where $Y = \int_0^N x(i)di$ is the total industry output.

3.2 Firms and Production Technology

Firm j in industry k is characterized by a core competence and flexible manufacturing. The marginal cost incurred by firm j in producing a variety i is $c_j(i)$. The core product ($i = 0$) has the lowest marginal cost, i.e., $c_j(i+1) > c_j(i)$. For ease of interpretation, assuming that the marginal cost function is linearly increasing in the number of products: $c_j(i) = c_j^0 + \psi i$. The mass of products produced by firm j is denoted by δ_j. In addition to marginal costs, firms invest in R&D for each variety i, with investment denoted by $k_j(i)$. The total cost of R&D investment is $\gamma_j k_j(i)$. Benefits from R&D investments come in the form of higher quality: $z_j(i) = 2\theta_j k_j(i)^{0.5}$. Firms also pay a uniform trade cost if they are exporters, with $t_j > 0$ for exporters and $t_j = 0$ for domestic firms. The total profit of firm j is:

$$\Pi_j = \int_0^{\delta_j} \left[(p_j(i) - c_j(i) - t_j)x_j(i) - \gamma_j k_j(i) \right] \, di \tag{5}$$

Firm j chooses the scale of production ($x_j(i)$), the scope of product line (δ_j), and R&D investment ($k_j(i)$) to maximize profits subject to demand constraints.

The optimal scale of production is:

$$x_j(i) = \frac{[a^0 + \beta z_j(i)] - b'e(X_j + Y) - c_j(i) - t_j}{2b'(1-e)} \tag{6}$$

where $b' = \frac{b}{L}$ and $X_j = \int_0^{\delta_j} x_j(i)\, di$ is total output of firm j.

The optimal R&D investment satisfies:

$$\frac{\partial \Pi_j}{\partial k_j(i)} = 0 \quad \Rightarrow \quad k_j(i) = \frac{\beta^2 \theta_j^2}{\gamma_j^2}(1-e)^2 x_j(i)^2 = \frac{\eta_j}{\gamma_j}(1-e)^2 x_j(i)^2 \tag{7}$$

where $\eta_j = \frac{\beta^2\theta_j^2}{\gamma_j}$ denotes R&D effectiveness. Lowering γ_j (e.g., through R&D tax credits) increases η_j. The first-order condition in Equation (7) imply that firms will invest in R&D to the point where the marginal cost of R&D investments equals the marginal returns.

Substituting into the quality function:

$$z_j(i) = 2\theta_j k_j(i)^{0.5} = 2\frac{\beta\theta_j^2}{\gamma_j}(1-e)x_j(i) = 2\frac{\eta_j}{\beta}(1-e)x_j(i) \tag{8}$$

Plugging this into Equation (6), we obtain:

$$x_j(i) = \frac{a^0 - b'e(X_j + Y) - c_j(i) - t_j}{2(1-e)(b-\eta_j)} \tag{9}$$

where $b' = b'/L$. For $x_j(i) > 0$, it must be that $b > \eta_j$.

The optimal scope δ_j is defined by $x_j(\delta_j) = 0$:

$$c_j(\delta_j) = a^0 - b_j'e(X_j + Y) - t_j \tag{10}$$

Equation (10) captures the inverse relationship between scale X_j and scope δ_j. This is shown as a downward sloping curve $\delta(X)$ in Figure 1

Substituting into Equation (9), we get:

$$x_j(i) = \frac{c_j(\delta_j) - c_j(i)}{2(1-e)(b_j' - \eta_j)} \tag{11}$$

Equations (8), (10), and (11) give us the optimal choice of firms for each product they produce.

3.3 Aggregate Production and Quality

To understand the impact of R&D cost changes on firm's production, scope and quality, we aggregate product-specific optimal equilibrium equations to get firm's aggregate production and quality.

Aggregating over all varieties i in Equation (11) yields aggregate scale of production:

$$X_j = \int_0^{\delta_j} x_j(i)\, di = \frac{\delta_j c_j(\delta_j) - \int_0^{\delta_j} c_j(i)\, di}{2(1-e)(b_j' - \eta_j)} \tag{12}$$

The optimal investments in R&D is similarly given as:

$$K_j = \int_0^{\delta_j} k_j(i)\, di = \frac{\eta_j}{\gamma_j (b_j' - \eta_j)^2} \int_0^{\delta_j} [c_j(\delta_j) - c_j(i)]^2\, di \tag{13}$$

The aggregate quality of products produced by firm j is:

$$Z_j = \frac{\eta_j}{\beta(b_j' - \eta_j)} \int_0^{\delta_j} [c_j(\delta_j) - c_j(i)]\, di \tag{14}$$

The equations (12) and (14) characterizes a non-linear relationship[6] between aggregate output X_j, quality Z_j and product scope δ_j. For small values of δ_j, expanding the range of products enables the firm to increase output by tapping into new markets and exploiting economies of scope, resulting in an increase in X_j. However, beyond a threshold level δ_j^*, the marginal benefit of adding new varieties declines due to cannibalization effects: new varieties compete with existing ones, eroding demand and reducing profits. Consequently, further expansion in product scope can reduce the overall scale of the

[6]Since, if $\phi(\delta_j) = \delta_j c_j(\delta_j) - \int_0^{\delta_j} c_j(i) \implies \phi(\delta_j) = (a - beY - beX_j - c_j^0)\delta_j - \psi \frac{\delta_j^2}{2}$ which gives as a non-linear relationship of scope with both scale and quality.

firm's operations. Reducing scale feeds back to reduced quality of products. This is represented as a non-linear graph $X(\delta)$ and $Z(\delta)$ in Figure (1).

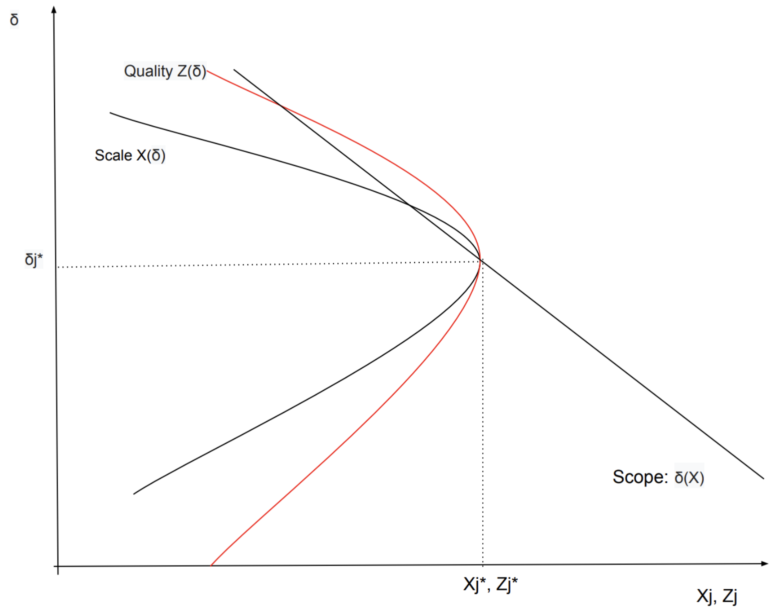

Figure 1: Equilibrium Scale, Scope and Quality

Each firm is characterized by an equilibrium $(X_j^*, \delta_j^*, Z_j^*)$ that satisfies (10) – (14). The industry equilibrium is $\{\mathbf{\Delta}_{J\times1}, \mathbf{X}_{J\times1}, \mathbf{K}_{J\times1}\}$, with $Y = \sum_j X_j$.

Proposition 1. *For a decrease in R&D cost γ_j, firms with a larger scale X_j or average scale X_j/δ_j invest more in R&D (K_j).*

Proof. See Appendix.

Proposition 2. *For a decrease in R&D cost γ_j, firms with larger scale X_j or average scale X_j/δ_j experience a greater increase in aggregate product quality (Z_j).*

Proof. See Appendix.

Proposition 3. *As R&D cost γ_j falls, firms with a larger scale X_j or an average scale X_j/δ_j reduce the scope more (δ_j).*

Proof. See Appendix.

Proposition 4. *With greater product differentiation (lower e), larger firms make higher R&D investments, achieve higher product quality, and reduce product scope.*

Proof. See Appendix.

3.4 Cost vs Quality Competence

The firm's optimal choice of scale ($x_j(i)$), scope (δ_j), and quality $z_j(i)$ would determine whether firms increases price with an increase in marginal costs (follow cost-competence) or reduces price with an increase in marginal costs (follow quality-competence).

Substituting Equation (8) and Equation (11) into the demand equation $p_j(i) = [a^0 + \beta z_j(i)] - \frac{b}{L}[(1-e)x_j(i) + eY]$ gives us the equilibrium prices in terms of marginal costs.

$$p_j(i) = \frac{b' - 2\eta_j}{2(b' - \eta_j)} c_j(i) + \frac{2\eta_j - b'}{2(b' - \eta_j)} c_j(\delta_j) - b'eY \tag{15}$$

For firms where $b' > 2\eta_j$, an increase in marginal costs leads to an increase in price and thus follows a cost-based competence (since $b' - \eta_j$ is positive for $x_j(i) > 0$). Whereas, for firms where $2\eta_j > b'$, an increase in marginal costs reduces price and follows a quality-based competence. It is important to note that a reduction in the cost of R&D investments, γ_j, increases η_j, thus increasing a firm's incentive to follow quality-based competence. Moreover, this condition is more prevalent for exporting firms with bigger market size (L) and thus lower b'.

4 Datasets and Stylized Facts

To test our theoretical propositions, we exploit datasets from two different sources: (a) a well-known dataset at the firm level known as PROWESS, maintained by the Centre for Monitoring of the Indian Economy (CMIE); and (b) Department of Scientific and Industrial Research (DSIR), Ministry of Science and Technology, Govt. of India.

4.1 PROWESS

PROWESS provides updated and detailed information on all listed firms and a larger set of unlisted firms covering all sectors of the economy, starting from the early 1990s until the present day, thus reprsenting a panel dataset. For our purpose, we focus only on 9,200+ firms that belong to the manufacturing sector during the 1992–2007 period. The database is compiled from audited annual reports of firms and information submitted to the Ministry of Corporate Affairs (MCA), Government of India. These firms are predominantly private Indian firms or are affiliated to private business groups, with a small fraction of firms that are either government or foreign owned.[7] The dataset also provides information on a variety of firm-level characteristics, including, but not limited to, total sales, exports, imports, raw materials expenses, capital employed, labour costs, gross value added, and assets, among others.

This dataset is unique in terms of its coverage —- especially since it provides data from the early 1990s in a panel format, both of which are crucial for our purpose. Below we list the other advantages:

1. to assess the first-order effects of the policy change, we exploit a key outcome vari-

[7] The coverage of the PROWESS database is quite extensive in terms of economic activities in the organized industrial sector. These firms are also responsible for more than 70% of all the output produced, 75% (95%) of corporate (excise duty) taxes collected by the Govt. of India.

able - the R&D expenditure of a firm. One of the main arguments in this paper is that the R&D tax credit induced the firms with in-house R&D units, especially the ones that have R&D of more than 50 million INR, to invest more in their R&D in upgrading the quality of the range of the products they produce. Firms must report information on R&D expenditure as per section 217 of the Companies Act. i.e. As per section 217(1)(e), the information shall be attached to every balance sheet laid before a firm in the Annual General Meeting, in a report by its board of directors.

2. a unique feature of the PROWESS database is that it captures detailed information on quantity sold and value of sales of each product manufactured by a firm. The 1956 Companies Act requires firms to report detailed production data for all products they manufacture. The products in our data set, therefore, should be viewed as narrowly defined categories within industries rather than a specific product variety, such as barcode scanner datasets. There are over 4000 unique products in our sample. These product codes were then mapped on to the NIC 2008 5-digit level industries. We also use information to calculate the quality of each product produced by a firm, following the methodology of Khandelwal et al. (2013) and utilizing the elasticity of substitution coefficient at the industry level (2-digit) from Fujiy et al. (2023).

4.2 DSIR

One of the key ingredients of the R&D tax credit change was that the policy applied only to firms that had an in-house R&D unit. We exploit this information to understand whether a firm that had in-house R&D was differentially affected compared to firms that did not have such facilities.

The DSIR provides the directory of the recognized in-house R&D units of firms for each year.[8] The information provided in these directories includes firm names, address, the year in which the in-house R&D facility is recognized, and the year until which this recognition is valid. In addition, these reports follow three different cut-offs in terms of in-house R&D expenditure to classify firms: (i) firms with in-house R&D of < 10 million INR; (ii) firms with in-house R&D of 10–50 million INR; and (iii) firms with in-house R&D of > 50 million INR. We extract all this information from the annual reports and match these with PROWESS firms based on the names of the firms using a combination of fuzzy and manual handcoding.

Using the DSIR reports, we first create the eligibility status of firms that availed the benefits of the weighted tax deduction scheme. In particular, a firm is coded as eligible if that firm was registered with DSIR, and had an in-house R&D facility any time between 1992 and 2007. Next, we use the above-specified cut-offs to separate three different sets of firms based on their capacity for in-house R&D expenses, which serves as our key treatment variable.

4.3 Stylized Facts

Stylized fact #1: A small set of firms had in-house R&D facility

On average, about 8.3% of the firms in our sample had in-house R&D units over the time period. Of these, approximately 58% of the firms had in-house R&D expenditure less than 10 million (the lowest category), 32% had in-house R&D expenditure in the range of 10–50 million INR (the medium category), and the remaining 10% of the firms had in-house R&D expenditure of more than 50 million INR (the highest category).

Stylized fact #2: R&D expenses and product quality were significantly higher for firms in the highest category.

[8] DSIR Directory

Table 1 presents some statistics. An average firm in the highest category spent 168.5 million towards R&D, which was about 9.5 times higher than firms in the medium category and about 85 times higher than firms in the lowest category.

In terms of quality, a firm in the highest category produced an average product whose quality was 12 times higher than the average product of firms that belonged to the medium category.

5 Empirical Strategy

Our main goal is to estimate the differential impact of the R&D tax credit policy on key firm and firm-product level outcomes. We do so by differentiating firms into three categories of in-house R&D expenditure and use the following simple differences-in-differences framework:

$$\begin{aligned} x_{it} = \beta_1 Treated_{jt} &+ \beta_2 (Treated_{jt} \times R\&D\ Unit_{i,<10Million}) \\ &+\beta_3 (Treated_{jt} \times R\&D\ Unit_{i,10-50Million}) \\ &+\beta_4 (Treated_{jt} \times R\&D\ Unit_{i,>50Million}) \\ &+X_{it} + \eta_i + \phi_t + \theta_j^t + \epsilon_{it} \end{aligned} \tag{16}$$

x_{it} represents our outcome variable of interest for firm i at time t. x assumes the following outcomes: R& D expenditure, foreign technology transfer, establishment of new R&D unit, product entry, product quality, product level sales, product level quantity sold, and product level price (unit).

One of our key variables of interest is $Treated_{jt}$. This is an interaction of two terms – (i) $R\&D\ Reform_t$, a year dummy variable that takes a value of 1 in the post R&D tax credit policy period, i.e., for the period 1998–2007 for chemicals, pharmaceuticals, computer, electrical equipments, telecommunications and 2002–2007 for aircraft and 2004–2007 for automobiles and autoparts, and 0 otherwise; (ii) $Treated\ Industry_j$. This also takes a value 1 for the following industries: chemicals (2004 NIC 4-digit – 2411, 2412, 2413, 2421, 2422, 2424, 2429, and 2430), pharmaceuticals (2004 NIC 4-digit – 2423), computer and computer parts (2004 NIC 4-digit – 3000), electrical equipments (2004 NIC 4-digit – 3110, 3120, 3130, 3140, 3150, and 3190), telecommunication equipments (2004 NIC 4-digit – 3220), aircraft (2004 NIC 4-digit – 3530), and automobiles and Autoparts (2004 NIC 4-digit – 3410, 3420, and 3430). Therefore, these seven industries (at the 4-digit level) will serve as our treated group, while the rest will serve as the control group.

We then interact $Treated_{jt}$ with three dummies to indicate which category of in-house R&D unit does a firm belong to: (i) $R\&D\ Unit_{i,<10Million}$ – takes a value of 1 if the firm has in-house R&D expenses of less than 10 million INR; (ii) $R\&D\ Unit_{i,10-50Million}$ – takes a value of 1 if the firm has in-house R&D expenses of more than 10 million but less than 50 million INR; and (iii) $R\&D\ Unit_{i,>50Million}$ – takes a value of 1 if the firm has in-house R&D expenses of more than 50 million INR. All these triple differences would then depict the differential effects of firms that belong to the specified intervals of R&D expenses. So, our coefficients of interest are β_2, β_3, and β_4.

X_{it} is a vector of firm controls which includes the gross value added of a firm (indicator of size), age, and age squared of a firm. η_i are firm fixed effects and ϕ_t are year fixed effects. We also control for interactions of industry fixed effects (at 4-digit) with year specific trends, θ_j^t, to control for major time-varying changes at the industry level due to various industrial policies, such as delicensing and trade policy changes such as drop in tariffs (input and output), etc.[9] We cluster our standard errors at the 4-digit NIC 2004

[9] We also check our results by interacting industry fixed effects (at 2-digit level) with year fixed effects – the results remain the same.

level – the same level at which our treatment variable varies.

5.1 Pre-trends and Endogeneity Checks

Our basic estimates may still provide inconclusive evidence of the causal effect of the R&D tax credit policy for the following reasons: (a) differential time trends; and (b) reverse causality. In the following, we will consider each of them separately and show that our results are robust to both.

We start by comparing three key outcome variables of interest to show that firms in the treated group of industries were not different from firms in the control (or other) industries during the pre-policy period of 1992-1997. These variables are : (a) R&D expenses, (b) product entry (c) product quality. **Table 2** presents estimates using data from the prior policy period that reveal that there were no differences in time trends in these outcomes between the two groups.

Column (1) uses equation (16) and regresses R&D expenses on the interaction terms of $Treated\ Industry_j \times R\&D\ Reform_t$, except that we use t = 1992, 1993, 1994, 1995, 1995, 1996, and 1997 (rather than years following $R\&D\ Reform_t$), controlling for firm characteristics, firm and year fixed effects and interactions of industry year trends. The estimates in column (1) suggest that there is no differential time trend in the R&D expenses for firms in industries for which the R&D tax credit policy was implemented relative to other manufacturing firms. Interpreting it differently, the idea here is to introduce some counterfactual R&D tax credit policies to see if they had any impact on the R&D expenses of firms. Our estimates from this exercise indicate that there is limited evidence of a consistent impact of such counterfactual policy changes.

Columns (2) and (3) replace firm-level R&D expenses with firm-product level outcomes – product entry and product quality, respectively, and also replace firm fixed effects with firm-product fixed effects. The results show that the estimated coefficients on the interaction terms – year fixed effects with $Treated\ Industry_j$ dummy – are practically zero. Additionally, some of the interaction terms in columns (2) and (3) are positive and others are negative, lacking any consistent pattern. Therefore, we cannot reject the hypothesis that all the interaction terms are jointly equal to zero, and we conclude that firms in both groups followed a similar time trend with respect to key outcome variables in the pre-policy years.

Next, we check whether key firm characteristics play a crucial role in the execution of the R&D tax credit policy for the industries mentioned above before the first policy was announced in 1998. In other words, we check if there has been a lobbying effort by certain firms toward the implementation of the policy using data for the years 1992–1997. For example, if firms that belong to the highest category of R&D expenses lobby to receive a tax credit, they can use the money to invest in improving their product quality, thereby reaping additional gains from such a policy change. In effect, we run the following specification:

$$Treated\ Industry_j = \pi\ X_{it-1} + \theta_{jt} + \epsilon_{ijt} \tag{17}$$

$Treated\ Industry_j$ is as defined before – it takes a value 1 for all industries for which the R&D tax credit policy was announced. X is a vector of firm level characteristics – R&D expenditure, gross value-added (representing size of a firm), $R\&D\ Unit_{i,<10Million}$, $R\&D\ Unit_{i,10-50Million}$, and $R\&D\ Unit_{i,>50Million}$. θ_{jt} are industry (2-digit)–year fixed effects. We cluster our estimates at the 4-digit industry level.

We present our results in **Table 3**. Columns (1) – (5) regress our treated variable, $Treated_j$, on lagged R&D expenses, lagged gross value-added, and different indicators of firms that belong to the three categories of in-house R&D expenditure. The coefficients indicate no statistical correlation between our treatment variable and the independent variables. Combining all the above observations, we can conclude that the R&D tax credit policy was exogenous to the prevailing conditions of the firms' previous R&D and their size.

6 Result

6.1 First Order Effects

6.1.1 Intensive Margin – R&D Expenses

The primary purpose of the R&D tax credit was to encourage and promote domestic R&D activities. **Table 4** presents the result of the effect of the R&D tax credit policy on R&D expenses (**Panel A**) and expenses on foreign technology transfer (**Panel B**) of firms.

Column (1) of **Panel A** regresses R&D expenses of firms on $Treated_{jt}$ controlling for firm and year fixed effects. We find that firms belonging to industries where the policy was implemented registered an increase of 11% in R&D expenses[10].Column (2) introduces a triple interaction term in which we interact $Treated_{jt}$ with $R\&D\ Unit_i$. $R\&D\ Unit_i$ takes a value 1 for firms with in-house R&D unit. Our estimates show that the entire effect of the increase in R&D expenses is driven by firms with in-house R&D unit. Moreover, the effect jumps from 11 to 71%. Columns (3), (4), and (5) also introduce interactions of industry fixed effects (4-digit) with year trends, interactions of industry fixed effects (2-digit) with year fixed effects, and firm controls (age, age-squared and gross value-added). Our estimates remain positive and robustly significant. Overall, the effect of the increase in R&D expenses as a result of the R&D tax credit policy varies between 61-71%.

[10] 11% is calculated using (exp(0.107)-1)x100. Other estimates are calculated accordingly.

Next, we present our preferred empirical specification in columns (6) and (7) without and with firm controls, respectively. In particular, we introduce three indicators that show three different cut-off points regarding expenses of in-house R&D units of firms – $R\&D\ Unit_{i,<10Million}$, $R\&D\ Unit_{i,10-50Million}$, $R\&D\ Unit_{i,>50Million}$ – and their interaction with $Treated_{jt}$. We find that firms that had more than 50 million INR of in-house R&D expenses registered about 650% growth in R&D expenses, followed by firms with expenses on R&D between 10–50 million INR (148%) and firms with expenses on R&D below 10 million INR (12%).[11]

Panel B reruns all the specifications of **Panel A**, but uses firm expenses on foreign technology transfer as the outcome variable of interest. The idea is to check whether the R&D tax credit policy that significantly boosted domestic R&D, also simultaneously reduced firm's dependence on foreign technology transfer. We find limited evidence of such. Only firms that had in-house R&D expenses of less than 10 million INR lowered their dependence on foreign technology transfer, with no effect on other firms.

Event-Study Plots: A causal interpretation of our reduced form coefficients is subject to the assumption that R&D expenses for firms in R&D tax credit industries and others would have evolved comparably in the absence of the policy. Although the counterfactual cannot be directly tested, we exploit data prior to the policy change to estimate event-study specifications. In particular, we interact year fixed effects for five years prior to the policy announcement, and also seven years after, with $Treated_{ij}$. $Treated_{ij}$ assumes a value 1 if a firm i belongs to an industry for which the R&D tax credit policy was implemented.

[11]**Figure C.1** plots the R&D expenses of 4 different categories of firms using RD (regression discontinuity) design. The four different categories of firms are as follows: (i) 0 – firms with no in-house R&D unit; (ii) 1 – firms with in-house R&D unit of $<$ 10 million INR R&D expenses; (iii) 2 – firms with in-house R&D unit of 10–50 million INR of R&D expenses; and (iv) 3 – firms with in-house R&D unit of $>$ 50 million INR of R&D expenses. The figure clearly shows that firms with $>$ 50 million INR of R&D expenses and in-house R&D unit has 6–7 times more R&D expenses than its nearest counterpart (firms with 10–50 million INR of R&D expenses and in-house R&D unit).

As discussed earlier, the R&D tax credit policy was implemented in a staggered fashion. For chemicals, pharmaceuticals, computers, electrical equipment, and telecommunications it was implemented in 1998, while for aircraft it was in 2002 and for automobiles and auto parts it was in 2004. Therefore, in order to estimate the true event-study plot we follow Callaway & Sant'Anna (2021) and plot the coefficients for different years at the aggregate level (i.e., for all firms belonging to industries for which the R&D policy was implemented), for firms with in-house R&D unit, and for firms with in-house R&D unit and expenses of > 50 million INR. We use the following regression equation:

$$ln(R\&D_{ijt}) = \left(\lambda_t \times Treated_{ij}\right) + \eta_i + \phi_t + \theta_j^t + \epsilon_{ijt} \tag{18}$$

where $Treated_{ij}$ assumes the value 1 for three different indicators – (i) when firm i belongs to industry j for which the R&D tax credit policy was implemented; (ii) when firm i belongs to industry j for which the R&D tax credit policy was implemented and has in-house R&D unit; and (iii) when firm i belongs to industry j for which the R&D tax credit policy was implemented and has in-house R&D unit with expenses exceeding 50 million INR.

Panels A, **B**, and **C** in **Figure 3** plot the evolution of the R&D expenses for firms belonging to the categories defined above, controlling for firm fixed effects, year fixed effects, and industry-year trends following equation (18). We compare the coefficients obtained from the regressions of our control group with those of the treated group (industries that did not get the R&D tax credit). The plots imply that the R&D expenses before the policy change were economically small and not statistically significant, indicating that there were no differential pre-policy trends in R&D expenses between firms in treated industries or between firms in any three categories of the control group.[12] This

[12]The absence of pre-trends also negates the fact that other simultaneous reforms such as drop in tariffs

changed after the tax credit was implemented in 1998. The policy led to significant increase in the share of R&D expenses, especially by firms with in-house R&D units and firms with in-house R&D units and expenses of more than 50 million INR.[13,14,15]

6.1.2 Extensive Margin – New In-house R&D Unit

Having established that the R&D tax credit policy change positively impacted the amount of R&D expenses, especially by firms with more than 50 million INR of in-house R&D expenses, we now test whether there was a corresponding impact along the extensive margin of R&D units. Specifically, we examine whether the R&D tax credit policy led to the opening up of new in-house R&D units or not. Results are reported in **Table 5**.

DSIR reports a unique feature of the recognized in-house R&D dataset – the opening date of the in-house R&D unit. We use this aspect of the dataset to construct our outcome variable of interest. In particular, our dependent variable in this case takes a value of 1 if a firm opened up a new in-house R&D unit after the R&D tax credit policy was implemented. We find very limited evidence of the opening up of new in-house R&D units. Only firms that had R&D expenses between 10–50 million INR appeared to have opened new in-house R&D units after the policy reform.

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due to the WTO membership in 1994 had any effect on R&D expenses and R&D tax credit policy was simply an amplification effect.

[13]Similarly, we also the plot the yearly coefficients of firms with in-house R&D units and expenses of less than 10 million INR (**Panel A**) and firms with in-house R&D units and expenses between 10–50 million INR (**Panel B**) in **Figure C.2**. Although the results show a significant increase in the post-policy period for firms in both groups, the pre-trends are not significantly clear.

[14]We also use OLS to plot the coefficients for all firms belonging to the treated industries vs. others (**Panel A**) and firms that have in-house R&D units and R&D expenditure exceeding 50 million INR (**Panel B**) in **Figure C.3**. The trends show similar outcomes as **Figure 3** – firms with in-house R&D units and expenses exceeding 50 million INR contribute immensely to our results.

[15]We also use binned scatter plots, but only for firms with $>$ 50 million INR of in-house R&D expenses in **Panel A** of **Figure C.4**. The results remain the same – R&D expenses increase significantly after the policy is implemented, without much change around the implementation year. In other words, we do not find significant differences in the year pre- and after-policy.

Lastly, we check whether the observed increase in R&D was driven by incumbent or new firms with in-house R&D units. Our estimates show an overwhelming effect of incumbent firms with R&D expenses greater than 10 million INR (primarily by firms whose R&D expenses exceeded 50 million) driving the effect. We continue to find some meager evidence in the case of new in-house R&D units, but limited to firms with expenses between 10–50 million INR.

6.1.3 Industry and Firm Characteristics

Our results from the previous sections documented a tremendous rise in the amount of R&D expenditure by firms that already had in-house R&D units. We also show that this result is especially true for firms that spend more than 50 million INR on R&D. In addition, we find limited evidence of opening of new in-house R&D units. In this section, we uncover certain firm or industry characteristics that can offer competing explanations of the effect on the R&D expenditure. One of the key implications of our theory, specifically **Propositions 1** and **4**, is that the higher the market share of a firm, and higher the degree of product differentiation, the higher would be its investments in R&D. Following this, we test whether firms with $R\&D\ Unit_{i,>50Million}$, those that primarily make the R&D investments, belong to the differentiated products industry and are exporters or not. We present our results in **Table 6**.

We start by looking at the differentiated products industry in columns (1) and (2). For this classification we follow the Rauch (1999) index which introduced a product classification scheme that has been widely used to empirically identify differentiated goods. This is a key step forward in taking the concept of product differentiation to the data. Rauch (1999) classifies SITC (Standard International Trade Classification) 4-digit product categories into three groups: homogeneous, reference price, and differentiated products.

The first group comprises commodities that are traded on an organized exchange (e.g. steel, tea, or tobacco), while the second includes goods that are not sold on organized exchanges but have a benchmark price (e.g. chemicals with reference prices listed in industry guides). All remaining product categories are deemed differentiated.

One problem that limits the use of Rauch (1999) index in our case is that there is no direct concordance of SITC codes with NIC (India's National Industrial Classification) codes. In order to solve this problem, we first match 4-digit NIC codes with 6-digit HS (Harmonized System) codes using Debroy & Santhanam (1993). Now, for each 4-digit NIC code, we have a number of 6-digit HS code. We then match those 6-digit HS codes with the SITC 4-digit codes using the UN classification system. At the end, each 4-digit NIC code comprises of a number of 6-digit HS codes, and these 6-digit HS codes reflect whether a good is differentiated or not. Since we do not know the exact 6-digit HS code product produced by an Indian firm, we can only identify the corresponding industry (4-digit) of a firm to be classified as a differentiated product industry or not, based on the classification of the 6-digit HS products belonging to that industry.

However, there remains one problem in identifying a 4-digit industry to be differentiated or not. It is possible that within one 4-digit industry, some of the 6-digit HS codes follow the differentiated product category and some not. In this case, we classify that industry to be "less" differentiated if atleast 20% of the corresponding 6-digit HS codes are classified as either homogeneous or reference priced. Or else, if a 4-digit industry has 0 to $<$ 20% of its products (6-digit HS codes) classified as non-differentiated, we classify that industry to be "highly" differentiated industry. Our estimates show that $R\&D\ Unit_{i,>50Million}$ firms in "highly" differentiated industries have an overwhelmingly large effect (on R&D expenses) than any other sets of firms. $R\&D\ Unit_{i,>50Million}$ firms in "less" differentiated industries also register a positive and significant effect (392%), but in magnitude the effect is less than half (866%) of "highly" differentiated product industries.

PROWESS provides information on the export status of a firm. We exploit this aspect and classify a firm as an exporter if the average exports of a firm before 1998 are greater than zero. Columns (3) and (4) estimate the effect of the R&D tax credit policy on the R&D expenses for exporters and non-exporters, respectively, register the highest effect with no effect on any set of firms in the category of non-exporters or domestic firms.[16]

Figure 4 executes the coefficient plots following Callaway & Sant'Anna (2021) for both of these subcategories of firms – producing differentiated products (**Panel A**) and exporters (**Panel B**). The coefficient plots strongly corroborate both the theoretical and empirical findings.

6.2 Benchmark Results: Quality vs. Scope

A key implication from **Propositions 2** and 3 is that in response to R&D incentives, in our case a R&D tax credit, bigger firms with larger market share and belonging to the differentiated products industry will invest more in product quality than others. In addition, product scope will decrease with firm size. We now use unique features from our dataset to empirically test these propositions in **Table 7**.

As discussed above, a key feature of PROWESS is that it gives all the products produced by a firm. We exploit this aspect and create a variable "product entry" which assumes a value of 1 if a new product is produced or introduced in the market by a firm in a year t when such product was absent from the product portfolio of that firm in all

[16]We also check our results for one other key industry characteristic – end-user category and firm characteristic – ownership. The results are presented in **Table D.1**. We classify industries according to the end-use of the products produced by a 4-digit industry. Using the Iuput-Output table, we divide industries into intermediates (Column (1)) and final (Column (2)). The estimates show little to no difference between firms in these two categories – especially for $R\&D\ Unit_{i,>50Million}$. In the case of ownership, we find that the results are completely driven by domestic and not foreign firms.

the years before. And, 0 otherwise. Our outcome of interest, therefore, varies at the firm-product level rather than at the firm level. Therefore, we now substitute firm fixed effects with firm-product fixed effects and cluster our standard errors two-way at the industry (4-digit) and product level.

Columns (1) – (3) produce these results. Our estimates in column (1) show that $R\&D\ Unit_{i,>50Million}$ firms have the lowest probability of introducing a new product compared to firms with $R\&D\ Unit_{i,10-50Million}$ and $R\&D\ Unit_{i,<10Million}$, in response to a R&D tax incentive. And, this effect completely vanishes when we slice the sample for exporters (or firms with larger market size) in column (2) and firms producing differentiated products in column (3).

We now turn our focus on product quality in columns (4) – (6). We estimate product quality of the firms following the methodology developed by Khandelwal et al. (2013). The estimation is based on a utility function that computes the log of product quality for each firm-product-year observation. The product quality corresponds to the residual from an OLS estimation of the following equation:

$$ln(q_{ijpt}) + \sigma\, ln(p_{ijpt}) = \gamma_p + \alpha_{jt} + \eta_{ijpt} \tag{19}$$

where q is the amount of quantity sold by firm i belonging to industry j for product p at time t where p is the unit price charged. PROWESS is unique in the sense that it provides the quantity sold and the value of sales for each product produced by a firm. γ_p's denote product fixed effects as prices and quantities are not necessarily comparable across product categories, and α_{jt} controls for the demand and price index for each industry's (j) products. For our purpose, we use σ (2SLS) from Fujiy et al. (2023) for each 2-digit industry except leather and transport equipment.

We estimate the quality of each product produced by a firm using the equation above and use it as our outcome of interest. Our coefficients show that the R&D tax incentive significantly induced an increase in product quality, and the effect was concentrated only for firms that had in-house R&D units with R&D expenditure exceeding 50 million INR of expenses, i.e., $R\&D\ Unit_{i,>50Million}$. In addition, when we divide our firms into exporters (column (5)) and differentiated industries (column (6)), the aggregate result is driven only by those firms. In other words, exporters that invested more than 50 million INR in R&D belonging to the differentiated products industries invested in upgrading the range of products they produce in response to a R&D tax credit policy.

Figure 5 plots the yearly coefficients using product quality as the outcome variable of interest for $R\&D\ Unit_{i,>50Million}$ firms, employing Callaway & Sant'Anna (2021), for differentiated products (**Panel A**) and exporters (**Panel B**). Our plots clearly show that while there was no difference in the quality estimates of $R\&D\ Unit_{i,>50Million}$ firms in industries where the R&D tax credit was implemented before the policy reform, compared to others, it changed significantly afterward. The quality of the products increased significantly in the three years following the reform, then declined for a few years, and began to rise again thereafter. Our coefficient plots echo the theoretical underpinnings as depicted in **Figure 1**.[17]

6.3 What Happened to Sales, Quantity, and Price?

A quick follow–up question arises: What happened to the value of sales, the quantity sold, and the prices charged by these firms for the products produced during the period? The results are reported in **Table 8**. We find that firms in all three categories experienced

[17] Like before, **Panel B** of **Figure C.4** use a binned scatter plot for product quality of firms with $>$ 50 million INR of in-house R&D expenses. We find similar results – R&D expenses increased significantly after the policy was implemented, without much change around the implementation year.

an increase in sales value. The result is similar for exporters and firms producing differentiated products.

However, for firms belonging to $R\&D\ Unit_{i,<10Million}$, the increase in the value of sales is driven by both the quantity sold and the increase in price, but largely by the increase in the former than the latter. For firms belonging to $R\&D\ Unit_{i,10-50Million}$ and $R\&D\ Unit_{i,>50Million}$, the increase in sales value is completely driven by the increase in the price of the products. This price increase reflects an improvement in product quality.[18]

7 Quantifying the Gains

Given our findings in the last section, a key question that crops up is whether and how there were any unintended gains from the increase in product quality and scope as a result of the R&D tax rebate. In order to quantify the gains from the upgraded quality and variety due to the R&D tax credit policy, we use a two-tier utility aggregator. As in Equation (1), upper-tier preferences are Cobb–Douglas across industries $k = 1, \ldots, K$ with weights $\alpha_k > 0$. To tractably quantify the welfare change, we consider a CES aggregator for each industry k aggregated over various products (varieties) produced by multiple firms, i.e., within each group k, preferences are CES across individual varieties $i \in \Omega_{k,r}$ (where $r = (t+1, t)$) with elasticity of substitution $\sigma_k > 1$ and quality $z_{ik,r}$.

[18]**Table D.2** also checks what happened to other production factors (**Panel A**) and outcomes (**Panel B**) of those firms. Columns (1) – (4) use the amount of capital employed, skilled labour compensation, raw material expenses, and import of production units (raw materials and capital goods) as the dependent variables. We find a significant increase for all these production factors, but mainly for $R\&D\ Unit_{i,>50Million}$ firms. Interestingly, while expenses on domestic raw materials increased the most for $R\&D\ Unit_{i,10-50Million}$ firms, the increase in imported production units was largest for $R\&D\ Unit_{i,>50Million}$ firms. In addition, our results show that for both an increase in product scope or quality, input from skilled labour or managers is important. Columns (5) – (8) use promotional expenses (marketing + advertising + promotional expenses), gross value added (sales – raw material expenses), exports and domestic sales as dependent variables, respectively. Our estimates show an interesting result: R&D tax credit resulted in an increase in exports, especially for $R\&D\ Unit_{i,>50Million}$ and $R\&D\ Unit_{i,10-50Million}$ firms with a simultaneous drop in domestic sales. This implies that firms exported higher-quality products as a result of the R&D tax incentive.

$$Q_{k,r} \;=\; \left(\sum_{ik\in\Omega_{k,r}} z_{ik,r}^{1/\sigma_k}\, q_{ik,r}^{\frac{\sigma_k-1}{\sigma_k}} \right)^{\frac{\sigma_k}{\sigma_k-1}} . \tag{20}$$

We follow Sheu (2014) and define the price index as a factor τ_{t+1} by which the prices of all goods in time period t would have to be multiplied in order to give the same utility as the set of goods available in $t+1$.

$$\tau_{t+1} = \frac{P_{t+1}}{P_t} = \frac{\sum_{k\in K}\left(\left(\sum_{ik\in\Omega_{k,t+1}} z_{ik,t+1}\, p_{ik,t+1}^{1-\sigma_k}\right)^{\frac{1}{1-\sigma_k}}\right)^{\alpha_k}}{\sum_{k\in K}\left(\left(\sum_{ik\in\Omega_{k,t}} z_{ik,t}\, p_{ik,t}^{1-\sigma_k}\right)^{\frac{1}{1-\sigma_k}}\right)^{\alpha_k}} \tag{21}$$

If $z_{ik,t+1} \neq z_{ik,t}$ and Ω_k is the set of varieties that are available in both periods, i.e., $\Omega_k \subseteq (\Omega_{k,t+1} \cap \Omega_{k,t})$, we show in **Appendix E** that the aggregate price index can be decomposed into:

$$\tau_{t+1} = \prod_{k=1}^{K}\Big[\underbrace{\prod_{ik\in\Omega_k}\left(\frac{p_{ik,t+1}}{p_{ik,t}}\right)^{w_{ik,t+1}(\Omega_k)}}_{UnitPrice} \cdot \underbrace{\prod_{ik\in\Omega_k}\left(\frac{z_{ik,t}}{z_{ik,t+1}}\right)^{\frac{w_{ik,t+1}(\Omega_k)}{\sigma_k-1}}}_{Quality} \cdot \underbrace{\left(\frac{\lambda_{t+1}^{\Omega_k}}{\lambda_t^{\Omega_k}}\right)^{\frac{1}{\sigma_k-1}}}_{Variety}\Big]^{\alpha_k} \tag{22}$$

where,

$$w_{ik,t+1}(\Omega_k) = \frac{\left(\frac{s_{ik,t+1}(\Omega_k)-s_{ik,t}(\Omega_k)}{\ln s_{ik,t+1}(\Omega_k)-\ln s_{ik,t}(\Omega_k)}\right)}{\sum_{ik\in\Omega_k}\left(\frac{s_{ik,t+1}(\Omega_k)-s_{ik,t}(\Omega_k)}{\ln s_{ik,t+1}(\Omega_k)-\ln s_{ik,t}(\Omega_k)}\right)} \tag{23}$$

$$s_{ik,t+1}(\Omega_k) = \frac{p_{ik,t+1}\, q_{ik,t+1}}{\sum_{ik\in\Omega_k} p_{ik,t+1}\, q_{ik,t+1}} \tag{24}$$

and

$$\lambda_r^{\Omega_k} = \frac{\sum_{ik\in\Omega_k} p_{ik,r}\, q_{ik,r}}{\sum_{ik\in\Omega_{k,r}} p_{ik,r}\, q_{ik,r}} \quad r = (t+1, t) \tag{25}$$

7.1 Gains from Quality and Variety

We quantify the gains from upgraded variety using the framework above. We consider two time periods, pre-tax ($t = 1999$) and post-tax ($t + 1 = 2005$), and calculate the price factor τ_{t+1} as given in Equation (22). For each product i in industry k, the unit price $p_{ik,r}$ is calculated by dividing the sales value by the quantity. We follow Khandelwal et al. (2013) to get the quality estimates $z_{ik,r}$ for $r = (t, t+1)$.

The results in **Table 9** show that $\tau_{t+1} = 0.52$, indicating that the aggregate price index fell by 48% between 1999 and 2005, leading to significant welfare gains.[19]

To convert the price index to consumer surplus, we calculate the additional expenditure that the consumers have to spend to obtain the utility at time $t+1$, if prices remained as in time t.

$$\Delta C = E(U_{t+1}, P_t) - E_{t+1} = \frac{E_{t+1}}{P_{t+1}} P_t - E_{t+1} = (\frac{1}{\tau_{t+1}} - 1) E_{t+1} \tag{26}$$

The results show that the consumers will have to spend 2.02 times the expenditure in time t to get the same utility as in $t+1$ if price remained as in t.

To disentangle the gains from quality upgrades, ΔZ, we can substitute τ_{t+1} in Equation (26) and impose unit price and variety to remain unchanged. This gives us:

$$\Delta Z = \Bigg(\frac{1}{\prod_k \big[(\frac{z_{i,t}}{z_{i,t+1}})^{\frac{\omega_{i,t+1}}{\sigma_k - 1}} \big]^{\alpha_k}} - 1 \Bigg) E_{t+1} \tag{27}$$

The results show that the consumers will have to spend 1.46 times the expenditure in time t to get the same utility as in the time $t+1$ if quality was fixed at time t. This indicates

[19] Our results are also in line with the findings of Jain & Singh (2023) who utilize the same policy to examine it's effect on product prices of firms in the targeted industries. They find that the policy led to a significant decline in prices, mainly driven by a decline in mark-up, conditional on cost.

that the quality investments, following the R&D policy lead to significant welfare gains.

Further isolating the gains from variety by imposing unit price and quality remain unchanged, the price factor drops to 0.31, indicating that increased in product variety also lead to significant welfare gains.

8 Concluding Remarks

Do firms with heterogeneous in-house R&D capacity respond discordantly to an industrial policy aimed at boosting the R&D expenditure? In this paper, we examine a weighted R&D tax credit scheme introduced by the Government of India for firms with in-house R&D units, across manufacturing industries during the late 1990s and early 2000s . We divide firms into three different categories – firms with $<$ 10 million INR of R&D, firms with 10–50 million INR of R&D, and firms with $>$ 50 million INR of R&D – and estimate the effect of the R&D tax credit policy on the R&D expenses and product choices of these firms.

We exploit PROWESS to source detailed information on R&D expenses and production data on all products produced by these firms to calculate the probability of entry of new products and the quality of products. We find that firms with in-house R&D units significantly increased their R&D spending in response to policy. And this was largely driven by firms with incumbent in-house R&D units of $>$ 50 million INR of R&D.

Following, we find that firms in the lowest bracket of R&D cut-off, i.e. firms with $<$ 10 million INR of R&D, optimize the R&D investments by expanding their product range or scope, while the other two sets of firms optimize the same investments by increasing the quality of their product range. This effect is magnified for firms with access to a larger market size or firms that either export or produce differentiated products. We rationalize our findings using a multi-industry framework featuring heterogeneous firms that produce multiple differentiated products where consumer utility is derived along three dimensions: product scope, scale of products, and the quality of the products offered. Our theoretical approach extends standard models of heterogeneous firms (Melitz, 2003) by incorporating endogenous product scope and quality choices. This paper also highlights how R&D tax credits not only stimulate firm level innovation but also translate into substantial consumer welfare gains through improved product quality (43%) and expanded variety (69%) as aggregate price index dropped by 48%.

Our theory and empirical results provide novel evidence that an industrial policy, in the form of R&D tax incentives, can result in different outcomes for firms at different levels of R&D distribution.

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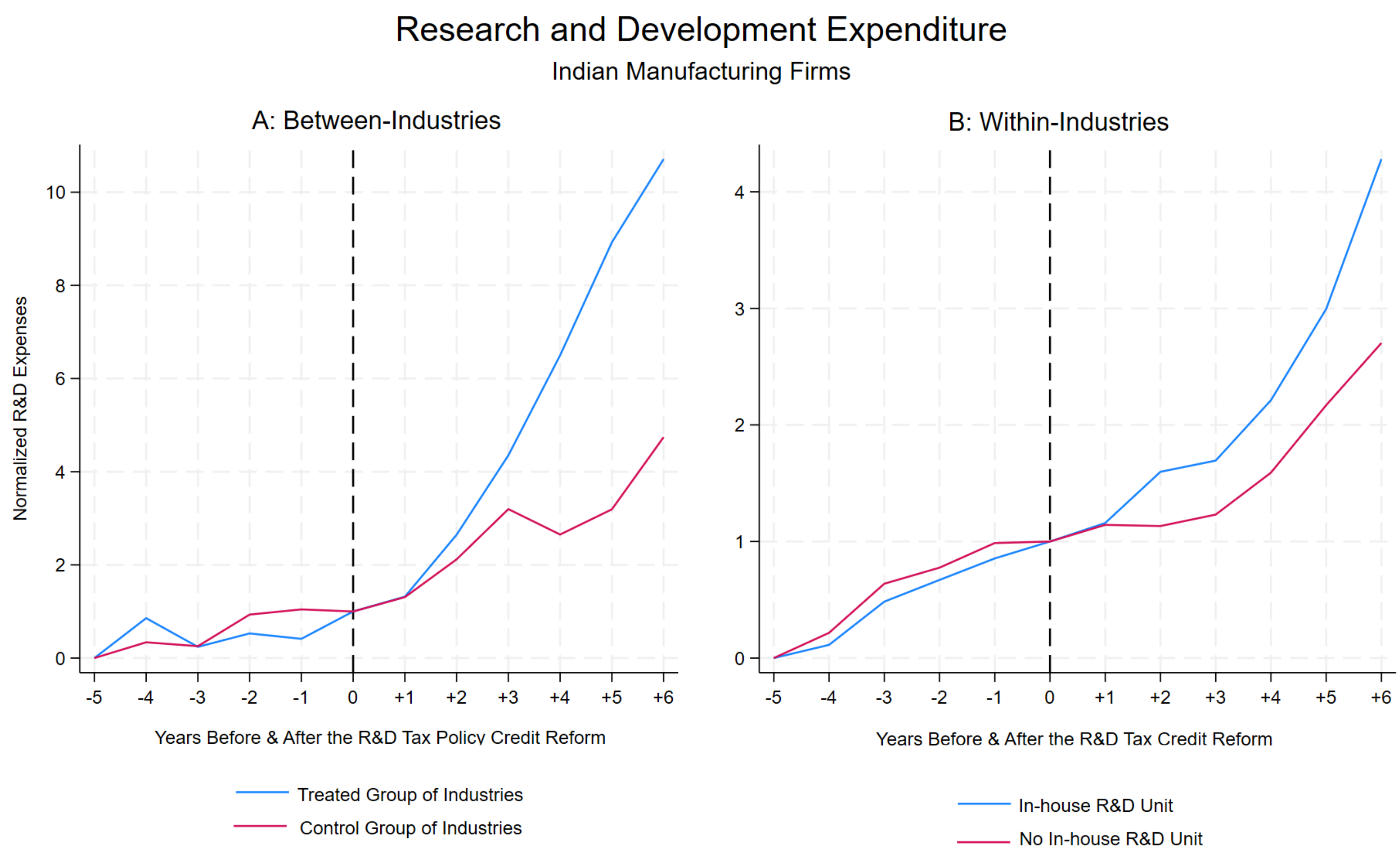

Figure 2: Research and Development Expenditure

Notes: Figure represents normalized Research and Development (R&D) Expenditure for Indian manufacturing firms. Panel A presents the values for treated (for whose the R&D tax credit policy was undertaken) and control group of industries. Panel B present the values for firms with recognized in-house R&D units versus firms with no in-house R&D units. The R&D tax credit policy was announced for the following industries: (1) chemicals, (2) drugs and pharmaceuticals, (3) electronic equipment, (4) computers, (5) telecommunication equipments, (6) aircrafts and helicopters, and (7) automobiles and auto parts.

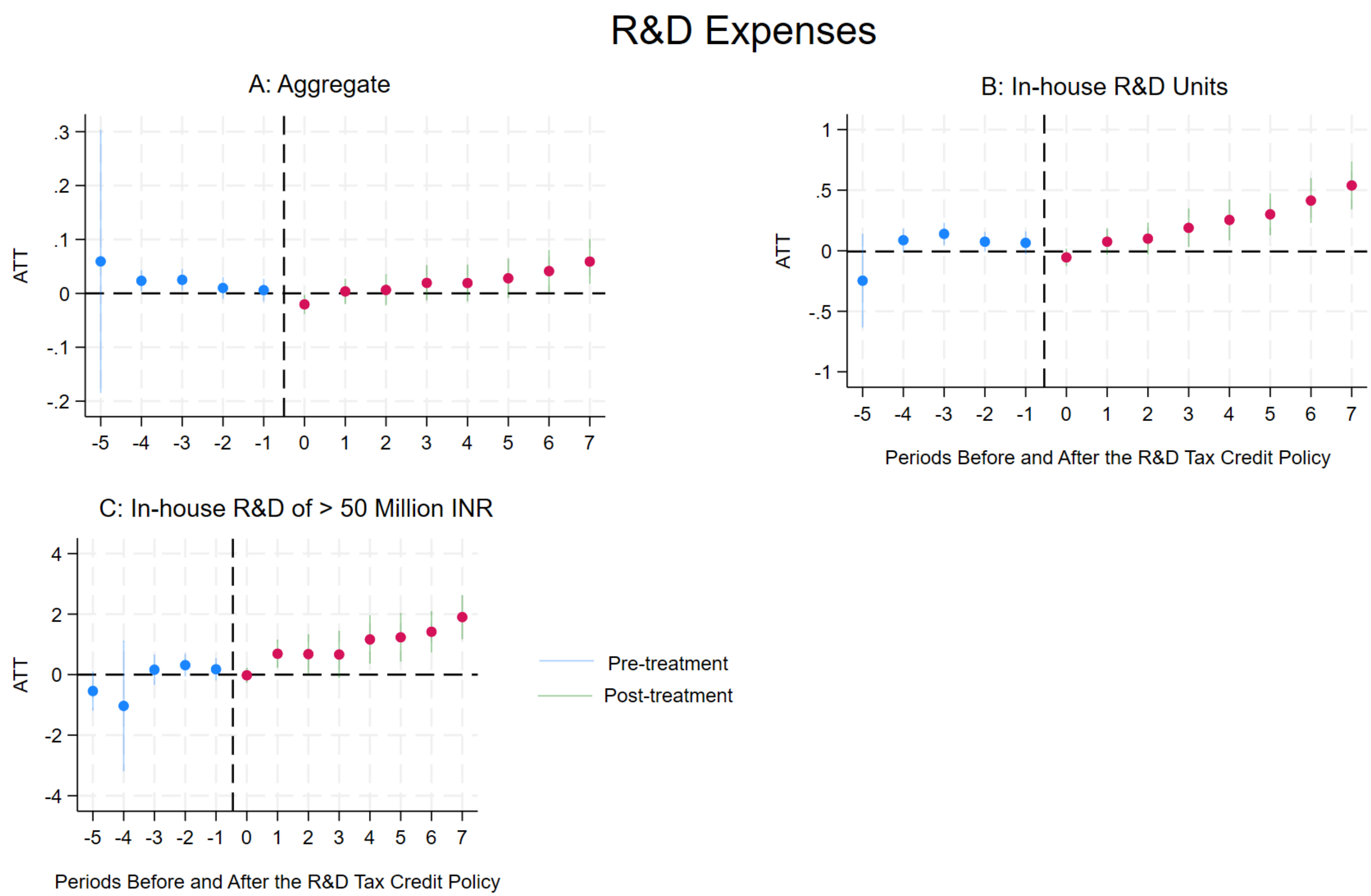

Figure 3: Effects of R&D Tax Credit on R&D Expenditure

Notes: Figure presents the Callaway & Sant'Anna (2021) coefficient estimates (and their 95% confidence intervals) of differences in the R&D expenses for firms in treated and control group of industries at the aggregate (Panel A) and for firms with in-house R&D unit and no in-house R&D unit (Panel B) and for firms with in-house R&D unit and expenses of more than INR 50 Million (Panel C) in treated and control group of industries. The treated group of industries are classified as industries for which the R&D tax credit reform was undertaken by the Govt. of India. The treated group of industries are: (1) chemicals, (2) pharmaceuticals, (3) electronic equipments, (4) computers, (5) telecommunications equipments, (6) manufacture of aircraft and helicopters, and (7) automobiles and auto parts. Our coefficient estimates are controlled for firm fixed effects, year fixed effects, and industry-year trends. Standard errors clustered at the industry (4-digit) level.

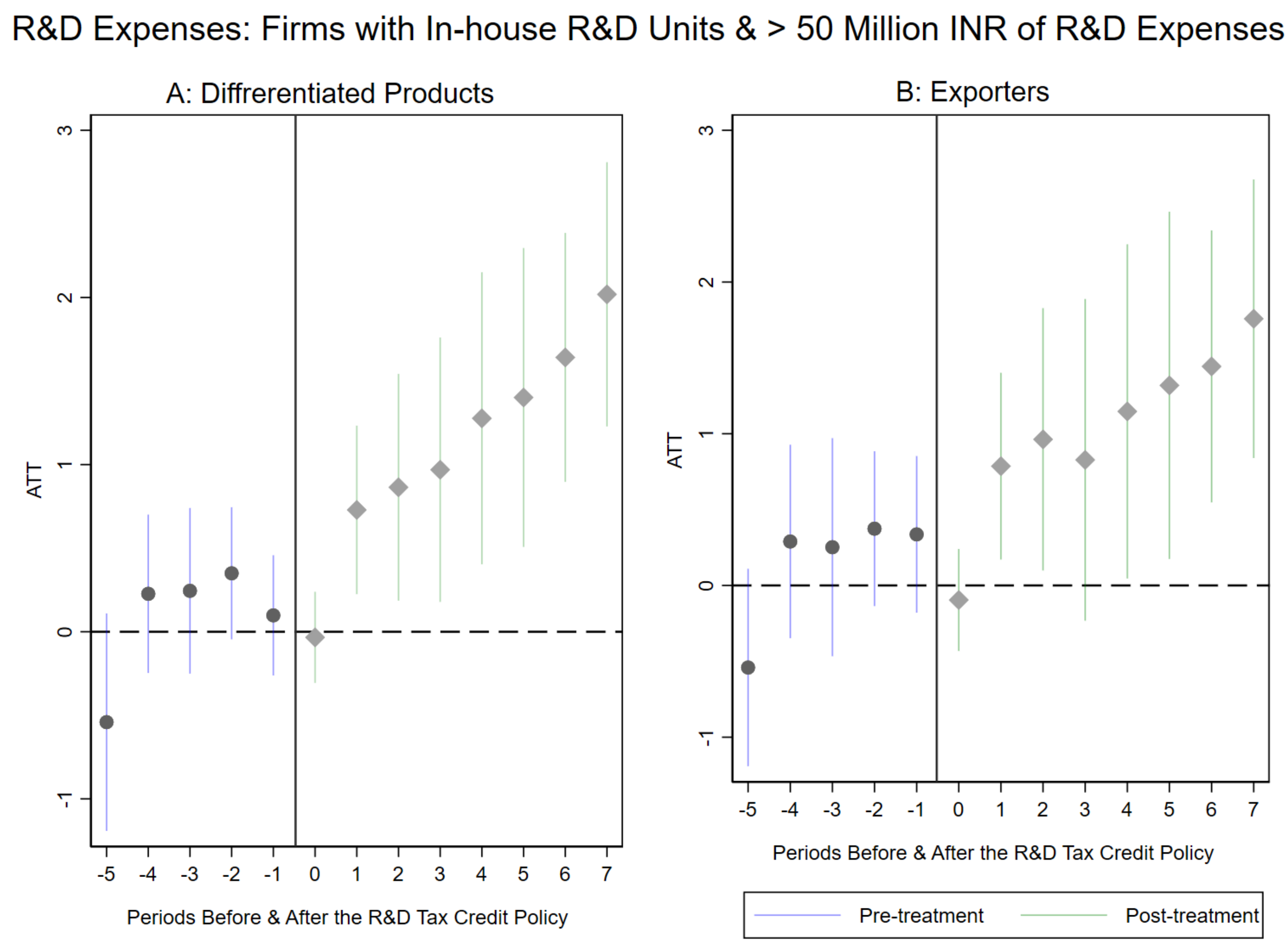

Figure 4: Effects of R&D Tax Credit on R&D Expenditure – Firms with > 50 million INR R&D and In-house R&D Unit
Notes: Figure presents the Callaway & Sant'Anna (2021) coefficient estimates (and their 95% confidence intervals) of differences in the R&D expenses of firms with in-house R&D units and R&D expenses of more than 50 million INR which in treated and control group of industries for the differentiated products (Panel A) and exporters (Panel B). The treated group of industries are classified as industries for which the R&D tax credit reform was undertaken by the Govt. of India. The treated group of industries are: (1) chemicals, (2) pharmaceuticals, (3) electronic equipments, (4) computers, (5) telecommunications equipments, (6) manufacture of aircraft and helicopters, and (7) automobiles and auto parts. Our coefficient estimates are controlled for firm fixed effects, year fixed effects, and industry-year trends. Standard errors clustered at the industry (4-digit) level.

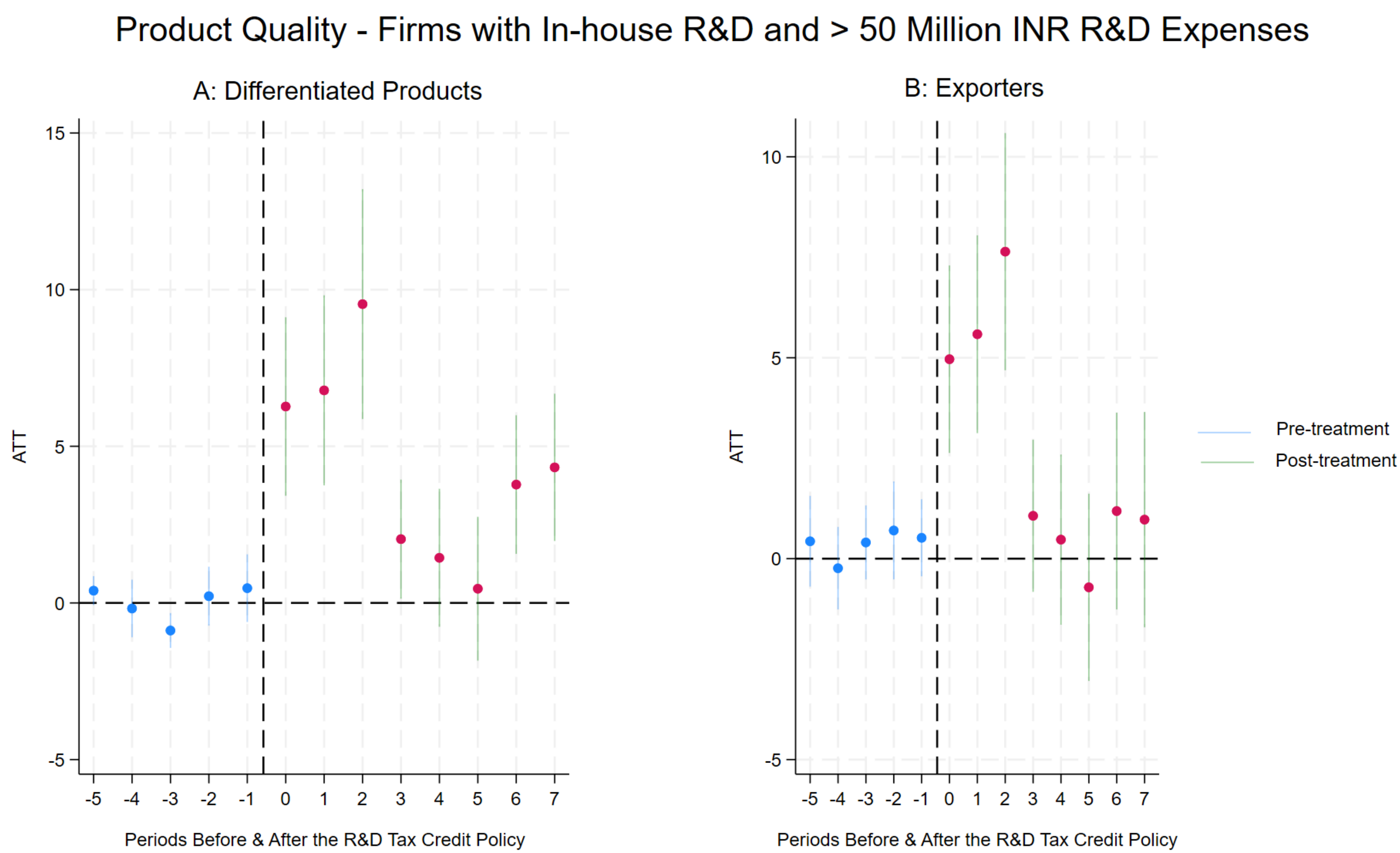

Figure 5: Effects of R&D Tax Credit on Product Quality – Firms with $>$ 50 million INR R&D and In-house R&D Unit

Notes: Figure presents the Callaway & Sant'Anna (2021) coefficient estimates (and their 95% confidence intervals) of differences in the product quality of firms with in-house R&D units and R&D expenses of more than 50 million INR which in treated and control group of industries for the differentiated products (Panel A) and exporters (Panel B). The treated group of industries are classified as industries for which the R&D tax credit reform was undertaken by the Govt. of India. The treated group of industries are: (1) chemicals, (2) pharmaceuticals, (3) electronic equipments, (4) computers, (5) telecommunications equipments, (6) manufacture of aircraft and helicopters, and (7) automobiles and auto parts. Our coefficient estimates are controlled for firm-product fixed effects, year fixed effects, and industry-year trends. Standard errors clustered at the industry (4-digit) level.

Table 1: Summary Statistics – R&D Expenditure, Product Entry, and Product Quality

	R&D Expenditure (1)	Product Entry (2)	Product Quality (3)
All Firms	2.528	0.149	1.90e-09
$R\&D\ Unit_{i,<10\ Million}$	2.247	0.146	0.059
$R\&D\ Unit_{i,10-50\ Million}$	18.379	0.135	0.171
$R\&D\ Unit_{i,>50\ Million}$	168.494	0.132	2.179

Notes: Numbers show the average value for a firm. Column (1) presents R&D Expenses of a firm in INR (Indian Rupees) Millions. Column (2) presents the probabilities of a new product being introduced by a firm. Column (3) presents the estimates of an individual product produced by a firm. This is unit-free.

Table 2: Differences in Pre-Trends: Treated and Control Industries

	R&D Expenditure (1)	Product Entry (2)	Product Quality (3)
Treated Industry$_j$ × *Year*$_{1992}$	0.001	–0.010	–0.240
	(0.024)	(0.034)	(0.166)
Treated Industry$_j$ × *Year*$_{1993}$	0.009	–0.021	–0.255
	(0.024)	(0.034)	(0.209)
Treated Industry$_j$ × *Year*$_{1994}$	–0.016	–0.027	–0.127
	(0.019)	(0.032)	(0.225)
Treated Industry$_j$ × *Year*$_{1995}$	0.002	0.006	0.184
	(0.016)	(0.030)	(0.217)
Treated Industry$_j$ × *Year*$_{1996}$	0.009	0.017	0.073
	(0.008)	(0.018)	(0.289)
Treated Industry$_j$ × *Year*$_{1997}$	0.022	0.018	0.069
	(0.013)	(0.019)	(0.144)
R-Square	0.64	0.88	0.54
N	57,040	132,568	119,497
Firm Controls	✓	✓	✓
Firm FE	✓	X	X
Firm-Product FE	X	✓	✓
Year FE	✓	✓	✓
Industry FE (4-digit) × Year Trend	✓	✓	✓

Notes: All the regressions are run for the years 1992–1997. Columns (1), (2), and (3) use expenses on research and development, product entry, and product quality as the dependent variables, respectively. *R&D Subsidy*$_j$ is the treated dummy. It takes a value 1 for the industries (at 4-digit level) for which a tax deduction of 150% was announced for any in-house R&D capital and revenue expenditure incurred by firms. The industries which were listed in the R&D tax credit are the following: (1) drugs and pharmaceuticals, (2) electronic equipment, (3) computers, (4) telecommunications equipment, (5) chemicals, (6) manufacture of aircraft and helicopters, and (7) automobiles and auto parts. '*Year*$_{1992}$', '*Year*$_{1993}$', '*Year*$_{1994}$', '*Year*$_{1995}$', '*Year*$_{1996}$', '*Year*$_{1997}$' are year dummies. These dummies are equal to 1 for the respective years. Firm controls include the age of a firm and the age squared of a firm. Numbers in the parentheses are clustered standard errors at the industry (4-digit) level for columns (1) and (2). For columns (3) and (4), the standard errors are two-way clustered at the firm-product and industry (4-digit) level. Intercepts are not reported. ***, **, * denotes statistical significance at 1%, 5%, and 10%.

Table 3: Endogeneity Checks: R&D Tax Credit Policy

	Treated Industry$_j$				
	(1)	(2)	(3)	(4)	(5)
R&D Expenses$_{it-1}$	0.002				
	(0.002)				
Gross Value-added$_{it-1}$		0.000			
		(0.000)			
$R\&D\ Unit_{i,<10Million}$			0.006		
			(0.004)		
$R\&D\ Unit_{i,10-50Million}$				0.015	
				(0.013)	
$R\&D\ Unit_{i,>50Million}$					0.010
					(0.014)
R-Square	0.98	0.98	0.98	0.98	0.98
N	62,805	61,841	71,771	71,771	71,771
Industry FE (2-digit) × Year FE	Yes	Yes	Yes	Yes	Yes

Notes: Columns (1) – (5) use *Treated Industry$_j$* as the dependent variable. It takes a value 1 for the following industries: chemical, pharmaceuticals, electrical equipments, computers, telecommunication equipment, aircraft, and automobile parts. R&D Expenses is the R&D expenditure of a firm; Gross Value-added (= sales - raw material expenses) is the gross value-added of a firm; $R\&D\ Unit_{i,<10Million}$ takes a value 1 if a firm's in-house R&D unit has expenses less than 10 million INR; $R\&D\ Unit_{i,10-50Million}$ takes a value 1 if a firm's in-house R&D unit has expenses between 10–50 million INR; and $R\&D\ Unit_{i,>50Million}$ takes a value 1 if a firm's in-house R&D unit has expenses more than 50 million INR. Numbers in the parentheses are robust standard errors clustered at the 4-digit industry level. ***, **, * denotes statistical significance at 1%, 5%, and 10%.

Table 4: R&D Tax Credit and Technology Adoption Expenditure – Intensive Margin

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: R&D Expenditure	Aggregate					R&D Categories	
$Treated_{jt}$	0.107**	–0.032	–0.044**	–0.135*	–0.040*	–0.021	–0.011
	(0.043)	(0.030)	(0.020)	(0.071)	(0.020)	(0.021)	(0.024)
$Treated_{jt} \times R\&D\ Unit_i$		0.539***	0.539***	0.535***	0.478***		
		(0.062)	(0.063)	(0.063)	(0.050)		
$Treated_{jt} \times R\&D\ Unit_{i,<10\ Million}$						0.193***	0.113***
						(0.041)	(0.034)
$Treated_{jt} \times R\&D\ Unit_{i,<10-50\ Million}$						1.014***	0.908***
						(0.078)	(0.085)
$Treated_{jt} \times R\&D\ Unit_{i,>50\ Million}$						2.181***	2.012***
						(0.300)	(0.225)
N	162,342	162,342	162,342	162,342	133,180	162,342	133,180
R-square	0.59	0.61	0.61	0.62	0.65	0.62	0.65
Panel B: Foreign Technology Transfer	Aggregate					R&D Categories	
$Treated_{jt}$	–0.018	–0.025	–0.036	0.038	–0.022	–0.029	–0.015
	(0.026)	(0.024)	(0.024)	(0.092)	(0.023)	(0.026)	(0.024)
$Treated_{jt} \times R\&D\ Unit_i$		0.029	0.029	0.022	0.005		
		(0.025)	(0.025)	(0.025)	(0.024)		
$Treated_{jt} \times R\&D\ Unit_{i,<10\ Million}$						–0.052*	–0.060**
						(0.029)	(0.025)
$Treated_{jt} \times R\&D\ Unit_{i,10-50\ Million}$						–0.055	–0.088
						(0.081)	(0.083)
$Treated_{jt} \times R\&D\ Unit_{i,>50\ Million}$						0.415*	0.309
						(0.223)	(0.234)
N	162,341	162,341	162,341	162,341	133,179	162,341	133,179
R-square	0.56	0.56	0.56	0.57	0.61	0.56	0.61
Firm Controls	X	X	X	X	✓	X	✓
Firm FE	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	X	✓	✓	✓
Industry FE (4-digit) × Year Trend	X	X	✓	X	✓	✓	✓
Industry FE (2-digit) × Year FE	X	X	X	✓	X	X	X

Notes: Panel A uses research and development expenses (current plus capital) and Panel B uses expenses made on account of foreign technology transfer by a firm as the dependent variable, respectively. $Treated_{jt}$ takes a value 1 for all years since the Govt. of India announced the tax rebate for certain industries (at 4-digit level) and 0 otherwise. For example, it takes a value 1 for firms belonging to chemical, pharmaceuticals, electrical equipments, computers, telecommunication equipment industries after the year 1997. For aircraft, it takes value 1 after 2001 and for automobile parts after 2003. $R\&D\ Unit_i$ takes a value 1 for firm i that has a registered in-house R&D unit with DSIR (Department of Scientific and Industrial Research). $R\&D\ Unit_{i,<10\ Million}$, $R\&D\ Unit_{i,10-50\ Million}$, and $R\&D\ Unit_{i,>50\ Million}$ takes value 1 for firms whose registered R&D unit has expenses less than 10 Million INR, between 10–50 Million INR, and greater than 50 Million INR, respectively. Firm controls include age of a firm, age squared, and real gross value-added of a firm. Standard errors are clustered at 4-digit industry level. Intercepts are not reported. *,**,*** denotes 10%, 5%, and 1% level of significance, respectively.

Table 5: R&D Tax Credit and Technology Adoption Expenditure – Extensive Margin

	New R&D Unit $= 1$ *if year* > 1998				R&D Expenditure	
					Incumbent R&D Unit	New R&D Unit
	(1)	(2)	(3)	(4)	(5)	(6)
$Treated_{jt}$	0.004					
	(0.004)					
$Treated_{jt} \times R\&D\ Unit_i$		0.038*				
		(0.023)				
$Treated_{jt} \times R\&D\ Unit_{i,<10\ Million}$			–0.028	–0.010	0.415***	0.022
			(0.022)	(0.028)	(0.087)	(0.127)
$Treated_{jt} \times R\&D\ Unit_{i,10-50\ Million}$			0.039	0.079**	0.342***	0.615***
			(0.037)	(0.037)	(0.111)	(0.230)
$Treated_{jt} \times R\&D\ Unit_{i,>50\ Million}$			0.042	0.033	1.619***	0.071
			(0.040)	(0.034)	(0.253)	(0.136)
R-Square	0.05	0.05	0.05	0.19	0.70	0.63
N	13,302	13,302	13,302	12,205	8,682	3,523
Firm Controls	X	X	X	✓	✓	✓
Industry FE (2-digit)	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
Industry FE (4-digit) × Year Trend	✓	✓	✓	✓	✓	✓

Notes: All the regressions are for the years 1992–2007. Columns (1) – (4) use a dummy variable as the dependent variable. It takes a value 1 if a firm registers a new R&D unit with DSIR (Department of Scientific and Industrial Research) after the Govt. of India announced the tax rebate for certain industries (chemical, pharmaceuticals, electrical equipments, computers, telecommunication equipment, aircraft, and auto parts). $R\&D\ Unit_i$ takes a value 1 for firm i that has a registered in-house R&D unit with DSIR (Department of Scientific and Industrial Research). $R\&D\ Unit_{i,<10\ Million}$, $R\&D\ Unit_{i,10-50\ Million}$, and $R\&D\ Unit_{i,>50\ Million}$ takes value 1 for firms whose registered R&D unit has expenses less than 10 Million INR, between 10–50 Million INR, and greater than 50 Million INR, respectively. Firm controls include the age of a firm, age squared, and the real gross value-added of a firm. Standard errors are clustered at 4-digit industry level. Intercepts are not reported. *,**,*** denotes 10%, 5%, and 1% level of significance, respectively.

Table 6: R&D Tax Credit and Technology Adoption Expenditure – Industry & Firm Heterogeneity

	R&D Expenditure			
	Industry Characteristic		Firm Characteristic	
	Differentiated Products		Exporters	
	Highly	Less	Yes	No
	(1)	(2)	(3)	(4)
$Treated_{jt}$	–0.427	–0.016	–0.012	–0.002
	(0.470)	(0.017)	(0.039)	(0.003)
$Treated_{jt} \times R\&D\ Unit_{i,<10\ Million}$	0.138***	0.072*	0.094**	0.009
	(0.049)	(0.039)	(0.043)	(0.066)
$Treated_{jt} \times R\&D\ Unit_{i,10-50\ Million}$	1.204***	0.853***	0.872***	0.143**
	(0.043)	(0.097)	(0.080)	(0.071)
$Treated_{jt} \times R\&D\ Unit_{i,>50\ Million}$	2.286***	1.593***	2.066***	–0.008
	(0.229)	(0.089)	(0.168)	(0.005)
N	24,687	109,033	56,731	76,449
R-square	0.64	0.64	0.65	0.45
Firm Controls	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Industry FE (4-digit) × Year Trend	✓	✓	✓	✓

Notes: All the regressions are for the years 1992–2007. Columns (1) – (4) use research and development expenses (current plus capital) by a firm as the dependent variable, respectively. $Treated_{jt}$ takes a value 1 for all years since the Govt. of India announced the tax rebate for certain industries (at 4-digit level) and 0 otherwise. For example, it takes a value 1 for firms belonging to chemical, pharmaceuticals, electrical equipments, computers, telecommunication equipment industries after the year 1997. For aircraft, it takes value 1 after 2001 and for automobile parts after 2003. $R\&D\ Unit_{i,<10\ Million}$, $R\&D\ Unit_{i,10-50\ Million}$, and $R\&D\ Unit_{i,>50\ Million}$ takes value 1 for firms whose registered in-house R&D unit with DSIR (Department of Scientific and Industrial Research) has expenses less than 10 Million INR, between 10–50 Million INR, and greater than 50 Million INR, respectively. Firm controls include age of a firm, age squared, and real gross value-added of a firm. Standard errors are clustered at 4-digit industry level. Intercepts are not reported. *,**,*** denotes 10%, 5%, and 1% level of significance, respectively.

Table 7: R&D Subsidy and Firm Product Choice – Scope vs. Quality

	Product Entry			Product Quality		
	All	Exporters	Differentiated Products	All	Exporters	Differentiated Products
	(1)	(2)	(3)	(4)	(5)	(6)
$Treated_{jt}$	–0.016**	–0.022***	–0.024	0.549	1.535	0.211
	(0.006)	(0.006)	(0.016)	(1.280)	(1.334)	(2.216)
$Treated_{jt} \times R\&D\ Unit_{i,<10\ Million}$	0.050***	0.038***	0.041***	0.159	0.067	–0.309
	(0.008)	(0.008)	(0.009)	(0.573)	(0.603)	(0.370)
$Treated_{jt} \times R\&D\ Unit_{i,10-50\ Million}$	0.052***	0.039***	0.030***	1.220*	1.065	–0.064
	(0.007)	(0.007)	(0.009)	(0.672)	(0.699)	(0.400)
$Treated_{jt} \times R\&D\ Unit_{i,>50\ Million}$	0.019*	0.007	0.003	4.480***	4.060***	4.012***
	(0.010)	(0.010)	(0.012)	(1.144)	(1.147)	(1.137)
R-Square	0.32	0.33	0.3485	0.20	0.17	0.18
N	285,210	107,824	59,835	248,661	105,339	59,811
Firm Controls	✓	✓	✓	✓	✓	✓
Firm-Product FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
Industry FE (4-digit) X Year Trend	✓	✓	✓	✓	✓	✓

Notes: All the regressions are for the years 1992–2007 and employ firm-product-year level data. Columns (1) – (3) uses product entry: it takes a value 1 when a new product appears in the sample; columns (4) – (6) use product quality of a firm as the dependent variable, respectively. We use Khandelwal et al. (2013) to estimate the product quality. For estimation of product quality, we use the elasticities of substitution at the HS2 industry level from Fujiy et al. (2023) using the 2SLS method. $Treated_{jt}$ takes a value 1 for all years since the Govt. of India announced the tax rebate for certain industries (at 4-digit level) and 0 otherwise. For example, it takes a value 1 for firms belonging to chemical, pharmaceuticals, electrical equipments, computers, telecommunication equipment industries after the year 1997. For aircraft, it takes value 1 after 2001 and for automobile parts after 2003. $R\&D\ Unit_{i,<10\ Million}$, $R\&D\ Unit_{i,10-50\ Million}$, and $R\&D\ Unit_{i,>50\ Million}$ takes value 1 for firms whose registered in-house R&D unit with DSIR (Department of Scientific and Industrial Research) has expenses less than 10 Million INR, between 10–50 Million INR, and greater than 50 Million INR, respectively. Firm controls include the age of a firm, age squared, and the real gross value-added of a firm. Numbers in the parentheses are two-way clustered standard errors at industry and product level. ***, **, * denotes statistical significance at 1%, 5%, and 10%.

Table 8: R&D Subsidy and Firm-Product Sales

	Product Sales			Product Quantity			Product Price (Unit)		
	All	Exporters	Differentiated Products	All	Exporters	Differentiated Products	All	Exporters	Differentiated Products
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$Treated_{jt}$	–0.068*	–0.050	0.227	–0.086	–0.063	–0.190	–0.119***	–0.111***	–0.209
	(0.038)	(0.040)	(0.144)	(0.058)	(0.060)	(0.142)	(0.037)	(0.038)	(0.169)
$Treated_{jt} \times R\&D\ Unit_{i,<10\ Million}$	0.193***	0.170**	0.146*	0.280***	0.260***	0.306***	0.122***	0.103**	0.136
	(0.068)	(0.070)	(0.078)	(0.095)	(0.098)	(0.110)	(0.036)	(0.041)	(0.107)
$Treated_{jt} \times R\&D\ Unit_{i,10-50\ Million}$	0.200***	0.159**	0.238***	0.105	0.078	–0.005	0.163***	0.163***	0.231*
	(0.068)	(0.069)	(0.080)	(0.096)	(0.097)	(0.101)	(0.036)	(0.035)	(0.120)
$Treated_{jt} \times R\&D\ Unit_{i,>50\ Million}$	0.475***	0.440***	0.632***	0.062	0.037	0.119	0.273***	0.258***	0.461***
	(0.139)	(0.139)	(0.163)	(0.137)	(0.137)	(0.163)	(0.064)	(0.067)	(0.159)
R-Square	0.34	0.31	0.3563	0.38	0.37	0.36	0.57	0.54	0.49
N	285,201	229,262	59,834	285,192	229,254	59,831	180,578	145,538	36,392
Firm Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓
Firm-Product FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Industry FE (4-digit) X Year Trend	✓	✓	✓	✓	✓	✓	✓	✓	✓

Notes: All the regressions are for the years 1992–2007 and employ firm-product-year level data. Columns (1) – (3) use product level sales; columns (3) and (4) use quantity of product sold by a firm as the dependent variable, respectively. $Treated_{jt}$ takes a value 1 for all years since the Govt. of India announced the tax rebate for certain industries (at 4-digit level) and 0 otherwise. For example, it takes a value 1 for firms belonging to chemical, pharmaceuticals, electrical equipments, computers, telecommunication equipment industries after the year 1997. For aircraft, it takes value 1 after 2001 and for automobile parts after 2003. $R\&D\ Unit_{i,<10\ Million}$, $R\&D\ Unit_{i,10-50\ Million}$, and $R\&D\ Unit_{i,>50\ Million}$ takes value 1 for firms whose registered in-house R&D unit with DSIR (Department of Scientific and Industrial Research) has expenses less than 10 Million INR, between 10–50 Million INR, and greater than 50 Million INR, respectively. Firm controls include the age of a firm, age squared, and the real gross value-added of a firm. Numbers in the parentheses are two-way clustered standard errors at the industry and product level. ***, **, * denotes statistical significance at 1%, 5%, and 10%.

Table 9: Welfare Gains from R&D Tax Credit Policy

	Aggregate	**Quality**	**Variety**
Price Index τ	0.52	1.50	0.31
Consumer Surplus (CS)	2.02 E_{2019}	1.46 E_{2019}	0.72 E_{2019}

Online Appendix for
R&D Tax Credit and Product Quality vs. Scope

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A Theory – Proofs

A.1 Preferences and Demand

Each consumer maximizes a two-tier utility function that depends on the consumption levels $q(i)$ and the quality $z(i)$, $i \in [1, N]$, where N is the number of differentiated goods produced in each industry k. The upper-tier utility is a Cobb Douglas over sub-utility functions, weighted by its expenditure share. The upper-tier is:

$$U = \prod_k u(k)^{\alpha_k} \tag{A.1}$$

The lower tier utility function can be defined as:

$$u(k) = \left[a^0 \int_0^N q(i)di - \frac{1}{2} b \Big[(1-e) \int_0^N q(i)^2 di + e \Big\{ \int_0^N q(i)^2 di \Big\}^2 \Big] \right] + \beta \int_0^N q(i)\tilde{z}(i)di \tag{A.2}$$

Utility depends on the quantity $q(i)$ and its interaction with the quality $z(i)$. The parameter e is an inverse measure of product differentiation. If $e = 0$, the products are highly differentiated.

Maximizing utility subject to budget constraints gives us the demand function

$$\mathcal{L} = \left[a^0 \int_0^N q(i)di - \frac{1}{2} b \Big[(1-e) \int_0^N q(i)^2 di + e \Big\{ \int_0^N q(i)^2 di \Big\}^2 \Big] \right] + \beta \int_0^N q(i)\tilde{z}(i)di + \lambda [\int_0^1 p(i)q(i) - I]$$

$$\frac{\partial \mathcal{L}}{\partial q(i)} = [a^0 + \beta \tilde{z}(i)] - b[(1-e)q(i) + e\int_0^N q(i)] - \lambda p_i = 0$$

Let $\lambda = 1$

$$\implies p(i) = [a^0 + \beta \tilde{z}_i] - b[(1-e)q(i) + e\int_0^N q(i)di] \tag{A.3}$$

If there are L consumers, then the total demand for product i is $x(i) = Lq(i)$. Thus,

$$\implies p(i) = [a^0 + \beta \tilde{z}(i)] - b'[(1-e)x(i) + e\int_0^N x(i)di] \tag{A.4}$$

Here, $b' = b/L$

A.2 Firms and Production Technology

Firms j in industry k is characterized by a core competence and flexible manufacturing. The marginal cost incurred by firm j in producing a variety i is $c_j(i)$. The firms also invests in upgrading their quality of their product i by incurring $k_j(i)$ and in their overall brand by incurring $\bar{K}_j$. The return to quality investment is given by $z_j(i) = 2\theta k_j(i)^{1/2}$.

The firms choose the number of products they produce δ_j, the quantity of each product $x_j(i)$, investments in product quality $k_j(i)$ and in overall quality $\bar{K}_j$ to maximize its profits given the demand.

$$\max_{x_j(i), k_j(i), \bar{K}_j, \Omega_j} \Pi_j = \int_0^{\delta_j} \Big[[p_j(i) - c_j(i)]x_j(i) - \gamma k_j(i)\Big]di$$

$$\frac{\partial \Pi_j}{\partial x_j(i)} = p_j(i) + x_j(i)\frac{\partial p_j(i)}{\partial x_j(i)} + \int_0^{\delta_j} x_j(s)\frac{\partial p_j(s)}{\partial x_j(i)} ds \forall s \notin i - c_j(i) = 0$$

$$\implies p_j(i) = b'[(1-e)x_j(i) + eX_j] + c_j(i)$$

Here $X_j = \int_0^{\delta_j} x_j(i)di$ is the total quantity of products produced by firm j. From the demand equation, $p_j(i) = [a^0 + \beta z_j(i)] - b'[(1-e)x_j(i) + eY]$, where, Y is the total output of the industry $Y = \int_0^N \int_0^{\delta_j} x_j(i)didj$.

Substituting we get the equilibrium output at the firm-product level

$$x_j(i) = \frac{[a^0 + \beta z_j(i)] - c_j(i) - b'e(X_j + Y)}{2b'(1-e)} \tag{A.5}$$

The firm chooses the number of products δ_j such that $x_j(\delta) = 0$.

FOC with respect to the investments in quality of individual varieties is given as:

$$\frac{\partial \Pi_j}{\partial k_j(i)} = x_j(i) \frac{\partial p_j(i)}{\partial z_j(i)} \frac{\partial z_j(i)}{\partial k_j(i)} - \gamma = 0$$

$$\implies \gamma_j k_j(i)^{0.5} = \beta(1-e)\theta x_j(i) \tag{A.6}$$

In order to derive the implications of investment in quality for the firm's sales across varieties, $x_j(i)$, we utilize Equation (A.5) combined with the FOCs of optimal investment (A.6)

$$x_j(i) = \frac{[a^0 + \beta z_j(i)] - c_j(i) - b'e(X_j + Y)}{2b'(1-e)}$$

Substituting for $z_j(i)$ and expanding in terms of $k_j(i)$, we get:

$$\implies x_j(i) = \frac{a^0 - c_j(i) - t_j - b'e(X_j + Y)}{2(1-e)\left[b' - \eta_j\right]} \tag{A.7}$$

Here

$$c_j(\delta_j) = a^0 - t_j - b'e(X_j + Y) \tag{A.8}$$

Therefore, the output of each variety is represented solely as a function of exogenous variables, the total production of the firm X_j and the total industrial production Y. Next, evaluating Equation (A.7) at $x_j(\delta) = 0$, we can rewrite the expression in terms of the firm's cost:

$$x_j(i) \;=\; \frac{c_j(\delta_j) - c_j(i)}{2(1-e)\ \left[b' - \eta_j\right]} \tag{A.9}$$

Here $\eta_j = \frac{\beta^2 \theta^2}{\gamma_j}$ is the effectiveness of R&D investments.

Aggregating the individual varieties i produced by firm j, to get aggregate scale:

$$X_j = \int_0^{\delta_j} x_j(i)\,\mathrm{d}i = \int_0^{\delta_j} \frac{c_j(\delta) - c_j(i)}{2(1-e)\left[b' - \eta_j\right]}\,\mathrm{d}i. \tag{A.10}$$

Solving for equilibrium prices by utilizing the FOC from profit maximization and Eq. (11):

Substituting Equation (8) and Equation (11) into the demand equation $p_j(i) = [a^0 + \beta z_j(i)] - \frac{b}{L}[(1-e)x_j(i) + eY]$ gives us the equilibrium prices in terms of marginal costs.

$$p_j(i) = \frac{b' - 2\eta_j}{2(b' - \eta_j)} c_j(i) + \frac{2\eta_j - b'}{2(b' - \eta_j)} c_j(\delta_j) - b'eY \tag{A.11}$$

Similarly, aggregate R&D investment K_j and quality Z_j is given as

$$K_j = \int_0^{\delta_j} k_j(i)\,di = \frac{\eta_j}{4\gamma_j(b'_j - \eta_j)^2} \int_0^{\delta_j} [c_j(\delta_j) - c_j(i)]^2\,di \tag{A.12}$$

$$Z_j = \frac{\eta_j}{\beta(b'_j - \eta_j)} \int_0^{\delta_j} [c_j(\delta_j) - c_j(i)]\,di \tag{A.13}$$

B Proofs of Propositions

B.1 Impact of R&D Credits on Scale

This section derives the impact of R&D credits on scale and how does it differs by firm size, i.e., firms with higher scale X_j or average scale X_j/δ_j.

Equation(12) gives us the equilibrium scale for a firm j:

$$X_j = \int_0^{\delta_j} x_j(i)di = \frac{\int_0^{\delta_j}[c_j(\delta_j) - c_j(i)]di}{2(1-e)[b' - \eta_j]} = \frac{\delta_j c_j(\delta_j) - \int_0^{\delta_j} c_j(i)di}{2(1-e)[b' - \eta_j]} \tag{B.1}$$

where,

$$c_j(\delta_j) = a^0 - b'_j e(X_j + Y) - t_j$$

Our aim is to derive dX_j as a function of exogeneous shocks while taking into account oligopolistic interactions. In order to totally differentiate X_j, we express it as:

$$X_j = \frac{\phi_j(\delta_j)}{D}$$

$$\implies dX_j = \frac{d\phi_j}{D} - \frac{dD\phi_j}{D^2}$$

Where $\phi_j = \delta_j c_j(\delta_j) - \int_0^{\delta_j} c_j(i)di$ is the cost integral in the numerator and $D = 2(1 - e)[b' - \eta_j]$ is the denominator.

Totally differentiating the numerator, $\phi_j(\delta_j) = \int_0^{\delta_j} [c_j(\delta_j) - c_j(i)]\, di$.

$$d\phi_j \;=\; \delta_j\, c_j'(\delta_j)\, d\delta_j \;-\; \int_0^{\delta_j} dc_j(i)\, di.$$

(*None of the shocks effect the entire cost schedule but rather only the marginal variety cost, and hence the second term drops out*)

Totally differentiating the denominator,

$$D = 2(1-e)\Big[\frac{b}{L_j} - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big]$$

$$\implies dD = 2(1-e)[\frac{-b}{L_j^2}dL_j + \frac{\beta^2\theta_j^2}{\gamma_j^2}d\gamma_j + 2\frac{\beta^2\theta_j}{\gamma_j}d\theta_j]$$

$$\implies dD = -2(1-e)\frac{b'}{L_j}dL_j + 2(1-e)\frac{\beta^2\theta^2}{\gamma_j^2}d\gamma_j + 4(1-e)\frac{\beta^2\theta_j}{\gamma_j}d\theta_j$$

Substitute into $dX_j = \dfrac{d\phi_j}{D} - \dfrac{\phi_j\, dD}{D^2}$.

$$dX_j \;=\; \frac{\delta_j\, c_j'(\delta_j)\, d\delta_j}{D} \;-\; X_j\, \frac{dD}{D}.$$

Explicitly,

$$\boxed{dX_j \;=\; \frac{\delta_j\, c_j'(\delta_j)\, d\delta_j}{2(1-e)\Big[b_j' - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big]} \;-\; X_j\,\frac{-2(1-e)\frac{b'}{L_j}dL_j + 2(1-e)\frac{\beta^2\theta^2}{\gamma_j^2}d\gamma_j + 4(1-e)\frac{\beta^2\theta_j}{\gamma_j}d\theta_j}{2(1-e)\Big[b_j' - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big]}} \tag{B.2}$$

$$c'(\delta_j)d\delta_j = -dt_j - b_j'edX_j - b_j'edY - \frac{b_j'}{L_j}e(X_j+Y)dL_j \tag{B.3}$$

where, Equation (B.3) is simply the total differentiation of $c_j(\delta_j)$.

We combine both equations and collect the dX_j terms on one side:

$$\implies dX_j = \frac{\begin{aligned}&-\;\delta_j\, dt_j - \delta_j b_j' e dX_j - \delta_j b' e\, dY\\ &-\frac{\delta_j b_j' e}{L_j}\,(X_j+Y)\,dL_j\\ &+X_j\Big[2(1-e)\frac{b'}{L_j}dL_j - 2(1-e)\frac{\beta^2\theta^2}{\gamma_j^2}d\gamma_j - 4(1-e)\frac{\beta^2\theta_j}{\gamma_j}d\theta_j\Big]\end{aligned}}{2(1-e)\Big[b_j' - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big]}$$

$$\implies dX_j + \frac{\delta_j b_j' e dX_j}{2(1-e)\Big[b_j' - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big]} = \frac{\begin{aligned}&-\;\delta_j\, dt_j - \delta_j b_j' e dX_j - \delta_j b_j' e\, dY\\ &-\frac{\delta_j b_j' e}{L_j}\,(X_j+Y)\,dL_j\\ &+X_j\Big[2(1-e)\frac{b'}{L_j}dL_j - 2(1-e)\frac{\beta^2\theta^2}{\gamma_j^2}d\gamma_j - 4(1-e)\frac{\beta^2\theta_j}{\gamma_j}d\theta_j\Big]\end{aligned}}{2(1-e)\Big[b_j' - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big]}$$

$$
\begin{aligned}
&- \delta_j\, dt_j - \delta_j b_j' e dX_j - \delta_j b_j' e\, dY \\
&- \frac{\delta_j b_j' e}{L_j} (X_j + Y)\, dL_j
\end{aligned}
$$

$$
\implies \frac{dX_j\Big[2(1-e)\Big[b_j' - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big] + \delta_j b_j' e\Big]}{2(1-e)\Big[b_j' - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big]} = \frac{+ X_j\Big[2(1-e)\frac{b'}{L_j}dL_j - 2(1-e)\frac{\beta^2\theta^2}{\gamma_j^2}d\gamma_j - 4(1-e)\frac{\beta^2\theta_j}{\gamma_j}d\theta_j}{2(1-e)\Big[b_j' - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big]}
$$

Dividing by δ_j throughout and canceling the denominator terms results in the following.

$$
\begin{aligned}
\frac{dX_j}{\delta_j}\Big[2(1-e)\Big[b_j' - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big] + \delta_j b_j' e\Big] &= - dt_j \; - \; b_j' e\, dY \\
&+ \frac{b_j' e}{L_j}\Big[\, 2(1-e)\frac{X_j}{\delta_j} - e\big(X_j + Y\big)\Big]\, dL_j \\
\implies \qquad & - 2(1-e)\frac{X_j}{\delta_j}\frac{\beta^2\theta_j^2}{\gamma_j^2} d\gamma_j \\
& - 4(1-e)\frac{X_j}{\delta_j}\frac{\beta^2\theta_j}{\gamma_j} d\theta_j
\end{aligned}
$$

This can be expressed as:

$$
A_j^{-1} dX_j \; + \; b_j' e\, dY \; = \; d\chi \tag{B.4}
$$

where,

$$
A_j^{-1} = \frac{\Big[2(1-e)\Big[b_j' - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big] + \delta_j b_j' e\Big]}{\delta_j} \tag{B.5}
$$

and

$$d\chi = -dt_j + \frac{b_j' e}{L_j}\Big[2(1-e)\frac{X_j}{\delta_j} - e\big(X_j + Y\big)\Big] dL_j - 2(1-e)\frac{X_j}{\delta_j}\frac{\beta^2\theta_j^2}{\gamma_j^2}d\gamma_j - 4(1-e)\frac{X_j}{\delta_j}\frac{\beta^2\theta_j}{\gamma_j}d\theta_j \tag{B.6}$$

$d\chi$ is a composite term that captures the effect of exogeneous shocks to firm $j's$ reaction function.

Equation (B.4) represents a system of equations for $\bar{m}$ firms where any change in a firm's scale X_j also impacts the other firm's scale $X_{j\prime}$ through industrial output Y.

We now solve for $\bar{m}$ equations as follows:

Multiply Equation (B.4) by A_j, sum over $\bar{m}$ reaction functions, and collect dY terms on one side to get:

$$dY = \frac{\sum_{j\prime} A_{j\prime} d\chi_{j\prime}}{1 + e\sum_{j\prime} A_{j\prime} b_{j\prime}'} \tag{B.7}$$

Next, substitute this back into Equation (B.4) to get dX_j as follows:

$$\boxed{dX_j = \frac{A_j}{1 + e\sum_{j\prime} b_{j\prime}' A_{j\prime}}\Big[d\chi_j(1 + e\sum_{j\prime} b_{j\prime}' A_{j\prime}) - b_j' e \sum_{j\prime} A_{j\prime} d\chi_{j\prime}\Big]} \tag{B.8}$$

Hence, dX_j is derived purely in the form of a firm's own reaction function and the reaction functions of the other firms.

Therefore, the effect of a negative change in γ_j (R&D cost reduction), for $d\chi_{j\prime} = 0$, $j\prime \neq j$, is:

$$dX_j = A_j\Big[2(1-e)\frac{X_j}{\delta_j}\frac{\beta^2\theta_j^2}{\gamma_j^2}\Big]\frac{1 + e\sum_{j\prime \neq j} b_{j\prime}' A_{j\prime}}{1 + e\sum_{j\prime} b_{j\prime}' A_{j\prime}} d\gamma_j > 0 \tag{B.9}$$

From Equation (B.9), we can show that the impact on scale for a unit decrease in cost of R&D tax credit investments is higher for larger firms, i.e., firms with higher scale or average scale.

$$\frac{dX_j}{d\gamma_j} = \Bigg[A_j\Big[2(1-e)\frac{\beta^2\theta_j^2}{\gamma_j^2}\Big]\frac{1 + e\sum_{j\prime \neq j} b_{j\prime}' A_{j\prime}}{1 + e\sum_{j\prime} b_{j\prime}' A_{j\prime}}\Bigg]\frac{X_j}{\delta_j} \tag{B.10}$$

B.2 Impact of R&D Credits on Scope

The effect on product scope $d\delta_j$ can be derived using the dX_j equation and (B.3):

$$d\delta_j = \frac{2(1-e)\Big[b'_j - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big] dX_j + X_j\Big[-2(1-e)\frac{b'}{L_j}dL_j + 2(1-e)\frac{\beta^2\theta^2}{\gamma_j^2}d\gamma_j + 4(1-e)\frac{\beta^2\theta_j}{\gamma_j}d\theta_j\Big]}{\delta_j c'_j(\delta_j)}$$

Inducing a change in γ_j, and substituting the relevant expression for dX_j, we get:

$$\implies d\delta_j = \frac{2(1-e)\Big[b'_j - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big] A_j\Big[-2(1-e)\frac{X_j}{\delta_j}\frac{\beta^2\theta_j^2}{\gamma_j^2}\frac{1+e\sum_{j'\neq j} b'_{j'}A_{j'}}{1+e\sum_{j'} b'_{j'}A_{j'}}d\gamma_j\Big] + X_j\Big[2(1-e)\frac{\beta^2\theta^2}{\gamma_j^2}d\gamma_j\Big]}{\delta_j c'_j(\delta_j)}$$

Note that the big term multiplied with A_j is negative for a positive unit change in $d\gamma_j$, the result we had established was for a negative unit change in $d\gamma_j$. This is crucial to understand the results.

Taking the common terms outside, we get the expression in final form as:

$$d\delta_j = \frac{2(1-e)\frac{\beta^2\theta_j^2}{\gamma_j^2}X_j}{\delta_j c'_j(\delta_j)}\Big[1 - \frac{2(1-e)\Big[b'_j - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big]}{2(1-e)\Big[b'_j - (\frac{\beta^2\theta_j^2}{\gamma_j})\Big] + \delta_j e b'_j}\frac{1+e\sum_{j'\neq j} b'_{j'}A_{j'}}{1+e\sum_{j'} b'_{j'}A_{j'}}\Big]d\gamma_j \qquad \text{(B.11)}$$

Since both the big fractions in the parenthesis are less than 1, the entire term is a positive value for a positive unit change in $d\gamma_j$, i.e., an increase in R & D cost leads to an increase in product scope, therefore for our purposes, a decrease in the same (therefore η_j increases) leads to a reduction in product scope, δ_j.

Equation (B.12) can then be written as:

$$\frac{d\delta_j}{d\gamma_j} = \Bigg[\frac{2(1-e)\eta_j}{c'_j(\delta_j)\gamma_j}\Big[1 - \frac{2(1-e)(b'_j - \eta_j)}{2(1-e)(b'_j - \eta_j) + \delta_j e b'_j}\frac{1+e\sum_{j'\neq j} b'_{j'}A_{j'}}{1+e\sum_{j'} b'_{j'}A_{j'}}\Big]\Bigg]\frac{X_j}{\delta_j} \qquad \text{(B.12)}$$

B.3 Impact of R&D Credits on Quality

Our aim is to derive dZ_j as a function of both endogeneous and exogeneous shocks while taking into account oligopolistic interactions. We follow the same procedure as in the derivation of dX_j. Some intermediary algebraic steps will be omitted this time for brevity.

Given:

$$Z_j = \frac{\eta_j}{\beta(b'_j - \eta_j)} \int_0^{\delta_j} [c_j(\delta_j) - c_j(i)]di = \frac{\eta_j}{\beta(b'_j - \eta_j)} \left[\delta_j c_j(\delta_j) - \int_0^{\delta_j} c_j(i)di\right] \tag{B.13}$$

Where,

$$c_j(\delta_j) = a^0 - b'_j e(X_j + Y) - t_j$$

In order to totally differentiate Z_j, we express it as:

$$Z_j = N.\phi_j(\delta_j)$$

$$\implies dZ_j = dN\phi_j + d\phi_j N$$

Where ϕ_j is the cost integral, and N is the fractional term outside.

We now compute each differential in turn:

Differentiate the Cost Integral $\phi_j(\delta_j) = \int_0^{\delta_j} [c_j(\delta_j) - c_j(i)]\, di$.

$$d\phi_j \;=\; \delta_j\, c'_j(\delta_j)\, d\delta_j \;-\; \int_0^{\delta_j} dc_j(i)\, di.$$

(*None of the shocks effect the entire cost schedule but rather only the marginal variety cost, and hence the second term drops out*)

Differentiate the fractional term

$$\frac{\eta_j}{\beta(b'_j - \eta_j)} = \frac{\beta\theta_j^2 L_j}{[b\gamma_j - \beta^2\theta_j^2 L_j]}$$

The total differentiation term, dN, will be a function of three terms:- γ_j, L_j and θ_j, specifically as:

$$dN = \frac{\partial N}{\partial \gamma_j} d\gamma_j + \frac{\partial N}{\partial L_j} dL_j + \frac{\partial N}{\partial \theta_j} d\theta_j$$

Which after the appropriate differentiation becomes:

$$dN = \frac{\beta\theta_j}{[b\gamma_j - \beta^2\theta_j^2 L_j]^2} \Big[-\theta_j b L_j d\gamma_j + \theta_j b\gamma_j dL_j + 2L_j b\gamma_j d\theta_j\Big]$$

Substitute into

$$dZ_j = dN\phi_j + d\phi_j N$$

$$\implies dZ_j = \frac{\beta\theta_j}{[b\gamma_j - \beta^2\theta_j^2 L_j]^2} \Big[-\theta_j b L_j d\gamma_j + \theta_j b\gamma_j dL_j + 2L_j b\gamma_j d\theta_j\Big]\phi_j + \frac{\beta\theta_j^2 L_j}{[b\gamma_j - \beta^2\theta_j^2 L_j]} [\delta_j\, c_j'(\delta_j)\, d\delta_j]$$

After substituting for $\phi_j = \frac{Z_j}{N}$ and $c'(\delta_j)d\delta_j$, and further simplifying, we get:

$$\boxed{dZ_j = \frac{Z_j[-\theta_j b L_j d\gamma_j + \theta_j b\gamma_j dL_j + 2L_j b\gamma_j d\theta_j] + \beta\theta_j^3 L_j^2 \delta_j [-dt_j - b_j' e dX_j - b_j' e dY - \frac{b_j'}{L_j} e(X_j + Y) dL_j]}{\theta_j L_j [b\gamma_j - \beta^2\theta_j^2 L_j]}} \tag{B.14}$$

Now we take dZ_j and dY terms on one side, and finally express it in the form:

$$A_j^{-1} dZ_j \ + \ b_j' e\, dY \ = \ d\chi \tag{B.15}$$

Where:

$$A_j^{-1} = \frac{[b\gamma_j - \beta^2\theta_j^2 L_j]}{\beta\theta_j^2 L_j \delta_j} \tag{B.16}$$

and

$$d\chi = -dt_j - b_j' e dX_j - b_j' e dY - \frac{b_j'}{L_j} e(X_j + Y) dL_j + \frac{Z_j[-\theta_j b L_j d\gamma_j + \theta_j b\gamma_j dL_j + 2L_j b\gamma_j d\theta_j]}{\beta\theta_j^3 L_j^2 \delta_j} \tag{B.17}$$

$d\chi$ is a composite term that captures the effect of exogeneous shocks to firm $j's$ reaction function. We now solve for $\bar{m}$ equations in a similar fashion as for dX_j and get in the final form:

$$\boxed{dZ_j = \frac{A_j}{1 + e\sum_{j\prime} b'_{j\prime} A_{j\prime}} \Big[d\chi_j (1 + e \sum_{j\prime} b'_{j\prime} A_{j\prime}) - b'_j e \sum_{j\prime} A_{j\prime} d\chi_{j\prime} \Big]} \tag{B.18}$$

Hence, dZ_j is derived purely in the form of a firm's own reaction function and the reaction functions of the other firms.

Therefore, the effect of a negative change in γ_j (R&D cost reduction), for $d\chi_{j\prime}$ = 0, $j\prime \neq j$, is:

$$dZ_j = A_j \frac{1 + e\sum_{j\prime \neq j} b'_{j\prime} A_{j\prime}}{1 + e\sum_{j\prime} b'_{j\prime} A_{j\prime}} \Big[\frac{Z_j}{\delta_j} \frac{b}{\beta \theta_j^2 L_j} \Big] d\gamma_j > 0 \tag{B.19}$$

C Graphs

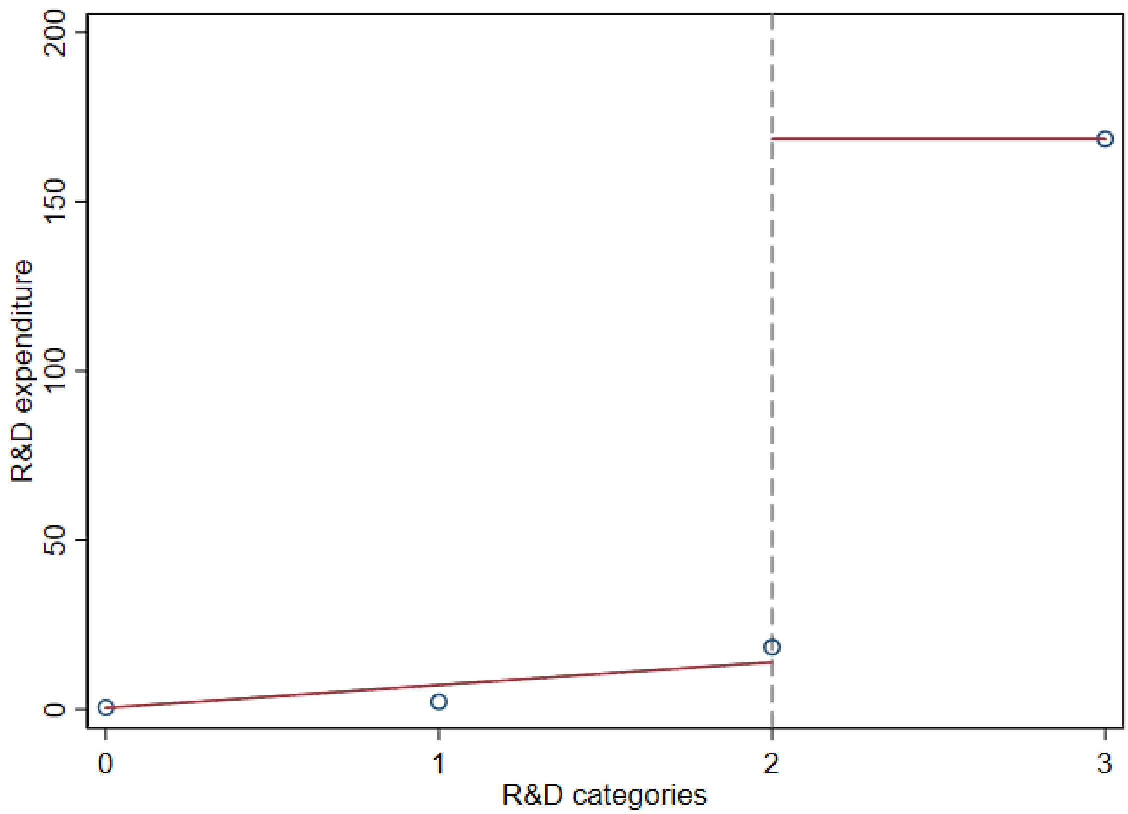


Figure C.1: R&D Expenses of Different R&D Categories

Notes: Figure presents the RDD (Regression Discontinuity Design) estimate of R&D Expenses for 4 different categories of firms: (a) 0 – firms with no in-house R&D unit; (b) 1 – firms with in-house R&D unit of $<$ 10 million INR R&D expenses; (c) 2 – firms with in-house R&D unit of 10–50 million INR of R&D expenses; and (d) 3 – firms with in-house R&D unit of $>$ 50 million INR of R&D expenses. Our coefficient estimates are controlled for firm fixed effects.

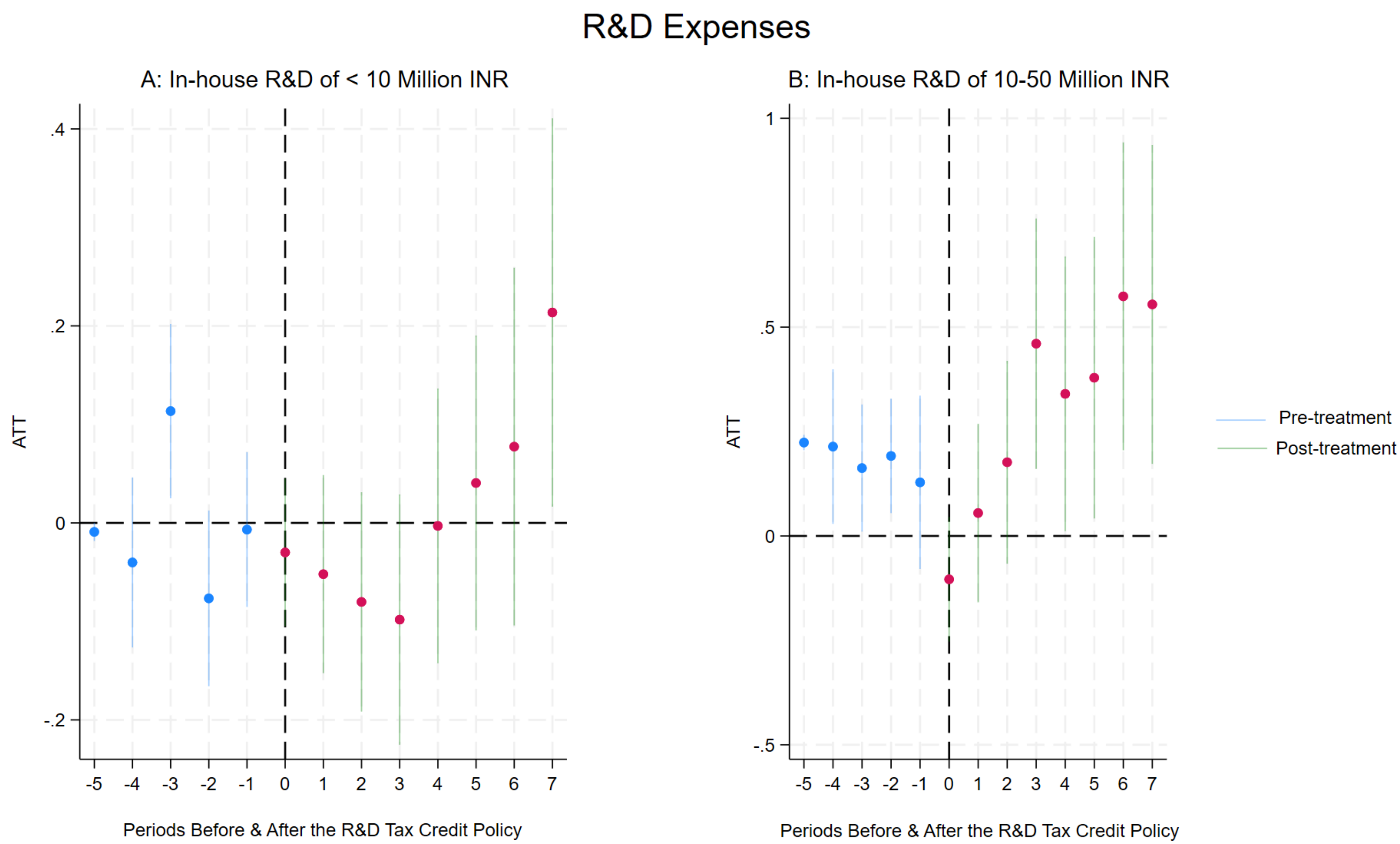
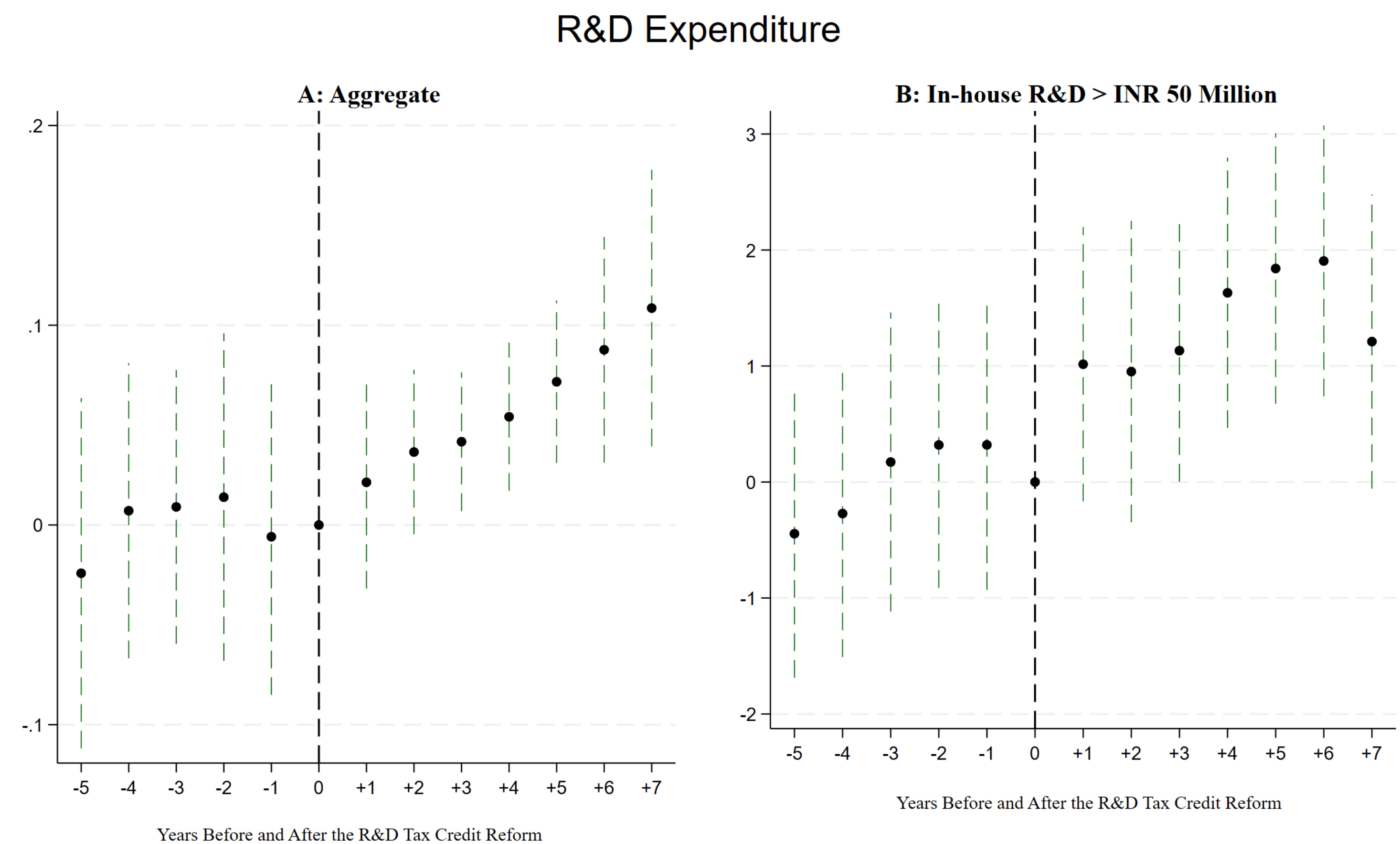


Figure C.2: Effect of R&D Tax Credit on R&D Expenditure – Other Firms

Notes: Figure presents the Callaway & Sant'Anna (2021) coefficient estimates (and their 95% confidence intervals) of differences in the R&D expenses for firms with in-house R&D units and expenses of less than INR 10 Million (Panel A) in treated and control group of industries and for firms with in-house R&D units and expenses between INR 10–50 Million (Panel B) in treated and control group of industries. The treated group of industries are classified as industries for which the R&D tax credit reform was undertaken by the Govt. of India. The treated group of industries are: (1) chemicals, (2) pharmaceuticals, (3) electronic equipments, (4) computers, (5) telecommunications equipments, (6) manufacture of aircraft and helicopters, and (7) automobiles and auto parts. Our coefficient estimates are controlled for firm fixed effects, year fixed effects, and industry-year trends. Standard errors clustered at the industry (4-digit) level.



Notes. OLS coefficient estimates (and their 95% confidence intervals) are reported.

Figure C.3: Effect of R&D Tax Credit on R&D Expenditure – OLS

Notes: Figure presents the OLS coefficient estimates (and their 95% confidence intervals) of differences in the R&D expenses for firms in treated and control group of industries at the aggregate (Panel A) and for firms with in-house R&D expenses for more than INR 50 Million (Panel B) in treated and control group of industries. The treated group of industries are classified as industries for which the R&D tax credit reform was undertaken by the Govt. of India. The treated group of industries are: (1) drugs and pharmaceuticals, (2) electronic equipment, (3) computers, (4) telecommunications equipment, (5) chemicals, (6) manufacture of aircraft and helicopters, and (7) automobiles and auto parts. Our coefficient estimates are controlled for firm fixed effects, year fixed effects, and industry-year trends. Regressions Standard errors clustered at the industry (4-digit) level.

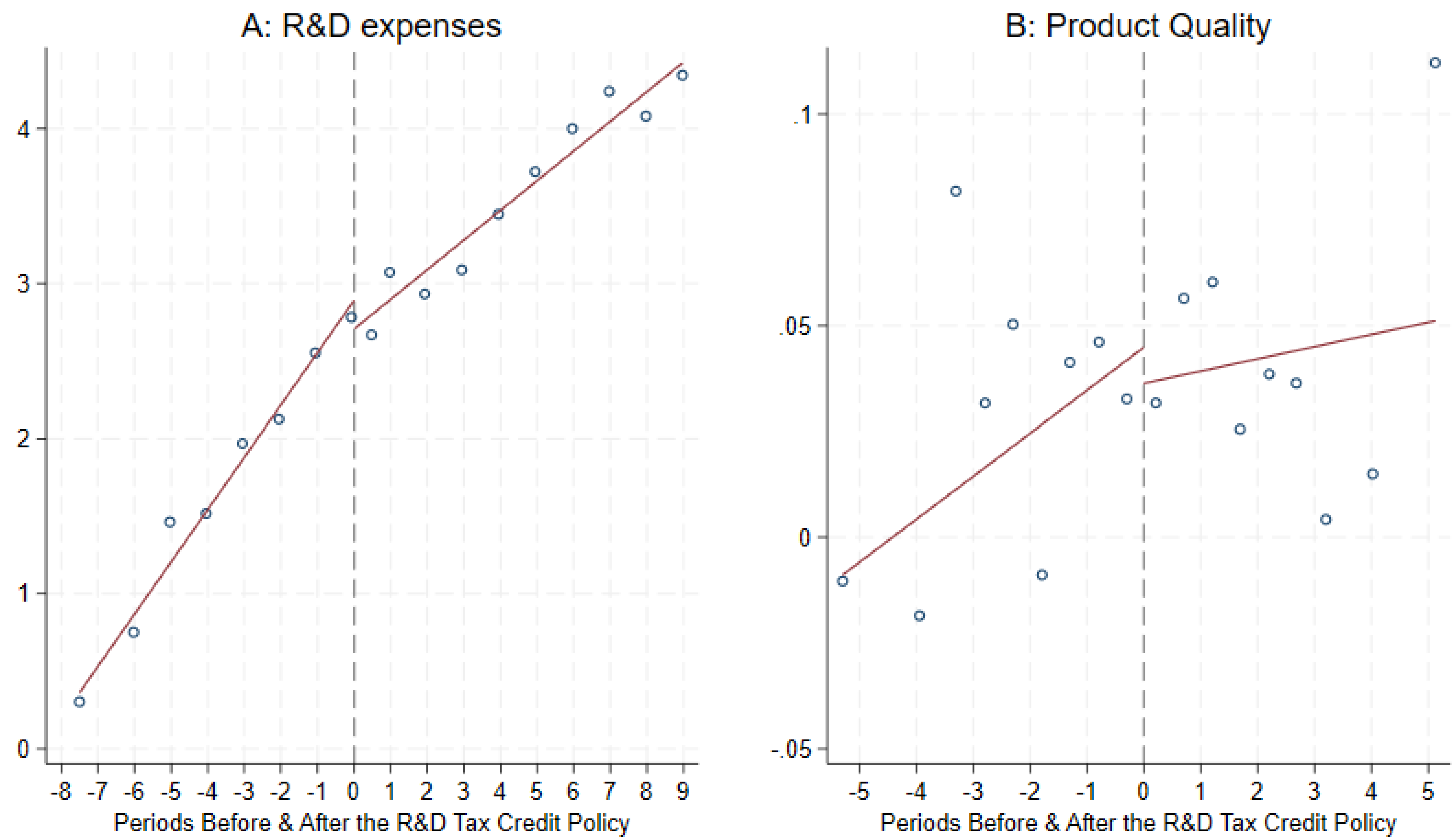


Figure C.4: Effect of the R&D Tax Credit Policy on R&D Expenditure and Product Quality for Firms with > 50 Million INR of R&D Expenses – Bin Scatter Plots

Notes: Figure presents the binned scatter plots for R&D Expenses (Panel A) Product Quality (Panel B) only for firms with more than INR 50 Million of in-house R&D expenses. The sample consists of the following industries for which the R&D tax credit reform was undertaken by the Govt. of India: (1) drugs and pharmaceuticals, (2) electronic equipment, (3) computers, (4) telecommunications equipment, (5) chemicals, (6) manufacture of aircraft and helicopters, and (7) automobiles and auto parts. Firm fixed effects are included.

D Tables

Table D.1: R&D Tax Credit and Technology Adoption Expenditure – Industry & Firm Heterogeneity (Contd.)

	R&D Expenditure			
	Industry Characteristic		Firm Characteristic	
	End-user Category		Ownership	
	Intermediates	Final	Domestic	Foreign
	(1)	(2)	(3)	(4)
$Treated_{jt}$	–0.015	–0.091**	–0.015	–0.064
	(0.021)	(0.043)	(0.025)	(0.092)
$Treated_{jt} \times R\&D\ Unit_{i,<10\ Million}$	0.118***	0.230*	0.138***	–0.191
	(0.030)	(0.128)	(0.035)	(0.187)
$Treated_{jt} \times R\&D\ Unit_{i,10-50\ Million}$	0.905***	0.613***	0.934***	0.619**
	(0.090)	(0.088)	(0.087)	(0.236)
$Treated_{jt} \times R\&D\ Unit_{i,>50\ Million}$	1.963***	1.943***	2.279***	0.832
	(0.229)	(0.516)	(0.153)	(0.662)
N	71,554	61,626	126,653	6,526
R-square	0.67	0.62	0.64	0.70
Firm Controls	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Industry FE (4-digit) × Year Trend	✓	✓	✓	✓

Notes: All the regressions are for the years 1992–2007. Columns (1) – (4) use research and development expenses (current plus capital) by a firm as the dependent variable, respectively. $Treated_{jt}$ takes a value 1 for all years since the Govt. of India announced the tax rebate for certain industries (at 4-digit level) and 0 otherwise. For example, it takes a value 1 for firms belonging to chemical, pharmaceuticals, electrical equipments, computers, telecommunication equipment industries after the year 1997. For aircraft, it takes value 1 after 2001 and for automobile parts after 2003. $R\&D\ Unit_{i,<10\ Million}$, $R\&D\ Unit_{i,10-50\ Million}$, and $R\&D\ Unit_{i,>50\ Million}$ takes value 1 for firms whose registered in-house R&D unit with DSIR (Department of Scientific and Industrial Research) has expenses less than 10 Million INR, between 10–50 Million INR, and greater than 50 Million INR, respectively. Firm controls include age of a firm, age squared, and real gross value-added of a firm. Standard errors are clustered at 4-digit industry level. Intercepts are not reported. *,**,*** denotes 10%, 5%, and 1% level of significance, respectively.

Table D.2: R&D Tax Credit and Firm Performance

	Panel A: Production Factors			
	Capital Employed	Skilled Labour Compensation	Raw Materials	Import of Production Units
	(1)	(2)	(3)	(4)
$Treated_{jt}$	–0.007	–0.018	–0.059	0.001
	(0.032)	(0.022)	(0.054)	(0.052)
$Treated_{jt} \times R\&D\ Unit_{i,<10\ Million}$	0.045	0.203***	0.204**	0.094
	(0.074)	(0.039)	(0.089)	(0.107)
$Treated_{jt} \times R\&D\ Unit_{i,10-50\ Million}$	0.143	0.316***	0.755***	0.479***
	(0.115)	(0.062)	(0.154)	(0.105)
$Treated_{jt} \times R\&D\ Unit_{i,>50\ Million}$	0.142**	1.181***	0.564**	0.721**
	(0.067)	(0.295)	(0.230)	(0.293)
R-Square	0.91	0.64	0.84	0.77
N	131,436	133,180	133,178	133,180
	Panel B: Outcomes			
	Promotional Expenses	Gross Value-added	Exports	Domestic Sales
	(6)	(7)	(8)	(9)
$Treated_{jt}$	–0.031	–0.234**	–0.031	–0.005
	(0.024)	(0.108)	(0.050)	(0.030)
$Treated_{jt} \times R\&D\ Unit_{i,<10\ Million}$	0.209***	–0.023	0.285***	–0.006
	(0.048)	(0.250)	(0.099)	(0.024)
$Treated_{jt} \times R\&D\ Unit_{i,10-50\ Million}$	0.582***	0.676***	0.758***	–0.086***
	(0.087)	(0.207)	(0.119)	(0.031)
$Treated_{jt} \times R\&D\ Unit_{i,>50\ Million}$	0.927***	1.382***	1.264***	–0.225*
	(0.113)	(0.497)	(0.273)	(0.122)
R-Square	0.81	0.63	0.75	0.97
N	133,180	133,180	133,180	132,423
Firm Controls	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Industry FE (4-digit) X Year Trend	✓	✓	✓	✓

Notes: All the regressions are for the years 1992–2007 and employ firm-year level data. Column (1) use capital employed; column (2) use skilled labour or managerial compensation; column (3) use raw materials expenditure; column (4) use import of production units (raw materials plus capital goods); column (5) use promotional expenses (advertising + marketing + distribution); column (6) use gross value-added (sales – raw materials); column (7) use exports; and column (8) use domestic sales of a firm as the dependent variable, respectively. $Treated_{jt}$ takes a value 1 for all years since the Govt. of India announced the tax rebate for certain industries (at 4-digit level) and 0 otherwise. For example, it takes a value 1 for firms belonging to chemical, pharmaceuticals, electrical equipments, computers, telecommunication equipment industries after the year 1997. For aircraft, it takes value 1 after 2001 and for automobile parts after 2003. $R\&D\ Unit_{i,<10\ Million}$, $R\&D\ Unit_{i,10-50\ Million}$, and $R\&D\ Unit_{i,>50\ Million}$ takes value 1 for firms whose registered in-house R&D unit with DSIR (Department of Scientific and Industrial Research) has expenses less than 10 Million INR, between 10–50 Million INR, and greater than 50 Million INR, respectively. Firm controls include age of a firm, age squared, and real gross value-added of a firm. Standard errors are clustered at 4-digit industry level. ***, **, * denotes statistical significance at 1%, 5%, and 10%.

E Proofs: Quantifying the Welfare Gains from the R&D Tax Rebate Policy

We consider a two-tier utility aggregator. At the upper tier, preferences are Cobb–Douglas across industries $k = 1, \ldots, K$ with weights $\alpha_k > 0$ satisfying $\sum_k \alpha_k = 1$:

$$U_t \;=\; \prod_{k=1}^{K} Q_{k,t}^{\alpha_k}. \tag{E.1}$$

Within each group k, preferences are CES across individual varieties $i \in \Omega_{k,r}$ (where $r = (t+1, t)$) with elasticity of substitution $\sigma_k > 1$ and quality $z_{ik,r}$:

$$Q_{k,r} \;=\; \left(\sum_{ik \in \Omega_{k,r}} z_{ik,r}^{1/\sigma_k} \, q_{ik,r}^{\frac{\sigma_k - 1}{\sigma_k}} \right)^{\frac{\sigma_k}{\sigma_k - 1}}. \tag{E.2}$$

The corresponding aggregate price index for industry k is:

$$P_{k,r} = \Big(\sum_{i \in \Omega_{k,r}} z_{ik,r} \, p_{ik,r}^{1-\sigma_k} \Big)^{\frac{1}{1-\sigma_k}}. \tag{E.3}$$

We now follow Sheu (2014) in defining the price index:

The price index is defined as a factor, τ_{t+1}, by which the prices of all goods in time period t would have to be multiplied in order to give the same utility as the set of goods available in $t+1$. This price factor compensates for changes in price, quality, and variety that occured between time periods t and $t+1$, allowing for the measurement of welfare changes over time.

The price index for our nested structure is:

$$\tau_{t+1} = \frac{P_{t+1}}{P_t} = \frac{\sum_{k \in K} \Big(\Big(\sum_{ik \in \Omega_{k,t+1}} z_{ik,t+1} \, p_{ik,t+1}^{1-\sigma_k} \Big)^{\frac{1}{1-\sigma_k}} \Big)^{\alpha_k}}{\sum_{k \in K} \Big(\Big(\sum_{ik \in \Omega_{k,t}} z_{ik,t} \, p_{ik,t}^{1-\sigma_k} \Big)^{\frac{1}{1-\sigma_k}} \Big)^{\alpha_k}} \tag{E.4}$$

In the CES unit-cost function, following Sato (1976) and Vartia (1976), the conventional price index (without quality and variety change) can be written as:

$$\frac{P_{t+1}^{CES}}{P_t} = \prod_{ik \in \Omega_k} \left(\frac{p_{ik,t+1}}{p_{ik,t}}\right)^{w_{ik,t+1}(\Omega_k)} \tag{E.5}$$

This is a geometric mean of the individual price changes, where the weights $w_{ik,t+1}(\Omega_k)$ are computed using the cost shares $s_{ik,t+1}(\Omega_k)$ in the two periods, as follows:

$$s_{ik,t+1}(\Omega_k) = \frac{p_{ik,t+1}\, q_{ik,t+1}}{\sum_{ik \in \Omega_k} p_{ik,t+1}\, q_{ik,t+1}} \tag{E.6}$$

And therefore,

$$w_{ik,t+1}(\Omega_k) = \frac{\left(\frac{s_{ik,t+1}(\Omega_k) - s_{ik,t}(\Omega_k)}{\ln s_{ik,t+1}(\Omega_k) - \ln s_{ik,t}(\Omega_k)}\right)}{\sum_{ik \in \Omega_k} \left(\frac{s_{ik,t+1}(\Omega_k) - s_{ik,t}(\Omega_k)}{\ln s_{ik,t+1}(\Omega_k) - \ln s_{ik,t}(\Omega_k)}\right)} \tag{E.7}$$

Where the numerator is the logarithmic mean of cost shares, and the weights are normalised and add up to unity.

Given this, we can decompose our aggregate price index (E.4) in terms of price, quality, and variety change respectively.

Hence, given $z_{ik,t+1} \neq z_{ik,t}$ and $\Omega_k \subseteq (\Omega_{k,t+1} \cap \Omega_{k,t})$, then the aggregate price index is:

$$\tau_{t+1} = \prod_{k=1}^{K} \Big[\prod_{ik \in \Omega_k} \left(\frac{p_{ik,t+1}}{p_{ik,t}}\right)^{w_{ik,t+1}(\Omega_k)} \cdot \prod_{ik \in \Omega_k} \left(\frac{z_{ik,t}}{z_{ik,t+1}}\right)^{\frac{w_{ik,t+1}(\Omega_k)}{\sigma_k - 1}} \cdot \left(\frac{\lambda_{t+1}^{\Omega_k}}{\lambda_t^{\Omega_k}}\right)^{\frac{1}{\sigma_k - 1}} \Big]^{\alpha_k} \tag{E.8}$$

Where,

$$\lambda_r^{\Omega_k} = \frac{\sum_{ik \in \Omega_k} p_{ik,r}\, q_{ik,r}}{\sum_{ik \in \Omega_{k,r}} p_{ik,r}\, q_{ik,r}} \quad r = (t+1, t) \tag{E.9}$$

The above price index is our two-tier price index where the lower CES tier is decomposed into price (p_{ik}), quality (z_{ik}), and variety change (λ_r) respectively, hence the aggregate price index is simply the cobb-douglas weighted geometric mean of the CES decomposed price index.

Proof:

In order to prove Equation (E.8), we need to only concentrate on the CES tier. We follow Feenstra (1994) for our price index decomposition.

Given (E.3) and (E.6), express the expenditure share on each variety as:

$$s_{ik,r}(\Omega_{k,r}) = \left(\left(\sum_{ik\in\Omega_{k,r}} z_{ik,r}\, p_{ik,r}^{1-\sigma_k}\right)^{\frac{1}{1-\sigma_k}}\right)^{\sigma_k-1} z_{ik,r}\, p_{ik,r}^{1-\sigma_k}$$

$$\implies s_{ik,r}(\Omega_{k,r})^{\frac{1}{\sigma_k-1}} = \left(\sum_{ik\in\Omega_{k,r}} z_{ik,r}\, p_{ik,r}^{1-\sigma_k}\right)^{\frac{1}{1-\sigma_k}} z_{ik,r}^{\frac{1}{\sigma_k-1}}\, p_{ik,r}^{-1}$$

Using the definition of (E.4), we write:

$$\implies \frac{\left(\sum_{ik\in\Omega_{k,t+1}} z_{ik,t+1}\, p_{ik,t+1}^{1-\sigma_k}\right)^{\frac{1}{1-\sigma_k}}}{\left(\sum_{ik\in\Omega_{k,t}} z_{ik,t}\, p_{ik,t}^{1-\sigma_k}\right)^{\frac{1}{1-\sigma_k}}} = \frac{s_{ik,t+1}(\Omega_{k,t+1})^{\frac{1}{\sigma_k-1}}\, p_{ik,t+1}\, z_{ik,t+1}^{\frac{-1}{\sigma_k-1}}}{s_{ik,t}(\Omega_{k,t})^{\frac{1}{\sigma_k-1}}\, p_{ik,t}\, z_{ik,t}^{\frac{-1}{\sigma_k-1}}} \tag{E.10}$$

The expenditure share on each variety at time r can be written as the product of expenditure share on each variety in the set of overlapping goods, Ω_k (E.6), and the variety change term, $\lambda_r^{\Omega_k}$ (E.9) as follows:

$$s_{ik,r}(\Omega_{k,r}) = \frac{p_{ik,r}\, q_{ik,r}}{\sum_{ik\in\Omega_{k,r}} p_{ik,r}\, q_{ik,r}} = \underbrace{\frac{p_{ik,r}\, q_{ik,r}}{\sum_{ik\in\Omega_k} p_{ik,r}\, q_{ik,r}}}_{s_{ik,r}(\Omega_k)} \cdot \underbrace{\frac{\sum_{ik\in\Omega_k} p_{ik,r}\, q_{ik,r}}{\sum_{ik\in\Omega_{k,r}} p_{ik,r}\, q_{ik,r}}}_{\lambda_r^{\Omega_k}} \tag{E.11}$$

We substitute this into (E.10) and get:

$$\implies \frac{s_{ik,t+1}(\Omega_k)^{\frac{1}{\sigma_k-1}}\, p_{ik,t+1}\, z_{ik,t+1}^{\frac{-1}{\sigma_k-1}}\, {\lambda_{t+1}^{\Omega_k}}^{\frac{1}{\sigma_k-1}}}{s_{ik,t}(\Omega_k)^{\frac{1}{\sigma_k-1}}\, p_{ik,t}\, z_{ik,t}^{\frac{-1}{\sigma_k-1}}\, {\lambda_t^{\Omega_k}}^{\frac{1}{\sigma_k-1}}}$$

Now, taking the geometric mean across varieties $ik \in \Omega_k$, and utilizing weights as in

(E.7), we get:

$$\implies \prod_{ik\in\Omega_k}\left(\frac{p_{ik,t+1}}{p_{ik,t}}\right)^{w_{ik,t+1}(\Omega_k)} \cdot \prod_{ik\in\Omega_k}\left(\frac{z_{ik,t}}{z_{ik,t+1}}\right)^{\frac{w_{ik,t+1}(\Omega_k)}{\sigma_k-1}} \cdot \prod_{ik\in\Omega_k}\left(\frac{s_{ik,t+1}(\Omega_k)}{s_{ik,t}(\Omega_k)}\right)^{\frac{w_{ik,t+1}(\Omega_k)}{\sigma_k-1}} \cdot \left(\frac{\lambda_{t+1}^{\Omega_k}}{\lambda_t^{\Omega_k}}\right)^{\frac{1}{\sigma_k-1}}$$

Taking the natural log of the geometric mean of cost shares, it boils down to 0 as the total expenditure on overlapping goods Ω_k in both time periods is the same, hence the geometric mean is unity. This implies:

$$\implies \frac{P_{t+1}^{CES}}{P_t} = \underbrace{\prod_{ik\in\Omega_k}\left(\frac{p_{ik,t+1}}{p_{ik,t}}\right)^{w_{ik,t+1}(\Omega_k)}}_{Price} \cdot \underbrace{\prod_{ik\in\Omega_k}\left(\frac{z_{ik,t}}{z_{ik,t+1}}\right)^{\frac{w_{ik,t+1}(\Omega_k)}{\sigma_k-1}}}_{quality} \cdot \underbrace{\left(\frac{\lambda_{t+1}^{\Omega_k}}{\lambda_t^{\Omega_k}}\right)^{\frac{1}{\sigma_k-1}}}_{variety} \tag{E.12}$$

This is the CES price index similar to (E.5) but takes into account quality and variety changes. Taking the cobb-douglas weighted geometric mean of this gives us our Aggregate Price Index, as in (E.8).