R&D, International Sourcing and the Joint Impact on Firm Performance*

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Published in American Economic Review 105(12): 3704-3739

Abstract

This paper studies the impact of an R&D cost shock on R&D investments, imported inputs and their joint impact on firm performance. We introduce imported inputs into a model of R&D and endogenous productivity, and show that R&D and international sourcing are complementary activities. Exploiting the introduction of an R&D tax credit in Norway in 2002, we find that cheaper R&D stimulated not only R&D investments but also imports of intermediates, quantitatively consistent with the model. An implication of our work is that improved access to imported inputs promotes R&D investments and, ultimately, technological change.

JEL: F10, F12, F14, O30, O33.

Keywords: Imports, innovation, intermediate inputs, productivity, R&D, heterogeneous firms.

*We thank seminar participants at Johns Hopkins SAIS, Norwegian School of Economics and Business Administration, the Norwegian School of Management, Norwegian Institute of International Affairs, Penn State, Stanford, participants at the Conference on Offshoring and International Production, Tübingen, June 2013, the NBER summer institute 2012, ETSG 2012 and NOITS 2012, as well as Teresa Fort, Beata Javorcik, Rob Johnson, Nina Pavcnik and Daniel Xu for helpful comments and valuable discussion. This paper is part of the research activities at the Centre for the Study of Equality, Social Organization, and Performance (ESOP) at the Department of Economics at the University of Oslo. ESOP is supported by the Research Council of Norway. Data received from Statistics Norway has been essential for the project and for the paper.

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1 Introduction

Understanding the role of international trade in explaining aggregate productivity remains a key question in economics. Recent empirical research has documented a strong positive impact of access to imported intermediates on firm performance. A different strand of the literature has highlighted how productivity evolves endogenously and responds to firms' investment in research and development (R&D). In this paper, we argue that the incentive to invest in R&D responds to firms' access to imported inputs and vice versa, and that both new knowledge and imported inputs give rise to cost reductions at the micro and macro level.

We propose a quantitative model with heterogeneous firms to analyze the relationship between investment in knowledge (R&D) and imports of intermediate goods. R&D and imports of intermediates are both subject to fixed costs.[1] In equilibrium, firm-level R&D investments and imports are complementary activities. Complementarity arises as R&D on average increases future profits and revenue, thereby making it more profitable to cut costs by sourcing inputs internationally, while enhanced international sourcing in turn makes R&D investments more profitable.

We emphasize two main implications of the model. First, our model delivers a novel channel by which trade affects R&D investment and firm performance. Input trade liberalization stimulates both imports and innovation, bringing about cost reductions both at the firm and at the aggregate level. In the model, declining input trade barriers lower marginal production costs and raise profits. The benign effect of declining input barriers on the expected future value of the firm is greater for firms investing in R&D relative to those who do not. This is due to the fact that the former group of firms face a greater increase in marginal profits as a result of a decline in trade barriers. As a consequence, trade liberalization will induce more firms to invest in R&D.Our work thus offers a new mechanism through which imports foster R&D and ultimately leads to productivity gains, which may help explain why a number of studies find large firm-level productivity gains associated with input trade liberalization, e.g. Amiti and Konings (2007), Goldberg et al. (2010) and Khandelwal and Topalova (2011). Second, and conversely, lower R&D costs raise the returns to both R&D and imports of inputs, thereby promoting not only technology upgrading but also international sourcing. R&D therefore lowers marginal costs directly and indirectly: The direct effect goes through improved productivity, while the indirect effect goes through cost savings on intermediate inputs realized through outsourcing.

[1]Halpern et al. (2011) and Gopinath and Neiman (2011) show that a model with fixed costs per imported product is consistent with observed trade flows in Hungary and Argentina, respectively. It is also consistent with the facts that we document in Section 2.2.

The model is motivated by a set of stylized facts for firm-level R&D and imports, as well as by reduced form evidence suggesting that lower R&D costs boost both investment in knowledge and imports. In the early 2000s, an R&D tax credit was introduced in Norway. We use a difference-in-differences methodology, exploiting the fact that the R&D tax credit lowered marginal R&D costs for only a subset of firms. The reduced form evidence shows that lower marginal R&D costs had a large impact on both investment in knowledge and imports of foreign varieties. We complement the reduced form evidence with a structural estimation of the returns to R&D and imports. To do so, we build a structural estimator in the spirit of Doraszelski and Jaumandreu (2013) and Aw et al. (2011), among others, and estimate the joint impact of R&D and imports on revenue and marginal costs. We explicitly control for the fact that input costs are heterogeneous across firms, as firms may reduce their costs by importing foreign varieties. A novel feature of our framework is that we can disentangle the direct effect of R&D on marginal cost and revenue from the indirect effect of R&D through its impact on equilibrium imports. Our structural estimates show that both investment in knowledge and foreign sourcing drive down marginal cost. A firm that performs R&D in every period has on average 26 percent higher revenue compared to a firm that never invests in R&D. If we rank firms according to their number of imported products, a firm in the third quartile in terms of internationally sourced products has roughly 20 percent higher sales than the median firm (Section 5).[2] This translates into substantial cost differences across firms. Furthermore, the total effect of R&D (direct and indirect) is substantially higher than the direct effect only (Section 6).

Finally, we compare the estimated impacts from the reduced form with the impacts from the estimated model. We do so by simulating the estimated model, asking how much international sourcing the model predicts in response to the actual surge in R&D investments that occurred in the aftermath of the Norwegian R&D policy reform. We then compare the import growth in the simulation with our reduced form estimates. This enables us to evaluate the importance of the theoretical mechanism proposed in this paper relative to competing hypotheses. We find that most of the import surge that occurred in the aftermath of the policy change can be attributed to the proposed theoretical mechanism. This suggests that cost complementarities between R&D and international sourcing are quantitatively important. We do not rule out that other mechanisms may also help explain the results from our natural experiment, but the structural results show that our proposed theoretical mechanism goes a long way in explaining the reduced form results. Moreover, one-fifth of revenue growth among R&D starters came from sourcing more foreign products, illustrating

[2] A product refers to a unique 4-digit HS code. Among the firms in our sample, the median (3rd quartile) number of imported products was 26 (51) in 2005.

how trade amplifies cost reductions from R&D.

The paper makes three main contributions. First, we develop a new model that highlights the complementarity between R&D investment and other cost-saving activities such as imports of intermediates, and identify a new source of gains from trade. R&D policy has an impact not only on innovation, but also on imports, while trade policy affects marginal costs both through changes in import prices and through changes in the incentive to innovate. Hence, our work proposes a specific mechanism for why trade in intermediates affects R&D and productivity. Second, based on a reduced form and a structural estimator, using novel firm-level data on R&D and imports, we quantify the interdependence between R&D investments and importing and their joint impact on revenue and costs. One of the main advantages of our approach is that we are able to compare estimates from both structural and reduced form frameworks. This gives us confidence in our proposed mechanism and in the external validity of our results. The combined theoretical and empirical results show that trade and R&D interact, and that our work is relevant for the literatures that consider trade or R&D in isolation. More generally, our work can inform government policy by showing both the direct and indirect effects of a specific program.

Our analysis brings together three strands of the literature. First, our work relates to the literature on R&D and firm performance. Doraszelski and Jaumandreu (2013) build and estimate an empirical model of endogenous productivity to examine the impact of investment in knowledge on the productivity of firms, extending the knowledge capital model pioneered by Griliches (1979). Aw et al. (2011) estimate the returns to R&D and exporting for the Taiwanese electronics industry. Both of these papers assume that input costs are homogeneous across firms, ruling out the possibility of further cost reductions through sourcing decisions.

Second, our work relates to the literature on foreign sourcing and productivity. The importance of intermediate inputs for productivity growth has been emphasized in several theoretical papers, e.g. Ethier (1979, 1982), Romer (1987, 1990) and Markusen (1989). Halpern et al. (2011) estimate a model of importers using Hungarian micro data and find that importing more varieties leads to large measured productivity effects. Recent work by Gopinath and Neiman (2011) also find large negative measured productivity effects from a collapse in imports following the Argentine crisis of 2001-2002. The empirical studies of Amiti and Konings (2007), Goldberg et al. (2010) and Khandelwal and Topalova (2011) all find that declines in input tariffs are associated with sizable measured productivity gains. Compared to our work, these papers do not consider the role of investment in knowledge. As a consequence they are unable to disentangle the effects of imports relative to R&D investments on measured productivity.[3] Third, our work relates to the literature on com-

[3]Goldberg et al. (2010) find that lower input tariffs are associated with increased R&D expenditures,

plementarities between exports and technology adoption. Empirical work by Bustos (2011) and Lileeva and Trefler (2010) show that trade integration can induce exporters to upgrade technology. While these papers focus on demand-side complementarities, our work emphasizes supply-side complementarities. Bloom et al. (2011) focus on the effect of imports from developing countries on technology upgrading and productivity in OECD countries. While we investigate the role of intermediate imports, they examine the impact of import competition. Theoretical work by Atkeson and Burstein (2011) and Costantini and Melitz (2007) also emphasize the impact of market size on innovation, and highlight the general equilibrium and dynamic effects of trade shocks on innovation. But the connection between imports and innovation has received scant attention in the literature. Three exceptions are Glass and Saggi (2001), Goel (2012) and Rodriguez-Clare (2010). While these papers are primarily concerned with the wage effects of offshoring, our paper focuses on complementarity and the returns to imports and innovation.

The remainder of this paper is organized as follows. Section 2 documents a set of stylized facts about R&D and imports, while Section 3 presents reduced form evidence. Section 4 develops the model, and in Section 5 we structurally estimate the model. In Section 6 we present a simulation exercise, allowing us to quantify the effect and relative importance of the proposed theoretical mechanism, while Section 7 concludes.

2 Data and Empirical Regularities

2.1 Data

Our data is a biennial panel of Norwegian manufacturing firms for the period 1997 to 2005. The data is gathered from three different sources. First, balance sheet data is from Statistics Norway's Capital database, which is an annual unbalanced panel of all non-oil manufacturing joint-stock firms. It includes approximately $8,000$ firms per year, including around 90 percent of all manufacturing firms.[4] The panel provides information about revenues, costs of intermediates, value added, employment and capital stock. Second, information about firm-level imports is assembled from customs declarations. This data makes up an unbalanced panel of each firm's annual import value for each HS 4-digit product. Third, this panel is matched with Statistics Norway's R&D survey. The survey provides biennial information on firm-level R&D investment and R&D personnel for a subset of the firms in the manufacturing

which is consistent with our framework. But the authors do not disentangle the direct impact of tariffs on productivity from the indirect impact of tariffs on R&D and productivity.

[4]Statistics Norway's capital database is described in Raknerud et al. (2004).

Table 1: R&D investment and import participation, 2003.

	R&D investment		
Importing	No	Yes	Total
No	5.4	1.2	6.6
Yes	37.0	56.4	93.4
Total	42.4	57.6	100

Notes: Percent of firms with positive R&D investment or/and imports in 2003.

sector.[5] Further details on the R&D survey are provided in the Appendix Section J.1. We merge all three sources based on a unique firm identifier. After dropping firms with either zero employment, missing capital stocks or missing value added, we get an unbalanced panel of roughly 850 firms per year. Our sample accounts for 63 percent of total revenue and 53 percent of total employment in non-oil manufacturing joint-stock firms.

2.2 Facts on R&D and Importing

We start by documenting four basic facts about R&D and imported inputs, which will guide our theory and econometric model.

Fact 1: Only a subset of firms invest in R&D. Among the firms that do, almost all firms import. This is illustrated in Table 1. More than 40 percent of the firms do not invest in R&D. Among those that do, as much as 98 percent source products from abroad. As for those that do not invest in R&D, 13 percent are non-importers.[6]

Fact 2: Firms investing in R&D are larger, source more foreign products, have a higher import share and labor productivity compared to non-R&D firms. Table 2 gives average numbers for R&D firms (firms with positive R&D investment) and non-R&D firms (firms with no R&D investment). R&D firms have more than 50 percent as many employees, import twice as many products, have a 60 percent higher import share and have a 13 percent labor productivity advantage compared to non R&D firms.

We also run a set of simple regressions with log firm characteristics as left-hand side variables, and a dummy indicating whether a firm has positive or zero R&D investment as the right-hand side variable, while controlling for industry effects (NACE 2-digit). The results in column (1) of Table 3 show that the correlation between positive R&D investment

[5] Firms with 50 or more employees are always sampled in the survey.

[6] The share of firms importing is large because the sample of firms is biased towards medium-sized and large firms, see Section 2.1. The share of importing firms across all firms (firms sampled in the R&D data and firms not sampled in the R&D data) was 64 percent in 2003.

Table 2: R&D vs. Non-R&D firms, 2003.

	R&D firms	Non-R&D firms
Employees	198	127
No. of imported products	45	22
Import share	.21	.13
Labor productivity	606	537
No. of obs.	480	349

Notes: Imported products refer to unique HS 4-digit products. R&D firms are firms with positive R&D investment. Import share is defined as firm import value relative to operating costs. Labor productivity is defined as real value added relative to employees in 1000 NOK. All numbers are simple averages across the two groups.

and employment, import participation, import share, number of imported products and labor productivity also holds within a given industry.

Fact 3: *Firms starting to invest in R&D ("R&D starters") grow faster, increase their import share and the number of imported varieties compared to all other firms.* We estimate a regression similar to the one above, but with firm and year fixed effects, utilizing the whole sample from 1997 to 2005. The interpretation of the R&D dummy coefficient is thus the log point change in the dependent variable when a firm switches from zero R&D to positive R&D. Column (2) of Table 3 illustrates that switching is associated with growth in firm size as well as a shift in firms' sourcing strategy, as firms start to import a larger number of products and increase the share of imports relative to total costs.

Fact 4: The extensive margin accounts for a substantial part of year-to-year changes in R&D investments. Figure 1 provides a decomposition of the biennial changes in total R&D expenditure. We distinguish between three groups and examine their contribution to R&D growth. The three groups are: Firms starting to do R&D (including new entrants), firms who stop doing R&D (including exiting firms) and continuing R&D performers. In all periods, the extensive margin (defined as the R&D starters and stoppers) accounts for around half of the total change in R&D investments.

3 Complementarity between R&D and Outsourcing: A Natural Experiment

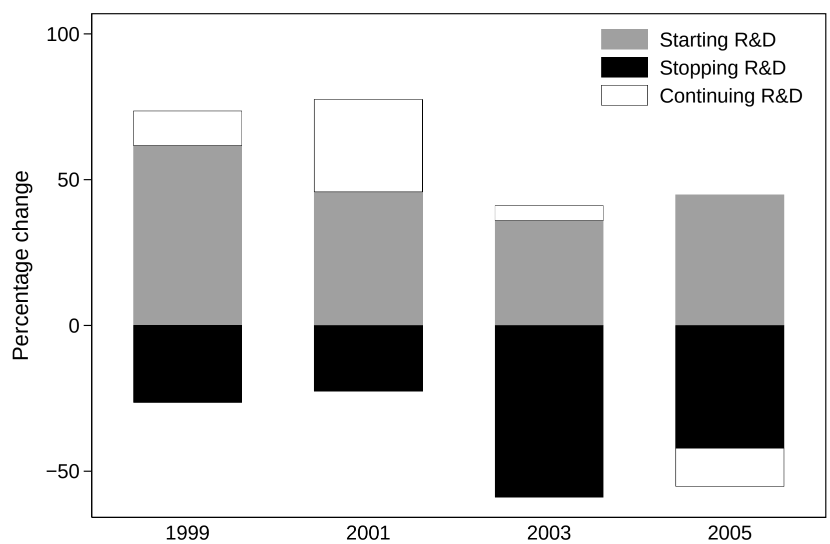
The stylized facts presented above point to a positive association between R&D and international outsourcing. In this section, we present reduced form evidence that lower R&D

Table 3: R&D premia.

Dependent variable:	(1)		(2)	
Employees	.55***	(.10)	.05**	(.02)
Import dummy	.06**	(.03)	-.01	(.01)
No. imported products	.61***	(.10)	.09***	(.03)
Import share	.58***	(.15)	.17**	(.07)
Labor productivity	.12***	(.03)	.03	(.02)
N	829		4,263	
Industry FE	Y		N	
Firm FE	N		Y	
Year FE	N		Y	

Notes: The independent variable is an R&D dummy = 1 if R&D investment is positive. Column (1) shows estimated R&D dummy coefficients from a regression with industry fixed effects using the 2003 cross-section. Standard errors clustered by 2-digit industry. Column (2) shows estimated R&D dummy coefficients from a regression with firm and year fixed effects, using all data from 1997 to 2005. Standard errors in parentheses clustered by firm. *** = p-val<.01, ** = p-val<.05, * = p-val<.1. All firm characteristics except import dummy are in logs. Imported products refer to unique HS 4-digit products. Import share is defined as firm import value relative to operating costs. N refers to the number of observations in the regression with employees as the dependent variable.

Figure 1: Decomposition of changes in R&D.



Notes: Changes in R&D investments between period $t-2$ and t. Years at the horizontal axis refer to year t.

costs lead to more R&D as well as more outsourcing. We do so by conducting a difference-in-difference analysis which exploits the introduction of an R&D credit in Norway in the early 2000s. The reduced form estimates are consistent with the model that is subsequently presented in Section 4. In the model, lower R&D costs encourages imports because R&D raises firm profits (either through demand or productivity) and imports are subject to fixed costs. We explore the mechanisms that may be driving the reduced form results in Section 3.4 as well as in Section 6.

3.1 Background

A major reform of Norway's innovation policy was undertaken in January 2002 as a tax credit for R&D expenditures, *Skattefunn*, was introduced. The reform followed a proposal by a government-appointed commission formulated in a green paper to the Ministry of Trade and Industry.[7] The commission had been appointed to suggest policy measures aimed at encouraging business sector R&D investments. The Norwegian Parliament had in 2000 agreed to make increased R&D investments a national priority, acknowledging that Norwegian R&D investments were significantly lower than those of countries regarded as natural peers. The political ambition was to reach the OECD average R&D level (relative to GDP) by 2005. There was a general sense that "something had to be done" in order to secure the development of a sustainable and knowledge-based industrial structure.

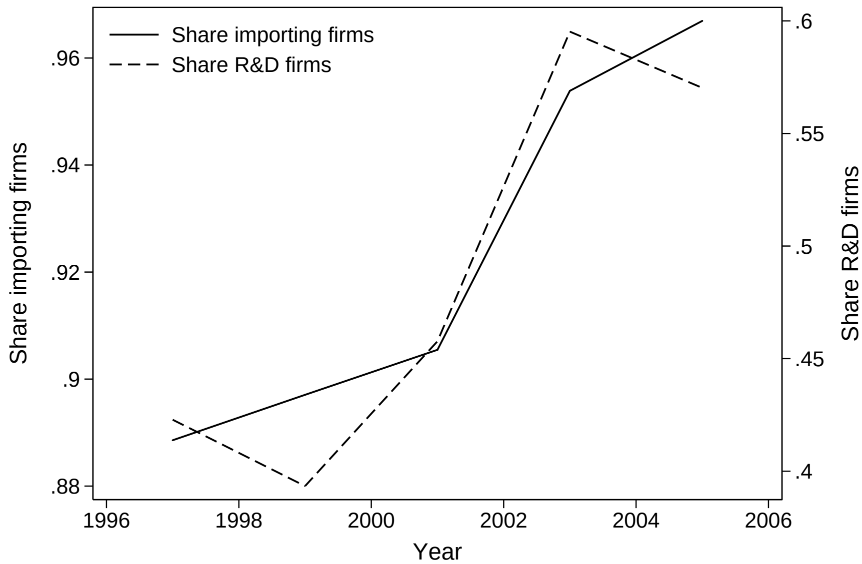
The tax credit offers several advantages for assessing the impact on trade and R&D. First, it was a relatively clean policy experiment, as the reform was not part of a greater overhaul of the tax system. Second, the reform itself was not initiated in response to major macroeconomic shocks to the economy, which is often the case. Third, the final details of the reform were announced only months prior to the introduction of the reform, which limited the scope for anticipation effects and strategic behavior.

The scheme is a "rights-based" R&D tax credit, which allows firms to deduct from taxes payable 20 percent of their R&D expenditures.[8] Firms are entitled to the tax credit only as long as the R&D project has been approved by the Research Council of Norway beforehand. In order to qualify for the scheme, a project must be limited and focused, and it must be aimed at generating new knowledge, information or experience that is presumed to be of use for the enterprise in developing new or improved products, services or manufacturing/processing methods. An evaluation of the policy reform in 2007 found that around 50

[7] http://www.regjeringen.no/en/dep/nhd/documents/Official-Norwegian-Reports/2000/nou-2000-7.html?id=376058

[8] Originally, only small and medium sized enterprises (SMEs) were eligible, but already in 2003 large enterprises (with more than 100 employees) were included as well. Large enterprises are treated slightly different from SMEs, as they receive a 18 percent reduction in taxes payable.

Figure 2: Share of R&D and importing firms.



Notes: A firm is defined as an R&D firm if R&D spending > 0.

percent of the projects which until then had been approved as eligible for the tax credit, had produced one or more product or process innovations, while around 12 percent had obtained one or more patents.[9]

The R&D tax credit is general and neutral across projects. All enterprises, irrespective of their tax liabilities, are eligible.[10] There are no additional constraints or incentives based on region or sector. However, the tax credit was capped at R&D expenditures exceeding NOK 4 million (USD 0.5 million), implying that the scheme lowered the marginal cost of R&D only among firms with less than NOK 4 million of R&D. In the next Section, we will exploit this feature of the scheme in order to estimate the impact of reduced marginal costs of R&D on R&D investments and imports. Note that except for purchases from a few pre-approved domestic R&D institutions, only intramural R&D investments are eligible for the tax credit, so that for instance the price of imported products or services is not affected by the reform.[11]

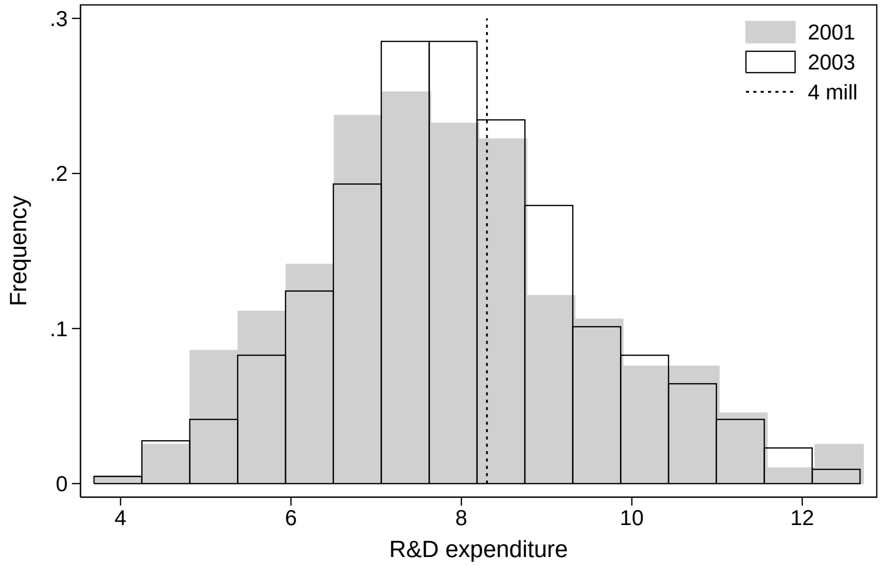
Figure 2 illustrates the substantial changes that occurred in the manufacturing sector during our sample period. The share of R&D firms increased from 42 to 57 percent from

[9] http://www.ssb.no/emner/10/02/rapp_200736.

[10] If the tax credit exceeds the tax payable by the firm, the difference is paid to the firm like a negative tax or a grant. If the firm is not in a tax position at all, the whole amount of the credit is paid to the firm as a grant.

[11] In 2003, 80 percent of total R&D investment was classified as in-house.

Figure 3: R&D expenditure pre- and post-reform.



Notes: R&D expenditure is measured in 1000 NOK, in logs.

1997 to 2005, while the share of importers (firms with positive imports) increased from 89 to 97 percent.[12] Most of the change in R&D investments and importing took place between 2001 (pre-reform) and 2003 (post-reform). At the same time, there was a surge in the average number of imported products, with an 18 percent increase over the period.[13] Almost all manufacturing industries experienced an increase in both import and R&D participation. In 21 out of 26 industries the share of importers rose, while in 25 industries the share of firms investing in R&D increased.[14] We summarize the most popular imported products in terms of count (i.e., the number of firms importing these products) and in terms of value in Table 14 in the Appendix.

Figure 3 shows the distribution of log R&D expenditure pre- and post-reform, with the filled bars representing the distribution of R&D in 2001, and the unfilled bars representing the distribution in 2003. The solid vertical line shows the NOK 4 mill threshold. The change in the distribution is also consistent with the policy change: There is a spike in the post-

[12]Importers are by construction sourcing their own inputs. These firms are incurring the cost of importing themselves, rather than buying the products through a domestic intermediary. This suggests that the imported inputs may be specialized to the firm's production process.

[13]We define a product as a unique HS 4-digit variety.

[14]NACE 2-digit industries. A list of the industries can be found here: `http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=NACE_1_1&StrLanguageCode=EN&IntPcKey=&StrLayoutCode=EN`.

reform distribution right below the threshold, while the distribution above the threshold shows smaller changes.

3.2 A Difference-in-Differences Model

As described above, the R&D policy change lowered the marginal cost of R&D by 20 percent for firms with less than NOK 4 million in R&D expenditures (USD 0.5 million), while the marginal cost of R&D remained unchanged for firms with more than NOK 4 million in R&D spending. We exploit this feature of the tax credit in a difference-in-differences (DID) framework. In a nutshell, we identify the impact of lower R&D costs on R&D activity and imports by using the fact that only firms ex-ante below the threshold were exposed to the policy change.[15] As argued in Section 3.1, the R&D tax credit is a clean natural experiment, since there were no other major changes to the tax code.

We proceed as follows. We split firms into two groups, a treatment group and a control group, according to their pre-reform R&D investment, and examine subsequent R&D and imports. Define $H_{1i} = 1$ if average pre-reform R&D in 1999 and 2001 was less than NOK 4 million. Let $H_{1i} = 0$ if pre-reform R&D in 1999 and 2001 was more than NOK 4 million. In 2001, 17 percent of the firms were classified in the control group. Additional descriptives about the treatment and control groups are presented in Table 13 in the Appendix.

Figure 4 plots average R&D expenditure for the two groups of firms. The trend in R&D investment is relatively similar across the two groups, with the exception of the shift occurring for the treatment group between 2001 and 2003. Figure 5 plots the average number of products imported for the same two groups. The pattern is roughly similar here, with a large increase in the number of products imported for the treatment group post-reform. Hence, simple descriptives suggest that those firms whose marginal costs of R&D were affected due to the introduction of the tax credit increased both R&D investment and their imports relative to the control group.

Consider the following difference-in-differences model:

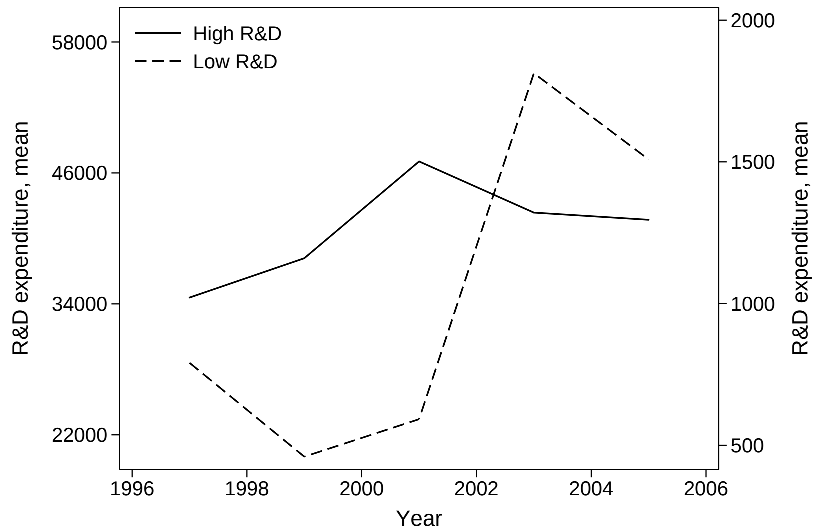
$$y_{it} = \alpha_i + \delta_t + \beta_t \left(H_{1i} \times \delta_t \right) + \gamma X_{it} + \epsilon_{it}, \tag{1}$$

where the outcome variable y_{it} is log R&D investment for firm i in year t.[16] α_i and δ_t are

[15] In the model presented in Section 4, R&D is a binary variable. In the binary case, firms with more than NOK 4 million of R&D are by construction not affected by the reform, as there is no possibility for these firms to increase their R&D any further. We discuss intermediate cases in Appendix Section G and show that only firms below the threshold are affected by the policy change in a model where firms face a menu of different R&D fixed costs.

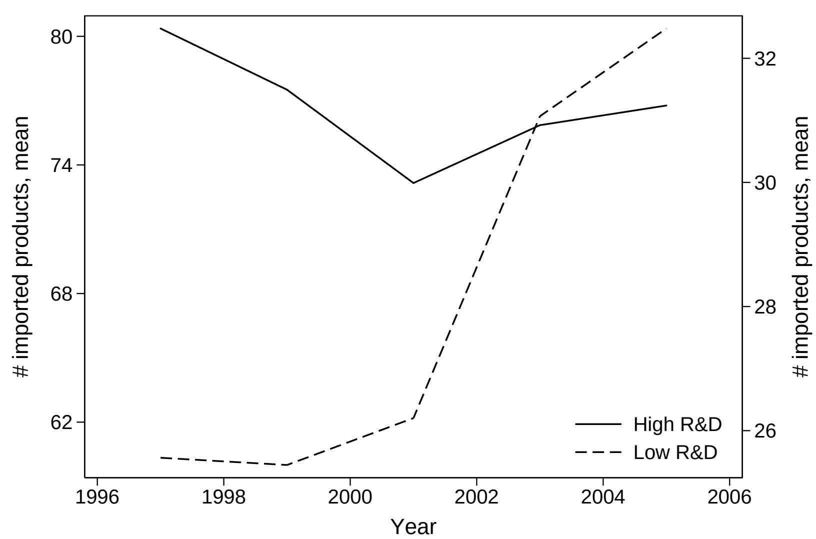
[16] Observations with zero R&D are lost due to the log transformation. The extensive margin of R&D (from zero to positive R&D) is not identified because the control group by construction has positive R&D

Figure 4: Average R&D investment. Index, 1997=1.



Notes: A firm is defined as High R&D if average R&D in 1999 and 2000 was above NOK 4 million. R&D expenditure is a simple average of R&D of the firms belonging to the group. Left axis: High R&D (1000s NOK), right axis: Low R&D (1000s NOK).

Figure 5: Average number of products imported.



Notes: A firm is defined as High R&D if average R&D in 1999 and 2000 was above NOK 4 million. Number of imported products is a simple average of the # of imported products of the firms belonging to the group. Left axis: High R&D, right axis: Low R&D.

firm and year fixed effects and X_{it} is a vector of controls: employment, capital stock, labor productivity (all in logs), and a firm exit and entry indicator.[17] Importantly, β_t is a vector of coefficients for the interaction between H_{1i} and δ_t. We expect that β_{1999} and β_{2001} are zero, while β_{2003} and β_{2005} are positive (1997 is the omitted year dummy). This would indicate that growth in R&D in the years prior to reform was similar for the treatment and control group, while growth was higher post-reform for the treatment group (all conditional on the vector of controls X_{it}). Intuitively, we are comparing the growth of R&D pre- to post-reform, for two firms that have the same level of employment and labor productivity, etc., but that differ according to their assignment to treatment and control group.

A potential concern is that β may be biased due to mean reversion. For example, a firm may be classified as $H_{1i} = 0$ in year t due to a positive idiosyncratic R&D shock. If the shock is transitory, we should expect lower R&D in $t + 1$. Hence, growth for $H_1 = 0$ firms may be lower than for $H_1 = 1$ firms even in the absence of the introduction of the R&D policy. In practice, however, mean reversion is most likely negligible in our particular case. First, R&D investment is highly autocorrelated. The correlation for R&D spending and R&D employment is 0.91 and 0.95, respectively, suggesting that idiosyncratic shocks are small. Second, as the definition of H_1 is based on R&D spending averaged over 1999-2001, transitory shocks should be averaged out. Third, as we will see in the results section, we perform a placebo test that does not produce mean reversion.

Nevertheless, we proceed by defining two alternative treatment groups, which will alleviate any remaining concerns. Our first approach is to estimate $r_{it} = \alpha_i + \delta_t + \epsilon_{it}$, where r_{it} is R&D expenditure and α_i and δ_t are firm and year fixed effects, and then define the treatment group based on predicted R&D in 2001, $\hat{r}_{i2001}$. Formally, we define $H_{2i} = I\left[\hat{r}_{i2001} < 4 \text{ mill}\right]$. Hence, transitory shocks are eliminated from the determination of H_{2i}.

Our second approach is to define the treatment group based on industry, rather than firm, characteristics. We proceed by calculating the share of firms within each NACE 5-digit sector with less than 4 million in R&D spending. We then define $H_{3i} = 1$ if this share is more than half on average in 1999-2001. The autocorrelation in the share variable is 0.75, showing that some industries are inherently big R&D spenders while others are not. Our treatment and control groups are therefore determined by arguably exogenous technological characteristics of the industry.

A further concern is that our DID estimator may pick up differential trends across treatment and control groups, even after controlling for firm size and the other variables in X_{it}.

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investments.

[17] $Entry_{it} = 1$ if the firm is present in t but not in $t-1$, and 0 otherwise. $Exit_{it} = 1$ if the firm is present in t but not in $t+1$, and 0 otherwise. Because we have balance sheet data for both 1996 and 2006, we can calculate these indicators for all the years with R&D data (1997, 1999, 2001, 2003 and 2005).

We therefore also estimate a model with firm-specific random trends, sometimes referred to as a correlated random trend model. Let

$$y_{it} = \alpha_i + \delta_t + g_i t + \beta \left(H_{i1} \times t \geq 2002\right) + \gamma X_{it} + \epsilon_{it}$$

where g_i is a firm-specific trend coefficient. Here, the treatment $(H_{1i} \times t \geq 2002)$ may be arbitrarily correlated with either α_i or the firm-specific trend g_i. Differencing this yields the model

$$\Delta y_{it} = \Delta\delta_t + g_i + \beta\Delta \left(H_{i1} \times t \geq 2002\right) + \gamma\Delta X_{it} + \Delta\epsilon_{it} \tag{2}$$

which we estimate by fixed effects.

Our hypothesis is that the reduction in R&D costs did not only affect R&D investment but also international outsourcing. Hence, we want explore the impact on the number of imported products of firms exposed to the reform relative to firms not exposed to the reform. To do so, we need to tweak our DID regressions to accommodate the fact that the number of imported products is a non-negative discrete variable. Specifically, we estimate a fixed effects Poisson pseudo-MLE model, following Wooldridge (2010).[18] The number of imported products, n_{it}, is assumed to be a realization from the Poisson distribution, $n_{it} \sim Possion\left(\mu_{it}\right)$, where the conditional expectation of μ_{it} is

$$E\left[n_{it}\right] = exp\left[\alpha_i + \delta_t + \eta \left(H_{1i} \times \delta_t\right) + \gamma X_{it}\right]. \tag{3}$$

Note that differencing n_{it} is not feasible in the Poisson framework (as Δn_{it} would then take negative values). We do, however, allow for group-specific trends by including the term $t \times H_{1i}$. The conditional expectation is then

$$E\left[n_{it}\right] = exp\left[\alpha_i + \delta_t + g\left(t \times H_{1i}\right) + \beta \left(H_{i1} \times t \geq 2002\right) + \gamma X_{it}\right]. \tag{4}$$

The Poisson model yields a straightforward interpretation of the coefficients in the model: $\exp\left(\beta\right)$ measures the percent change in number of imported products, n_{it}, due to the introduction of the R&D tax credit.

3.3 Results

Table 4 presents results with log R&D expenditure as the dependent variable. Estimates from equation (1) are reported in columns (1) - (3) and estimates from equation (2) are reported in columns (4) - (7). The empirical results on firms' R&D expenditure suggest

[18]See also Silva and Tenreyro (2006) for an application of the Poisson model for estimating gravity models.

that the R&D policy reform had a large and significant impact on R&D investment. In the specifications without firm-specific trends, the interaction between the year dummy and H_i is always close to zero prior to the reform and turns positive after the reform, showing that firm-level growth in R&D investment picked up after 2002, but only for the treatment group.

Since trends in R&D spending may be different across groups even in the absence of reform, we include firm-specific trends in columns (4) - (6), which are our preferred specifications. They show that the R&D policy raised R&D investment by 0.30 to 0.54 log points. Finally, column (7) presents results from a placebo test. Here, we instead compare outcomes for firms with ex ante R&D investment between NOK 4 and 8 million (placebo treatment) with firms with ex ante R&D spending of more than NOK 8 million (placebo control). Irrespective of outcome variable and specification, we always find a coefficient near zero. This suggests that our methodology delivers unbiased estimates, and in particular that mean reversion is not affecting our results. Moreover, in every specification, dropping the control variables X_{it} changes the estimates only slightly, underscoring the robustness of the results.

Table 5 presents results with the number of imported products as the dependent variable. Estimates from equation (3) are reported in columns (1) - (3) and estimates from equation (4) are reported in columns (4) - (7). Since n_{it} is a non-negative discrete variable, we exploit the full variation in the data by estimating the fixed effects Poisson pseudo-MLE model. Importantly, the Poisson model also utilizes the zeros of n_{it}, which are lost if using a log transformation. n_{it} is defined as the number of imported HS products at the 4-digit level. We also estimated the model after defining n_{it} as the number of 6- or 8-digit products. The results remain virtually unchanged compared to the baseline results reported here. Our preferred specifications with group-specific trends (columns (4) to (6)) suggest that the R&D policy reform generated an 8 to 14 percent increase in the number of imported products. Again, the falsification test presented in column (7) produces an insignificant estimate close to zero.[19]

In sum, by exploiting the natural experiment of the policy change, we find evidence of not only more R&D spending but also more sourcing of foreign inputs as a consequence of lower R&D costs.

[19]Column (7) presents results from the same type of placebo test as employed when analyzing R&D expenditure. Hence, we compare outcomes for firms with ex ante R&D investment between NOK 4 and 8 million (placebo treatment) with firms with ex ante R&D spending of more than NOK 8 million (placebo control).

Table 4: The R&D policy reform and R&D expenditure.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1999×H	-.08	-.13	.11				
	(.11)	(.11)	(.11)				
2001×H	-.06	-.06	.03				
	(.12)	(.12)	(.12)				
2003×H	.40***	.25*	.24*				
	(.14)	(.13)	(.14)				
2005×H	.24*	.09	.08				
	(.13)	(.13)	(.13)				
>2002×H				.54***	.35**	.29**	-.03
				(.14)	(.14)	(.15)	(.22)
Control group	H_1	H_2	H_3	H_1	H_2	H_3	H_1
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Threshold	4 mill	4 mill	4 mill	4 mill	4 mill	4 mill	8 mill
N	1635	1635	1625	963	963	963	386
Firms	597	597	596	414	414	414	140

Notes: Dependent variable R&D expenditure in logs. Standard errors in parentheses clustered by firm. *** = p-val<.01, ** = p-val<.05, * = p-val<.1. Control groups defined based on: H_1: actual R&D, H_2: predicted R&D, H_3: industry R&D (see Section 3.2). Firm controls: employment, capital stock, labor productivity (all in logs), a firm exit and a firm entry indicator.

Table 5: The R&D policy reform and Number of imported products (HS 4), Poisson MLE.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1999×H	.00	.01	-.01				
	(.03)	(.03)	(.03)				
2001×H	.06*	.11***	.04				
	(.03)	(.04)	(.04)				
2003×H	.17***	.22***	.15***				
	(.04)	(.05)	(.05)				
2005×H	.17***	.22***	.16***				
	(.04)	(.05)	(.05)				
>2002×H				.08**	.08*	.14***	.03
				(.04)	(.04)	(.04)	(.06)
Control group	H_1	H_2	H_3	H_1	H_2	H_3	H_1
Group trends	No	No	No	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Threshold	4 mill	4 mill	4 mill	4 mill	4 mill	4 mill	8 mill
N	3411	3411	3399	3411	3411	3399	566
Firms	859	859	858	859	859	858	147

Notes: Standard errors in parentheses clustered by firm. *** = p-val<.01, ** = p-val<.05, * = p-val<.1. Control groups and group trends defined based on: H_1: actual R&D, H_2: predicted R&D, H_3: industry R&D (see Section 3.2). Firm controls: employment, capital stock, labor productivity (all in logs), a firm exit and a firm entry indicator.

Table 6: R&D, Firm Scale and Number of Imported Products

	(1)	(2)	(3)
>2002×H	.10***	.08**	.05
	(.04)	(.04)	(.04)
Control group	H_1	H_1	H_1
Group trends	Yes	Yes	Yes
Firm controls	No	Yes	Yes
Log profits	No	No	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	3442	3411	2592
Firms	865	859	723

Notes: Standard errors in parentheses clustered by firm. *** = p-val<.01, ** = p-val<.05, * = p-val<.1. Estimation based on Poisson pseudo-MLE as in Table 5.

3.4 Robustness and Mechanisms

R&D, Firm Scale and Imports. The model presented in Section 4 suggests that controlling for time-varying firm characteristics in the DID model should reduce the magnitude of the coefficient of interest, β. The reason is that profits and firm size should rise in response to lower R&D costs. These variables will therefore be positively correlated with the number of imported inputs.[20] To investigate further the link between R&D, firm scale and import demand we estimate equation (4) sequentially adding firm-level control variables. In Column (1) of Table 6 we report estimates from equation (4) using no firm controls, in column (2) we introduce the same firm controls as in the baseline case reported in Table 5 which include employment, capital stock, labor productivity (all in logs), a firm exit and a firm entry indicator. Finally in column (3) we use the baseline firm controls and add firm profits (in logs). As we would expect, adding firm controls likely to be correlated with firm scale reduces both the sign and the significance of the treatment effect (β).

China competition. Recent research by Bloom et al. (2011) has shown that import competition from low-cost countries affects innovation rates in developed countries. From 2001 to 2005, the Chinese import share in Norway increased from 3.0 to 5.6 percent.[21] A potential concern is therefore that our results may confound the effect of the R&D policy with import

[20] We do not expect a perfect correlation because firm characteristics may be partly unobserved. Moreover, in the model the number of imported inputs is finite, so that large firms may increase productivity and sales without expanding the number of imported inputs.

[21] Imports from China relative to total imports, from www.ssb.no/muh.

Table 7: Robustness: China competition.

	log R&D	Number of imported products
>2002×H	.61***	.08**
	(.15)	(.04)
Control group	H_1	H_1
Group trends	No	Yes
Firm controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
N	806	2819
Firms	345	713

Notes: Standard errors in parentheses clustered by firm. *** = p-val<.01, ** = p-val<.05, * = p-val<.1. Column 2 is based on Poisson pseudo-MLE as in Table 5. Control group and group trends defined based on actual R&D (see Section 3.2).

competition effects. Our DID approach is, however, robust to any such concern if the effect of low-cost competition is uniform across our treatment and control group. Nevertheless, we investigate this issue by estimating the DID model only on industries that were relatively unaffected by the rise in low-cost imports. Specifically, we order NACE 2-digit industries according to percentage point increase in the Chinese import share from 2001 to 2005. We then estimate the model only on industries below the 75th percentile in terms of Chinese import share growth, and include firm fixed effects and trends as used in the baseline specifications.[22] Table 7 shows DID results with log R&D expenditure and the number of imported products as outcome variables. We find that coefficient estimates are very similar to the baseline estimates reported above. Hence, we conclude that low-cost import competition does not seem to bias our results.

Next, we explore whether the R&D cost shock shifted imports toward certain sourcing countries or product types, and whether it affected firm exports. In sum, we find that the R&D cost shock raised the number of imported products across all product types. We find no evidence that the R&D policy reform increased sourcing from low-wage countries, and no evidence that firm exports were affected, all consistent with the model in Section 4.

Imports from low-wage countries. We decompose imported products into the number of imported HS4 products from OECD countries n_{it}^{OECD} and non-OECD countries $n_{it}^{\sim OECD}$.

[22]The industries with Chinese import share growth above the 75th percentile are: NACE 17, 35, 19, 18, 32 and 30, with NACE 30 being the industry with the highest percentage point change in the import share. Details on matching of Chinese trade data to NACE sectors are presented in the Appendix.

Table 8: Robustness: Imported HS4 products and R&D intensity of imports.

	OECD	Non-OECD	Capital	Non-capital	R&D intensity of imports
>2002×H	.08**	.01	.09**	.07*	-.03
	(.04)	(.09)	(.02)	(.04)	(.05)
Control group	H_1	H_1	H_1	H_1	H_1
Group trends	Yes	Yes	Yes	Yes	No
Firm controls	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
N	3411	2686	3339	3369	2318
Firms	859	655	838	846	823

Notes: Standard errors in parentheses clustered by firm. *** = p-val<.01, ** = p-val<.05, * = p-val<.1. Columns 1-4: The dependent variable is the number of imported products. Estimation based on Poisson pseudo-MLE as in Table 5. Column 5: Dependent variable is the R&D intensity of imports. Estimation is based on OLS. Control group and group trends defined based on actual R&D (see Section 3.2).

In 2001, average n_{it}^{OECD} was almost 13 times higher than $n_{it}^{\sim OECD}$, primarily reflecting the importance of the EU as the main trading partner. We then estimate the same Poisson model as presented in Table 5, but with n_{it}^{OECD} and $n_{it}^{\sim OECD}$ as dependent variables. Columns (1) and (2) in Table 8 show the results for the interaction variable defined above, >2002×H (similar to column (4) in Table 5). We identify an increase in the number of imported OECD products and no impact on the number of non-OECD products. This suggests that the R&D policy did not induce substitution toward inputs from low-wage countries.

Imports of capital goods. We decompose imported products into the number of imported HS4 capital goods n_{it}^{cap} versus non-capital goods $n_{it}^{\sim cap}$. Capital goods are classified according to the BEC nomenclature.[23] In 2001, the average number of imported non-capital goods was roughly 50 percent higher than the number of imported capital goods. Columns (3) and (4) show the regression results, using the same methodology as columns (1) and (2). The results suggest that the reform in R&D policy affected imports of both capital and non-capital goods, and almost to the same extent.

R&D intensity of imports. We create a firm-level measure of R&D intensity embodied in imports. We hypothesize that the firm's R&D activities may be complementary with R&D that is embodied in its imports (see e.g. Coe and Helpman (1995)). We proceed by calculating industry-specific R&D intensities for the OECD countries, and then assigning

[23]BEC categories 4 and 6 are defined as capital goods. BEC codes are matched to HS 6-digit codes using the UN correspondence. Since the analysis is performed at the HS 4-digit level, we classify a given HS 4-digit code as capital if more than half of the 6-digit products (within a 4-digit product) are capital goods.

every imported HS product to an industry and consequently an R&D intensity. Firm-level R&D import intensity for firm i is then the weighted mean across firm i's imported products.[24] For our sample as a whole, the average import R&D intensity increased from 2.5 percent in 1997 to 3.2 percent in 2005. However, as shown in column 5, we do not find evidence that embodied R&D in imports was affected by the R&D policy change.

Number of exported products. We investigate whether the policy change had any impact on exports. This paper emphasizes supply-side complementarities, but the previous literature, e.g Bustos (2011), has emphasized the importance of demand-side complementarities (i.e. R&D and export opportunities). We therefore re-estimate the model with the number of exported products, or alternatively total export value or exports as a share of total revenue, as the dependent variables. Our results suggest that the policy change did not affect firms' exporting behavior, with estimated coefficients insignificant and close to zero.[25]

Finally, we explore whether firm profits also increased as a consequence of the policy reform. Table 9 reports results using as the dependent variable an indicator function for whether profits are positive or not. This is our preferred specification as profits are negative for 22 percent of the firm-years in our sample.[26] Across specifications in columns (1) to (3), we find a positive and mostly significant impact on profits. We also investigate whether the effect is heterogeneous across firms. Our hypothesis is that low productivity firms benefits more from the tax credit than high productivity firms, as high productivity firms may already invest in R&D. We isolate the impact on low productivity firms by excluding firms with labor productivity higher than the 2001 median value. This is denoted by "Low LP" in columns (4) to (6). In this case, the point estimates are markedly higher, consistent with the hypothesis.

4 A Model of R&D and International Sourcing

Motivated by the facts presented in Section 2 and the reduced form evidence on the complementarity between R&D and imports in Section 3, we build a model of R&D and international sourcing of intermediates. In our model, marginal costs fall or quality rises as a result of investment in R&D and the use of imported inputs, but due to the presence of fixed costs, only the largest and most productive firms are able to undertake both activities, which is consistent with facts 1 and 2. R&D investment raises the endogenous performance of the firm, thereby increasing firm size, the equilibrium import share and the number of imported

[24] More details on the procedure are presented in the Appendix.

[25] Detailed results available upon request.

[26] Profits are defined as operating income minus operating costs. The sample is therefore greatly reduced if using the log of profits as the dependent variable.

Table 9: Profits

>2002×H	.14*	.17**	.05	.29***	.32***	.08
	(.07)	(.09)	(.06))	(.09)	(.10)	(.08)
Control group	H_1	H_2	H_3	H_1	H_2	H_3
Group trends	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Sample	All	All	All	Low LP	Low LP	Low LP
N	3376	3376	3376	2115	2115	2115
Firms	844	844	844	553	553	553

Notes: Standard errors in parentheses clustered by firm. *** = p-val<.01, ** = p-val<.05, * = p-val<.1. The dependent variable is a dummy variable for positive/negative profits. Estimation based on Poisson pseudo-MLE as in Table 5. Control groups and group trends defined based on: H_1: actual R&D, H_2: predicted R&D, H_3: industry R&D (see Section 3.2).

products, which is in line with fact 3.

The R&D side of the model builds on Griliches (1979) knowledge capital model, as well as more recent work by Aw et al. (2011) and Doraszelski and Jaumandreu (2013). Firms may choose to invest in R&D, which on average lowers their marginal costs or raises their product quality, both of which have a benign impact on revenue and profits. The returns to R&D are subject to uncertainty, reflecting the fact that some R&D projects ultimately fail.

Firms may choose to source intermediate inputs from the domestic or foreign market, as in Goldberg et al. (2010) and Halpern et al. (2011). Imported inputs lower marginal costs through two channels emphasized in the theoretical as well as the empirical literature. First, their quality-adjusted price is potentially lower. Second, following product-variety models with intermediate inputs, a larger set of imported inputs means more specialized intermediates, which lower the effective input cost.

4.1 Production

The output of the firm i is given by

$$\ln y_{it} = \beta_l \ln l_{it} + \beta_k \ln k_{it} + \gamma \ln V_{it} + \tilde{\omega}_{it}, \tag{5}$$

where l_{it} is employment, k_{it} is capital stock and $\tilde{\omega}_{it}$ is a Hicks neutral productivity term. V_{it} is the quantity of an intermediate input bundle, defined as $V_{it} = \prod_{j=1}^{J} v_{ijt}^{\gamma_j/\gamma}$, where $j = 1, .., J$

denotes intermediate input j and $\gamma = \sum_{j=1}^{J} \gamma_j$. Labor and intermediates are flexible inputs, whereas capital is fixed in the short run, i.e. determined by investment and the capital stock in year $t-1$. As we describe below, intermediate input j may potentially have a domestic and an imported component that are combined according to a CES aggregator. Importantly, input prices and productivity are endogenous, as the firm may change the value of these variables by either importing or investing in R&D.

The product market is characterized by monopolistic competition, and the demand curve faced by firm i is of the standard Dixit-Stiglitz form. Hence demand is

$$y_{it} = \phi_{it} \Phi_t p_{it}^{-\eta}, \tag{6}$$

where p_{it} is firm i's price, ϕ_{it} is a firm-specific demand shifter, Φ_t is an industry-wide demand shifter, and $\eta > 1$ is the constant elasticity of demand. Given these assumptions, the firm charges a price that is a constant mark-up over marginal costs, $p_{it} = \left(\frac{\eta}{\eta-1}\right) c_{it}$, where c_{it} is marginal costs.

As shown in Appendix Section A, short-run marginal costs conditional on capital stock k_{it} are

$$\ln c_{it} = \frac{1}{\beta_l + \gamma} \left[\kappa_1 + (1 - \beta_l - \gamma) \ln y_{it} - \beta_k \ln k_{it} + \beta_l \ln w_t + \gamma \ln Q_{it} - \tilde{\omega}_{it}\right], \tag{7}$$

where w_t is the wage common to all firms, $Q_{it} = \prod_j^J \left(q_{ijt} / \left(\gamma_j / \gamma\right)\right)^{\gamma_j/\gamma}$ is the price index of the intermediate input bundle and κ_1 is a constant.[27] By using the expressions for the demand function and the optimal price p_{it} together with marginal costs, the revenue function can be formulated as (see Appendix Section B)

$$\ln r_{it} = \kappa_2 + \frac{1}{\zeta} \ln \Phi_t + \frac{\eta - 1}{\zeta} \left(\beta_k \ln k_{it} - \beta_l \ln w_t - \gamma \ln Q_{it}\right) + \omega_{it} + \epsilon_{it} \tag{8}$$

where $\omega_{it} \equiv (1/\zeta) \left[\ln \phi_{it} + (\eta - 1) \tilde{\omega}_{it}\right]$, $\zeta \equiv 1 + (1 - \beta_l - \gamma)(\eta - 1) > 1$, the error term ϵ_{it} is classical measurement error and κ_2 is a constant.[28]

The variable ω_{it}, from now on named *firm performance*, is an endogeneous state variable and captures two sources of heterogeneity that is unobserved to the econometrician: firm specific demand shocks (quality), ϕ_{it}, and firm specific productivity, $\tilde{\omega}_{it}$. R&D spending may raise productivity or product quality, both of which boost firm performance. We turn to the modeling of this relationship in Section 4.3, while we now turn to role of imported

[27] $\kappa_1 \equiv \ln\left(\beta_l^{-\beta_l} \gamma^{-\gamma}\right)$.

[28] $\kappa_2 \equiv \frac{1-\eta}{\zeta}\left[\kappa_1 + (\beta_l + \gamma) \ln\left(\frac{\eta}{\eta-1}\right)\right]$.

intermediates.

4.2 Intermediate Inputs

Firms' sourcing strategies may vary. Each of its J intermediate inputs are either sourced from the domestic market or assembled from a combination of a foreign and a domestic variety of the product. The quantity of an intermediate input j can be expressed as

$$v_{ijt} = \left[(b_j x_{ijtF})^{(\theta-1)/\theta} + x_{ijtH}^{(\theta-1)/\theta} \right]^{\theta/(\theta-1)} \tag{9}$$

where $x_{ijtF} \geq 0$ and $x_{ijtH} > 0$ are the quantities of foreign and domestic inputs, $\theta > 1$ is the elasticity of substitution, and b_j is a quality shifter for the foreign variety. If the firm only sources the input domestically then $v_{it} = x_{ijtH}$. The prices of domestic and foreign varieties are $\tilde{q}_{jtH}$ and $\tilde{q}_{jtF}$. We normalize domestic prices to one, $\tilde{q}_{jtH} = 1$, so that $\tilde{q}_{jtF}$ is the relative foreign price. The firm specific price index of the intermediate v_{ijt} is then

$$q_{ijt} = \begin{cases} 1 & \text{if } j \text{ is a pure domestic input} \\ \left[1 + (\tilde{q}_{jtF}/b_{jt})^{1-\theta} \right]^{1/(1-\theta)} < 1 & \text{if } j \text{ is a composite of domestic and foreign inputs} \end{cases} \tag{10}$$

Importing intermediates reduces unit costs for two reasons. First, the production technology implies that imports and domestic inputs are imperfect substitutes and that firms gain from variety. Second, the quality-adjusted price of imports $\tilde{q}_{jtF}/b_{jt}$ may be lower than the domestic price (but not necessarily). If a firm chooses to employ a composite good rather than to rely on domestic inputs only, it faces a cost reduction. Taking logs, the cost reduction of composite good j when imports are used is (in absolute value)

$$a_{jt} \equiv \frac{1}{\theta - 1} \ln \left[1 + (\tilde{q}_{jtF}/b_{jt})^{1-\theta} \right]. \tag{11}$$

Following Halpern et al. (2011), we define $G(n_{it})$ as the Cobb-Douglas share of intermediate inputs using imports relative to all intermediate inputs, $G(n_{it}) = \sum_{j \in M} \gamma_j/\gamma$, where n_{it} is the number of imported products and M denotes the set of intermediates with imports. As shown in Appendix B, given that relative prices of imports are the same for all intermediate products, $a_{jt} = a_t$, input prices in the revenue function can now be expressed as a function of the import share: $\ln Q_{it} = -a_t \gamma G(n_{it}) - \kappa_4$.[29] The revenue function can

[29] $\kappa_4 = \sum_{j=1}^{J} (\gamma_j/\gamma) \ln(\gamma_j/\gamma)$.

then be rewritten as

$$\ln r_{it}\left(\Phi_t, k_{it}, w_t, a_t, n_{it}, \omega_{it}\right) = \kappa_2^{'} + \frac{1}{\zeta}\ln\Phi_t + \frac{\eta-1}{\zeta}\left(\beta_k \ln k_{it} - \beta_l \ln w_t + a_t\gamma G\left(n_{it}\right)\right) + \omega_{it} + \epsilon_{it}, \tag{12}$$

where $\kappa_2^{'}$ is a constant .[30] In the empirical model in Section 5, we estimate the revenue function and quantify the returns to R&D and sourcing of foreign products. As is standard in this class of models, variable profits are proportional to revenue, $\pi_{it} = r_{it}(1 - \frac{\eta-1}{\eta}(\beta_l + \gamma))$.

We proceed by determining the firm's optimal number of imported products. We emphasize that the structural estimation conditions on the observed choice of number of imported products, so that the estimator is not sensitive to how we model these discrete decisions. Importing a variety of product j is associated with a fixed firm specific cost f_i per product. We motivate this assumption with the evidence on the dominant role of the extensive margin in explaining aggregate import growth, which suggests that imports entail per-period per-product fixed costs.[31] When deciding on which products to import, the firm faces a trade off between reducing marginal cost and paying the fixed cost f_i. As the cost savings per product is larger for products with a high expenditure share γ_j, while the fixed cost f_i is constant, the firm is more likely to outsource the high γ_j products. Without loss of generality, we order intermediate products according to their expenditure share, so that $\gamma_1 > \gamma_2 > ... > \gamma_J \geq 0$. The firm chooses n_{it} to maximize net profits,

$$\Pi_{it}\left(\omega_{it}, \Theta_{it}\right) = \max_{n_{it}\in[0,1,..,J]}\left\{\pi\left(\Phi_t, k_{it}, w_t, a_t, n_{it}, \omega_{it}\right) - n_{it}f_i\right\}. \tag{13}$$

where Θ_{it} is a vector representing the firm's economic enviroment, $\Theta_{it} = \{k_{it}, f_i, a_t, w_t, \Phi_t\}$. We let $n_{it}^{*}\left(\omega_{it}, \Theta_{it}\right)$ denote the optimal number of imported products. The firm finds it optimal to increase n_{it} as long as the change in variable profits from importing one more product is larger than the additional fixed cost f_i.

We emphasize two properties of the equilibrium $G()$ function. First, $G\left(n_{it}\right) \in [0,1]$ is increasing and concave in n_{it} (but not continuous). Second, $G()$ is identical across firms within an industry. This occurs because the cost shares γ_j are identical across firms and because fixed costs f_i do not vary across products. Note that both properties of the $G()$ function would survive in a more general model where the γ_j's vary across firms, but where the *distribution* of the γ_j's is constant across firms. Appendix Section H shows that both properties of the $G()$ function are strongly supported by our data. Next, we turn to the decision about whether or not to invest in R&D.

[30] $\kappa_2^{'} = \kappa_2 + \gamma\kappa_4\left(\eta - 1\right)/\zeta$

[31] See e.g. Halpern et al. (2011) and Gopinath and Neiman (2011).

4.3 R&D Investments

Firm performance (ω_{it}) depends on a firm's choice of R&D with a lag. Following Doraszelski and Jaumandreu (2013) and Aw et al. (2011), we assume that firm performance evolves over time following a controlled first-order Markov process that depends on whether or not the firm conducts R&D, as well as a random shock:

$$\omega_{it} = \alpha_0 + \alpha_1 \omega_{it-1} + \alpha_2 \omega_{it-1}^2 + \alpha_3 d_{it-1} + \xi_{it}, \tag{14}$$

where d_{it-1} is a dummy taking the value 1 if the firm has positive R&D expenditure in period $t-1$ and α_3 is assumed to be positive. Our modeling of R&D is motivated by the fact that a large number of firms report zero R&D investment.[32] The empirical analysis also includes an alternative specification with continuous R&D expenditure. R&D may boost both productivity $\tilde{\omega}_{it}$ (e.g. due to process innovation) and demand ϕ_{it} (e.g. due to product innovation or quality upgrading). We do not attempt to empirically disentangle the two channels, instead we quantify their joint impact.[33] The uncertain nature of firm performance is captured by the term ξ_{it}, which is mean independent of all information known at $t-1$. Importantly, ξ_{it} is not anticipated by the firm, and is therefore uncorrelated with the remaining right-hand side variables.

We proceed by characterizing the optimal R&D choice of the firm. As in the case with imported intermediates, we emphasize that the structural estimation conditions on the observed choice of R&D investments, so that the estimator is not sensitive to how we model these discrete decisions.

R&D requires a fixed cost f_d. As innovating firms reap the benefits of R&D investments in future periods, the decision to invest in R&D is a dynamic problem. The firm's decision problem regarding R&D investment can then be expressed as a Bellman equation:

$$V(\omega_{it}; \Theta_{it}) = \Pi(\omega_{it}; \Theta_{it}) + \max_{d_{it}} \{\delta E[V(\omega_{it+1}|\omega_{it}, d_{it}=1; \Theta_{it})] - f_d, \delta E[V(\omega_{it+1}|\omega_{it}, d_{it}=0; \Theta_{it})]\} \tag{15}$$

The firm chooses to invest in R&D if the expected net present value of future profit flows minus the cost of innovating f_d is higher when investing in R&D as compared to not investing

[32] This is true in general as well as for our data set.

[33] E.g. if product innovation boosts demand while lowering productivity, we will capture the net impact of the two effects. Note that a Markov process for ω_{it} is only equivalent to having separate Markov processes for $\tilde{\omega}_{it}$ and $\ln \phi_{it}$ when the persistence terms in the $\tilde{\omega}_{it}$ and $\ln \phi_{it}$ Markov processes are identical. Formally, if $\tilde{\omega}_{it} = \alpha_{01} + \alpha_1 \tilde{\omega}_{it-1} + \alpha_{31} d_{it-1} + \xi_{1it}$ and $\ln \phi_{it} = \alpha_{02} + \alpha_1 \ln \phi_{it-1} + \alpha_{32} d_{it-1} + \xi_{2it}$, then $\omega_{it} = \tilde{\alpha}_0 + \alpha_1 \omega_{it-1} + \tilde{\alpha}_3 d_{it-1} + \tilde{\xi}_{it}$, where $\tilde{\alpha}_0 \equiv ((\eta-1)\alpha_{01} + \alpha_{02})/\zeta$, $\tilde{\alpha}_3 \equiv ((\eta-1)\alpha_{31} + \alpha_{32})/\zeta$ and $\tilde{\xi}_{it} \equiv ((\eta-1)(\xi_{1it}) + \xi_{2it})/\zeta$. **?** show that identifying separate Markov processes is only feasible if observing at least two markets in which the firm's product is sold.

in R&D,

$$E\left[V\left(\omega_{it+1}|\omega_{it}, d_{it}=1; \Theta_{it}\right)\right] - f_d > E\left[V\left(\omega_{it+1}|\omega_{it}, d_{it}=0; \Theta_{it}\right)\right]. \tag{16}$$

Recall that Θ_{it} is a vector representing the firm's economic enviroment ($\Theta_{it} = \{k_{it}, f_i, a_t, w_t, \Phi_t\}$. All variables in Θ_{it} are assumed to be constant over time ($\Theta_{it+1} = \Theta_{it}$, so that $a_{t+1} = a_t$, and so on), and there is perfect foresight about them, so that uncertainty about the future path of e.g. import prices does not enter the decision problem. As is common in this class of problems, the policy function takes a simple form, with $d_{it} = 1$ if $\omega_{it} > \underline{\omega}\left(\Theta_{it}, f_d\right)$. Hence, only firms above a certain performance threshold invest in R&D, and the threshold depends on the economic environment, Θ_{it}, and the costs of undertaking R&D, f_d. Here we focus on the costs of importing. Reduced foreign sourcing costs today and in the future (higher a_t) lower the threshold $\underline{\omega}()$. We develop intuition for this result here, while Appendix Section D shows the result in a numerical simulation of the full model.

Reduced foreign sourcing costs for all future periods (higher a_t) make R&D more profitable if

$$\frac{\partial E\left[V\left(\omega_{it+1}|\omega_{it}, d_{it}=1; \Theta_{it}\right)\right]}{\partial a_t} > \frac{\partial E\left[V\left(\omega_{it+1}|\omega_{it}, d_{it}=0; \Theta_{it}\right)\right]}{\partial a_t}. \tag{17}$$

Because there is no closed form solution for net profits Π_{it}, there is no closed form solution for the value function. We can, nevertheless, examine how gross profits respond to higher a_t. By the properties of the profit function (see Appendix Section C), we have

$$\frac{\partial^2 \pi_{it}}{\partial \omega_{it} \partial a_t} > 0, \tag{18}$$

which means that a marginal increase in performance ω_{it} yields higher profits when sourcing costs are low (a_t high). R&D in year $t-1$ increases expected performance in year t, $E\left(\omega_{it}|\omega_{it-1}, d_{it-1}=1\right) - E\left(\omega_{it}|\omega_{it-1}, d_{it-1}=0\right) = \alpha_3 > 0$. Hence, lower sourcing costs (higher a_t) in t and all future periods, lead to a greater increase in expected profits in $t+1$ when $d_{it} = 1$ compared to when $d_{it} = 0$ (see Appendix Section C):

$$\frac{\partial E\left[\pi_{it+1}\left(\omega_{it}, d_{it}=1, \Theta_{it}\right)\right]}{\partial a_t} > \frac{\partial E\left[\pi_{it+1}\left(\omega_{it}, d_{it}=0, \Theta_{it}\right)\right]}{\partial a_t}. \tag{19}$$

In words, a marginal decline in current and future import costs has a larger positive impact on expected profits for R&D firms because R&D firms have on average higher performance. Hence, the hurdle $\underline{\omega}()$ is decreasing in a_t, so that lower input trade barriers make more firms invest in R&D. We summarize this in the following proposition.

Proposition 1. *Lower foreign sourcing costs in year t and all future periods (higher a_t) will increase the expected profitability of R&D and lower the R&D threshold $\underline{\omega}\left(\right)$, inducing more* *firms to invest in R&D.*

4.4 Imports and R&D

In the previous section we analysed the effect of a change in firms' foreign sourcing cost. Next, we focus on the role of a change in R&D costs. This section shows that lower R&D costs f_d increase the future expected number of imported products for firms switching from no R&D to R&D (henceforth, R&D starters). First, falling R&D costs f_d lower the R&D hurdle $\underline{\omega}\left(\Theta_{it}, f_d\right)$, inducing more firms to switch to R&D. Appendix Section C shows that the performance of R&D firms first-order stochastically dominates the performance of non-R&D firms. Higher performance, in turn, raises the return to importing the marginal product because

$$\frac{\partial\left[\pi\left(\omega_{it}, n_{it}, \Theta_{it}\right)-\pi\left(\omega_{it}, n_{it}-1, \Theta_{it}\right)\right]}{\partial \omega_{it}} \quad > \quad 0. \tag{20}$$

(see Appendix C). Hence, the optimal number of imported inputs, $n_{it}^*\left(\omega_{it}, \Theta_{it}\right)$ is increasing in ω_{it}. This implies that the expected number of imported products in $t+1$ is higher for firms that invested in R&D in t relative to firms that did not invest in R&D in t (see Appendix Section C):

$$E\left[n^*\left(\omega_{it+1}\left(\omega_{it}, d_{it}=1\right), \Theta_{it}\right)\right] \geq E\left[n^*\left(\omega_{it+1}\left(\omega_{it}, d_{it}=0\right), \Theta_{it}\right)\right],$$

We summarize this in the following proposition.

Proposition 2. *Higher performance raises the return to importing the marginal product. Hence, lower R&D costs f_d increase the expected optimal number of imported products in year $t+1$ for firms induced to invest in R&D in year t.*

The key economic mechanism behind Propositions 1 and 2 is that both importing and R&D investment raise the expected profits of the firm. A firm induced to engage in R&D is then more likely to engage in importing because the marginal returns to importing is higher for more profitable firms. Similarly, lower trade cost on foreign intermediates leads to more importing which raises profits and encourages investment in R&D.

5 Structural Estimation

5.1 The Empirical Model

We proceed by developing a structural empirical model based on the set up presented in Section 4. The main goal of this section is to estimate the model and to quantify the returns to R&D and imports, assessing both the direct and indirect effect of R&D on marginal costs. In the proceeding section, we use the estimated model to evaluate whether the complementarity hypothesis described in Proposition 2 can explain the rise in aggregate imports estimated in Section 3, providing external validity of the research design. Ideally, we would also have wanted to evaluate Proposition 1 - that changes in trade costs affect the firms' R&D choice. However, we did not identify any large changes in sourcing costs a_t during the sample period that would have allowed us to do this.

A key feature of our model is that intermediate input prices vary across firms as some firms import more inputs than others. The empirical facts on R&D investment and sourcing behavior presented in Section 2 show that starting R&D and importing new products are positively correlated. Hence, if we ignore the importing side when estimating the returns to R&D, we capture the sum of the direct effect of R&D on performance (that R&D affects productivity) and the indirect effect of R&D (that R&D affects marginal costs through its impact on sourcing). Our approach aims to disentangle these direct and indirect effects of R&D.

5.1.1 $1st$ Stage

In order to estimate the impact of R&D investment and international sourcing on revenue and productivity, we proceed in two steps. First, we estimate the revenue function in equation (21). Second, we estimate the Markov process governing the evolution of firm performance from equation (14). As is well known, OLS estimates of the revenue function suffer from simultaneity bias, as firm performance ω_{it} is likely to affect the demand for inputs. We therefore use the insights from Levinsohn and Petrin (2003), that demand for static inputs such as materials can be used to recover unobserved performance.

Let the value of a firm's total demand for intermediates, m_{it},[34] be a function of the state variables firm performance, ω_{it}, and capital, k_{it}. In addition, and departing from the previous literature, demand depends on intermediate prices, which varies across firms due to heterogeneity in the number of imported products n_{it}. We therefore express intermediate demand as $m_{it} = F(\omega_{it}, k_{it}, n_{it})$. Given monotonicity in ω_{it} for all relevant k_{it} and n_{it}, we

[34]Note that m_{it} is defined as the value of intermediates, i.e. $m_{it} = V_{it}Q_{it}$.

invert $F()$ to yield performance, ω_{it}, as a function of intermediates, capital and the number of imported inputs, $\omega_{it} = \tilde{F}(m_{it}, k_{it}, n_{it})$.[35] Hence, we can use these variables to control for performance in the revenue function, and we can rewrite the revenue function (12) as

$$\ln r_{it} = \kappa_2^{'} + \delta_t + h(m_{it}, k_{it}, n_{it}) + \epsilon_{it} \tag{21}$$

where $\delta_t = \ln \Phi_t/\zeta - (\eta - 1)\beta_l \ln w_t/\zeta$ is a fixed effect capturing industry-wide demand and cost trends and $h(m_{it}, k_{it}, n_{it}) = [(\eta - 1)/\zeta][\beta_k \ln k_{it} + \gamma a_t G(n_{it})] + \tilde{F}(m_{it}, k_{it}, n_{it})$ captures the firm specific variables. Note that wages are determined on the industry level rather than at the firm level. We motivate this assumption with the highly coordinated and centralized wage setting regime in Norway.

To proceed we need to specify the functional form of $G(n_{it})$. In general, the shape of $G()$ will depend on the distribution of cost shares across products, and we refer the reader to Appendix Section H for empirical evidence on the relationship between number of imported products and cost shares of imported intermediates. A functional form that fits the data quite well is $G(n_{it}) = \ln(1 + n_{it}) / \ln(1 + n_{max})$, where n_{max} is the maximum number of imported products.[36] This function is consistent with the theoretical prediction that $G()$ is concave and that $G(n_{it}) \in [0, 1]$ (see Section 4.2). As in Section 3, we let n_{it} refer to the number of imported HS products at the 4-digit level. To aid estimation, we also assume that the quality adjusted price of imports relative to the price of domestic inputs is constant across years ($a_t = a$). This is motivated by the fact that there were no significant shocks to trade costs during the sample period. We provide evidence that our empirical results are robust to relaxing this assumption (see Section 5.3).

In the $1st$ stage, we estimate equation (21) by OLS. In order to allow for heterogeneity in production technology and demand across manufacturing sectors, we estimate the revenue function separately for each NACE 2-digit sector in our sample (industry subscripts are suppressed for clarity).[37]

The $h()$ function is approximated by a linear combination $\ln m_{it}$, $\ln k_{it}$ and $G(n_{it})$ as well as these variables squared. The $1st$ stage estimation is unable to identify the effect of imports on revenue, as the contribution of imported products enters both directly (as $\gamma a G(n_{it})$) and indirectly through the performance term ω_{it}.

[35] Recall that the fixed cost of importing f_i is firm-specific. Hence, conditional on ω_{it} and k_{it}, we have variation in $m_{it} = F(\omega_{it}, k_{it}, n_{it})$ as some firms have low fixed costs, and as a consequence lower intermediate prices and higher n_{it}. With no heterogeneity in f_i, the relationship between ω_{it} and n_{it} would be deterministic, so that writing $m_{it} = F(\omega_{it}, k_{it})$ would be sufficient.

[36] We use the 99th percentile in the data, which is $n_{max} = 179$.

[37] We estimate on every NACE 2-digit sector with more than 20 firms present. They are NACE 15, 20, 21, 22, 24, 25, 26, 27, 28, 29, 31, 32, 33, 34, 35 and 36.

We have chosen to specify a non-parametric control function, $F()$ which is incorrectly specified given our chosen functional forms, but which may be consistent with more general models. We derive a parametric control function consistent with the chosen functional forms and report the results from an alternative estimation approach in Section 5.3.

5.1.2 $2nd$ stage

In the $2nd$ stage, we first rewrite performance in terms of predicted h_{it} from the $1st$ stage,

$$\hat{\omega}_{it} = \hat{h}_{it} - \beta_k^* \ln k_{it} - \gamma^* aG\left(n_{it}\right), \tag{22}$$

where superscript $*$ denotes that the variable is multiplied by $(\eta - 1)/\zeta > 0$. Using (22) to substitute for ω_{it} and ω_{it-1} into the Markov process from equation (14) then yields

$$\begin{aligned} \hat{h}_{it} = \alpha_0 + \beta_k^* \ln k_{it} + \gamma^* aG\left(n_{it}\right) + \alpha_1 \left[\hat{h}_{it-1} - \beta_k^* \ln k_{it-1} - \gamma^* aG\left(n_{it-1}\right)\right] \\ + \alpha_2 \left[\hat{h}_{it-1} - \beta_k^* \ln k_{it-1} - \gamma^* aG\left(n_{it-1}\right)\right]^2 + \alpha_3 d_{it-1} + \xi_{it}. \end{aligned} \tag{23}$$

This is the $2nd$ stage estimating equation, which relates predicted revenue to the current and lagged capital stock, the number of imported inputs, lagged predicted revenue and the R&D dummy d_{it-1}.

We proceed by estimating equation (23) by generalized method of moments (GMM). As $\hat{h}_{it-1}$, k_{it-1} and d_{it-1} are determined in $t-1$, and since ξ_{it} is the unanticipated part of firm performance in year t, these variables are orthogonal to the error term. The number of imported products n_{it}, however, responds to the error term. The lagged n_{it-1}, on the other hand, was chosen before ξ_{it}, and is therefore uncorrelated with the shock. In our baseline specification, we therefore instrument $G\left(n_{it}\right)$ with the lagged value $G\left(n_{it-1}\right)$. The instrument set also consists of these variables squared. We also allow the R&D term to vary according to the size of the firm; specifically we add an interaction term $\alpha_3^S Small_i \times d_{it-1}$ where $Small_i = 1$ if the firm's initial employment is smaller than median employment in the sample, and $Small_i = 0$ otherwise.[38] Finally, we allow the constant term in the Markov process to vary by industry by including industry (NACE 2-digit) fixed effects. In sum, this gives us 24 moment conditions and 22 unknowns (α_0, α_1, α_2, α_3, α_3^S, β_k^*, $\gamma^* a$ and 15 industry dummies). Our estimates are then found by minimizing the sum of squared sample moments. We report coefficient estimates using equal weights for every moment (one-step estimator) and report specifications tests using a two-step estimator.[39]

[38]The median hours worked per firm is 141,000 hours, or 79 employees given 1,800 hours worked annually per employee.

[39]In practice, the one-step and two-step estimators produce very similar results. Two-step estimators are

The $2nd$ stage enables us to identify the impact of R&D investments and imports of intermediate inputs on firm performance. Given that outsourcing reduces marginal costs, we expect that $\gamma^* a$ is positive. Given that R&D investment positively shifts the firm performance process, we expect that α_3 is positive. Given the estimates of β_k^* and $\gamma^* a$, one can back out performance $\hat{\omega}_{it}$ from equation (22).

5.1.3 Identification

In the $1st$ stage revenue function, the number of imported products n_{it} enters both in the control function $\tilde{F}()$, as input prices vary according to sourcing strategy, and directly in $G(n_{it})$. Hence, the impact of imports on revenue is not identified in the $1st$ stage. This is reminiscent of the methodology in Ackerberg et al. (2006), where identification occurs exclusively in the $2nd$ stage. The role of the $1st$ stage is therefore to isolate and eliminate the portion of output that is determined by either unanticipated shocks or by measurement error.

In the $2nd$ stage (equation (23)), we identify the impact of R&D and imported intermediates on firm performance by exploiting variation in d_{it-1} and n_{it-1} conditional on lagged performance ω_{it-1}. Performance is captured by the term $(\hat{h}_{it-1} - \beta_k^* \ln k_{it-1} - \gamma^* a G(n_{it-1}))$ in equation (23), ensuring that any spurious correlation between, e.g., $\hat{h}_{it}$ and imports is controlled for. The remaining variation that is unobservable to the econometrician, ξ_{it}, is mean independent of all information known at $t-1$, and is therefore uncorrelated with the instrument set.

The control function approach allows us to estimate the import and R&D effect by comparing outcomes of two equally productive firms that differ only in their sourcing or R&D behavior. Conditional on firm performance, the number of imported intermediate goods, n_{it}, varies across firms due to variation in the import fixed cost f_i. Note that the way we model the discrete R&D and importing decisions is not essential for identification, as we condition on the observed R&D and importing choice in the data. Hence, our estimator is robust to alternative models of the R&D and import decision.

5.2 Results

The parameter estimates from the estimation of equations (21) and (23) are reported in Table 10.

Column 1 reports the baseline results. Column 2 does not instrument n_{it} with lagged values, which would be the preferred specification if the number of imported products were

found to have finite-sample bias in short panels (Altonji and Segal, 1996).

Table 10: GMM Estimates.

	(1) Baseline	(2) n exogenous	(3) No imports	(4) Continuous R&D
Capital (β_k^*)	.69***	.74***	.80***	.68***
	(.05)	(.04)	(.03)	(.05)
No. imported products ($a\gamma^*$)	1.06***	.66***		1.05***
	(.32)	(.17)		(.32)
Productivity$_{t-1}$ (α_1)	.42***	.43***	.45***	.41***
	(.05)	(.05)	(.05)	(.05)
Productivity$^2{}_{t-1}$ (α_2)	.04***	.04***	.04***	.04***
	(.01)	(.01)	(.01)	(.01)
R&D$_{t-1}$ (α_3)	.08***	.08***	.10***	.01***
	(.03)	(.04)	(.03)	(.00)
$\times Small_i$ (α_3^S)	-.10**	-.09**	-.10**	-.01**
	(.04)	(.04)	(.04)	(.00)
Industry FE	Yes	Yes	Yes	Yes
N	2495	2495	2495	2495
Firms	927	927	927	927

Notes: Robust standard errors in parentheses, clustered by firm. *** p-val<.01, ** p-val<.05, * p-val<.1. R&D is a binary variable in (1)-(3), and log 1+R&D expenditure in (4). Estimates of constant term omitted from table.

uncorrelated with the shock ξ_{it}. Column 3 is estimated under the restriction that intermediate input prices are homogeneous and that the number of imported products does not have any impact on firm performance. Formally, this amounts to ignoring the term $\gamma^* aG(n_{it})$ in the $1st$ as well as the $2nd$ stage. As pointed out in section 4.3, our specification of R&D as a binary dummy variable is motivated by the fact that a large number of firms report zero R&D investment. We also estimate an alternative specification with log R&D expenditure as the independent variable. The results are reported in Column 4.

The capital coefficient β_k^* is positive and significant across all specifications, implying that variable costs are lower and revenue is higher for firms with higher capital stock. The $a\gamma^*$ coefficient captures the effect of the number of imported products on revenue. In the baseline case, the elasticity of revenue with respect to imported products is approximately 0.20.[40] To get a sense for the economic significance of this result, we rank firms according to their number of imported products. Based on the estimated elasticity of revenue, we find that a firm in the third quartile in terms of international sourced products has roughly 20

[40]Recall that we have used the specification $G(n_{it}) = \ln(1+n_{it})/\ln(1+n_{max})$, so $\partial\hat{h}_{it}/\partial\ln n_{it} = a\gamma/\ln(n_{max}+1) \times n/(n+1)$. When $n/(n+1) \approx 1$, then $\partial\hat{h}_{it}/\partial\ln n_{it} \approx 0.20$.

percent higher sales than the median firm.[41] The specifications reported in column (2) and (4) show the same pattern, although the magnitudes are somewhat smaller in these cases. In all four specifications, the impact of lagged productivity on current productivity, measured by α_1 and α_2, is strong and precisely estimated, indicating that serial correlation in ω_{it} is high.

The short-run impact of R&D investment on revenue, captured by α_3, is 8 percent. However, the R&D impact is heterogeneous across firms; α_3^S is negative and significant, suggesting that R&D only generates growth among large firms. A potential explanation for this is that capacity constraints are less binding for large firms. For example, small firms may have to reduce output during a transition phase when the R&D activity is starting. The estimate of α_3 only captures the one period impact of R&D investments, while our dynamic model predicts a potentially different response in the long run. We therefore calculate the mean long-run impact of R&D on revenue based on the estimates from the baseline case (column (1)). Iterating on the Markov process in equation (23), we find that a firm performing R&D in every period on average has 24 percent higher sales compared to a firm that never invests in R&D.[42] Of course, the total impact of R&D on revenue (and marginal costs) is higher than this, since R&D enables the firm to reduce costs by sourcing more foreign varieties. We calculate the magnitude of this indirect effect in the counterfactual in Section 6.

An important finding is that the R&D effect is estimated to be higher in the case where heterogeneity in input prices are not controlled for (column (3)). In this case, the R&D effect appears more than 25 percent higher. We view this as additional empirical evidence of the complementarity between R&D and trade in intermediates. Due to the complementarities between R&D and other cost-saving activities such as imports of intermediates, dropping the import channel will lead to an estimate of the impact of R&D that also includes the indirect effect through more imports.

We check the validity of the instruments with an overidentification test. The baseline model in column (1) in Table 10 produces a J-statistic and p-value of .04 and 0.98 respectively, indicating we cannot reject the null that the over-identifying restrictions are valid.

5.3 Additional Robustness Tests

Parametric control function Our baseline specification uses a non-parametric control function ω_{it}, which allows us to estimate the 1st stage with a polynomial in m_{it}, k_{it} and

[41]The 3rd quartile and median of the distribution of the number of imported products are 51 and 26 in 2005.

[42]We calculate the long-run impact of R&D by setting $d_{it-1} = 0$ in every period for a perpetual non-innovator and $d_{it-1} = 1$ in every period for a perpetual innovator.

n_{it} (the $h()$ function). This section develops an alternative estimator based on the assumed functional form of the production function.

Appendix Section E shows that the control function for ω_{it} becomes

$$\omega_{it} = \kappa_5 - \frac{1}{\zeta}\ln\Phi_t + \beta_l^* \ln w_t - \gamma^* aG(n_{it}) + \ln m_{it} - \beta_k^* \ln k_{it}. \quad (24)$$

Inserting the Markov process into the revenue function, and then substituting ω_{it-1} and ω_{it-1}^2 with the parametric $\tilde{F}$ above yields the estimating equation (see Appendix F)

$$\begin{aligned} \ln\tilde{r}_{it} &= \kappa_6 + \beta_k^* \ln\tilde{k}_{it} + \gamma^* aG(\tilde{n}_{it}) + \\ &\quad +\alpha_1^{'}\left(\ln\tilde{m}_{it-1} - \gamma^* aG(\tilde{n}_{it-1}) - \beta_k^* \ln\tilde{k}_{it-1}\right) \\ &\quad +\alpha_2\left(\ln\tilde{m}_{it-1} - \gamma^* aG(\tilde{n}_{it-1}) - \beta_k^* \ln\tilde{k}_{it-1}\right)^2 + \alpha_3\tilde{d}_{it-1} + \tilde{\xi}_{it} + \tilde{\epsilon}_{it}, \end{aligned}$$

where ˜ denotes variables expressed relative to yearly means. We estimate the model by GMM using the same instruments as in the main text. Here, we identify all parameters of interest in the $1st$ stage, i.e. there is no need to estimate the model in two stages. Column (1) in Table 11 shows the results; overall the estimates are quite close to the baseline.

The expressions above highlight a potential problem with the non-parametric approach used in the baseline. Inserting equation (24) into the revenue function in equation (12) shows that the resulting $h()$ function becomes simply $h() = \ln m_{it}$, i.e. it is no longer a function of k_{it} and n_{it}. Hence, the $1st$ stage is incorrectly specified given the assumptions of the model. However, the baseline non-parametric specification may be justified within more general theoretical specifications, for instance if there is more dynamics in the maximization problem of the firm.

Non-constant relative import prices A potential concern is that the advantage of importing intermediates is assumed identical and constant across all intermediate products and years, i.e. $a_{jt} = a$. Import prices trended downwards during the sample period (Figure 11 in the Appendix), suggesting that a more flexible specification may be preferred. As a further robustness check we estimate a specification where we allow a to vary over time and across small and large firms, with $Small_i$ defined as above. The $1st$ stage of the estimation procedure is modified by including the interaction terms $G(n_{it}) \times Year_t$ and $G(n_{it}) \times Small_i$ in the polynomial $h(k_{it}, m_{it}, n_{it})$. The $2nd$ stage is altered in a similar fashion, by including the same set of interaction terms and instrumenting with with their lagged values. The results are shown in Table 11 column (2). Our findings suggest that a is indeed not constant, as there is some evidence that import prices were slightly higher earlier in the sample period,

Table 11: GMM Estimates. Sensitivity.

	Struct. $F()$		Variable a	
Capital (β_k^*)	.57***	(.06)	.66***	(.05)
No. imported products ($a\gamma^*$)	1.76***	(.39)	1.24***	(.29)
×1999			-.13***	(.03)
×2001			-.11***	(.03)
×2003			-.19***	(.02)
$\times Small_i$			-.30**	(.01)
Productivity$_{t-1}$ (α_1)	.61***	(.04)	.39***	(.05)
Productivity$^2{}_{t-1}$ (α_2)	.20***	(.05)	.04***	(.01)
R&D$_{t-1}$ (α_3)	.05**	(.03)	.03	(.02)
$\times Small_i$ (α_3^S)	-.13***	(.04)	-.04	(.04)
Industry FE	Yes	(.01)	Yes	
N	2495		2495	
Firms	927		927	

Notes: Robust standard errors in parentheses, clustered by firm. *** p-val<.01, ** p-val<.05, * p-val<.1. Omitted categories are year 2005 and $Small_i = 0$.

and also that small firms faced slightly higher relative import prices. However, accounting for time-varying relative import prices do not materially change any conclusions from the baseline case, as the overall effects are quite close to the baseline.

Export status The previous literature has emphasized the impact of exporting on productivity dynamics. A common technique is to include the lagged export status of the firm in the Markov process for productivity (e.g., Aw et al. (2011) and De Loecker (2010)). As a simple robustness check, we therefore include lagged export status in equation (14), and re-estimate the model. We find that this extension has a negligible impact on our results and that the estimated coefficient for lagged exports is not significantly different from zero (detailed results available upon request).

6 Simulation: Quantifying Effects and Importance

In this paper, we have emphasized one particular mechanism that gives rise to complementarity between R&D investments and trade in intermediates. In this section, we evaluate the empirical importance of this mechanism. We know from our reduced form results in Section 3 that the decline in R&D costs due to the tax credit introduced in 2002 raised the average number of imported products per firm by 8-14 percent (see Table 5 columns (4)-

(6)). Here we ask what the increase in imports would have been according to the structural model (see Sections 4 and 5), given the increase in R&D observed in the data. We find that our model produces a 7.7 percent increase in the average number of imported products for R&D starters. This suggests that most of the effect from the reduced from evidence can be explained by our proposed theoretical mechanism.

Note that we do not rely on, or estimate, the decision rule for R&D investment in the simulation. Instead, we simply condition on the observed R&D status of the firm and then infer their optimal imports, using the estimated parameters of the model. An alternative evaluation strategy would be to model the R&D decision rule explicitly, and then feed the R&D subsidy into the model to investigate both changes in R&D and imports. We choose the simpler approach for two reasons. First, conditioning on observed R&D enables us to simulate the model without explicitly modeling the R&D decision, which would entail an additional layer of assumptions as well as parameters to be estimated. We remain relatively agnostic when it comes to the exact determinants behind the firms' R&D decisions. Second, as the main objective of the paper is to assess the interdependence between R&D and imports, and not to estimate the determinants of R&D itself, for our purposes it is not strictly necessary to estimate the R&D decision rule.

First, we calculate predicted 2001 revenue for all the firms in our sample, that is, $\widehat{\ln r_{i2001}}$, using the estimates from the $1st$ stage in equation (21). Given the estimate of $\gamma^* a$ from the $2nd$ stage, we construct the vector of predicted revenues for any potential choice of n, that is, $\widehat{\ln r_{i2001}} (n)$. Given knowledge about per-product fixed cost f_i and the elasticity of substitution σ (see the paragraph below), the vector of gross profits $\hat{\pi}_{i2001} (n)$ as well as the optimal n_i^* and net profits $\hat{\pi}_{i2001} (n_i^*) - n_i^* f_i$ are calculated according to equation (13). This gives us a 2001 baseline simulation of imported inputs in the economy.

For each firm, per-product fixed costs f_i are drawn from a lognormal distribution, $\ln f_i \sim N(\mu, \sigma_{\ln f})$.[43] μ and $\sigma_{\ln f}$ represent the mean and standard deviation of $\ln f_i$ and are calibrated according to the following procedure. A high f_i leads to fewer firms importing. We therefore calibrate μ to match the share of non-importers in the model to the same share in the data. Variation in f_i leads to more variation in n_i^* across firms with similar performance. We therefore calibrate $\sigma_{\ln f}$ to match the standard deviation of $\ln (n_i^* / \hat{r}_{i2001} (n_i^*))$ in the model to the same standard deviation in the data. This results in $\mu = 4.75$, which equals 34,100 USD or 0.14 percent of median revenue. All target moments and calibrated values are summarized in Table 12. The elasticity of substitution (σ) is set to 4, which is the mean

[43] We draw 50 f_i for each firm, so that the simulated sample is 50 times larger than the actual sample. This ensures that variability in the f_i draws has a negligible impact on the target moments described in this paragraph.

Table 12: Simulation.

		Value
Target moments:	Share non-importers	0.086
	Stdev $\ln\left(n_{i2001}/r_{it2001}\right)$	1.38
Calibrated parameters:	μ	5.32
	$\sigma_{\ln f}$	1.36
Counterfactual change in n^*:	$\sum_{i\in\Omega} n_i^{*cf} / \sum_{i\in\Omega} n_i^*$	7.7%
% revenue growth for R&D starters, total:	$\sum_{i\in\Omega} \hat{r}_i^{cf}\left(n_i^{*cf}\right) / \sum_{i\in\Omega} \hat{r}_{i2001}\left(n_i^*\right)$	10.3%
% revenue growth for R&D starters, no import adjustment:	$\sum_{i\in\Omega} \hat{r}_i^{cf}\left(n_i^*\right) / \sum_{i\in\Omega} \hat{r}_{i2001}\left(n_i^*\right)$	8.3%

1990-2001 elasticity at the SITC-3 level reported by Broda and Weinstein (2006).

We can now shock our economic environment. Using the population of firms that are operating both pre- and post-reform (2001 and 2005), we identify the set Ω of firms that were not investing in R&D in 2001 but were investing in R&D in 2005 and classify them as *R&D starters*. These firms are part of the treatment group in the DID analysis presented in Section 3, and are accordingly exposed to the R&D policy shock.[44] 18 percent of the firms are classified as R&D starters. We then ask what the level of revenue for the R&D starters would be in 2005 according to our model, if they invested in R&D in 2003. In other words, we calculate predicted revenue and profits $\widehat{\ln r_i^{cf}}(n)$ and $\hat{\pi}_i^{cf}(n)$ for the R&D starters by adding the revenue gains from R&D estimated in the previous section (from equation (23)), keeping all else constant.[45] Finally, we let the R&D starters reoptimize their number of imported inputs n_i^{*cf}.

We evaluate the fit of the model by comparing the simulated change in the number of imported products with the reduced form results. The results in Section 3 indicated that the R&D policy raised the average number of imported products by firms exposed to the shock by 8-14 percent (see Table 5). The corresponding average simulated increase, $\hat{n} \equiv \sum_{i\in\Omega} n_i^{*cf} / \sum_{i\in\Omega} n_i^*$, is 7.7 percent, suggesting that our model can explain most of the import surge among firms exposed to the policy shock.

Note that we never estimated a relationship between R&D and imports in the structural model. Rather, we estimated revenue conditional on imports and R&D. As a consequence, there is nothing in the model that mechanically produces a counterfactual growth in n close to the actual growth in n. In the Appendix Section I, we also explore the full distribution

[44] The regressions of the policy reform on the number of imported inputs use both zero-R&D and positive-R&D firms in the treatment and control groups. As such, the reduced form results capture the extensive margin adjustment that is the focus of the model.

[45] Specifically, $\widehat{\ln r_i^{cf}}(n) = \widehat{\ln r_{i2001}}(n) + d\omega$ for R&D starters and $\widehat{\ln r_i^{cf}}(n) = \widehat{\ln r_{i2001}}(n)$ for all other firms, where $d\omega$ is the short run change in performance according to the estimated Markov process (equation (23)).

of actual and simulated n_i. Also note that R&D is a binary decision in the model while it is continuous in the data. The R&D policy reform is likely to have affected both the intensive and extensive margin of R&D investment, whereas the theoretical model only includes the extensive margin. Adding the intensive margin to the model would in all likelihood give a stronger counterfactual increase in foreign sourcing $\hat{n}$. Hence, we interpret our simulation results as a lower bound on the complementarity effect between R&D and imports.

Next, we decompose the growth in revenue. R&D starters sell more as R&D on average increases their performance ω_{it}, but also since higher performance makes them import more products, which lowers costs and increases revenue. The two last rows in Table 12 decompose the growth in revenue. Aggregate revenue growth for R&D starters is $\sum_{i\in\Omega} \hat{r}_i^{cf}\left(n_i^{*cf}\right) / \sum_{i\in\Omega} \hat{r}_{i2001}\left(n_i^*\right)$, which is 10.3 percent. Revenue growth for R&D starters given that firms cannot reoptimize n_i is $\sum_{i\in\Omega} \hat{r}_i^{cf}\left(n_i^*\right) / \sum_{i\in\Omega} \hat{r}_{i2001}\left(n_i^*\right)$, which is 8.3 percent. Hence, roughly one-fifth ((10.3-8.3)/10.3) of aggregate revenue growth among R&D starters stems from sourcing more foreign products, illustrating how trade amplifies marginal cost reductions in our model. In our view, that an R&D policy can boost revenue (and lower costs) of this magnitude due to imports is indeed remarkable.

7 Conclusions

The returns to R&D investments are well documented. There is also substantial empirical evidence on the impact of imported intermediates on firms' productivity. What we know less about is the relationship between R&D investment and international sourcing. This paper attempts to close the gap. We have developed a model proposing a simple mechanism for complementarity between R&D investment and trade in intermediates. The model is motivated by reduced form evidence suggesting that an R&D reform that led to lower R&D costs had a benign impact not only on R&D but also on imports. We propose a straightforward and novel mechanism by which input trade liberalization fosters R&D investment. In the model, declining input trade barriers lower marginal production costs and raise firm profits. This in turn raises the relative returns to incurring R&D costs. We develop a structural estimator and quantify the returns to foreign sourcing and R&D investments. Our estimates show substantial returns to both activities, and underscore the importance of accounting for the complementarity between them.

In this paper we have emphasized one particular theoretical channel that gives rise to complementarity, but there may be other mechanisms that are operating at the same time. For example, R&D may be complementary to a set of inputs that are not always available in the domestic market. We have also sacrificed some realism in the model by ruling out intensive margin changes in R&D, which may also affect sourcing decisions. However, by comparing our reduced form estimates with a simulation based on the estimated structural model, we are able to evaluate the importance of the theoretical mechanism we propose. We find that most of the import surge that occurred in the aftermath of the policy change can be attributed to the proposed theoretical mechanism. Hence, the results suggest that our proposed theoretical mechanism goes a long way in explaining the reduced form results from Section 3We find that one-fifth of revenue growth among R&D starters stems from sourcing more foreign products, while the remaining part stem from R&D investment. An important implication of our work is therefore that R&D policies have ramifications beyond innovation, and that international trade can amplify the benign impact of such policies on performance and growth.

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Appendix

A Short-run Marginal Costs

In this section we derive the firm's short-run marginal costs. The production function is $y_{it} = l_{it}^{\beta_l} k_{it}^{\beta_k} V_{it}^{\gamma} e^{\tilde{\omega}_{it}}$, where the firm specific aggregate of intermediates is given by $V_{it} = \prod_j^J v_{ijt}^{\gamma_j/\gamma}$. Define Q_{it} as the associated firm specific price index, $Q_{it} = \prod_j^J \left(\frac{q_{ijt}}{\gamma_j/\gamma}\right)^{\gamma_j/\gamma}$. Cost minimization requires that

$$\frac{\partial y_{it}/\partial l_{it}}{w_t} = \frac{\partial y_{it}/\partial V_{ijt}}{Q_{it}}. \tag{25}$$

The partial derivatives are

$$\begin{aligned}\frac{\partial y_{it}}{\partial l_{it}} &= \frac{\beta_l}{l_{it}} e^{\tilde{\omega}_{it}} k_{it}^{\beta_k} l_{it}^{\beta_l} V_{it}^{\gamma} = \frac{\beta_l}{l_{it}} y_{it} \\ \frac{\partial y_{it}}{\partial V_{it}} &= \frac{\gamma}{V_{it}} e^{\tilde{\omega}_{it}} k_{it}^{\beta_k} l_{it}^{\beta_l} V_{it}^{\gamma} = \frac{\gamma}{V_{it}} y_{it}\end{aligned}$$

Inserting this into equation (25) yields

$$V_{it} = l_{it} \frac{w_t}{Q_{it}} \frac{\gamma}{\beta_l}. \tag{26}$$

We can insert this expression back into the production function, which yields

$$\begin{aligned} y_{it} &= l_{it}^{\beta_l} k_{it}^{\beta_k} \left(l_{it} \frac{w_t}{Q_{it}} \frac{\gamma}{\beta_l} \right)^{\gamma} e^{\tilde{\omega}_{it}} \quad \Longleftrightarrow \\ l_{it} &= \beta_l^{\gamma/(\beta_l+\gamma)} \gamma^{-\gamma/(\beta_l+\gamma)} y_{it}^{1/(\beta_l+\gamma)} k_{it}^{-\beta_k/(\beta_l+\gamma)} w_t^{-\gamma/(\beta_l+\gamma)} Q_{it}^{\gamma/(\beta_l+\gamma)} e^{-\tilde{\omega}_{it}/(\beta_l+\gamma)}. \end{aligned} \tag{27}$$

Conditional upon capital k_{it} and price of capital ρ_t, a firm's costs are given by

$$\begin{aligned} C\left(w_t, \rho_t, Q_{it}, k_{it}, y_{it}\right) &= \rho_t k_{it} + w_t l_{it} + Q_{it} V_{it} \\ &= \rho_t k_{it} + w_t l_{it} \frac{\beta_l + \gamma}{\beta_l} \\ &= \rho_t k_{it} + \frac{\beta_l + \gamma}{\beta_l} \beta_l^{\gamma/(\beta_l+\gamma)} \gamma^{-\gamma/(\beta_l+\gamma)} y_{it}^{1/(\beta_l+\gamma)} k_{it}^{-\beta_k/(\beta_l+\gamma)} w_t^{1-\gamma/(\beta_l+\gamma)} Q_{it}^{\gamma/(\beta_l+\gamma)} e^{-\tilde{\omega}_{it}/(\beta_l+\gamma)} \end{aligned}$$

where we used equation (26) for the second equality and equation (27) for the third equality. Log of short-run marginal costs are then

$$\ln c_{it} = \frac{1}{\beta_l + \gamma} \left[\kappa_1 + (1 - \beta_l - \gamma) \ln y_{it} - \beta_k \ln k_{it} + \beta_l \ln w_t + \gamma \ln Q_{it} - \tilde{\omega}_{it} \right],$$

where $\kappa_1 = \ln \left(\beta_l^{-\beta_l} \gamma^{-\gamma} \right)$ which is identical to expression (7) in the main text.

B The Revenue Function

In this section, we show how to derive the revenue function, which is subsequently used in estimation. We start with rewriting short-run marginal costs (see (7)) as a function of revenue and price instead of quantity produced, using that $y_{it} = r_{it}/p_{it}$ and that the optimal price is given by $p_{it} = \left(\frac{\eta}{\eta-1}\right) c_{it}$:

$$\begin{aligned}
\ln c_{it} &= \frac{1}{\beta_l + \gamma}\left[\kappa_1 + (1-\beta_l-\gamma)\left(\ln r_{it} - \ln\frac{\eta}{\eta-1} - \ln c_{it}\right) - \beta_k \ln k_{it} + \beta_l \ln w_t + \gamma \ln Q_{it} - \tilde{\omega}_{it}\right] \implies \\
\ln c_{it} &= \kappa_1 + (1-\beta_l-\gamma)\left(\ln r_{it} - \ln\frac{\eta}{\eta-1}\right) - \beta_k \ln k_{it} + \beta_l \ln w_t + \gamma \ln Q_{it} - \tilde{\omega}_{it},
\end{aligned}$$

Demand is given by $y_{it} = p_{it}^{-\eta}\Phi_t\phi_{it}$, where η is the elasticity of substitution, Φ_t is an industry-wide demand shifter and ϕ_{it} is a firm-specific demand shifter. Using this together with expression for optimal price, we can write revenue as $r_{it} = \left(\frac{\eta}{\eta-1}\right)^{1-\eta} c_{it}^{1-\eta}\Phi_t\phi_{it}$. Inserting the expression for marginal costs derived above into this expression for revenue yields

$$\begin{aligned}
\ln r_{it} &= (1-\eta)\ln\frac{\eta}{\eta-1} + (1-\eta)\ln c_{it} + \ln\Phi_t + \ln\phi_{it} \implies \\
\ln r_{it} &= \kappa_2 + \frac{1}{\zeta}\ln\Phi_t + \frac{\eta-1}{\zeta}\left(\beta_k \ln k_{it} - \beta_l \ln w_t - \gamma \ln Q_{it}\right) + \omega_{it} + \epsilon_{it},
\end{aligned}$$

where we defined $\kappa_2 = \frac{1-\eta}{\zeta}\left[\kappa_1 + (\beta_l+\gamma)\ln\frac{\eta}{\eta-1}\right]$, $\zeta \equiv 1 + (1-\beta_l-\gamma)(\eta-1) > 1$, $\omega_{it} = (1/\zeta)\ln\phi_{it} + \tilde{\omega}_{it}(\eta-1)/\zeta$, and added the classical measurement error term ϵ_{it}.

Recall that the import share $G(n_{it})$ is defined as $G(n_{it}) = \sum_{j\in M}\gamma_j/\gamma$. The price index on inputs is $Q_{it} = \prod_{j=1}^{J}\left(\frac{q_{ijt}}{\gamma_j/\gamma}\right)^{\gamma_j/\gamma}$. Hence we can rewrite the log price index as

$$\ln Q_{it} = \sum_{j=1}^{J}\frac{\gamma_j}{\gamma}\ln\left(\frac{q_{ijt}}{\gamma_j/\gamma}\right) = -\sum_{j\in M}\frac{\gamma_j}{\gamma}a_t - \sum_{j=1}^{J}\frac{\gamma_j}{\gamma}\ln\frac{\gamma_j}{\gamma} = -a_t G(n_{it}) - \kappa_4,$$

where $\kappa_4 = \sum_{j=1}^{J}(\gamma_j/\gamma)\ln(\gamma_j/\gamma)$. We can therefore rewrite the revenue function as

$$\ln r_{it} = \kappa_2^{'} + \frac{1}{\zeta}\ln\Phi_t + \frac{\eta-1}{\zeta}\left(\beta_k \ln k_{it} - \beta_l \ln w_t + \gamma a_t G(n_{it})\right) + \omega_{it} + \epsilon_{it}, \tag{28}$$

where $\kappa_2^{'} = \kappa_2 + \gamma\kappa_4(\eta-1)/\zeta$.

Since capital is fixed in the short run, a given demand shock does not translate into a proportional increase in revenue. This is captured by the ζ term. A high ζ means that marginal cost is very sensitive to output changes. Consequently, a positive demand shock leads to a smaller increase in revenue when ζ is high, as the cost increase is passed on to higher prices, which depresses demand. In the case of $\zeta = 1$, marginal costs are constant, which would be the case if capital is a flexible input.

C Marginal returns to R&D and foreign sourcing

In this section, we first show that lower sourcing costs increase profits and that the magnitude is increasing in performance, ω_{it} (see Section 4.3). Next, we show that higher firm performance and lower foreign sourcing costs increase the marginal returns from foreign sourcing (see Section 4.4).The Return to R&D

Using the expression for revenue in equation (12), we can write variable profits as

$$\begin{aligned}\pi_{it} &= (1-\frac{\eta-1}{\eta}(\beta_l+\gamma))\exp\left[\kappa_2^{'}+\frac{1}{\zeta}\ln\Phi_t+\frac{\eta-1}{\zeta}\left(\beta_k\ln k_{it}-\beta_l\ln w_t+a_t\gamma G\left(n_{it}\right)\right)+\omega_{it}+\epsilon_{it}\right] \\ &= \Xi_{it}e^{(\eta-1)a_t\gamma G(n_{it})/\zeta+\omega_{it}},\end{aligned}$$

where $\Xi_{it}\equiv(1-\frac{\eta-1}{\eta}(\beta_l+\gamma))\exp\left[\kappa_2^{'}+\frac{1}{\zeta}\ln\Phi_t+\frac{\eta-1}{\zeta}\left(\beta_k\ln k_{it}-\beta_l\ln w_t\right)+\epsilon_{it}\right]$. Differentiating with respect to a, we get

$$\frac{\partial\pi_{it}}{\partial a_t} = \pi_{it}\frac{\eta-1}{\zeta}\gamma G\left(n_{it}\right)>0.$$

Moreover,

$$\frac{\partial^2\pi_{it}}{\partial a_t\partial\omega_{it}}=\pi_{it}\frac{\eta-1}{\zeta}\gamma G\left(n_{it}\right)>0.$$

Hence, lower sourcing costs raise profits and the magnitude is increasing in performance.

Using the expressions above and the assumption about constant and perfect knowledge about future Θ_{it}, we have

$$\frac{\partial E\left[\pi_{it+1}\left(\omega_{it},d_{it},\Theta_{it}\right)\right]}{\partial a_t}=\frac{\eta-1}{\zeta}\gamma G\left(n_{it+1}\right)E\left[\pi_{it+1}\left(\omega_{it},d_{it},\Theta_{it}\right)\right].$$

From the Markov process and profit function, it follows that $E\left[\pi_{it+1}\left(\omega_{it},d_{it}=1,\Theta_{it}\right)\right]>E\left[\pi_{it+1}\left(\omega_{it},d_{it}=0,\Theta_{it}\right)\right]$. This implies that

$$\frac{\partial E\left[\pi_{it+1}\left(\omega_{it},d_{it}=1,\Theta_{it}\right)\right]}{\partial a_t}>\frac{\partial E\left[\pi_{it+1}\left(\omega_{it},d_{it}=0,\Theta_{it}\right)\right]}{\partial a_t},$$

as stated in the main text.

C.1 The Return to Foreign Sourcing

The marginal change in profits from sourcing one more variety from the foreign market is

$$\pi\left(\omega_{it}, n_{it}, \Theta_{it}\right) - \pi\left(\omega_{it}, n_{it}-1, \Theta_{it}\right) = \Xi_{it} e^{\omega_{it}} \left(e^{(\eta-1)a_t \gamma G(n_{it})/\zeta} - e^{(\eta-1)a_t\gamma G(n_{it}-1)/\zeta}\right).$$

Differentiating with respect to a_t yields

$$\frac{\partial\left[\pi\left(\omega_{it}, n_{it}, \Theta_{it}\right) - \pi\left(\omega_{it}, n_{it}-1, \Theta_{it}\right)\right]}{\partial a_t} = \Xi_{it} e^{\omega_{it}} \frac{\eta-1}{\zeta}\gamma \left(e^{(\eta-1)a_t\gamma G(n_{it})/\zeta} G\left(n_{it}\right) - e^{(\eta-1)a_t\gamma G(n_{it}-1)/\zeta} G\left(n_{it}-1\right)\right) > 0,$$

which is positive since $\Xi_{it} > 0$, $\eta > 1$, $a_t > 0$ and $G\left(n_{it}\right)$ is increasing in n. Hence, a decline in the cost of foreign sourcing (an increase in a_t) raises marginal profits from foreign sourcing.

Differentiating with respect to ω_{it} yields

$$\frac{\partial\left[\pi\left(\omega_{it}, n_{it}, \Theta_{it}\right) - \pi\left(\omega_{it}, n_{it}-1, \Theta_{it}\right)\right]}{\partial \omega_{it}} = \Xi_{it} e^{\omega_{it}} \left(e^{(\eta-1)a_t\gamma G(n_{it})/\zeta} - e^{(\eta-1)a_t\gamma G(n_{it}-1)/\zeta}\right) > 0.$$

Hence, higher performance also increases marginal returns to foreign sourcing. Hence, the optimal number of imported inputs, $n^*_{it}\left(\omega_{it}, \Theta_{it}\right)$ is increasing in ω_{it} and a_t.

We use the expressions above to show that the expected number of imported inputs is higher for R&D firms than non-R&D firms. Using the Markov process, we have

$$\Pr\left[\omega_{it} < \omega_0 \quad | \quad d_{it-1}, \omega_{it-1}\right] \quad = \quad \Pr\left[\xi_{it} < \omega_0 - \alpha_0 - \alpha_1\omega_{it-1} - \alpha_2\omega^2_{it-1} - \alpha_3 d_{it-1}\right].$$

Hence, $\Pr\left[\omega_{it} < \omega_0 | d_{it-1} = 0, \omega_{it-1}\right] > \Pr\left[\omega_{it} < \omega_0 | d_{it-1} = 1, \omega_{it-1}\right]$ for all ω_0, implying that the performance of R&D firms first-order stochastically dominates the performance of non-R&D firms. Because $n^*\left(\right)$ is a non-decreasing function in ω_{it}, the following holds:

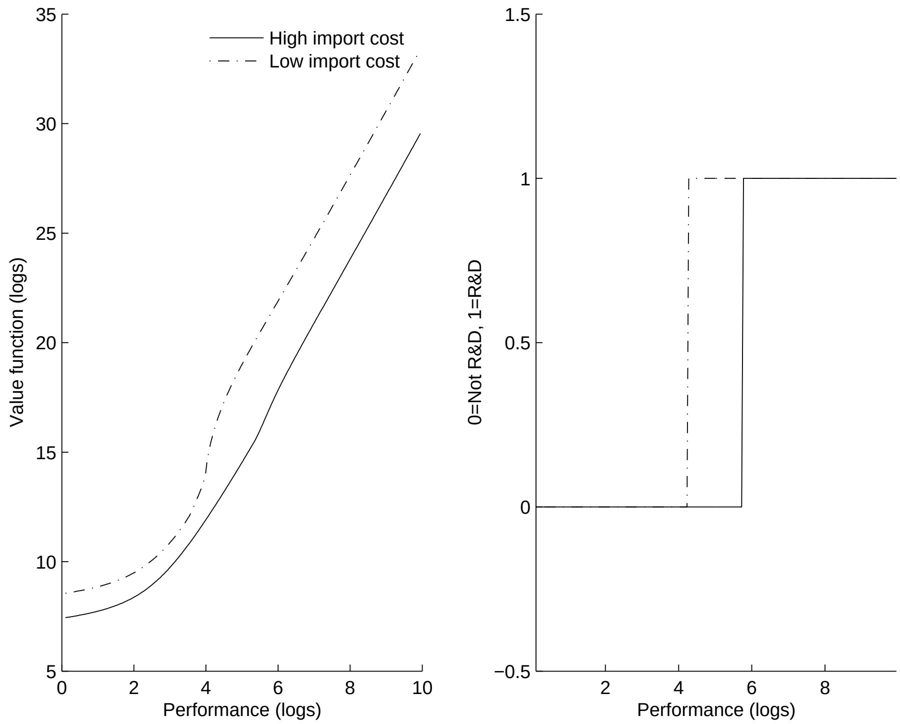
$$E\left[n^*\left(\omega_{it+1}\left(\omega_{it}, d_{it}=1\right), \Theta_{it}\right)\right] \geq E\left[n^*\left(\omega_{it+1}\left(\omega_{it}, d_{it}=0\right), \Theta_{it}\right)\right],$$

i.e. the expected number of imported inputs in $t+1$ is higher for year t R&D firms compared to non-R&D firms, all else equal.

D Lower Sourcing Costs and R&D

Proposition 1 states that a decline in foreign sourcing costs (higher a_t) lowers the R&D threshold $\underline{\omega}()$. This section shows that the proposition holds in a full numerical simulation of the model. We proceed as follows. First we pick a set of common parameter values, summarized in the footnote of Figure 6, and a high and low value of the import cost, $a_2 > a_1$.

Figure 6: Lower import costs and the impact on R&D



Parameter values used: $\delta = 0.95$, $\alpha_0 = .2$, $\alpha_1 = 0.9$, $\alpha_2 = 0$, $\alpha_3 = 0.04$, $\eta = 4$, $\zeta = 1$, $\ln f_i = 13.1$, $\ln f_d = 13.8$, $J = 10$. ξ_{it} is i.i.d. normal with mean 0 and standard deviation 0.2. Log performance ω_{it} has support $[0.1, 10]$ and is discretized with 200 points on a grid. All other variables are normalized to 1, so that log revenue becomes $\ln r_{it} = \frac{\eta-1}{\zeta} a\gamma G(n_{it}) + \omega_{it}$. Low import cost: $a_2\gamma = 2.0$, high import cost: $a_1\gamma = 0.4$. As in the main text, we use $G(n_{it}) = \ln(1 + n_{it}) / \ln(1 + n_{max})$.

Second, we discretize log performance and iterate over the value function in equation (15) until convergence, separately in the a_1 and a_2 case. The left graph in Figure 6 shows the value function for a_2 (low import cost, dotted line) and a_1 (high import cost, solid line.) The right graph shows the optimal R&D choice as a function of the state variable performance, for low import costs (dotted line) and high import costs (solid line). Trade liberalization leads to a decline in the cutoff $\underline{\omega}$ and hence more firms perform R&D when import costs are lower.

E The Control Function

Our baseline methodology uses the control function $\omega_{it} = \tilde{F}(m_{it}, k_{it}, n_{it})$ where $\tilde{F}()$ is approximated by a second order polynomial. In this section, we derive the functional form of

$\tilde{F}()$ under the assumption that the production function is Cobb-Douglas. In the subsequent section, we modify the estimating model to account for this change.

Recall that the production function is $y_{it} = l_{it}^{\beta_l} k_{it}^{\beta_k} V_{it}^{\gamma} e^{\tilde{\omega}_{it}}$, where the firm specific aggregate of intermediates is given by $V_{it} = \prod_j^J v_{ijt}^{\gamma_j/\gamma}$. Define Q_{it} as the associated firm specific price index, $Q_{it} = \prod_j^J \left(\frac{q_{ijt}}{\gamma_j/\gamma}\right)^{\gamma_j/\gamma}$. Cost minimization requires that

$$\frac{\partial y_{it}}{\partial V_{it}} = \frac{Q_{it}}{(1-1/\eta)\, p_{it}}.$$

Solving the FOC,

$$V_{it} = \left(\frac{(1-1/\eta)\, p_{it}}{Q_{it}} l_{it}^{\beta_l} k_{it}^{\beta_k} \gamma e^{\tilde{\omega}_{it}}\right)^{1/(1-\gamma)}.$$

Substitute the output price by inverted demand, $p_{it} = y_{it}^{-1/\eta} \left(\Phi_t \phi_{it}\right)^{1/\eta}$ and substitute output by the production function yields

$$V_{it} = \left(\frac{(1-1/\eta)\left(l_{it}^{\beta_l} k_{it}^{\beta_k} V_{it}^{\gamma} e^{\tilde{\omega}_{it}}\right)^{-1/\eta} \left(\Phi_t \phi_{it}\right)^{1/\eta}}{Q_{it}} l_{it}^{\beta_l} k_{it}^{\beta_k} \gamma e^{\tilde{\omega}_{it}}\right)^{1/(1-\gamma)}.$$

From equation (26) we know that the ratio of the FOCs are $l_{it} = V_{ijt}\left(Q_{it}/w_t\right)\left(\beta_l/\gamma\right)$. Inserting this into the expression for V_{it} yields

$$V_{it} = \left(\frac{(1-1/\eta)\left(k_{it}^{\beta_k} V_{it}^{\gamma} e^{\tilde{\omega}_{it}}\right)^{-1/\eta} \left(\Phi_t \phi_{it}\right)^{1/\eta}}{Q_{it}} \left(V_{ijt} \frac{Q_{it}}{w_t} \frac{\beta_l}{\gamma}\right)^{\beta_l(1-1/\eta)} k_{it}^{\beta_k} \gamma e^{\tilde{\omega}_{it}}\right)^{1/(1-\gamma)}.$$

Rearranging and taking logs produces

$$\frac{\eta-1}{\eta}\tilde{\omega}_{it} + \frac{1}{\eta}\ln\phi_{it} = \kappa_3 - \frac{1}{\eta}\ln\Phi_t + \beta_l^+ \ln w_t + \left(1-\beta_l^+\right)\ln Q_{it} + \left(1-\gamma^+ - \beta_l^+\right)\ln V_{it} - \beta_k^+ \ln k_{it},$$

where $\kappa_3 = \ln\left[\gamma^{-1}\left(\beta_l/\gamma\right)^{-\beta_l(\eta-1)/\eta} \eta/\left(\eta-1\right)\right]$ and $+$ denotes multiplied by $\left(\eta-1\right)/\eta$.

Q_{it} and V_{it} are not observed, but m_{it} (materials expenditure) and n_{it} (number of imported inputs) are. Using the fact that $m_{it} = V_{it} Q_{it}$ and $\ln Q_{it} = -aG\left(n_{it}\right) - \kappa_4$ yields

$$\frac{\eta-1}{\eta}\tilde{\omega}_{it} + \frac{1}{\eta}\ln\phi_{it} = \kappa_3 - \gamma^+ k - \frac{1}{\eta}\ln\Phi_t + \beta_l^+ \ln w_t - \gamma^+ aG\left(n_{it}\right) + \left(1-\gamma^+ - \beta_l^+\right)\ln m_{it} - \beta_k^+ \ln k_{it}.$$

We have defined $\omega_{it} \equiv [\ln \phi_{it} + (\eta - 1)\tilde{\omega}_{it}]/\zeta$. Hence we can rewrite the expression as

$$\omega_{it} = \kappa_5 - \frac{1}{\zeta}\ln \Phi_t + \beta_l^* \ln w_t - \gamma^* aG(n_{it}) + \ln m_{it} - \beta_k^* \ln k_{it}, \tag{29}$$

where $\kappa_5 = \frac{\eta}{\zeta}\kappa_3 - \gamma^+\kappa_4$ and$*$ denotes multiplied by $(\eta - 1)/\zeta$. This is the functional form for $\omega_{it} = \tilde{F}(m_{it}, k_{it}, n_{it})$ in the Cobb-Douglas case.

F Estimation with Parametric $F()$ Function

In this section, we show how to estimate the model with the specific functional form for $\tilde{F}()$ derived in the previous section.

Let $\ln \tilde{r}_{it} \equiv \ln r_{it} - \ln \bar{r}_{it}$ denote revenue relative to yearly means. Define other variables correspondingly. Inserting the Markov process into the revenue function yields

$$\ln \tilde{r}_{it} = \beta_k^* \ln \tilde{k}_{it} + \gamma^* aG(\tilde{n}_{it}) + \alpha_1 \tilde{\omega}_{it-1} + \alpha_2 \widetilde{\omega_{it-1}^2} + \alpha_3 \tilde{d}_{it-1} + \tilde{\xi}_{it} + \tilde{\epsilon}_{it}.$$

The next step is to substitute $\tilde{\omega}_{it-1}$ and $\widetilde{\omega_{it-1}^2}$ with the control function in equation (29). It can be shown that $\widetilde{\omega_{it}^2} = \tilde{\omega}_{it}^2 + 2\mu\tilde{\omega}_{it} - var(\omega_{it})$, where $\mu = E(\omega_{it})$.[46] Then,

$$\begin{aligned}
\ln \tilde{r}_{it} \quad = \quad & \kappa_6 + \beta_k^* \ln \tilde{k}_{it} + \gamma^* aG(\tilde{n}_{it}) + \\
& + \alpha_1^{'} \left(\ln \tilde{m}_{it-1} - \gamma^* aG(\tilde{n}_{it-1}) - \beta_k^* \ln \tilde{k}_{it-1} \right) \\
& + \alpha_2 \left(\ln \tilde{m}_{it-1} - \gamma^* aG(\tilde{n}_{it-1}) - \beta_k^* \ln \tilde{k}_{it-1} \right)^2 + \alpha_3 \tilde{d}_{it-1} + \tilde{\xi}_{it} + \tilde{\epsilon}_{it}.
\end{aligned} \tag{30}$$

where $\kappa_6 = -\alpha_2 var(\omega_{it})$ and $\alpha_1^{'} = \alpha_1 + 2\mu\alpha_2$.

Compared to the empirical methodology in the main text, there are two main differences. First, we collapsed the two stages to one stage. Second, predicted revenue h_{it} used in the main text is here replaced with intermediate purchases m_{it}. The results from estimating equation (30) are shown in Section 5.3.

G General R&D Costs and Policy Reform

There is a slight disconnect between the model and the reduced form strategy, as R&D is a binary variable in the model whereas it is continuous in the data. The reduced form exploits the fact that marginal costs of R&D only falls for a subset of firms, and that only firms in

[46] $\widetilde{\omega_{it}^2} \equiv \omega_{it}^2 - E(\omega_{it}^2) = \omega_{it}^2 - \mu^2 - var(\omega_{it}) = (\omega_{it} - \mu)^2 + 2\omega_{it}\mu - 2\mu^2 - var(\omega_{it}) = \tilde{\omega}_{it}^2 + 2\omega_{it}\mu - 2\mu^2 - var(\omega_{it}) = \tilde{\omega}_{it}^2 + 2\mu\tilde{\omega}_{it} - var(\omega_{it})$.

this subset are treated by the policy reform. In this section, we first show that this logic also applies for the case of a binary R&D choice. Second, we show that it can also be extended to the case of multiple fixed costs.

Binary case The policy reform effectively reduced R&D costs by 20 percent up to a threshold of NOK 4 million, i.e. $f'_d = (1-\beta) f_d$ for $f_d \leq 4$ million and $f'_d = f_d - (4 \text{ million}) \beta$ for $f_d > 4$ million, where $\beta = 0.2$. From the model, we know that $d_{it} = 1$ if $\omega > \underline{\omega}(\Theta_i, f_d)$. A decrease in the R&D fixed costs from f_d to f'_d would lower $\underline{\omega}()$, which would make some firms switch from $d_{it} = 0$ to $d_{it} = 1$. Firms treated by the policy reform have by construction ex-ante R&D status $d_{it} = 0$, while the control group of unaffected firms have $d_{it} = 1$.

Multiple fixed costs Consider the case where firms face a menu of 4 different fixed costs, $f_d^1 < f_d^2 < \mathit{\Gamma} < f_d^3 < f_d^4$, where $\mathit{\Gamma} =$ NOK 4 million, and that the returns to R&D are increasing in the costs, $\alpha_2^1 < \alpha_2^2 < \alpha_2^3 < \alpha_2^4$. Denote the expected net present value of future profit flows for each choice V^k, $k = 1, .., 4..$ Before the policy reform, future profit flows minus the cost of innovating are $V^k - f_d^k$. After the policy reform, the future profit flows minus the cost of innovating are

$$
\begin{aligned}
&V^1 - (1-\beta) f_d^1 \\
&V^2 - (1-\beta) f_d^2 \\
&V^3 - \left[f_d^3 - \beta \mathit{\Gamma}\right] \\
&V^4 - \left[f_d^4 - \beta \mathit{\Gamma}\right].
\end{aligned}
$$

Now consider the choice between f_d^1 and f_d^2 before and after the reform. Before the reform, a firm would choose $k = 2$ whenever $V^2 - V^1 > f_d^2 - f_d^1$. After the reform, the firm would choose $k = 2$ whenever $V^2 - V^1 > (1-\beta)(f_d^2 - f_d^1)$. Hence, as long as $\beta > 0$ the firm is more likely to switch from $k = 1$ to $k = 2$ after the reform.

Now consider the choice between f_d^3 and f_d^4 before and after the reform. Before the reform, a firm would choose $k = 4$ whenever $V^4 - V^3 > f_d^2 - f_d^1$. After the reform, the firm would choose $k = 4$ whenever $V^4 - V^3 > f_d^4 - f_d^3$. Hence, the firm is not more likely to switch from $k = 3$ to $k = 4$ after the reform. This shows that the construction of the treatment and control group is equally valid in the case of non-continuous R&D costs.

H A Functional Form for $G(n_{it})$

The empirical methodology and simulation require a functional form for $G(n_{it})$. In this section, we show that our choice of $G(n_{it}) = \ln(1+n_{it}) / \ln(1+n_{max})$ fits the data well. We also provide evidence that the functional form is appropriate across different industries and across different types of firms.

Recall that $G(n_{it})$ is defined as the cost share of joint domestic and imported inputs relative to all inputs. Using the expression for the CES price index for a given input j in equation (10), the expenditure share of the foreign input in total spending on input j is

$$s_t = \left(\frac{\tilde{q}_{jtF}/b_{jt}}{q_{ijt}}\right)^{1-\theta} = \frac{(\tilde{q}_{jtF}/b_{jt})^{1-\theta}}{1+(\tilde{q}_{jtF}/b_{jt})^{1-\theta}},$$

which by assumption is constant across products (Section 4.2). Hence, the share of imports in total spending on inputs is

$$\frac{Imp_{it}}{m_{it}} = \frac{s_t \sum_{j=1}^{n} \gamma_j}{\gamma} = s_t G(n_{it}).$$

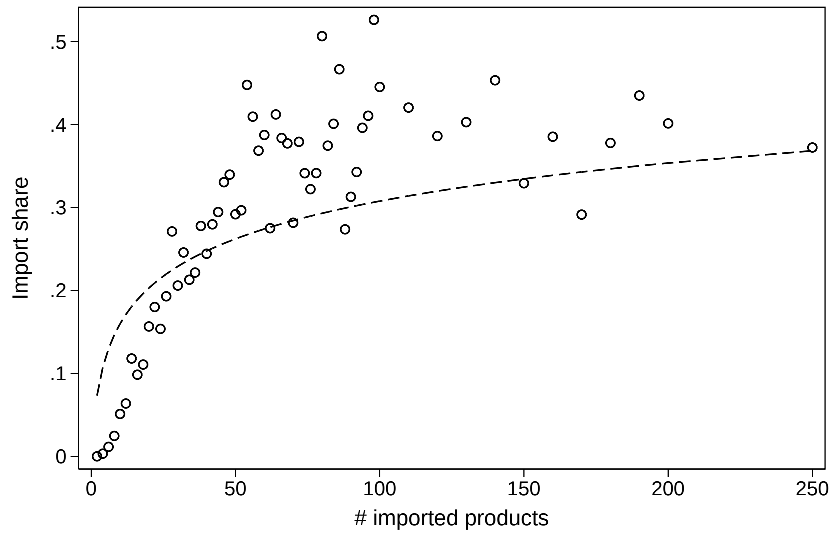
Both the total cost of inputs m_{it} and total imports Imp_{it} are observable in our data. We proceed by calculating the average $s_t\bar{G}(n)$ for every n found in our data, e.g $s_t\bar{G}(1)$ is the average import share across all firm-years with 1 imported product, and so on.

Figure 7 plots $s_t\bar{G}(n)$ against n for all firms in our sample. We have superimposed the function $\ln(1+n)$, which is represented by the dotted line. Overall, the chosen functional form captures the pattern in the data quite well. Next, Figure 8 shows the same plot separately for capital intensive and non-capital intensive firms, where capital intensive firms are defined as firms with a capital labor ratio above the median ratio. The G function fits relatively well for both groups of firms, suggesting that our assumption of a common G for all firms within an industry is a good approximation of the data. Finally, Figure 9 shows the same plot for the four largest manufacturing sectors (in terms of active number of firms). Again, our chosen functional form performs well for all industries.

I Simulation: The Distribution of Imported Products

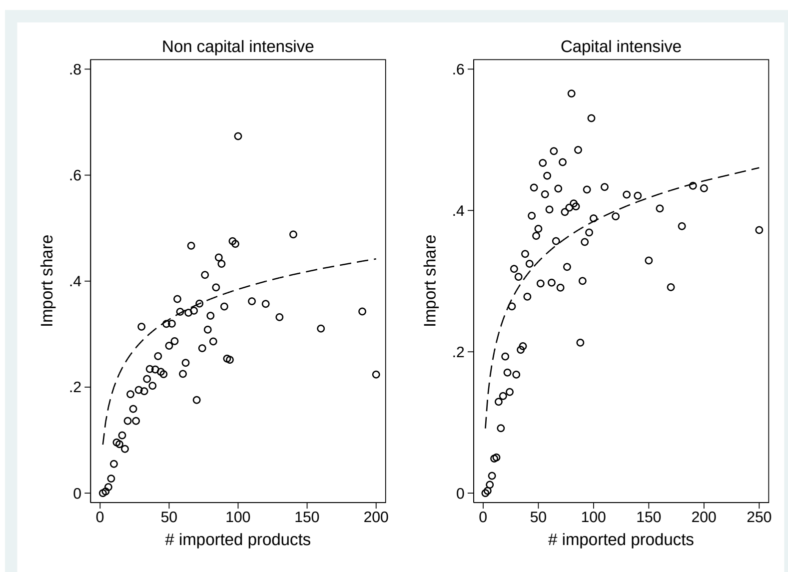
In this section, we explore the fit of the simulated distribution of the number of imported inputs, n_i^*. Figure 10 shows the histogram of the 2001 number of imported inputs; the black bars are data and the white bars are the simulation. Overall, the shapes of the simulated and actual distributions are quite close, although the model has too many firms in the first

Figure 7: Imported inputs and average import share.



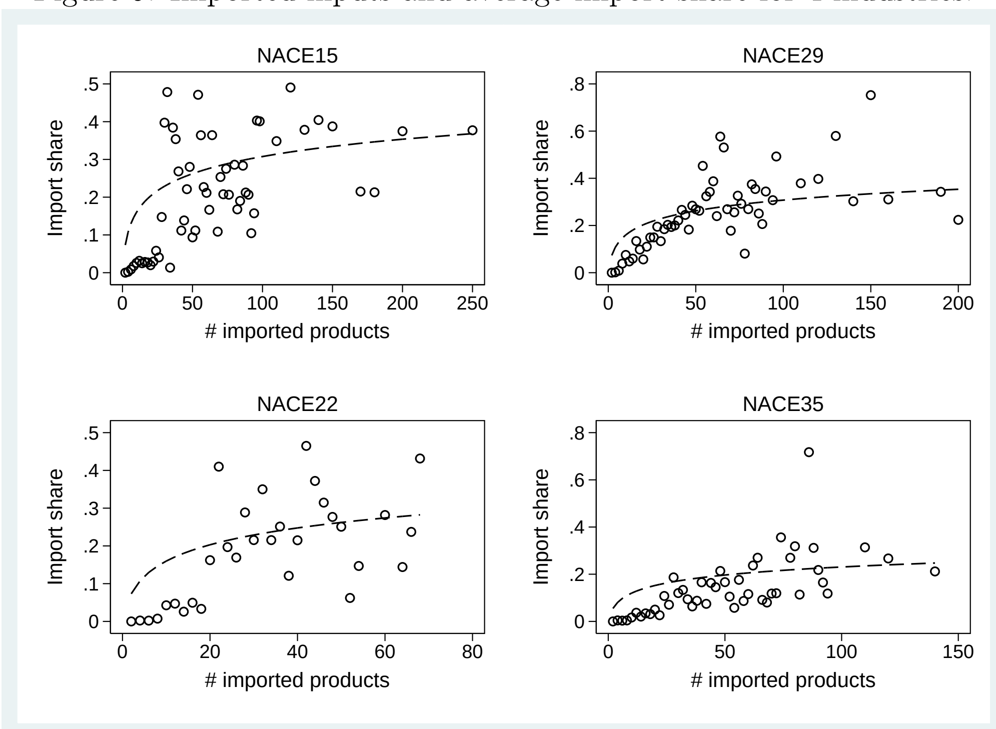
Notes: The number of imported inputs is grouped into bins of 1-2, 3-4, .., 99-100, 101-110, 111-120, .., 191-200, 200-. The vertical axis shows the average import share across firm belonging to each bin. The dotted line is the function $\ln(1+n)$.

Figure 8: Imported inputs and average import share. Capital intensive and non-capital intensive firms.



Notes: The number of imported inputs is grouped into bins of 1-2, 3-4, .., 99-100, 101-110, 111-120, .., 191-200, 200-. The vertical axis shows the average import share across firm belonging to each bin. The dotted line is the function $\ln(1+n)$.

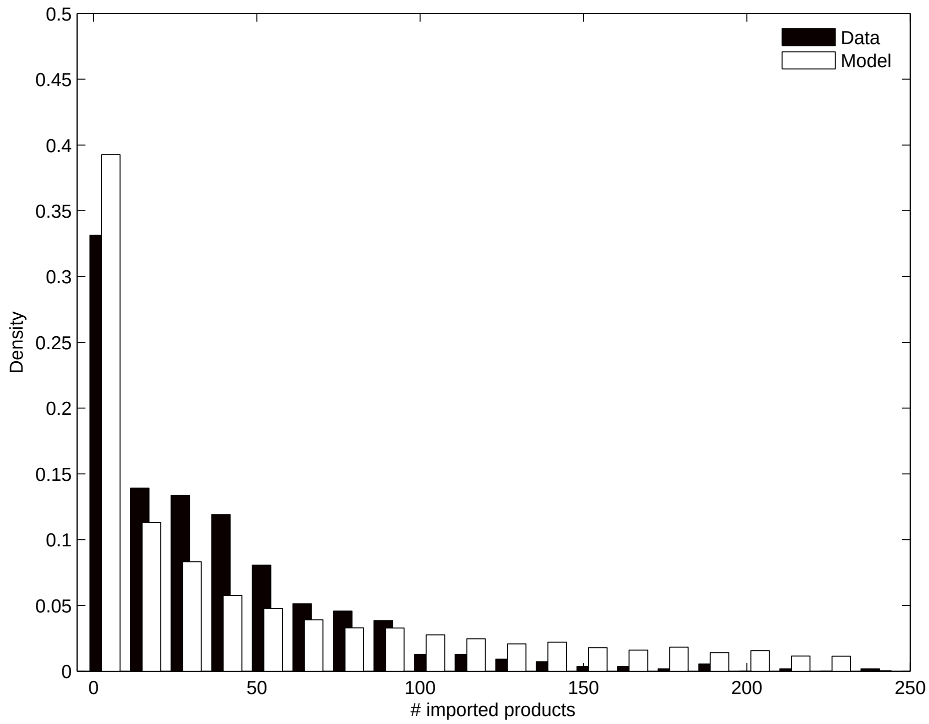
Figure 9: Imported inputs and average import share for 4 industries.



Notes: The number of imported inputs is grouped into bins of 1-2, 3-4, .., 99-100, 101-110, 111, 120, .., 191-200, 200-. The vertical axis shows the average import share across firm belonging to each bin. The dotted line is the function $\ln(1+n)$.

bin and too few firms some of the upper bins. Note that only the calibrated parameters μ and $\sigma_{\ln f}$ for the lognormal distribution of f_i is used to match this distribution.

Figure 10: Distribution of the number of imported inputs across firms. Data and simulation.



Notes: Imported products refer to unique HS 4-digit products.

J Data.

J.1 The Norwegian R&D data

The R&D survey measures R&D activity in the Norwegian business enterprise sector.[47] The statistics are comparable to statistics for other countries and are reported to the OECD and EUROSTAT. The R&D survey includes: (i) all firms with at least 50 employees; (ii) all firms with less than 50 employees and with reported intramural R&D activity in the previous survey of more than NOK 1 million or extramural R&D of more than NOK 3 million; (iii) among other firms with 10-49 employees a random sample was selected within each strata (NACE 2-digit and size class).

[47]It includes the entire manufacturing sector and the majority of the service sector, but leaves out some service industries with insignificant R&D activity.

J.2 Identifying import competing sectors

To rank the industries according to the degree of import competition from China, we use data gathered from Statistics Norway on Chinese imports to Norway. The data is based on the 2-digit SITC code, which cannot easily be matched to the 2-digit NACE code in the Capital database. Hence, to get around this problem, we use the correspondence table from Eurostat and count the number of 5-digit SITC sectors corresponding to each 2-digit NACE sector. We proceed by matching the 2-digit SITC sectors to the 2-digit NACE sector with the most 5-digit matches. Finally we calculate Chinese import shares (of total Norwegian imports) per NACE 2 sectors.

J.3 R&D intensity of imports

Using data from the OECD's iLibrary, we generate country-specific measures of R&D intensity for each manufacturing sector, given by the number of persons employed as R&D personnel relative to the total number of employees in the sector. We average across the relevant years.

While OECD R&D data is based on the 2-digit International Standard Industrial Classification (ISIC), our trade data follows the Harmonized System (HS) and the Standard International Trade Classification (SITC). To be able to match the trade data to the OECD data, we use a correspondence table from Eurostat, the statistical office of the European Union. Each HS number is matched at the 5-digit SITC level to the 2-digit ISIC code.

The imports for each firm are then aggregated to the 2-digit sector level and matched with the average R&D intensities for the source countries. Finally, the firm-level import R&D intensity is constructed as an average of the country and sector specific R&D intensities, weighted by each country-sector's share of the firm's total imports.

K Additional tables and figures

Table 13: Treatment and control groups, average, 2001.

	$H_{1i} = 1$	$H_{1i} = 0$
Employees	134	377
# imported products	26	73
Import share	0.18	0.28
Labor productivity	512	633
R&D expenditure	592	47,054
No. of obs.	668	136

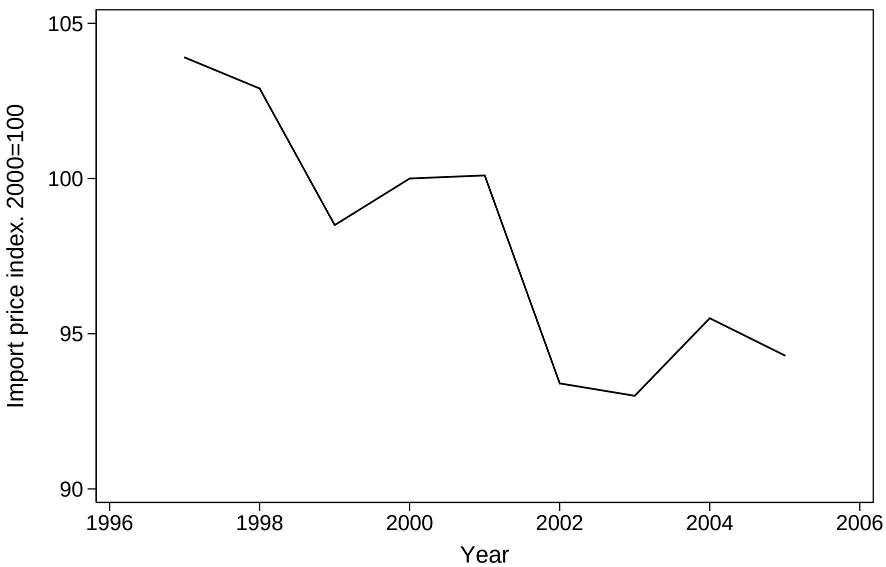
Notes: Imported products refer to unique HS 4-digit products. R&D expenditure is measured in 1000 NOK. Import share is defined as firm import value relative to operating costs. Labor productivity is defined as real value added relative to employees in 1000 NOK. All numbers are simple averages across the two groups.

Table 14: Most popular products.

Count	Value
8479 Machinery for public works, building or the like	7501 Nickle mattes
3926 Other articles of plastic (e.g. machines joints and gaskets, transmission, conveyor or elevator belts and belting)	2818 Aluminum oxide
7326 Forged or stamped articles of iron and steel, but not further worked	7601 Aluminum, not alloyed, unwrought

Notes: Imported products refer to unique HS 4-digit products. Column 1 shows the most popular products in our sample in terms of count, i.e., the number of firms importing these products. Column 2 shows the most popular products in terms of value.

Figure 11: Import price index. 1997-2005.



Notes: The figure shows the import price index for manufactured goods except food, beverages and tobacco. Year 2000=100. Source: http://ssb.no/en/utenriksokonomi/statistikker/uhvp.