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Using matched UK administrative data, this paper examines how global trade expansion during 2002-2011 affected R&D investment of British firms. We find that Chinese import competition significantly discouraged firm R&D. Booming export demand, by contrast, stimulated their innovation efforts, mitigating the adverse competition effect. Our findings further reveal heterogeneity. More productive firms increased R&D spending by more in response to foreign demand. Exporting firms were less hurt by Chinese penetration than non-exporters. These together indicate the uneven consequences of globalization over the past decades for firm innovation, more detrimental to domestic and less profitable firms.

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Disclaimer

1 Introduction

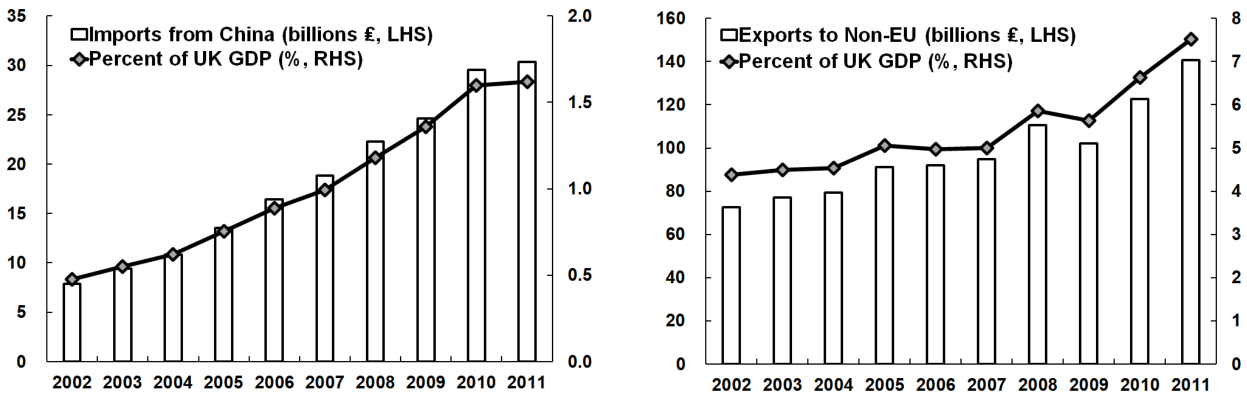
How international trade affects innovation is a central question for academics and policy makers as it relates to fundamental gains from trade liberalization. Beyond the traditional gains based on initial comparative advantages, more recent literature emphasizes the importance of dynamic gains from trade: Trade may induce endogenous changes in firm innovation and productivity, which will in turn determine the long-run consequences of free trade.

Using matched UK administrative data, this paper investigates how global trade expansion during 2002-2011 affected R&D investment of British manufacturers. We revisit the controversial effect of import competition on firm innovation. Following the literature, our analysis focuses on the specular growth of China in global trade since its entry into the World Trade Organization (WTO) in 2001. Empirical evidence on the effect of Chinese competition is mixed. Autor et al. (2020) show that rising Chinese imports adversely affected innovation for U.S. firms, whereas Bloom, Draca and Van Reenen (2015) find increased patenting and technological upgrading by European firms facing Chinese competition.[1] Relative to these studies focusing on import competition, we jointly assess the importance of export demand, exploiting detailed UK customs data. The past decades witnessed a rapid trade integration around the globe, in which firms in one country not only confronted increasing foreign competition but also gained better access to export markets. For the United Kingdom in Figure 1, the imports of goods from China as a ratio of the UK's gross domestic product (GDP) soured from 0.48 percent to 1.62 percent between 2002 and 2011 (left panel). The UK exports of goods to non-EU destinations during the same period, as a share of the national GDP, also rose from 4.38 percent to 7.51 percent (right panel). Therefore, a joint investigation into both import competition and export demand is crucial to get a better insight into the overall impact of globalization.

The data used in our analysis are drawn from three datasets: (1) firm R&D expenditures from UK corporate tax return data, (2) UK firms' trade transactions with non-EU countries, and (3) the Business Structure Database (BSD) which contains key firm characteristics for a near population of UK enterprises. We limit our attention to firm R&D as an outcome of interest. This is because innovation is the margin of adjustments most controversial in assessing the effect of Chinese competition. Several studies - including Bloom, Draca and Van Reenen (2015) who claimed a positive effect on innovation of European firms - find that

[1] Theories on how product-market competition affects innovation also suggest conflicting predictions (Shu and Steinwender (2019)). On the one hand, competition reduces the potential rents that firms can gain from innovating in a given market and thus their incentive to invest in innovation ("Schumpeterian effect"). On the other hand, tougher competition may induce firms to develop entirely new types of products or to introduce more efficient processes to shield themselves from the competition ("escape-competition effect").

Figure 1: Trades in Goods for United Kingdom



Note: 'Non-EU' indicates all destinations excluding 27 EU membership countries. Source: Office for National Statistics (ONS).

Chinese imports deteriorated sales and employment in manufacturing sectors.[2] Unlike the existing papers studying larger firms, this research covers relatively more small- and medium-size enterprises (SMEs) in UK manufacturing sectors, which is due to the use of corporate tax data for our analysis. Since 2000, the UK government provided tax incentives for R&D spending, and the majority of firms claiming the R&D tax returns are small and medium-sized.[3] An analysis of these SMEs that are less explored before not only complements the previous literature in understanding the heterogeneous responses to trade shocks across firms, but also has policy implications to foster these firms.

To summarize key results, we find that Chinese import competition significantly reduced UK firms' R&D, which is in line with Autor et al. (2020). UK firms in industries that were more exposed to rising Chinese imports experienced a larger fall in their R&D investment. No evidence is found that firms' own use of cheaper Chinese imports played any positive role to offset the negative competition effect. By contrast, we verify a stimulating effect of export demand on firms' innovation efforts. These suggest that booming export demand from outside the EU over the past decades had mitigated the adverse effect of rising Chinese imports to some degree. We further examine the heterogeneous effects of Chinese competition and export demand depending on firms' initial conditions. When it comes to Chinese competition, there is no significant difference in R&D responses over firm productivity. By contrast, we observe strong heterogeneity in the effects of export demand across UK firms'

[2] Autor et al. (2020) and Aghion et al. (2021) also find that product-market competition against China led to a fall in firm sales, employment and innovation for U.S. and French firms, respectively. For the UK, Foliano and Riley (2017) and De Lyon and Pessoa (2021) commonly find that UK manufacturing suffered from job losses facing Chinese import competition.

[3] Linking this R&D dataset with other datasets result in further attrition of some large firms due to many-to-many matches across different firm identifiers. For more details, see the data section.

productivity: Firms whose productivity is initially higher tend to raise their R&D spending by much more in response to an increase in foreign demand. We also find evidence that UK firms that initially engaged in exporting were less hurt by tougher Chinese competition. It would be because those firms that had already entered into exporting could more easily reallocate their sales away from the shrinking domestic market. These findings together indicate that globalization over the past decades had the uneven consequences for firm innovation, more adversely affecting purely domestic and less profitable firms.

This research relates to a broad empirical literature on trade and innovation. We investigate the long-standing debate on import competition and innovation. While empirical evidence is yet inconclusive, studies on developing countries such as Pavcnik (2002), Fernandes (2007), Amiti and Konings (2007), Topalova and Khandelwal (2011) and Iacovone (2012) provide supportive evidence of a positive impact of foreign competition on productivity and innovation. More recent work on advanced economies, such as Bloom, Draca and Van Reenen (2015) and Autor et al. (2020), suggests more conflicting results in the context of a surge in Chinese imports. This paper contributes to this strand of research as another case-study for an advanced economy - the United Kingdom. This paper also adds to literature on the interaction between export market access and technology upgrading of individual firms, which includes Lileeva and Trefler (2010), Bustos (2011), Coelli, Moxnes and Ulltveit-Moe (2020) and Aghion, Bergeaud, Lequien and Melitz (2018). Several papers find that an increase in export market size stimulates firm productivity by boosting the profitability of investments in technology. Using firm-level trade data, we establish the casual impact of export demand on firm R&D and assess its quantitative importance as well.

The remainder of the paper proceeds as follows. Section 2 describes the data source and section 3 details the empirical strategy. Section 4 presents the empirical results. Section 5 concludes.

2 Data

Our empirical analysis uses three datasets: (1) the UK corporate tax dataset which provides UK firms' R&D expenditures; (2) the UK customs dataset which contains detailed firm-level information on trades with non-EU countries; (3) the UK Business Structure Database (BSD) from the Office of National Statistics (ONS) which provides key characteristics on the universe of UK enterprises. The first two administrative datasets are managed by Her Majesty's Revenue and Customs (HMRC), the UK tax authority. The HMRC administrative datasets can be accessed and analysed only within a designated HMRC facility (HMRC Datalab).[4]

R&D Expenditure Data: The key variable in our analysis is R&D expenditures for individual UK firms which were reported for R&D tax reliefs to HMRC between 2002 and 2011. This information is obtained from the Research and Development Tax Credits (RDTC) dataset, an extension of the UK corporate tax return dataset (CT600). In 2000, the UK government introduced R&D tax incentives to support innovative activities of UK firms and operated the scheme until a major reform in 2012. The UK R&D tax credit allowed firms to deduct their qualified R&D spending with an enhanced rate from their taxable profits.[5]

Using firms' R&D expenditures as a key innovation input has its own merit. Several studies use patenting or total factor productivity (TFP) to measure firm innovation. However, changes in TFP could reflect other forces like markup changes rather than productivity changes due to innovation (Shu and Steinwender (2019)). Patenting, a popular measure of innovation output, is not without limitations: Not all innovations are patented. For instance, less than half of R&D performing UK firms patented during 2006-2011 (Dechezleprêtre et al. (2016)). Nor does patenting necessarily represent new innovation since firms may patent as a means to protect their existing knowledge from threats of imitation by competitors (Aghion et al. (2018) and Yamashita and Yamauchi (2020)). Another advantage of using the administrative dataset is that it provides information on R&D spending of small and medium-sized enterprises (SMEs), which is rare in the prior literature studies relying on survey data or financial statements for large listed firms.[6]

Business Structure Database: For key firm characteristics, we use the UK's Business Structure Database (BSD) maintained by the Office for National Statistics (ONS). The BSD contains annual information on the universe of active UK firms between 1997 and 2016, cov-

[4]The HMRC Datalab is a Research Data Centre (RDC) that allows approved researchers to use HMRC data in a secure environment. Merging these datasets with other datasets such as the BSD in this paper is also subject to a permission from HMRC.

[5]HMRC sets three main categories of R&D expenditures eligible for tax relief claims - staffing costs, consumables (water, electricity etc.) and software that are directly used for R&D. It is estimated that the R&D expenditures qualifying for tax reliefs for the year 2011 amount to approximately 70 percent of the current spending in the Business Enterprise Research and Development (BERD) data published by the ONS. For more details on the UK's R&D tax relief scheme, see Dechezleprêtre et al. (2016) and Guceri and Liu (2019).

[6]For instance, among the papers using R&D data, Bloom, Draca and Van Reenen (2015) study European listed firms from Amadeus. Xu and Gong (2017), Hombert and Matray (2018) and Autor et al. (2020) study U.S. firms from Compustat. Iacovone (2012) uses survey data on Mexican manufacturers that are more representative of large firms. Bøler, Moxnes and Ulltveit-Moe (2015) also use survey data for a subset of Norwegian firms with 50 or more employees.

ering nearly 99 percent of UK economic activity. Our analysis uses firm information such as enterprise reference number (Entref), employment, turnover, country of ownership, industry affiliation based on the 2003 revision of UK Standard Industrial Classification (UK SIC), year of birth (company start-up date), as well as location of company by UK postcode.

Firm-level Trade Data: We exploit the firm-level overseas trade data provided by HMRC. The trade dataset contains information on UK firms' import and export declarations with non-EU countries. These include the monthly value of exports and imports at the 8-digit Combined Nomenclature (CN) product-level and countries of destination or origin. The dataset covers the period from 1996 to 2011.[7] We aggregate the values of exports and imports at the 6-digit Harmonized System (HS) level and by year. In addition to the customs data, we also use the UN Comtrade database for bilateral trade flows at the HS 6-digit product level to construct additional trade variables explained later. When constructing industry-level import penetration measures, we further aggregate the HS 6-digit trade values by the 4-digit UK SIC industries using the correspondence table from Eurostat.

We link these datasets using the look-up tables provided internally by HMRC that match the different firm identifiers across datasets. We describe the detailed procedure of merging the datasets in Appendix A. The constructed dataset, named as "BSD-RD-Trade", is an unbalanced panel of 4,107 firms over the period between 2002 and 2011; the total number of firm-year observation is 33,958. The firms included are R&D performing firms in manufacturing sectors that reported a positive R&D spending to HMRC at least once between 2002 and 2011.[8] We set the sample period as such since it was in 2002 when the sufficient number of firms started to report their R&D expenditures for tax reliefs and when the scheme was extended to large corporations as well. Table 1 provides means and standard deviations of key variables. In columns 1 and 2, the mean turnover and employment are £7,671.6 thousand and 52.1 persons with standard deviations of 68,291.5 and 239.9, respectively. These firms are small in size compared to the firms in 12 European countries studied in Bloom, Draca and Van Reenen (2015) with a mean employment of 739.5. More than six out of 10 firms engage in extra-EU trade every year with average values of export and import of £1,418.6 thousand and £932.2 thousand, respectively. About four out of 10 firms spend on R&D every year, with an average value of £130.8 thousand. We also use an alternative dataset which

[7]Our analysis uses UK firms' trades with non-EU countries only, as the within-EU transactions during the period before 2005 are not available.

[8]Note that the R&D expenditures are available only for the R&D-tax-relief-claiming firms for a given year. Therefore, as in Dechezleprêtre et al. (2016) and Guceri and Liu (2019), we assume that non-claiming firms did not spend on R&D in that year.

combines the BSD and the R&D data, but does not incorporate the firm-level trade data (labelled as "BSD-RD"). This alternative sample includes 4,798 firms with the total number of firm-year observations being 39,736. Using this larger dataset, we test the robustness of our findings on the effect of industry-level import competition, for which firm-level trade information is not required. As shown in columns 3 and 4, the means of turnover (£8,8 million) and employment (59.3) in the BSD-RD dataset are slighter larger than those in our benchmark BSD-RD-Trade dataset, indicating that the former contains more large firms.

By the number of firms, the baseline BSD-RD-Trade sample is estimated to account for above 60 percent of all UK manufacturers that reported R&D to the tax authority for the year 2011.[9] The dataset is more representative of small- and medium-sized enterprises (SMEs), covering more than 70 percent of all R&D performing SMEs and over 30 percent of all large firms.[10] The firm coverage of the alternative BSD-RD sample rises to above 70 percent of all R&D reporting manufacturers, with over 80 and approximately 50 percent of SMEs and large firms, respectively.

Table 1: Descriptive Statistics

No. obs (firms)	BSD-RD-Trade sample 33,958 (4,107)		BSD-RD sample 39,736 (4,798)	
Variable	Mean	SD	Mean	SD
Turnover	7,671.6	68,291.5	8,850.7	67,584.3
Employment	52.1	239.9	59.3	235.8
Firm age	18.4	10.6	18.7	10.5
R&D expenditure	130.8	1204.4	160.9	1,802.6
R&D dummy	0.403	0.490	0.410	0.492
Export to non-EU	1,418.6	13,300		
Export dummy	0.653	0.475		
Import from non-EU	932.2	14,600		
Import from China	58.5	755.5		
Import dummy	0.613	0.486		

Note: All variables are at the firm level. Turnovers, R&D expenditures, exports and imports are in thousands of pounds sterling. Firm age is in years. Data source: HMRC Overseas Trade in Goods Statistics, HMRC R&D Tax Credit Dataset and ONS Business Structure Database.

[9]These estimates are based on Fowkes, Sousa and Duncan (2015) - a report published by HMRC which provides the number of R&D tax credit claims in manufacturing sectors in 2012.

[10]Until 2012, HMRC operated two distinct R&D tax credit schemes based on the firm size - "Large Company" and "SME". Our R&D dataset over the sample period (2002-2011) contains information on the specific scheme under which a firm's R&D tax claim was filed. After 2012, the UK government introduced another R&D support scheme - Research and Development Expenditure Credit (RDEC) - in April 2013 and gradually replaced the Large Company tax credit scheme which was abolished in 2017.

3 Empirical strategy

Our empirical analysis estimates the equation for UK firms' R&D which includes the measures of Chinese import competition and firm-specific export demand as key determinants. The baseline equation is:

$$\begin{aligned} RnD_{f(k),t} = \beta_1 IMP^{CN}_{k,t-1} + \beta_2 EXD^{nEU}_{f,t-1} + \gamma ln(Import_{f,t-1}) \\ + Controls_{f,t-1} + \alpha_f + \delta_{s,t} + \nu_{r,t} + \epsilon_{f,t} \end{aligned}$$

where subscripts f, k, s, r and t denote firm, UK SIC 4-digit industry, UK SIC 2-digit sector, geographic region defined by the first one or two letters of the outward code in the UK postcode and year, respectively. The outcome variable $RnD_{f(k),t}$ is a logarithm of firm R&D expenditure (in 2008 real). We add one to the nominal values of R&D before taking a log due to many zero observations.[11] We will also test R&D dummies as an alternative outcome for robustness. The equation above relates firm R&D expenditures to trade exposures as well as other firm characteristics. Chinese import penetration ($IMP^{CN}_{k,t-1}$) aims to test the two conflicting hypotheses as to whether foreign competition hinders ("Schumpeterian effect") or spurs ("escape competition effect") firm innovation. As in previous literature, we focus on the rise of Chinese imports for its salience and enormous scale over the past decades. Export demand from non-EU countries ($EXD^{nEU}_{f,t-1}$) captures the role of export market size in determining firm R&D.

(Chinese competition) Following the prior literature, we measure the exposure of UK firms to Chinese competition using UK imports from China for 215 industries, normalized by industry outputs:

$$IMP^{CN}_{k,t} = \frac{Import^{CN}_{k,t}}{Output_{k,2000}}$$

where $Import^{CN}_{k,t}$ denotes Chinese imports into the UK in industry k in year t, and $Output_{k,2000}$ is the aggregate turnover in industry k which is fixed at the pre-sample year 2000. This import penetration measure can be arguably exogenous from the perspective of an individual firm, as any single firm's decision is unlikely to induce changes in the aggregate level of

[11] This transformation is ad-hoc but is still less problematic as the average R&D expenditures in our dataset are 6-digit numbers (hundreds of thousands pounds sterling), and thus adding one to the original values does not seriously distort the overall distribution of R&D.

industry imports. But, one may still concern an omitted variable bias. The surge in Chinese imports could be correlated with unobserved factors that were also related to both UK import demand and the firm's investment R&D. To isolate the component of the growth of Chinese imports that is due to China's supply shocks, we adopt an instrumental strategy similar to Hombert and Matray (2018) and Autor et al. (2020). Specifically, we exploit China's exports to 20 other developed economies ('$D20$') in each year as an instrument for UK imports from China:[12]

$$IV for\ \ IMP_{k,t}^{CN} = \frac{Export_{k,t}^{CN \to D20}}{Output_{k,2000}}$$

where $Export_{k,t}^{CN \to D20}$ denotes China's exports to 20 advanced countries in industry k in year t. The underlying assumption in this identification strategy is that the high-income countries are similarly exposed to China's export supply shocks, such as falling trade costs and expanding product variety. Along with this IV strategy, we further control for any unobserved sector-specific demand and/or technology shocks by adding 2-digit SIC sector by year dummies.

(Export demand) We construct a firm-level measure of export demand outside the EU following Bombardini, Li and Wang (2018) and Aghion, Bergeaud, Lequien and Melitz (2018):

$$EXD_{f,t}^{nEU} = \textstyle\sum_p \sum_d \omega_{f,p,d} * ln(World\, Export_{p,d,t})$$

where $World\, Export_{p,d,t}$ denotes world exports (excluding the UK) of HS 6-digit product p into non-EU destination d in year t. $\omega_{f,p,d} = \frac{Export_{f,p,d,2000}}{\sum_p \sum_d Export_{f,p,d,2000}}$ and $Export_{f,p,d,2000}$ is a UK firm f's exports of product p to non-EU destination d averaged over 1998-2000 (pre-sample period).

The key assumption in this identification is that the global trade flows (excluding the UK) into a given product-destination market ($World\, Export_{p,d,t}$) reflects demand changes in that market which are exogenous to an individual UK firm f. This measure then aggregates the log of world exports across all the product-destination pairs, weighted by the relative importance of each market for the firm f's total non-EU exports ($\omega_{f,p,d}$). The HMRC

[12] The countries included here are Austria, Australia, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland and the United States.

trade dataset enables us to construct this firm-specific exposure to demand changes in each product-destination market. Note that this firm-level weight is based on its average exports over the pre-sample period between 1998 and 2000 to circumvent endogenous changes in the firm's exports due to innovation. Therefore, time variations in this measure stem only from $World\, Export_{p,d,t}$. This export demand measure is highly correlated with log firm exports (correlation of 0.602) as well as firm export dummies (0.579), suggesting that it is a strong predictor for the firm's *current* margins of export.

(Other controls) Apart from Chinese import penetration and firm-level export demand, we include firm-level imports ($Import_{f,t}$) as an additional variable. Its inclusion is based on Bøler, Moxnes and Ulltveit-Moe (2015) who document that R&D and importing are complementary activities.[13] We add other firm controls ($Controls_{f,t}$), such as firm size measured by log employment, turnover growth, and a dummy equal to one if the firm is foreign-owned in a given year. All the variables on the right-hand side of the equation are lagged by one year to avoid simultaneity.

By adding firm fixed effects (α_f), the analysis examines within-firm changes in R&D expenditures to trade shocks. As noted by Autor et al. (2020) and Lim, Trefler and Yu (2018), there is a possibility of pre-trends that would confound the true effect of industry-specific import competition. There could also be other unobservable shocks affecting firm R&D. To address these concerns, we introduce a comprehensive set of fixed effects. The 2-digit sector by year fixed effects ($\delta_{s,t}$) are aimed at absorbing any unobserved technology shocks or business cycle components for 22 broad manufacturing sectors. We further add region by year dummies ($\nu_{r,t}$) for 13 UK geographic regions.[14] This is to control for the potential effect of immigration of low-wage foreign workers into specific UK regions, which may affect firm R&D as a labor supply shock (Gray, Montresor and Wright (2020)).[15] Standard errors clustered by the 4-digit SIC industries.

[13]Under imperfect substitutability between domestic and imported inputs, firms may gain from input variety. Firms could also find the quality-adjusted prices of imported inputs from more productive foreign suppliers are lower than domestic ones. The use of imported inputs could raise the overall profitability which in turn encourages firm investment in productivity.

[14]The regions include Channel Islands, East Midlands, East of England, Greater London, Isle of Man, North East, North West, Northern Ireland, Scotland, South East, South West, Wales, and West Midlands.

[15]Gray, Montresor and Wright (2020) find that the increased supply of low-skill foreign workers from eight Central and Eastern European countries, driven by these countries' accession to EU in 2004, led to an increase in innovation by UK firms - primarily process innovation. The extent of immigration by these workers was largely different across UK regions and, interestingly, the paper finds a tendency of the immigrants to settle in areas where their compatriots were already settled.

4 Results

This section presents estimation results. To summarize, we find robust evidence that Chinese import competition was detrimental to UK firms' R&D. Export demand, by contrast, is found to significantly boost their R&D investment.

4.1 Baseline

Table 2 reports the baseline results. Column 1, which controls for firm and year fixed effects, shows a negative and highly significant coefficient on Chinese competition. Column 2 further includes for sector by year fixed effects that absorb unobserved demand or technological changes at the sector level. The coefficient becomes smaller in absolute terms (-6.042 $\rightarrow$ -4.235), but it is still highly significant. Changes in the size of the coefficient on Chinese competition shows the quantitative importance of controlling for sectoral trends as emphasized by Autor et al. (2020). Column 3 tests the most stringent specification which includes region by year fixed effects. The estimate for Chinese competition again becomes slightly smaller but remains significant (-4.235 $\rightarrow$ -3.989). Column 4 runs 2SLS using China's exports to other advanced countries in the same industry to isolate the supply-driven component of the rising Chinese imports. The first-stage F-statistic is 21.4, suggesting that the instrument is a strong predictor of Chinese imports into the UK.[16] The 2SLS estimate for Chinese competition is significant at five percent and is very similar in magnitude to the OLS counterpart in column 3 (-3.989 vs -4.098). These altogether indicate that firms in industries more exposed to Chinese import penetration reduced their R&D expenditures. To interpret, UK firms' R&D spending falls by approximately four percent for every percentage point rise in the exposure to Chinese import competition.

Is the rise of Chinese imports a unique competitive shock, or does it simply reflect the overall foreign competition that intensified over the course of globalization? To answer this, column 5 adds a measure of import penetration from all non-Chinese countries outside the EU (2nd row), along with Chinese competition. The coefficient for non-Chinese imports, by contrast, is not different from zero. On the contrary, even after controlling for contemporaneous changes in non-Chinese imports, there is no considerable change in the estimates for Chinese competition. Column 6 again instruments for Chinese imports and yields almost the same result. These suggest that the onslaught of low-cost Chinese imports, accelerated by its entry into the WTO in 2001, posed an unparalleled competitive threat to UK manufacturing firms, significantly discouraging their innovation endeavours.

[16] The coefficient on the instrument in the first-stage regression is 0.031 with the standard error of 0.007. The first-stage F-statistics reported herein are Kleibergen-Paap Wald statistic.

Table 2: Impact of Trade on Firm R&D

	OLS (1)	OLS (2)	OLS (3)	2SLS (4)	OLS (5)	2SLS (6)
Chinese competition	-6.042***	-4.235***	-3.989***	-4.098**	-4.271***	-4.554**
	(1.615)	(1.094)	(1.069)	(1.641)	(1.076)	(2.07)
Non-Chinese competition					0.361	0.414
					(0.649)	(0.831)
Export demand	0.065***	0.067***	0.064***	0.064***	0.064***	0.064***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Firm import	0.071***	0.071***	0.070***	0.070***	0.070***	0.070***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Firm size	0.231***	0.236***	0.218***	0.218***	0.217***	0.217***
	(0.087)	(0.080)	(0.078)	(0.077)	(0.077)	(0.077)
Turnover growth	0.027	0.027	0.032	0.032	0.031	0.031
	(0.063)	(0.063)	(0.063)	(0.063)	(0.063)	(0.063)
Foreign ownership	-0.159	-0.149	-0.166	-0.166	-0.166	-0.166
	(0.149)	(0.150)	(0.149)	(0.149)	(0.149)	(0.149)
Observations	28,966	28,966	28,966	28,966	28,966	28,966
N of firms	4,107	4,107	4,107	4,107	4,107	4,107
Adj R_squared	0.413	0.415	0.416		0.416	
1st-stage F-stat				21.4		18.0
Firm FE	Y	Y	Y	Y	Y	Y
Year FE	Y					
Sector-year FE		Y	Y	Y	Y	Y
Region-year FE			Y	Y	Y	Y

Note: The dependent variable is a logarithm of R&D expenditure at the firm level. Columns 4 and 6 run 2SLS instrumenting for Chinese import competition. Standard errors are clustered by the UK SIC 4-digit industries. Significance: *** p<0.01, ** p<0.05, * p<0.1. Data source: Author's calculations based on HMRC Overseas Trade in Goods Statistics, HMRC R&D Tax Credit Dataset and ONS Business Structure Database.

Next, we verify a stimulating role of export demand in firm R&D (3rd row), as it raises the potential returns to investment in technology. The result shows that UK firms' R&D spending increases by around six percent for every one unit increase in our measure of export demand. Recall that our export demand measure uses global trade flows into each destination that are plausibly exogenous to individual firms, weighted by individual firms' initial exports to each market. Therefore, it does not simply pick up a correlation, but can be interpreted as a casual impact running from export demand towards R&D.

We find a positive association between firms' importing (4th row) and their R&D spending, as supportive of the complementarity hypothesis between imported inputs and R&D of Bøler, Moxnes and Ulltveit-Moe (2015). Firm size, measured by log employment, is also an important factor determining their R&D spending, while turnover growth and foreign ownership were not significant.

One may be interested in the relative importance of each trade channel, import competition and export demand. Since these variables are measured in different scales, as a simplest quantification exercise, we compare the effects of a one standard deviation increase in each trade shock. Based on the estimates in column 4, a one standard deviation rise in the exposure to Chinese competition is associated with a reduction in R&D spending by approximately 27 percent (=-4.098*0.067).[17] A positive export demand shock by one standard deviation leads to an increase in firm R&D spending by about 55 percent (=0.064*8.609). Then, how large are these effects of trade-related shocks when compared to firm size - a key R&D determinant as documented in the literature? Note that a one standard deviation increase in log employment is related to an increase in firm R&D expenditures by about 31 percent (=0.218*1.402). These indicate that changes in the trade environment surrounding firms may exert an influence on firm R&D which is as large or even larger in magnitude than firm size. We may also infer that, while rising Chinese imports since 2002 significantly impeded firm R&D, increasing export demand from outside the EU during the same period may have mitigated this adverse effect to some degree.

4.2 Firm imports from China

In assessing the effect of Chinese imports, it is important to note that firms' own importing from China may affect the firms' R&D investment, independently of the competition channel. For instance, a greater supply of cheaper Chinese intermediate inputs may improve firm profitability, inducing more investments in innovation. Firms may also choose to offshore labor-intensive parts of their production to foreign affiliates in China and put more resources into inventions of new high-tech products (Bloom, Draca and Van Reenen (2015)). We check whether firms' own imports from China separately affected their R&D. To obtain casual identification, we build an instrument for firm imports from China, again exploiting China's exports to other developed countries:

$$IV\,for\ \ ln(Import_{f,t}^{CN}) = \textstyle\sum_p \psi_{f,p}^{CN} ln(Export_{p,t}^{CN\rightarrow D20})$$

where $Import_{f,t}^{CN}$ denotes either the values of firm imports from China or the number of HS 6-digit products imported from China (import variety). $Export_{p,t}^{CN\rightarrow D20}$ denotes China's

[17] For comparison, Autor et al. (2020) estimate that a one standard deviation exposure to Chinese competition reduced patenting of U.S. firms by 10 to 15 log points.

exports of HS 6-digit product p to 20 advanced countries in year t. $\psi_{f,p}^{CN} = \frac{Import_{f,p,2000}^{CN}}{\sum_p Import_{f,p,2000}^{CN}}$ and $Import_{f,p,2000}$ is UK firm f's imports of product p from China averaged over 1998-2000. Similarly to the industry-level instrument for Chinese competition, this firm-level instrument exploits the time variations in China's exports to 20 other advanced countries at the product level, which are weighted by the share of product p in the UK firms' initial imports from China. We separately add a binary indicator for firms' importing from other non-EU countries as well. Column 1 in Table 3 uses firms' import varieties from China, while column 2 uses firms' import values from China, each of which is instrumented for by the above-mentioned instrument. The proposed instrument has strong positive correlations with firms' import varieties (coefficient of 0.030) and their import values from China (0.098), both significant at one percent. We find that, in either measure, an increase in firms' own imports from China do not play any meaningful role in firm R&D. Chinese competition, which is not instrumented for in these columns, remains highly significant. Column 3 instruments for both Chinese competition and firms' own imports from China using the respective instruments. The coefficient on Chinese competition is essentially the same in size and is significant at 10 percent, whereas the estimate for firms' own imports from China is again not different from zero.[18] These imply that increased access to Chinese imports for firms did offset the negative effect of Chinese competition.[19]

4.3 Robustness

We test the robustness of our baseline results in several dimensions. We begin by testing whether our results are sensitive to firm size. Columns 1 and 2 of Table 4 run 2SLS excluding firms with employment of either less than 10 or more than 500, respectively. The coefficients for Chinese competition are all within the same range of -4.0 as the baseline result (column 5 of Table 2). Export demand appears to have much the same effect on R&D. These show that our results are not driven by a group of firms of a certain size.

Columns 3 and 4 run OLS and 2SLS for a linear probability model (LPM) using the R&D dummy as an outcome variable. These show that Chinese competition leads to a lower R&D participation rate. Specifically, a one percentage point rise in the exposure to Chinese competition reduces the probability of a firm to undertake R&D by 0.34 percentage points.

[18] Note that the instruments become weak when both firm imports from China and Chinese competition are instrumented. This could be partly because the two instruments rely on similar sources of time variations - China's exports to other advanced countries.

[19] The offshoring hypothesis would not be pertinent to the firms in this analysis as the majority of these firms are small and medium-sized, and thus would not engage in a multi-stage production process. Bloom, Draca and Van Reenen (2015) also show mixed evidence on the impact of Chinese input supply shocks which did not increase firm patenting, though positively affecting firm TFP and IT adoption.

Table 3: IV Estimations for Firm Imports from China

	(1)	(2)	(3)
Chinese competition	-4.266***	-4.142***	-4.480*
	(1.380)	(1.310)	(2.427)
Firm import varieties from China	0.741		
	(1.848)		
Firm import values from China		0.227	0.225
		(0.558)	(0.553)
Firm import dummy from non-China	0.516***	0.463**	0.464**
	(0.114)	(0.214)	(0.213)
Export demand	0.065***	0.060***	0.060***
	(0.014)	(0.019)	(0.019)
Employment	0.219**	0.193	0.193
	(0.089)	(0.134)	(0.133)
Turnover growth	0.033	0.030	0.030
	(0.063)	(0.064)	(0.064)
Foreign ownership	-0.158	-0.157	-0.157
	(0.151)	(0.152)	(0.152)
Observations	28,966	28,966	28,966
1st-stage F-stat	9.6	10.9	5.6
Firm FE	Y	Y	Y
Sector-year FE	Y	Y	Y
Region-year FE	Y	Y	Y

Note: The dependent variable is a logarithm of R&D expenditure at the firm level. Columns 1 and 2 instrument only for firms' imports from China, either import varieties or import values. Columns 3 instruments for both firms' import values from China and Chinese import competition. Standard errors are clustered by the UK SIC 4-digit industries. Significance: *** p<0.01, ** p<0.05, * p<0.1. Data source: Author's calculations based on HMRC Overseas Trade in Goods Statistics, HMRC R&D Tax Credit Dataset and ONS Business Structure Database.

This magnitude appears to be rather small compared to the effect on the level of R&D, which implies that the negative effect of Chinese imports was more pronounced on the intensive margin of R&D.

As an alternative model, we estimate a Poisson Pseudo-Maximum Likelihood (PPML) which is known to yield a more consistent estimator in the log-linear specifications with many zero observations for an outcome variable like R&D (Guceri and Liu (2019)). Column 4 shows that the coefficient on Chinese competition is negative and significant at five percent. But its absolute size (-1.888) is somewhat smaller relative to the OLS counterpart of -3.989 (column 4 of Table 2).[20] The estimate for export demand is much similar to the OLS counterpart

[20] Due to convergence issues, our PPML estimation does not allow for the stringent sector by year or region by year fixed effects. Instead, we control for firm and year fixed effects.

(0.064 vs 0.056). Column 6 estimates a reduced-form PPML in which Chinese competition is replaced by its instrument. The coefficient on the instrument (2nd row) is significant at ten percent. But the lower significance indicates that the measure of Chinese competition is already exogenous, and thus the instrument may offer no improvement for consistency.

Finally, we check the robustness of our findings on Chinese competition by using the alternative BSD-RD sample. Despite not accounting for firm-level export demand and imports, using this sample allows us to examine the effect of the *industry-level* Chinese competition for a greater number of firms. Columns 7 and 8 show the OLS and 2SLS results. The results confirm that Chinese competition substantially inhibited firm R&D, with the size of the coefficients largely in line with those from the baseline results.

4.4 Heterogeneity

We thus far document that import competition from China significantly discouraged R&D, while export demand encouraged it for *average* UK firms in our sample. One interesting pattern emerging from the prior literature is that the innovation response to trade shocks may vary across firms depending on their initial levels of productivity. This section explores the potential heterogeneity in R&D responses to both Chinese competition and export demand. We split firms into four groups based on the two-year lagged labor productivity within the 2-digit sector by year cells. Labor productivity herein is measured by turnover per employee.[21] $H_{f,t-2}$ or $L_{f,t-2}$ is defined as a dummy equal to one if a firm is above the 75th percentile or below the 25th percentile according to the two-year lagged productivity, respectively. we add the interaction terms for the trade shocks with these dummies as follows:

$$\begin{aligned} RnD_{f(k),t} = \; & \beta_1 IMP^{CN}_{k,t-1} + \beta_2 IMP^{CN}_{k,t-1} * H_{f,t-2} + \beta_3 IMP^{CN}_{k,t-1} * L_{f,t-2} \\ & + \beta_4 EXD^{nEU}_{f,t-1} + \beta_5 EXD^{nEU}_{f,t-1} * H_{f,t-2} + \beta_6 EXD^{nEU}_{f,t-1} * L_{f,t-2} \\ & + \beta_7 H_{f,t-2} + \beta_8 L_{f,t-2} + \gamma ln(Import_{f,t-1}) + Controls_{f,t-1} \\ & + \alpha_f + \delta_{s,t} + \nu_{r,t} + \epsilon_{f,t} \end{aligned}$$

Columns 1 and 2 in Table 5 report the results.[22] Column 1 uses the BSD-RD sample which contains more firms but without firm-level trade variables. The coefficient on the interaction between Chinese competition and the dummy for highly productive firms (2nd

[21]It would be ideal to use value-added instead of turnover in measuring labor productivity. But since information on vale-added is not available, we use turnover as a proxy.

[22]In the first-stage regressions, we use the interactions between the IV for Chinese competition and the productivity dummies as the instruments for $IMP^{CN}_{k,t-1} * H_{f,t-2}$ and $IMP^{CN}_{k,t-1} * L_{f,t-2}$.

Table 4: Robustness Check

	Empl>10 (1)	Empl<500 (2)	LPM(OLS) (3)	LPM(IV) (4)	Poisson (5)	Poisson (6)	BSD-RD(OLS) (7)	BSD-RD(IV) (8)
Chinese competition	-4.797**	-4.180**	-0.366***	-0.349**	-1.888**		-4.968***	-4.187**
	(2.101)	(1.656)	(0.090)	(0.149)	(0.782)		(1.090)	(1.626)
IV-Chinese competition						-0.031*		
						(0.019)		
Export demand	0.063***	0.063***	0.005***	0.005***	0.056***	0.057***		
	(0.022)	(0.013)	(0.001)	(0.001)	(0.016)	(0.016)		
Firm import	0.074***	0.069***	0.006***	0.006***	0.029***	0.030***		
	(0.012)	(0.010)	(0.001)	(0.001)	(0.007)	(0.007)		
Employment	0.083	0.222***	0.016**	0.016**	0.092	0.090	0.267***	0.247***
	(0.141)	(0.078)	(0.007)	(0.007)	(0.064)	(0.064)	(0.069)	(0.064)
Turnover growth	0.070	0.029	0.002	0.002	-0.010	-0.010	0.065	0.067
	(0.10)	(0.063)	(0.005)	(0.005)	(0.035)	(0.035)	(0.062)	(0.063)
Foreign ownership	-0.134	-0.142	-0.015	-0.015	-0.056	-0.061	-0.143	-0.152
	(0.162)	(0.155)	(0.013)	(0.013)	(0.117)	(0.115)	(0.140)	(0.139)
Observations	20,464	28,635	28,966	28,966	27,547	27,547	33,993	33,993
Adj R_squared			0.3716				0.4175	
1st-stage F-stat	28.0	21.2		21.4				24.6
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE					Y	Y		
Sector-year FE	Y	Y	Y	Y			Y	Y
Region-year FE	Y	Y	Y	Y			Y	Y

Note: Columns 1 and 2 are 2SLS results using the sub-samples of firms with employment of more than 10 and less than 500, respectively. Columns 3 and 4 run OLS and 2SLS using the R&D dummy as an outcome variable. Columns 5 and 6 estimates a fixed-effect poisson model for R&D. As a reduced-form specification, column 6 replace Chinese competition with its instrument ('IV-Chinese competition'). Column 7 and 8 are OLS and 2SLS from the 'BSD-RD' dataset. Standard errors are clustered by the UK SIC 4-digit industries, except for columns 5 and 6 in which standard errors are clustered by firms. Significance: *** p<0.01, ** p<0.05, * p<0.1. Data source: Author's calculations based on HMRC Overseas Trade in Goods Statistics, HMRC R&D Tax Credit Dataset and ONS Business Structure Database.

row) is positive (2.688), but marginally statistically insignificant. For the BSD-RD-Trade sample, the interaction terms for neither productivity dummies are different from zeros. Overall, there seems to be no significant difference between high and low productivity firms in their responses to Chinese competition. Instead, we observe strong heterogeneity in response to rising export demand (6th and 7th rows). Firms sitting above the 75th percentile of the labor productivity distribution tend to increase their R&D spending by around two thirds (=0.037/0.057) more than the average firms for a given export demand. It implies that more productive firms are better poised to take advantage of increasing foreign demand.

As another source of firm heterogeneity, we check whether the effect of import competition differs over a firm's initial exporting status:

$$\begin{aligned} RnD_{f(k),t} = \; & \beta_1 IMP^{CN}_{k,t-1} + \beta_2 IMP^{CN}_{k,t-1} * E_f + \beta_3 EXD^{nEU}_{f,t-1} \\ & + \gamma ln(Import_{f,t-1}) + Controls_{f,t-1} + \alpha_f + \delta_{s,t} + \nu_{r,t} + \epsilon_{f,t} \end{aligned}$$

where E_f denotes a dummy equal to one if firms exported at least once during the initial period (1998-2000). Column 3 in Table 5 shows that firms with prior exporting experience were less hurt by Chinese competition. The interaction term for the exporting dummy (4th row) is positive and significant at 10 percent. Quantitatively, the adverse impact of Chinese competition on R&D spending diminishes by more than half (-2.398 = -7.153 + 4.755) for initially exporting firms, when compared to the average firms (-7.153). It could be interpreted that those firms that had already entered into exporting were better able to reallocate their sales abroad in the face of tougher foreign competition in domestic markets.

4.5 Discussion

Our finding on the positive role of export demand for R&D corroborates the evidence from previous literature. The heterogeneous effect of export demand in favour of more productive firms is also consistent with the recent findings in Aghion, Bergeaud, Lequien and Melitz (2018) for French firms.

On the other hand, the deleterious impact of Chinese competition found in this paper, while in line with Autor et al. (2020), is at odds with Bloom, Draca and Van Reenen (2015). As previously noted, empirical evidence remains divided over whether foreign competition encourages or discourages innovation. The difference from Bloom, Draca and Van Reenen (2015), among others, may be partly due to different types of firms analysed.[23] Bloom, Draca

[23]It should also be noted that, while several papers including Bloom, Draca and Van Reenen (2015) use

Table 5: Heterogeneity in R&D Responses (2SLS)

	BSD-RD	BSD-RD-Trade	
	(1)	(2)	(3)
Chinese competition	-4.659***	-3.877**	-7.153***
	(1.535)	(1.532)	(2.465)
Chinese competition*High	2.688	0.070	
	(2.189)	(2.023)	
Chinese competition*Low	-0.264	-0.379	
	(2.351)	(2.406)	
Chinese competition*Exporter			4.755*
			(2.845)
Export demand		0.057***	0.060***
		(0.014)	(0.013)
Export demand*High		0.037***	
		(0.011)	
Export demand*Low		-0.010	
		(0.012)	
High	0.199*	0.025	
	(0.106)	(0.131)	
Low	-0.157	-0.071	
	(0.121)	(0.148)	
Firm import		0.068***	0.070***
		(0.010)	(0.010)
Employment	0.263***	0.253***	0.226***
	(0.066)	(0.078)	(0.078)
Turnover growth	0.113*	0.071	0.032
	(0.067)	(0.067)	(0.064)
Foreign ownership	-0.151	-0.163	-0.167
	(0.139)	(0.149)	(0.149)
Observations	33,993	28,966	28,966
1st-stage F-stat	8.2	7.2	10.5
Firm FE	Y	Y	Y
Sector-year FE	Y	Y	Y
Region-year FE	Y	Y	Y

Note: The dependent variable is a logarithm of R&D expenditure at the firm level. All columns run 2SLS instrumenting for the terms related to Chinese competition. In the first-stage regressions for columns 1 and 2, we use the interactions between the IV for Chinese competition and the productivity dummies ("High" and "Low") as the instruments for "Chinese competition*High" and "Chinese competition*Low". Likewise, in the first-stage for column 3, we use the interaction between the IV for Chinese competition and firms' initial exporting dummy ("Exporter") as the instruments for "Chinese competition*Exporter". Standard errors are clustered by the UK SIC 4-digit industries. Significance: *** p<0.01, ** p<0.05, * p<0.1. Data source: Author's calculations based on HMRC Overseas Trade in Goods Statistics, HMRC R&D Tax Credit Dataset and ONS Business Structure Database.

patenting as a measure of innovation, firms patent as means to protect their existing intellectual properties rather than new innovations. Firms might have a stronger incentive for this so called 'defensive patenting' and Van Reenen (2015) study large European firms, whereas a large fraction of UK firms in this paper are small- and medium-sized. These smaller firms are likely to have been more affected by the industry-level exposure to import competition: In many cases, they should operate within a single industry and thus have little scope for diversification to alleviate the competitive pressure.[24] Also noteworthy is the recent finding by Bloom, Romer, Terry and Van Reenen (2020) that even these large European firms (the same firms as in Bloom, Draca and Van Reenen (2015)) experienced a significant decline in their sales growth facing Chinese competition. The falling sales due to rising Chinese imports could have inflicted much more damage upon smaller firms, as R&D of these firms should rely more on internal cash flows, unlike the large firms with more reserved resources and better access to external finance.

In the context of the theoretical model of Aghion et al. (2005), most firms in our analysis would not be technological leaders within their industries, and thus be located on the downward-sloping line of the 'inverted U-shaped relationship' where increased competition may stifle innovation.

5 Concluding remarks

How firm innovation and productivity is affected by international trade has been at the heart of the debate over the long-run consequences of globalization. Empirical evidence has been mixed. Using the matched administrative datasets for UK firms' R&D expenditures and their trade exposures, this paper empirically investigates the impacts of Chinese competition and export demand on firm R&D. We document a strong, detrimental effect of foreign competition ramped up by Chinese imports on UK firms' R&D investment. Increased export demand from outside the EU, by contrast, stimulated their innovation endeavours, mitigating the negative effect of foreign competition. We also detect heterogeneity in their R&D responses to each trade shock. Exporting firms were less affected by surging Chinese imports. Firms with an initially high productivity responded more actively to a positive export demand shock. These together imply that innovations by domestic and less profitable firms were most severely hurt by globalization over the past decades, resulting in a widening productivity gap across firms.

against increasing threats of imitation by Chinese competitors. For instance, Yamashita and Yamauchi (2020) finds that, while Japanese firms increased patenting facing Chinese competition, the overall quality of the patents fell in terms of forward citations and the number of international patents. They argue that these findings are related to a defensive nature of patenting.

[24] As one interesting dimension of adjustment, Breinlich, Soderbery and Wright (2018) find that UK manufacturing firms shifted their sales from goods to services in response to increasing import competition. And this goods-to-service adjustment occurred among large firms with initially high R&D intensities.

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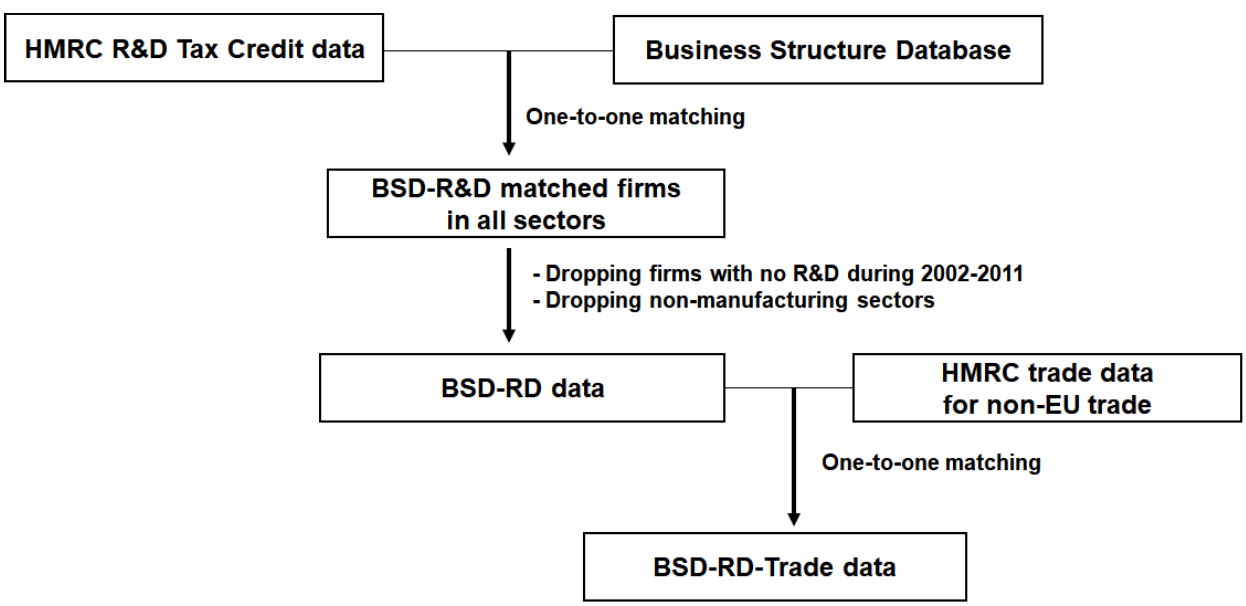
A Procedure for combining datasets

We combine the three UK administrative datasets using the look-up tables across different firm identifiers, which are provided internally by the HMRC Datalab.[25] One practical challenge is that a firm identifier in one dataset has many-to-many relationships with other identifiers from different datasets.[26] As the most conservative and transparent approach, we preserve only firms whose identifiers are matched one-to-one with one another across datasets. This results in dropping some large firms with multiple identifiers in any of the datasets. We first merge the BSD and the R&D dataset for firms that are matched one-to-one between the two identifiers of each dataset. Out of the matched firms, we keep those in manufacturing sectors that reported non-zero R&D expenditures to the HMRC at least once between 2002 and 2011. We label the merged dataset up to this stage as "BSD-RD" dataset. Next, we merge this BSD-RD dataset with the firm-level trade dataset to construct the benchmark "BSD-RD-Trade" sample.

Figure A1: Flow Chart of Dataset Construction



[25] The HMRC Datalab provides separate concordance tables for each pair of identifiers between the unique taxpayer reference number from the corporate tax dataset, enterprise reference number (Entref) from the BSD and value-added tax reference number (VRN). We first concord the Tradeid from the HMRC trade dataset into the VRN, which is then matched with the rest of the identifiers.

[26] As one notable example, firms' overseas transactions are reported at the value-added tax unit level, not at a consolidated national level. Large firms may also consist of multiple subsidiaries that each have own registration numbers. For these reasons, each identifier may have a many-to-many match with one another (Mion and Muuls (2015)).