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Firm R&D, Processing Trade and Input Trade Liberalisation: Evidence from Chinese Firms

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1. INTRODUCTION

THE nexus between firm innovation and trade liberalisation is an important research subject in the empirical trade literature, as firm innovation is an important channel for firms to realise productivity gains from trade. Some work in this area has focused on how output trade liberalisation affects firm research and development (R&D) inputs (Iacovone et al., 2013; Bloom et al., forthcoming). Since tariff reductions usually happen bilaterally, other research has concentrated on how cuts in foreign tariffs boost firm R&D activity (Aw et al., 2007, 2011; Lileeva and Trefler, 2010; Bustos, 2011). Some researchers have been paying more attention to the role of imported intermediate inputs by exploring how input trade liberalisation affects firm R&D behaviour (Kim and Nelson, 2000; Griffith et al., 2004; Hu et al., 2005; Goldberg et al., 2010).

The present paper examines the effect of input trade liberalisation on firm R&D by taking into account China's special treatment on imported intermediate inputs. After China's accession to the World Trade Organization (WTO) in 2001, the country experienced significant trade liberalisation in final outputs and intermediate inputs (Yu, 2015). Different from ordinary imports, processing imports in China enjoy zero tariffs and were not affected by the input trade liberalisation caused by the WTO accession. We thus take China's accession to the WTO as a quasi-natural experiment and perform difference-in-difference (DID) analysis by taking processing import firms as a control group. We also carefully deal with the possible endogeneity and serial correlation problems. We identify and drop imported capital goods to avoid potential contamination of our estimates. Overall, we find strong evidence that input trade liberalisation due to the WTO accession significantly fosters firm R&D activity.

This paper contributes to the literature in three important ways. First, it enriches our understanding of China's innovation activity in the new century. As China's labour costs have increased in recent years, the country's apparent comparative advantage based on its abundant labour endowment is shrinking. As a result, Chinese firms are eager to invest more in R&D to boost firm productivity to maintain their international competitiveness. Aggregated data from the *China Statistical Yearbook on Science and Technology* ascertain this conjecture. For example, the share of R&D in GDP rose from 0.6 per cent in 1995 to 1.23 per cent in 2004. The number of employees in the R&D sectors increased over 77 per cent during the same

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period. However, this idea is rarely supported by Chinese micro firm-level production data. This paper aims to fill this gap. We use disaggregated and firm-level production data and highly disaggregated transaction-level customs data from 2000 to 2006, to explore the relationship between firm R&D and input trade liberalisation.

Second, the paper contributes to understanding the channels and mechanisms of the effects of trade liberalisation on firm performance. Although firm innovation is a crucial channel to realise firm productivity gains from trade, previous studies have mostly focused on output trade liberalisation. A fall in domestic output tariffs generates tougher import competition, which in turn forces firms to invest more in R&D activities. By contrast, a reduction in foreign tariffs creates a large foreign market, which could make firms more profitable, so that they can invest more in R&D activities. Few papers have considered the impact of input trade liberalisation on firm R&D. However, import trade liberalisation plays a substantial role in firms' ability to realise productivity gains from trade (Amiti and Konings, 2007; Goldberg et al., 2010; Topalova and Khandelwal, 2011; Tian and Yu, 2015; Yu, 2015). The present paper thus picks up this job.

Third, the paper makes a contribution to the issue of empirical identification. Firm R&D activity may be endogenous to import tariffs. Usually firms with lower R&D investment are less productive. Accordingly, they could lobby the government for temporary protection (Bown and Crowley, 2013). It is well recognised that it is a challenging job to find an ideal instrument for import tariffs. However, China has special, zero-tariff treatment on processing imports. Further trade liberalisation has not impacted processing imports. Thus, we are able to take advantage of this situation using processing import firms as a control group to mitigate the endogeneity problem, and hence to explore the causal relation between input trade liberalisation and firm R&D.

The paper is related to two strands of the growth literature. The first strand is on the nexus between firm R&D and external trade liberalisation from trading partners. Grossman and Helpman (1991) was one of the pioneering works to model the impact of foreign trade liberalisation on firm R&D. In line with this idea, Yeaple (2005) shows that firms have a greater incentive to increase investment in technology in response to a fall in trade costs under a framework in which firms choose either high or low technology according to the observed random ability of workers. Verhoogen (2008) examines the impact of currency validity on firm R&D activity using Mexican data. By assuming that more productive firms choose to produce higher quality products and pay higher wages, he shows that home currency depreciation forces high-productivity firms to invest more in improving product quality, which is accompanied by greater within-industry wage discrepancies. Lileeva and Trefler (2010) forcefully argue that foreign tariff reduction leads to more exports from high-productivity Canadian firms; the increase in exports is associated with more R&D inputs in new product innovation. By comparison, we also control for foreign market size, but focus on input trade liberalisation.

The second strand of literature examines the impact of output trade liberalisation on firm R&D. Iacovone et al. (2013) study the impact of China entering the WTO on Mexican firms, and they find that more productive firms invest more in R&D. Bloom et al. (forthcoming) find that the elimination of import quotas on Chinese goods in Europe since 2001 has increased domestic competition, which in turn has improved firm-level technology upgrading as well as the mobility of labour towards more productive firms. Finally, some other research explores reductions in foreign tariffs and import tariffs. Bustos (2011) studies the effect of bilateral trade liberalisation and finds that bilateral tariff reductions in import tariffs and external tariffs encourage firms to use high technology and improve productivity. Yu (2015) examines the impact of three types of tariff reductions: import tariffs on output goods, import tariffs on imported intermediate inputs and foreign tariffs. However, his focus is the effect of trade liberalisation on firm productivity. In this paper, we explore the impact of input trade liberalisation on firm innovation, controlling for the size of foreign market access and output trade liberalisation.

The rest of the paper is organised as follows. Section 2 describes the data and measures of the key variables. Section 3 presents our empirical strategy and reports our estimation results. Section 4 concludes.

2. DATA

To investigate the impact of intermediate trade liberalisation on firm R&D, we use the following highly disaggregated large, panel data set: firm-level production data, transaction-level trade data and tariff data.

The firm-level production data come from a large firm-level data set that covers around 230,000 manufacturing firms per year over 2000–06. The data are collected and maintained by China's National Bureau of Statistics in an annual survey of manufacturing enterprises. Briefly, the survey covers two types of manufacturing firms: all state-owned enterprises (SOEs); non-SOEs with annual sales more than 5 million RMB (or equivalently, $730,000). The survey reports more than 100 financial variables listed in three accounting sheets (i.e. balance sheet, loss and benefit sheet and cash flow sheet) and covers all the required variables used in the analysis, such as number of employees, firm sales, firm R&D and firm exports.

However, such a raw data set could be noisy, in the sense that it includes some unqualified samples.[1] Following Feenstra et al. (2014) and Yu (2015), we delete observations according to the basic rules of the generally accepted accounting principles. Accordingly, the total number of observation is reduced to 438,165 for 2000–06. Around one-third of the firms were dropped from the sample after the screening process.[2]

Data on firm R&D are available from 2001 to 2006 but are missing for 2004. As shown in Table 1, firm R&D expenses increased during the sample years. The main interest of this paper is to examine changes in firm R&D in response to changes in trade liberalisation, for two types of firms: processing firms and non-processing firms. Unfortunately, firm processing information is not available from the firm-level data. However, as Dai et al. (2012) point out, processing firms are usually pure exporters that sell all their products abroad. We instead break all firms into the two categories: pure exporters and non-pure exporters. Columns (3) and (5) report firm R&D for pure exporters and non-pure exporters, respectively. By way of comparison, non-pure exporters invest more in R&D than pure exporters do during the sample years, suggesting that processing exporters are less innovative. This observation is consistent with the finding that processing firms are usually less productive (Dai et al., 2012; Tian and Yu, 2015; Yu, 2015).

The information covered by the firm-level production data set is rich. However, it is silent on the type of firm exports, so we are not able to distinguish processing exports and ordinary exports. We hence appeal to the product-level trade data set provided by the general customs.

[1] For example, some firms have negative exports and even a negative number of employees.
[2] For more detail about the data screening, see Yu (2015).

TABLE 1
Key Firm Characteristics by Pure and Non-pure Exporters

Firm Log R&D	*All Firms*		*Pure Exporter*		*Non-pure Exporter*	
Year	*Mean (1)*	*Std. (2)*	*Mean (3)*	*Std. (4)*	*Mean (5)*	*Std. (6)*
2001	11.71	2	11.49	1.62	11.72	2.01
2002	11.76	2.01	11.04	1.86	11.78	2.01
2003	11.78	2.03	11.29	1.79	11.8	2.03
2005	12.36	2.16	11.51	1.93	12.38	2.16
2006	12.62	2.2	11.81	1.99	12.64	2.2
All years	12.13	2.13	11.46	1.88	12.14	2.14
Other firm characteristics						
Labour	4.91	1.08	5.29	1.03	4.89	1.08
Sales	103,751	876,144	56,855	214,120	105,652	892,633
TFP (Olley-Pakes)	1.17	0.34	1.15	0.23	1.17	0.34

The disaggregated transaction-level monthly trade data set contains a huge number of observations. It includes 118,333,831 observations during the sample period from 2000 to 2006. There were more than 286,000 firms engaged in international trade during this period. For each transaction, the data set compiles three types of information: (i) basic trade information, which includes value (measured in US current dollars), trade status (export or import), quantity, trade unit and value per unit; (ii) trade mode and pattern, such as destination country for exports, origin country for imports, routing countries (i.e. whether the product is shipped through an intermediate country/regime), customs regime (e.g. processing trade or ordinary trade), transport mode (i.e. by sea, truck, air or post) and customs port (i.e. where the product departs or arrives); and (iii) firm-level information, in particular, seven variables are included: firm name, identification number set by customs, city of firm location, telephone number, postal code, name of manager/CEO and firm ownership type (e.g. foreign affiliate, private or SOE).

To understand whether a firm engages in processing trade, we need to merge firm production-level data and transaction-level trade data. However, the matching is particularly challenging, since the trade and production data share no common identification (Wang and Yu, 2012). Therefore, we take a detour by using the firm name (in Chinese), telephone number and postal code as identification variables.[3] Briefly, the merged data cover roughly 30 per cent of the exporters and account for 53 per cent of the total export value reported in the original production data. Compared with the original trade data, the merged data show a similar proportion of ordinary importers and processing importers, as in Yu (2015). Thus, a caveat here is that our estimation results only apply to large trading firms due to our data limitation.

Finally, tariff data can be accessed directly from the WTO. China's tariff data are available at the Harmonized System (HS) 6-digit level for 2000–06. For our estimation purposes, we first aggregate tariffs to the Chinese industry classification (CIC) 2-digit level. Given that every firm corresponds to a particular industry, we are able to find the associated industry-level output tariffs for all firms.

[3] The detailed method and technique are described in Yu (2015).

TABLE 2
Summary Statistics of Key Variables (2001–06)

	Full Sample				*Merged Sample Avg.*
	Avg.	*2001*	*2003*	*2006*	
Labour	4.92	5.11	4.98	4.87	5.38
	(1.08)	(1.08)	(1.07)	(1.08)	(1.11)
Firm profit(log)	6.72	6.44	6.56	6.98	7.40
	(1.93)	(1.97)	(1.89)	(1.93)	(1.92)
Industry-level output tariff	11.07	17.19	11.86	9.82	11.53
	(8.15)	(9.91)	(6.74)	(5.51)	(7.51)
Pure exporter indicator	0.04	0.04	0.04	0.04	0.01
	(0.19)	(0.20)	(0.19)	(0.19)	(0.10)
Pure processing indicator					0.55
					(0.42)

Note:
Numbers in parentheses are standard deviations.
Source: China's National Bureau of Statistics, calculated by the authors.

Table 2 presents the summary statistics for some key variables both in the full sample and in the merged sample used in the estimations. We also report the mean and standard deviations for each key variable by year. It is clear that industrial output tariffs are decreasing over years. Simultaneously, survival firms are getting larger and profitable. By sharp contrast, the proportion of pure exporters is not changed much over years. This interprets why the statistics of key variables shown in Table 1 for all firms and for non-pure exporters look similar. The last column shows the summary statistics for corresponding key variables used in the full-sample data. It turns out that the means of all variables do not change much between using the full-sample data and merged-sample data. Finally, the last column of Table 2 also reports the main statistics of a new variable – pure processing indicator, which is only available from the merged-sample data set.

3. EMPIRICS AND RESULTS

a. Benchmark Estimates with the Full Sample

In this section, we use the unmerged firm-level production data. Before the regression, we first compare the major information of the firms with positive R&D and no R&D in Table 3.

TABLE 3
Comparison between Zero R&D and Positive R&D

	Productivity	*Labour*	*Profit*	*Pure Exporter*
R&D = 0	1.16	4.82	6.63	0.04
R&D > 0	1.19	5.53	7.76	0.02
Diff	−0.02***	−0.71***	−1.13***	0.02***
	(−19.16)	(−190)	(−150)	(30.92)

Note:
Robust *t*-values are in parentheses, and *** denotes 1% level of significance. The data are computed from the unmerged full-sample data.

It is apparent that firms with positive R&D are larger, more productive and more profitable, and they export less of their product and have lower proportion of pure exporters. This is consistent with our argument that most pure exporters are processing exporters and usually invest less in R&D.

To examine the effect of input trade liberalisation on firm R&D, we consider the following empirical specification:

$$\ln RnD_{it} = \beta_1 \mathrm{WTO}_t + \beta_2 PureExporter_i + \beta_3 \mathrm{WTO}_t \times PureExporter_i + \epsilon_{it}, \qquad (1)$$

where RnD_{it} denotes firm i's R&D inputs in year t. WTO_t is a dummy variable that equals one after 2001 and zero before 2001. $PureExporter_i$ is an indicator that equals one if firm i is a pure exporter and zero otherwise. With this set-up, pure exporters are treated as a control group to capture the fact that most pure exporters are processing exporters, which were not affected by further input tariff cuts after the WTO accession. If this specification is supported by the data, we shall observe that β_1 should be positive and significant, indicating that firms have more R&D investment after the WTO accession. β_2 is expected to be statistically insignificant in the sense that after matching the control group and the treatment group, pure exporters' R&D investment would not be significantly different from non-pure exporters before WTO accession. However, the key variable, the interaction term between the WTO dummy and the pure exporter indicator, must be negative and significant, suggesting that non-pure-exporting firms' R&D would significantly increase due to the WTO accession compared with its counterpart of pure exporters.

It is worthwhile stressing that the independence of irrelevant alternatives is a crucial assumption for the DID analysis. The idea is that pure exporters and non-pure exporters are different in many respects, although some variables may affect the R&D behaviour of both types of exporters. For instance, as documented by Dai et al. (2012) and Yu (2015), processing exporters are also pure exporters and processing exporters are less productive and less profitable than non-processing exporters. To avoid this potential pitfall of violating, we include control variables, such as firm Olley and Pakes's (1996) total factor productivity, firm profits and firm size (proxied by number of employees) in all estimations throughout the paper. Finally, previous works also suggest that SOEs may have less incentive to engage in R&D behaviour, since they receive an extra subsidy from the government (Hsieh and Klenow, 2009). And, because they are more productive, multinational corporations may invest more in R&D inputs (Keller and Yeaple, 2009). We thus also include a control for firm ownership type by including the SOE indicator and the foreign indicator in all the regressions.

By abstracting away year-specific fixed effects, the estimates in column (1) in Table 4 show that firms have more R&D investment after the WTO accession. More importantly, the negative and significant coefficient of the interaction term between the WTO dummy and the pure exporter indicator suggests that non-pure exporters have more R&D activity after the WTO accession. Meanwhile, the lower the industrial output tariffs, the higher the firm R&D. More productive firms invest more in R&D activity. Finally, larger firms and more profitable firms have more R&D activity. These findings are consistent with the conventional findings in the literature.

Still, there may be a concern that the increases in firm R&D were caused by other macroeconomic shocks, such as appreciation of the renminbi (RMB). We thus include year-specific fixed effects in columns (2) to (4) in Table 4. All the estimation results remain robust and insensitive to those in column (1) after controlling for year-specific and firm-specific fixed effects.

TABLE 4
Benchmark Estimates

Firm R&D (log)	*(1)*	*(2)*	*(3)*	*(4)*
WTO indicator	0.284***			
	(6.73)			
Pure exporter indicator	0.15	0.11	0.28	0.50**
	(0.63)	(0.47)	(1.47)	(2.34)
WTO indicator ×pure exporter indicator	−0.564**	−0.520**	−0.696**	−0.525**
	(−2.27)	(−2.11)	(−2.56)	(−2.53)
Industry output tariff	−0.009***	−0.007***	−0.007***	−0.003*
	(−6.92)	(−5.62)	(−4.53)	(−1.88)
Firm productivity (in log)	0.636***	0.554***	0.464***	0.140**
	(15.16)	(13.23)	(7.30)	(2.30)
Firm size (in log)	0.442***	0.457***	0.454***	0.411***
	(42.71)	(44.32)	(27.52)	(10.28)
Firm profit (in log)	0.328***	0.312***	0.307***	0.131***
	(48.06)	(45.75)	(29.50)	(10.18)
SOE indicator	0.08	0.103**	0.09	0.21**
	(1.51)	(2.11)	(1.49)	(2.15)
Foreign indicator	−0.01	−0.02	−0.01	−0.09
	(−0.50)	(−0.64)	(−0.28)	(−0.74)
Year-specific fixed effects	No	Yes	Yes	Yes
Firm-specific fixed effects	Yes	Yes	Yes	Yes
Year covered	2001–06	2001–03	2001–05	
Number of observations	43,407	43,407	11,456	31,448
R-squared	0.32	0.33	0.31	0.31

Notes:
(i) Pure exporters served as the control group in the estimations. The simple average industry-level output tariff is computed at the CIC 4-digit level.
(ii) Robust t-values are in parentheses.
(iii) *** and ** denote 1% and 5% level of significance.

Thus far, our estimation sample covers five years from 2001 to 2006. An interesting question is how the WTO accession affected firm R&D in the very short run. Column (3) in Table 5 presents estimation results for the sample from 2001 to 2003. All the previous results remain robust. Finally, in addition to RMB appreciation against the US dollar, the Multi Fibre Agreement was phased out in 2005 (Khandelwal et al., 2013). The year-specific fixed effect is a good control for RMB appreciation, but it cannot handle the industrial heterogeneity caused by the termination of the Multi Fibre Agreement. To address this concern, we hence drop 2006 from the estimates in column (4). It turns out that the key coefficient of β_3 is still negative and statistically insignificant. Thus, our results are not sensitive to the event of RMB appreciation in 2006.

In the estimates in columns (2) to (4), even after imposing firm-specific import tariffs, the pure exporters' variable is still not significant. This is because the status of pure exporters is not invariant over time. Firms can switch from pure exporters to non-pure exporters, or vice versa. However, a firm might be pure exporters in one year and not in another year; though this transition is not frequent (the probability of transition from pure exporters to non-pure exporters is 25 per cent, and the reverse direction is only 1.5 per cent.), it may still cause problems in the classification of different groups, so we instead use the firms who are pure

TABLE 5
Estimates with Control Group: Initial Pure Exporter

Firm R&D (log)	*(1)*	*(2)*	*(3)*
WTO indicator	0.246***	0.25***	0.282***
	(8.93)	(8.77)	(6.14)
Pure exporter indicator	0.24		
	(1.36)		
WTO indicator × pure exporter indicator	−0.50**	−0.603**	−0.691**
	(−2.74)	(−3.08)	(−3.35)
Industry output tariff	−1.183***	−1.838***	−2.244***
	(−10.37)	(−7.47)	(−5.60)
Firm productivity (in log)	0.581***	0.313***	0.407***
	(17.66)	(6.45)	(4.69)
Firm size (in log)	0.466***	0.584***	0.639***
	(57.34)	(18.42)	(12.55)
Firm profit (in log)	0.345***	0.197***	0.204***
	(64.36)	(19.57)	(12.60)
SOE indicator	0.013	−0.091	−0.006
	(0.35)	(−1.10)	(−0.05)
Foreign indicator	−0.071***	0.053	0.116
	(−3.31)	(0.56)	(0.86)
Year-specific fixed effects	No	No	No
Firm-specific fixed effects	No	Yes	Yes
Number of observations	43,524	43,524	16,851
R-squared	0.34	0.32	0.37

Notes:
(i) In column (1) to (3), pure exporters in the initial year served as the control group in the estimations so that there is no variation of the control group across years.
(ii) Column (3) drops the firms who are non-exporters in the initial year. The simple average industry-level output tariff is computed at the CIC 4-digit level.
(iii) Robust *t*-values are in parentheses.
(iv) *** and ** denote 1% and 5% level of significance.

exporters in the initial year as control group in Table 5.[4] In column (3), we take a further step to drop those non-exporting firms in the initial years, because they were not affected by the tariff before WTO accession. It turns out that the number of observation drops a lot, but our previous main findings still hold well.

Still, our estimates thus far may suffer from some possible drawbacks as pure exporting firms (i.e. our control group) are not necessarily processing exporters, as some pure exporters may still only engage in ordinary trade although they sell their whole products abroad. To address such a concern, we use the merged data between firm-level production data and product-level custom data.

b. Estimates with the Merged Sample

Thus far, all the estimations have used the full-sample, firm-level production data, which reports each firm's export status but not processing status. To understand whether a firm

[4] We thank a referee for the suggestion.

TABLE 6
Firm R&D Before WTO Accession: Using Merged Sample

R&D (log)	*Treatment: Non-pure Processing*	*Control: Pure Processing*	*Difference*	*t-value*
Unmatched	12.39	12.53	−0.14	−1.25
Matched (ATT)	12.39	12.24	0.14	0.73

Balance Tests

Merged	*Firm Productivity (in log)*	*SOE*	*FIE*	*Size (in log)*	*Capital (in log)*	*Profit (in log)*
Treatment	1.159	0.109	0.287	6.143	10.551	7.997
Control	1.148	0.099	0.286	6.190	10.560	8.129
Bias (%)	4.8	3.8	0.3	−3.6	−0.5	−6.2
t-value	1.41	0.66	0.06	−0.73	−0.10	−1.30

Notes:
(i) ATT, average treatment for the treated.
(ii) Robust *t*-values are in parentheses.

engages in processing trade, we need to merge the firm-level production data set and customs data set. With the merged data set, we are ready to examine the effect of input trade liberalisation on firm R&D using processing exporters as the control group. More importantly, it is well documented that some firms engage in processing trade and ordinary trade (Yu, 2015). Strictly speaking, such hybrid firms are not qualified to serve as the control group in our DID estimations, as their ordinary imports are also affected by further input trade liberalisation due to the WTO accession. We hence exclude hybrid firms from the control group and only keep pure processing firms to serve as the control group in the estimations.

However, as mentioned above, if pure processing firms and non-pure processing firms had significantly different levels of R&D before the WTO accession, the DID approach would be contaminated, since it could be that the R&D difference after the WTO accession indeed was not caused by trade liberalisation. To check this out, we first examine the mean of firm R&D for the two groups. As shown in the first module of Table 6, the log R&D difference between non-pure processing firms and pure processing firms before the WTO accession is statistically insignificant. Still, to make sure that pure processing firms are comparable to non-pure processing firms, we perform propensity score matching between pure processing firms and non-pure processing firms before the WTO accession. We use firm productivity, firm size (proxied by number of employees), firm capital, firm profit and firm ownership type as covariates. The lower module of Table 7 reports the results of the balance tests, in which the bias of all the chosen covariates is statistically insignificant and the overall bias of the specification is 3.2 per cent with a fairly high *p*-value (0.28), suggesting that our chosen covariates work well. The low *t*-value confirms that, overall, the difference in the level of R&D for the two groups is not statistically significant before the WTO accession. Thus, it is safe to use the DID estimates with the merged sample.

The estimates reported in Table 7 use the merged data to explore the effect of WTO accession on firm R&D. To make the results with the new data set comparable to those in Table 4, the estimations in column (1) of Table 7 still use pure exporters as the control group. The negative and significant coefficient of the pure exporter indicator suggests that pure exporters have less R&D investment compared with non-pure exporters. The interaction between the

TABLE 7
Impact of WTO Accession on Firm R&D Using Merged Data

Firm R&D (in log)	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
WTO indicator	0.437***	0.446***		0.349***	
	(7.74)	(7.94)		(5.50)	
Pure exporter indicator	−0.685***				
	(−3.65)				
Pure processing indicator		−0.898***			
		(−5.04)			
WTO indicator × pure exporter indicator	−0.361*				
	(−1.79)				
WTO indicator ×pure processing indicator		−0.585***	−0.708***	−0.799***	−0.533*
		(−3.07)	(−3.40)	(−2.77)	(−1.69)
Industry output tariff				(0.00)	(0.01)
				(−0.64)	(−1.20)
Firm productivity (in log)				0.163*	0.410***
				(1.65)	(3.45)
Firm size (in log)				0.381***	0.539***
				(5.83)	(6.60)
Firm profit (in log)				0.131***	0.239***
				(6.19)	(9.26)
SOE indicator				0.373*	0.31
				(1.73)	(1.03)
Foreign indicator				(0.19)	(0.25)
				(−0.88)	(−0.78)
Weighted world GDP (log)					0.072***
					(3.68)
Year-specific fixed effect	No	No	Yes	No	Yes
Firm-specific fixed effect	No	No	Yes	Yes	Yes
Number of observations	18,208	18,208	18,208	12,285	8,626
R-squared	0.01	0.02	0.10	0.13	0.07

Notes:
(i) Robust *t*-values are in parentheses.
(ii) *** and * denotes 1% and 10% level of significance.

WTO dummy and the pure exporter indicator also has a negative and significant term, indicating that non-pure exporters have more R&D investment after the WTO accession. These results are consistent with their counterparts in column (1) of Table 4.

The rest of Table 7 replaces the pure exporter indicator with the pure processing indicator, as firms' processing information is available in the merged data set. Column (2) yields similar results as those in column (1). We thus include firm-specific fixed effects and year-specific fixed effects in column (3). Accordingly, the WTO indicator and the pure processing indicator are absorbed away from the estimations. The interaction of the WTO indicator and the pure processing indicator is negative and significant, once again, suggesting that ordinary firms and hybrid firms have more R&D investment after the WTO accession. Finally, to rule out the possibility that non-pure processing firms have more R&D investment after the WTO accession because of other driving forces, such as output trade liberalisation and larger foreign market size, the estimates in columns (4) and (5) control for several other variables, as mentioned above. In particular, estimates in column (5) include importing countries' GDP weighted by their bilateral trade volume as an additional variable to capture the increase in access to foreign markets due to the trade liberalisation imposed by China's trading partners (Liu and Meissner, 2015). And it still yields results very close to those in column (3).

c. Placebo Tests

There may still be a concern about possible serial correlation, as the data sample is for six years (2001–06). Bertrand et al. (2004) point out that some unobservable macroeconomic factors would generate a time serial problem in the error term, which could in turn lead to an upward bias in our key estimated coefficients. To address this potential challenge, following Bertrand et al. (2004), we conduct following placebo tests by first dividing our whole sample into two periods (i.e. before and after WTO accession), and take the mean average of each variable in the two periods to perform the first-difference estimations. Table 8 presents the new estimation results using this approach. The results are once again qualitatively identical and quantitatively close to their counterparts in Table 7.

TABLE 8
Further Estimates with Two Periods Only

Firm R&D (in log)	*(1)*	*(2)*	*(3)*	*(4)*
WTO indicator	0.191***			
	(3.30)			
Pure processing indicator	−0.898***			
	(−5.04)			
WTO indicator ×pure processing indicator	−0.425**	−0.850***	−1.147***	−0.971***
	(−2.17)	(−3.80)	(−3.22)	(−2.63)
Industry output tariff			−0.025***	(0.01)
			(−3.65)	(−0.57)
Firm productivity (log)			(0.01)	(0.06)
			(−0.04)	(−0.28)
Firm size (log)			0.833***	0.19
			(5.41)	(0.98)
Firm profit (log)			0.222***	0.170***
			(4.39)	(2.93)
SOE indicator			0.27	0.59
			(0.61)	(1.22)
Foreign indicator			0.73	1.41
			(0.99)	(1.64)
Weighted world GDP (log)				(0.01)
				(−0.19)
Year-specific fixed effects	No	Yes	No	Yes
Firm-specific fixed effects	No	Yes	Yes	Yes
Number of observations	11,678	11,678	7,190	7,190
R-squared	0.01	0.11	0.14	0.20

Notes:
(i) Robust *t*-values are in parentheses.
(ii) *** and ** denotes 1% and 5% level of significance.

TABLE 9
Estimates with Ordinary Firms Only in Control Group

Firm R&D (in log)	*Treatment Group: Ordinary Firms*		*Tobit Estimates with Zero R&D*		*PPML*
	(1)	*(2)*	*(3)*	*(4)*	*(5)*
WTO indicator	0.278	0.327*	−0.227	−0.664	1.002***
	(1.56)	(1.89)	(−0.53)	(−1.27)	[0.001]
Pure processing indicator	0.095	0.133	3.001***	5.704***	−0.716***
	(0.55)	(0.78)	(5.28)	(8.28)	[0.001]
WTO indicator × pure processing indicator	−0.314*	−0.374**	−2.307***	−1.724**	−0.059***
	(−1.69)	(−2.07)	(−3.90)	(−2.43)	[0.001]
Industry output tariff				−0.097***	−0.016***
				(−8.15)	[0.000]
Firm productivity (log)		1.602***		4.410***	1.000***
		(25.26)		(14.81)	[0.000]
Firm size (log)				5.415***	
				(60.42)	
SOE indicator	0.293***	0.322***	10.623***	4.701***	−0.644***
	(3.25)	(3.66)	(18.47)	(7.54)	[0.001]
Foreign indicator	−0.357***	−0.455***	−8.400***	−6.124***	−0.182***
	(−8.48)	(−11.03)	(−42.98)	(−28.89)	[0.000]
Year-specific fixed effects	Yes	Yes	Yes	Yes	Yes
Firm-specific fixed effects	Yes	Yes	No	No	No
Treatment group	Non-processing firms	Non-pure processing firms	Non-pure processing firms		
Number of observations	12,684	12,676	137,957	106,025	13,795

Notes:
(i) Robust *t*-values are in parentheses in columns (1)-(4), whereas robust standard errors are in the squared brackets.
(ii) Columns (3) and (4) regress on log R&D by Tobit estimations in which we replace the regress and for firms with missing R&D expenses with zero.
(iii) Column (5) regresses on firm R&D by Poisson pseudo-maximum likelihood estimation and keeps only the observations with positive R&D, so the sample drops significantly.
(iv) ***, ** and * denotes 1%, 5% and 10% level of significance.

Thus far, we have seen rich evidence that non-pure processing exporters have invested more in R&D after China's accession to the WTO than pure processing firms have. However, as mentioned above, non-pure processing exporters include two types of firms: ordinary exporters and hybrid exporters. In addition to ordinary imports, hybrid firms also engage in processing imports, which are not affected by further cuts in import tariffs. Hence, there may be a concern that the effect of input trade liberalisation on ordinary exporters' R&D investment is underestimated in our previous exercises.

To address this potential pitfall, we drop hybrid firms from the sample. Accordingly, columns (1) and (2) of Table 9 use ordinary exporters as the new treatment group, whereas pure processing exporters still serve as the control group. The sample in Table 9 hence is about 40 per cent smaller compared with the sample in Table 8. Still, we see robust evidence that ordinary exporters have more R&D investment after the WTO accession than pure processing exporters do.

Furthermore, the sample with positive R&D accounts for only 20 per cent of the whole sample in the firm-level data set. This generates a large number of missing values when taking the log in our estimations. To handle the 'missing' R&D issue, we replace observations with missing R&D values with zero. In this way, we are able to perform Tobit estimation in columns (3) and (4) of Table 9, in which non-pure exporters are still used as the treatment group. The numbers of observations in columns (3) and (4) increase about ninefold compared with those in columns (1) and (2). Nevertheless, our key findings still hold firmly: non-pure processing firms invest more in R&D after the WTO accession. However, treating missing R&D as zero may cause unknown bias and enlarge the magnitude of the coefficient. Inspired by Santos Silva and Tenreyro (2006), we then use Poisson pseudo-maximum likelihood (PPML) regression to deal with zero and missing R&D in column (5).[5] The interaction term coefficient is still significantly negative though the magnitude decreases a little.

Still, it is possible that large firms have more R&D investment. Accordingly, firms with more R&D expenses are not necessarily more innovative. This tells us that it is reasonable to control for firm size directly. In addition to including the number of employees (as a proxy for firm size) in the regressions, we replace firm log R&D with firm R&D intensity, defined as a firm's R&D expenses over its sales, in the estimates in Table 10. We start off our regressions using full-sample, firm-level data in which the only information available is pure exporting status. The results are consistent with their counterparts in Table 4. Finally, we use the merged data set, which provides information on firms' pure processing status. After controlling for several other variables, the interaction term between the WTO indicator and the pure processing indicator is negative and significant at the conventional statistical level, confirming that input trade liberalisation leads to firm R&D growth after China's accession to the WTO.

d. Robustness Checks[6]

We use the WTO indicator to distinguish firm's different response to input trade liberalisation before and after China's WTO accession. A caveat here is the WTO indicator mainly captures the impact of WTO accession which includes not only input trade liberalisation but also some other forces such as the increased FDI inflow. To address such a concern, in our

[5] We thank a referee for such suggestions.
[6] We thank a referee for such suggestions.

TABLE 10
Impact on R&D Intensity

Sample	*Full Sample*			*Merged Sample*	
R&D Intensity	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
WTO indicator	0.004		0.079***	−0.006	
	(0.47)		(11.63)	(−0.13)	
Pure exporter indicator	−0.018	0.008	0.046		
	(−0.61)	(0.26)	(1.53)		
WTO indicator ×pure exporter Indicator	−0.054*	−0.078**	−0.052*		
	(−1.71)	(−2.48)	(−1.73)		
Pure processing indicator				0.175**	0.176**
				(2.55)	(2.56)
WTO indicator × pure processing indicator				−0.135*	−0.136*
				(−1.88)	(−1.90)
Industry output tariff	−0.001***	−0.001***	0.000	−0.005***	−0.005***
	(−5.20)	(−3.91)	(0.56)	(−5.92)	(−5.94)
Firm profit (log)	0.035***	0.031***	−0.001		
	(34.24)	(30.15)	(−0.61)		
Firm size (log)	0.033***	0.039***	0.030***		
	(18.02)	(20.63)	(5.42)		
Firm productivity (log)				0.130***	0.130***
				(6.05)	(6.04)
SOE indicator	0.151***	0.141***	−0.042*	0.318***	0.317***
	(14.67)	(13.65)	(−1.69)	(5.93)	(5.91)
Foreign indicator	−0.052***	−0.082***	−0.010	−0.127***	−0.127***
	(−11.75)	(−18.18)	(−0.47)	(−9.52)	(−9.46)
Year-specific fixed effect	Yes	Yes	Yes	No	Yes
Firm-specific fixed effects	No	No	Yes	Yes	Yes
Industry-specific fixed effects	No	Yes	No	No	No
Number of observations	323,933	323,933	323,933	79,342	79,342
R-squared	0.01	0.01	0.001	0.01	0.01

Notes:
(i) Robust *t*-values are in parentheses.
(ii) ***, ** and * denotes 1%, 5% and 10% level of significance.

estimates, we have already included both year-specific effects to wash out time-variant factors such as RMB appreciation and firm-specific effects to control for firm-variant factors. However, for the sake of completeness, we perform further robustness checks by replacing our original treat variable, the WTO indicator, with imported input tariff in Table 11. Following Topalova and Khandelwal (2011) and Yu (2015), we construct an industry-level input tariff, IIT, which is measured at 4-digit Chinese industry level as below:

$$IIT_{ft} = \sum_{n} \left(\frac{input_{nf}^{2002}}{\sum_{n} input_{nf}^{2002}} \right) \cdot \tau_{nt},$$

TABLE 11
Intermediate Input Tariff and Firm R&D

Firm R&D (in log)	*(1)*	*(2)*	*(3)*	*(4)*
Industry input tariffs	−0.116***	−0.029***	−0.032***	−0.023**
	(−32.60)	(−3.76)	(−3.82)	(−2.48)
Industry output tariffs		0.001	0.001	−0.001
		(0.83)	(0.43)	(−0.63)
Firm productivity (in log)			0.132**	0.128**
			(2.57)	(2.01)
Firm size (in log)			0.445***	0.433***
			(12.99)	(9.99)
Firm profit (in log)			0.134***	0.127***
			(12.28)	(9.20)
SOE indicator			0.10	0.198*
			(1.16)	(1.84)
Foreign indicator			0.04	−0.03
			(0.40)	(−0.19)
Year-specific fixed effect	Yes	Yes	Yes	Yes
Firm-specific fixed effects	Yes	Yes	Yes	Yes
Years covered	2001−2006	2001−2005		
Number of observations	57,111	42,587	37,303	27,260
R-squared	0.02	0.08	0.02	0.06

Notes:
(i) Robust *t*-values are in parentheses.
(ii) ***, ** and * denotes 1%, 5% and 10% level of significance.

where $input_{nf}^{2002}$ is the total input value of industry n used by industry f in 2002, whereas $\tau_n t$ is the import tariff of product n in year t. Data on industrial inputs are from China's input–output table (2002). Inspired by Topalova and Khandelwal (2011), the input weight for each industry is fixed at the initial period to avoid possible endogeneity between input tariffs and imported input volume.

Table 11 reports our estimation results. Column (1) shows that a decrease in industry input tariff leads to an increase in firm R&D, which is consistent with previous finding. Estimates in column (2) control for the industry output tariff whereas those in column (3) add more firm characteristics such as firm productivity and firm size. Our last estimates in column (4) drop observations in 2006 to rule out the possible impact of the termination of the Multi Fibre Agreement (MFA). In all estimates, we see that input tariff reductions boost firm R&D expenses.

4. CONCLUDING REMARKS

This paper considered how trade liberalisation on imported intermediate inputs affects firm innovation. The analysis took advantage of the fact that processing imports in China are duty free. Further trade liberalisation after WTO accession should not have an impact on processing imports. We thus used processing firms as a control group to employ difference-in-difference estimations. Our extensive empirical search found that non-processing firms have more R&D after China's accession to the WTO, suggesting that input trade liberalisation has boosted firm innovation since China acceded to the WTO.

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