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Export tightening, competition, and firm innovation: Evidence from the renminbi appreciation

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Abstract

This paper investigates how firm innovation reacts to changes in competitive pressure in the export market. We use the exchange rate appreciation of the renminbi during 2005–2007 as a natural experiment and exploit its differential impact on Chinese manufacturing firms with different export exposure. The appreciation reduced exports and imposed greater competitive pressure on exporters relative to non-exporters. In response, exporters increased innovation activities more than non-exporters. Using a difference-in-difference approach, we find that the research and development expenditure of exporters increased by 11% more than that of non-exporters during the appreciation period, and the new product development of exporters increased by nearly 1.5 times more than that of non-exporters. These results highlight the important role of competition in providing incentives for firm innovation.

1 | INTRODUCTION

One of the key ideas in international economics is that trade can bring dynamic gains by fostering innovation. Why is trade associated with more innovation? The recent trade literature has focused on two channels, one on the export side and one on the import side. On the export side, a number of papers have found that exports increase the incentive of innovation by expanding firms' market size.[1] On the import side, most of the studies have focused on the impact of increased import competition on the innovation behavior of domestic firms.[2]

In the present paper, we investigate a new channel linking trade and innovation: changes in competitive pressure in a firm's export markets. Following Galdón-Sánchez and Schmitz (2002), we define competitive pressure as the probability of closure. Since the probability of closure is negatively related to profits, forces that reduce firm profits are supposed to raise competitive pressure. Theoretically, increased competitive pressure can benefit innovation through several channels, such as reducing agency costs (Schmidt, 1997), releasing factors that are “trapped” in producing old goods, escaping competition in the existing product market (Aghion, Bloom, Blundell, Griffith, & Howitt, 2005), or increasing the incentive to gain market share (Raith, 2002).[3] For a firm with sales in multiple countries, competitive pressure may arise from either the domestic market or export destinations. Although empirical evidence on the impact of competition in the domestic market is considerable, less is known about the impact of competitive pressure from the export market. One possible reason for such lack of investigation is that it is difficult to observe exogenous shocks that systematically change firms’ competitive pressure in export markets.

Our study investigates the innovation response to competitive pressure in the export market that arises from exchange rate shocks. We use China’s exchange rate regime policy reform as a natural experiment and investigate the effect of the subsequent exchange rate appreciation on the innovation of Chinese manufacturing firms. Appreciation of the renminbi (RMB) increases the relative price (denominated in the local currency of the destination country) of a Chinese exporter against its competitors in the export destination, negatively affecting the Chinese exporter’s profits and translating into increased competitive pressure from the export market. We identify the impact of this by exploiting the heterogeneity across firms in their export status. Intuitively, appreciation increased competitive pressure in the foreign market relatively more for firms more reliant on exports. We employ a difference-in-difference approach to examine its impact on innovation.

One empirical challenge in our study is that the appreciation may affect firm innovation through channels other than changing the competitive pressure in the export market. First, the appreciation implies a tightened export market and contracts the total market size of exporters, discouraging innovation that displays economies of scale (market size effects). Second, the appreciation makes foreign exporters more competitive in domestic markets and increases the import competition faced by indigenous firms (import competition effect). Third, the appreciation lowers the prices of imported intermediated inputs, which may benefit innovation if imported inputs and innovation are complementary (imported inputs effect). We make several attempts to control for these alternative channels. For import competition effects, we include the import penetration ratio at the industry level and investigate whether the impact of the appreciation differs across industries with different import competition stances. For the imported inputs channel, we control for the firm’s intensity of use of intermediate inputs and investigate whether the effect of the appreciation differs across firms with different import intensity. Finally, by investigating the response of firms with different export dynamics, we provide suggestive evidence for market size effects. Our results suggest that these alternative channels do matter for innovation. However, they cannot explain our major empirical finding that the innovation behavior of the *ex ante* exporters rose faster than *ex ante* non-exporters during the appreciation period. First, since the foreign market contracts more for exporters under the appreciation, market size effects will predict that the innovation of exporters will fall, rather than rise, relative to non-exporters. Second, as long as exporters also have sales in the domestic market, as in Melitz (2003), pressures from import competition should be present for exporters, failing to explain why the innovation of exporters rose faster. We attribute this faster innovation growth of exporters to the increased competitive pressure in the export market induced by the appreciation.

To preview the results, we find that the RMB appreciation caused the research and development (R&D) expenditure of exporters to increase by 11 percent, and new product development to increase by nearly 1.5 times more than for non-exporters. We also find such effect to be heterogeneous across industries with different R&D intensities, and also across firms with different export dynamics.

This paper is related to a broad literature that studies the nexus between trade and innovation. Papers like Bustos (2011), Lileeva and Trefler (2010), Verhoogen (2008), and Aw *et al.* (2011) link exports to innovation through increased market size. These studies are usually set in an export expansion scenario, such as tariff reductions or exchange rate devaluation, and investigate the impact of increased export opportunities on firms' innovation (or upgrading) behaviors, such as R&D, product innovation, ISO certification and technology adoption from advanced countries. The present paper, however, is set in a scenario of export tightening (caused by the exchange rate appreciation) and therefore investigates the flip side of the coin. Interestingly, we find that firm innovation also rises under the exchange rate appreciation, which contradicts the prediction of the models that link export and innovation solely via market access. Therefore there must be some other forces at work. Another line of literature links trade and innovation through import competition. Papers like Bloom *et al.* (2016) and Iacovone *et al.* (2011) investigate the impact of increased import competition from China on the innovation behavior (patent, information technology adoption, just-in-time system, etc.) of European and Mexican firms, while Teshima (2008) investigates the impact of increased import competition resulting from the Mexican unilateral tariff reductions on firm innovation. Our study links with this literature in that we also investigate the impact of competition on firm innovation. However, we focus on the competitive pressure in firms' export markets instead of import competition in the domestic market. To the best of our knowledge, our paper is the first to study the impact of competitive pressure in foreign markets on innovation using firm-level micro-data.

This paper is also related to the literature that investigates the impact of exchange rate shocks on firm performance. Although this literature has a long history, there are still not many papers using firm-level data. Nucci and Pozzolo (2001, 2010) study how the exchange rate affects the investment and employment decisions of Italian manufacturing firms. Ekholm, Moxnes, and Ulltveit-Moe (2011) study the impact of the real exchange rate appreciation on the employment, productivity, and capital intensity of manufacturing firms in Norway. Micro-level studies on the RMB appreciation have recently also begun to emerge, but mostly focused on its impact on trade flows (Li, Ma, & Xu, 2015; Tang & Zhang, 2012). To the best of our knowledge, our paper is the first to study how exchange rate shocks affect the innovation behavior of firms.

The rest of this paper is organized as follows. Section 2 describes the data. Section 3 conducts a preliminary analysis on the impact of exchange rate appreciation on export, firm performance, and innovation. Section 4 estimates the impact of appreciation on firm innovation using a difference-in-difference approach. Section 5 conducts a series of robustness checks. Section 6 discusses industry and firm heterogeneity. Section 7 concludes.

2 | DATA

The firm-level data in this paper come from the Annual Survey of Industrial Firms (ASIF) conducted by the National Bureau of Statistics of China from 2001 to 2007. The survey includes all state-owned enterprises (SOEs) and those non-state-owned enterprises in the industrial sector with annual sales of RMB 5 million (or equivalently, about $650,000) or more. The dataset includes a comprehensive set of variables from firm's balance sheet, profit and loss statements, and cash flow statements, including firms' identity code, ownership, export status, employment, capital stock, and revenue. Importantly for this study, the survey reports information about annual R&D expenditure as well as revenue from new products for each firm.[4] We will use these two variables to construct the main measures of firm innovation. Because of the China Industry Census, R&D and new product data are missing in 2004. We restrict our sample to manufacturing industries.

To clean the data, we follow Feenstra, Li, and Yu (2014) and drop an observation if one of the following criterion is met: (1) Missing or negative values are reported for any of the following variables: total sales, total revenue, total employment, fixed capital, export value, intermediate inputs. (2) Export value exceeds total sales or share of foreign assets exceeds 1. (3) Fewer than least eight employees. Based on this cleaned dataset, we construct a balanced panel of firms that exist throughout the entire sample period. We conduct the subsequent analysis on the balanced panel for two reasons. First, our paper aims to study the within-firm performance change instead of cross-firm resource reallocation. Therefore firm entry and exit are not the focus of our study. Second, most micro-level studies on export and innovation rely on balanced panel data (e.g. Verhoogen, 2008; Lileeva & Trefler, 2010; Bustos, 2011). The final sample for subsequent analysis consists of 58,182 firms and 407,274 observations.[5]

3 | PRELIMINARY ANALYSIS

3.1 | Background: China's exchange rate regime reform and the RMB appreciation

On July 21, 2005, after 11 years of strictly pegging the RMB to the US dollar, the People's Bank of China (PBOC) announced a revaluation of the currency and a reform of the exchange rate regime. The reform transformed the Chinese yuan from a strict pegging to the US dollar into a managed float system that use an undisclosed basket of currencies as reference. The RMB saw an instant appreciation of 2.1% right after the announcement. The subsequent appreciation, however, proceeded in a gradual manner. Each day the PBOC announced its target for the following working day based on that day's RMB closing price in terms of a "central parity." The following day, the RMB exchange rate would be allowed to fluctuate against the dollar and other currencies within a band of plus or minus 0.3% around the central parity announced.[6] Despite the small movement allowed each day, by the end of December 2008, the RMB had actually appreciated 21% against the US dollar compared with its value prior to the reform. The effective nominal exchange rate had also appreciated by 21% (see Figure 1).

Several remarks about the reform and the appreciation are in order. First, the reform was initiated under a strong expectation of appreciation. By the time of the reform, China had maintained a huge current account surplus for over 10 years, accumulating foreign exchange reserves of $700 billion. It was widely believed that the RMB had been substantially undervalued to keep Chinese exports competitive. The reform signaled that the Chinese monetary authority would finally allow for greater exchange rate flexibility and a possible long-term appreciation. In this regard, the effects captured in our study reflect not only the effect of the actual appreciation, but also the expectations of future appreciation. Second, the gradual manner of the appreciation is important for our study. A gradual appreciation allows the firm to adjust to the competitive pressure without being wiped out of the market immediately. A drastic appreciation, by contrast, may lead to firm closure and discourage innovation through a strong market size effect. Actually, giving the domestic firms enough time to adjust to the competitive pressure is also a major reason why the Chinese government has adopted a managed floating exchange regime rather than an independently floating exchange rate regime.[7]

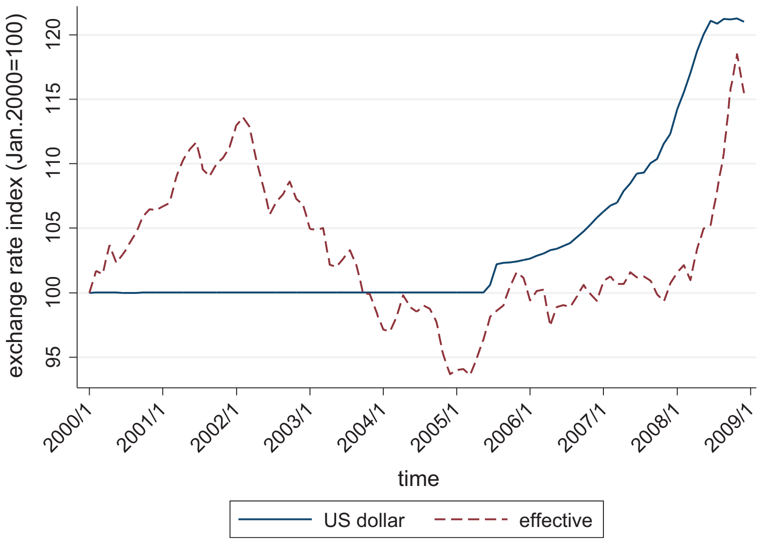

FIGURE 1 Nominal Exchange Rate of the RMB, 2000–2008 [Colour figure can be viewed at wileyonlinelibrary.com]

Note: This figure reports the RMB–dollar exchange rate index and the effective RMB exchange rate. The base period is January 2000, with the exchange rate index set to 100. An increase in the index implies an appreciation of the RMB.

3.2 | Export tightening

We start by examining whether the appreciation led to export tightening and increased competitive pressure for exporters. In Table 1(a) we calculate the average export growth, share of exporters (in terms of number of firms), and average export intensity (defined as exports over total sales) in each year. The share of exporters and average export intensity indicate exports at the extensive margin and intensive margin, respectively. The data show that all three indicators kept rising before 2005, but began to fall after then. Total export growth fell from 26.4% in 2004 to 13.6% in 2007, share of exporters fell from 41.1% to 38.1%, and average export intensity from 24.2% to 22.5%. Thus it is clear that the appreciation has led to sizable export tightening. Table 1(b) shows the fraction of firms that entered and exited the export market during the pre-appreciation period (2001–2004) and the appreciation period (2005–2007). Compared to the pre-appreciation period, the fraction of firms entering the export market decreased from 9.38% to 3.79%, while that of firms exiting the export market increased from 4.14% to 5.56%. This once again suggests that exports shrank at the extensive margin during the appreciation period.

The critical assumption we rely on for identification in the econometric analysis is that the appreciation imposed larger competitive pressure for exporters than for non-exporters. We would like to know whether such differential effects exist in the data. Following Galdón-Sánchez and Schmitz (2002) and Ekholm *et al*. (2012), we argue that greater potential negative impact of the appreciation translates to greater competitive pressure. Therefore, we examine whether the appreciation imposed a greater negative impact for exporters than for non-exporters. Table 2 reports the growth rate of employment, profits, and total sales for exporters and non-exporters during the appreciation period and pre-appreciation period, respectively. The growth rate difference between the two periods is also reported. It is evident from Table 2 that exporters experienced a much more severe slow-down in the growth of employment, profits, and sales under the appreciation. For example, compared to the pre-appreciation period, the employment growth rate reduced by 10.7 percentage points during

TABLE 1 Export Tightening

(a) Export Growth, Share of Exporters, and Average Export Intensity (%)			
Year	(1) Total export growth	(2) Proportion of exporters	(3) Average export intensity
2001	–	35.89	22.43
2002	23.81	37.35	22.93
2003	25.79	38.12	23.08
2004	26.35	41.09	24.24
2005	14.73	39.86	23.22
2006	22.85	39.67	23.01
2007	13.64	38.09	22.46

(b) Share of Firms by Entry and Exit Status (%)		
Type	(1) Pre-appreciation period	(2) Appreciation period
Start to export	9.38	3.79
Continue to export	31.72	34.31
Quit exporting	4.14	5.56
Never export	54.73	56.33

Notes: Part (a) reports total export growth, proportion of exporters, and average export intensity by year. Part (b) reports the proportion of firms that start to export, continue to export, quit exporting and never export during the pre-appreciation and appreciation period. All numbers are percentages. In part (b), the pre-appreciation period is 2001–2004 and the appreciation period 2005–2007. Start to export: export = 0 in the first year of the period, export = 1 in the last year of the period. Continue to export: export = 1 in the first year of the period, export = 1 in the last year of the period. Quit exporting: export = 1 in the first year of the period, export = 0 in the last year of the period. Never export: export = 0 in the first year of the period, export = 0 in the last year of the period.

the appreciation period for exporters but by only 4.5 percentage points for non-exporters. Profits and sales show a similar pattern. Thus the data suggest that the appreciation imposed a greater negative shock on exporters and this translates into increased competitive pressure.[8]

3.3 | Firm innovation

How, then, do firms' innovation activities respond to the competitive pressure imposed by the appreciation? Do exporters increase innovation faster than non-exporters because the incremental competitive pressure is greater? We measure innovation with two variables. The first is the annual R&D expenditure of the firm, and the second is new product development, defined as the revenue from sales of the new products over total sales revenue. R&D expenditure measures the input side of innovation, while new product revenue share measures the output side. Figure 2 shows the log R&D expenditure (Figure 2(a)) and the new product revenue share (Figure 2(b)) for exporters and non-exporters over the sample years. Two patterns emerge immediately from Figure 2, the most important figure in this paper. First, consistently with the literature, exporters on average have a better performance in innovation (Bustos, 2011; Lileeva & Trefler, 2010; Aw *et al*., 2011). They invest more in R&D and recoup a larger share of revenue from new products. Second, before 2005, R&D expenditure and new product revenue share had a similar *trend* for both exporters and non-exporters, while after 2005, both R&D and new product revenue share obviously rose faster

TABLE 2 Growth of Employment, Profit and Total Sales (%), for Exporters and Non-exporters

	Employment	Profit	Total sales
Exporter			
Appreciation period	3.29	87.90	17.23
Pre-appreciation period	13.95	116.40	34.01
Difference	–10.66	–28.54	–16.78
Non-exporter			
Appreciation period	2.60	117.91	23.59
Pre-appreciation period	7.12	104.83	32.92
Difference	–4.52	13.08	–9.33

Note: This table reports average growth rate of employment, profit and total sales during the appreciation period and pre-appreciation period, for exporters and non-exporters in 2004 separately. All numbers are in percentage points.

for exporters. Such a data pattern is consistent with our previous conjecture that the export tightening under the appreciation imposed larger competitive pressure for exporters than for non-exporters and induced more innovation from exporters. Notice that the innovation of non-exporters also rose slightly after 2005, possibly due to increased import competition resulting from the appreciation. We will control for import competition in our subsequent econometric analysis.

In order to show the innovation difference for exporters and non-exporters more clearly, we run the following regression in a flexible specification:

$$INV_{ft} = \alpha + \sum_{t=2002}^{2007} \beta_t EXP_{ft} \times Year_t + \sum_{t=2002}^{2007} Year_t + v_f + \varepsilon_{ft}, \quad (1)$$

where INV_{ft} is the innovation measure for firm f in year t. We include a full set of year dummies $Year_t$ as well as the exporter dummy interacted with the year dummy $EXP_{ft} \times Year_t$. v_f is firm fixed effects and ε_{ft} is the error term with conventional properties. A simple derivation shows that

$$\beta_t = E(INV_{ft}|EXP_{ft} = 1, Year = t) - E(INV_{ft}|EXP_{ft} = 0, Year = t). \quad (2)$$

Thus β_t measures the average innovation difference between exporters and non-exporter in year t. By tracking the evolution of β_t over the years we can see how the innovation difference has changed over time. This flexible specification has the advantage of not imposing arbitrary structure on the data. We plot the β_t. for 2002–2007, together with their 95% confidence intervals, in Figure 3. It is clear that the β_t are low and steady before 2005, but rose dramatically afterwards. The β_t in 2007 is almost four times its value in 2003, indicating that the RMB appreciation might have a large impact on the innovation behavior of exporters. However, the previous results might be caused by other firm and industry characteristics instead of exchange rate movements, so we control for these factors in the following econometric analysis.

4 | ESTIMATING THE IMPACT OF THE APPRECIATION ON FIRM INNOVATION

4.1 | Empirical strategy

Realizing that the appreciation has differential impact on exporters and non-exporters, we use a difference-in-difference (DID) estimation approach. In a seminal paper, Bertrand, Duflo, and

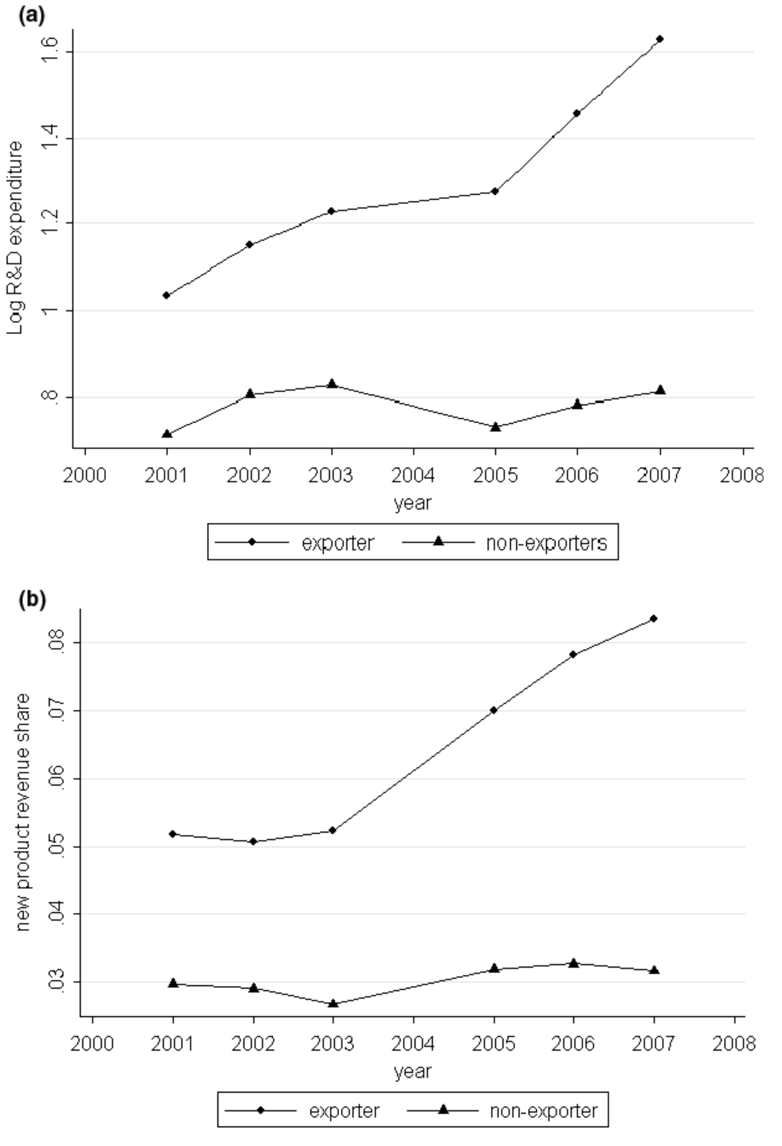

FIGURE 2 (a) Log R&D Expenditure and (b)New Product Revenue Share, by Exporters and Non-exporters

Mullainathan (2004) point out that a multiple-period DID specification (like that in equation (1)) with persistent dependent variable (such as R&D) may run into serious serial correlation problems and lead to over-rejection of the null hypothesis. To fix this problem, we adopt one of their suggested remedies and collapse the data into a pre-appreciation period (2001–2004) and a post-appreciation period (2005–2007). We take the following specification:

$$INV_{ft} = \alpha + \beta_1 Post05_t + \beta_2 EXP04_f \times Post05_t + \nu_f + \varepsilon_{ft}, \quad t = 0, 1, \tag{3}$$

where $t = 0$ and $t = 1$ refer to the pre-appreciation period and the appreciation period, respectively. INV_{ft} is the *year average* of innovation measure for firm f in period t. In the benchmark results, we use four indicators of innovation: log R&D expenditure; an R&D dummy that equals 1 if a firm conducts positive R&D and equals 0 otherwise; new product revenue share; and a new

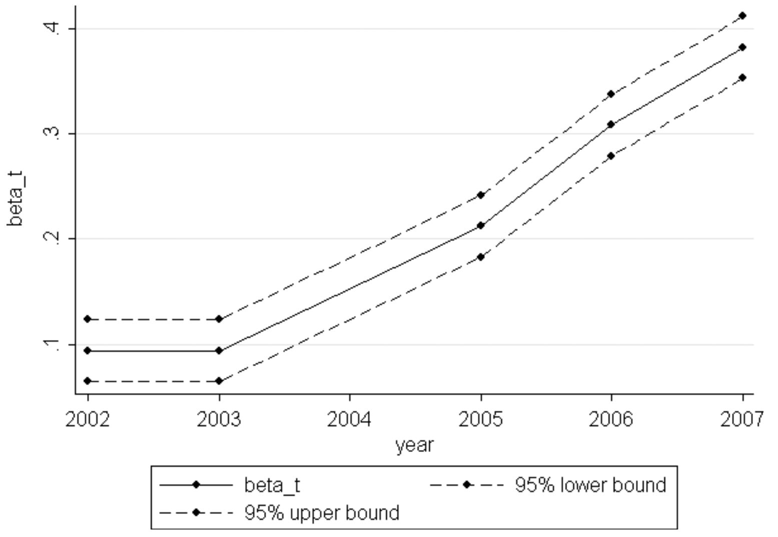

FIGURE 3 *βt*, 2002–2007

product development dummy that equals 1 if a firm has positive revenue share from new products. $Post05_t$ is a dummy variable that equals 1 for the years after (and including) 2005, and equals 0 otherwise.[9] $EXP04_f$ is a dummy variable that equals 1 for exporters in year 2004, and equals 0 for non-exporters.[10] v_f and ε_{ft} are again firm fixed effects and an error term. Taking first-difference between the two time periods for equation (3) yields

$$\Delta INV_f = \beta_1 + \beta_2 EXP04_f + \varepsilon_f^*. \tag{4}$$

Although equation (4) forms the core of our estimation equation, in practice, innovation growth might also be affected by other firm attributes and industry-specific shocks. To control for these confounding factors, we supplement equation (4) with a bunch of firm and industry control variables. Firm-level controls include firm-level TFP,[11] log employment, and log fixed capital stock. For industry-level controls, we include the import penetration ratio of each industry to control for the impact of import competition,[12] plus total export and total domestic sales (both in logs) to control for foreign and domestic demand shocks that might affect firm innovation through market size effects. All control variables take the value of the year prior to the appreciation shock (i.e., 2004) to avoid possible reverse causality.[13] This yields our final estimation equation:

$$\Delta INV_f = \beta_1 + \beta_2 EXP04_f + \beta_3 X_{f04} + \beta_4 X_{i04} + \varepsilon_f^*, \tag{5}$$

where X_{f04} and X_{i04} denote firm- and industry-level control variables, respectively. We estimate equation (5) using ordinary least squares (OLS). Standard errors are clustered at the four-digit industry level.[14] Table 3 reports the summary statistics of the major variables used in estimations.

4.2 | Results

Table 4 reports the benchmark estimation results. No matter which indicator is used to measure innovation, the coefficient of the export dummy ($EXP04_f$) is always positive and significant. This

TABLE 3 Summary Statistics for Major Variables

Variables	Mean	Std. Deviation
Dependent variable (ΔINV_f)		
Δlog R&D expenditure	0.129	1.694
ΔR&D dummy	–0.011	0.295
Δnew product revenue share	0.013	0.129
Δnew product dummy	0.040	0.257
Key independent variable		
Exporter dummy ($EXP04_f$)	0.411	0.492
Firm-level control variable		
TFP_OP[15]	4.284	1.163
Log employment	5.233	1.093
Log capital stock	8.996	1.724
Industry-level control variable		
Import penetration ratio	0.110	0.125
Log industry export	15.095	1.867
Log industry domestic sales	16.582	1.478

suggests that the innovation of exporters increased more than non-exporters during the appreciation period. Since we take logs of the R&D expenditure, the coefficient in column 1 suggests that the R&D investment by exporters increased by 11% more than by non-exporters. For new product revenue share (column 3), the new product revenue share for exporters increased by 0.1 percentage points more than that for non-exporters. This result may seem insignificant at first glance. However, the new product revenue share for non-exporters increased by only 0.066 percentage points during the same period. Thus the coefficient suggests that the increase in new product revenue share for exporters is actually nearly 1.5 times more than that of non-exporters. The import penetration ratio coefficient is also positively significant in some cases, though the significance is not robust to the measure of innovation.[16]

5 | ROBUSTNESS

5.1 | Using one year before and after the shock

In Section 4 we use the year average of innovation in the pre-appreciation and appreciation period as the dependent variable. Doing so takes advantage of innovation information in all years and helps to capture the full impact of the appreciation if any lagged effects exist. However, a potential problem with this approach is that our estimation result might also capture the effect of other policies that took effect during the appreciation period and influenced the innovations of exporters and non-exporters differently. As suggested by Bertrand *et al.* (2004), an alternative way to carry out estimation is to use just one year before and after the appreciation shock. To this end, we repeat the DID regression in equation (4), using the observations in year 2003 and 2006 only. The result reported in Table 5 show that the coefficient of the variable $EXP04_f$ is slightly smaller than the benchmark results in Table 5, but is nevertheless positive and highly significant.

TABLE 4 Baseline Regression Result

Dependent variable	(1) Δlog R&D	(2) ΔR&D dummy	(3) Δnew product revenue share	(4) Δnew product dummy
$EXP04_f$	0.112***	0.016***	0.010***	0.014***
	(4.73)	(4.52)	(5.96)	(4.04)
TFP	0.083***	0.010***	0.003***	0.010***
	(8.78)	(6.51)	(4.86)	(6.90)
Log employment	0.073***	0.003*	0.001	0.002
	(6.01)	(1.85)	(0.79)	(1.04)
Log capital	0.065***	0.005***	0.001***	0.002**
	(10.77)	(6.27)	(3.30)	(2.37)
Import penetration	0.084***	0.003	0.002**	0.001
	(4.14)	(1.31)	(2.06)	(0.23)
Industry export	–0.003	0.001	0.002***	0.002*
	(–0.28)	(0.99)	(4.19)	(1.96)
Industry domestic sales	0.009	0.001	–0.001**	–0.003*
	(0.62)	(0.06)	(–2.21)	(–1.86)
Constant	–1.350***	–0.143***	–0.019**	–0.020
	(–6.63)	(–6.55)	(–2.12)	(–0.94)
Observations	57,330	57,330	57,006	57,006
R-squared	.019	.005	.004	0.004

Notes: This table reports the estimation results for equation (5). The dependent variable is the difference of average innovation between the appreciation period and pre-appreciation period. $EXP04_f$ = 1, exporter in 2004. $EXP04_f$ = 0, non-exporter in 2004. t-values in parentheses.
*,**,*** indicate significance at 10%, 5%, and 1% level, respectively.

TABLE 5 Using One Year before and after the Shock

Dependent variable	(1) Δlog R&D	(2) ΔR&D dummy	(3) Δnew product revenue share	(4) Δnew product dummy
$EXP04_f$	0.108***	0.014***	0.011***	0.010**
	(3.69)	(2.80)	(5.27)	(2.09)
Firm-level controls	Yes	Yes	Yes	Yes
Industry-level controls	Yes	Yes	Yes	Yes
Observations	57,330	57,330	57,006	57,006
R-squared	.007	.002	.004	.001

Notes: This table reports the regression results of equation (5), using only one year before and after the exchange rate regime reform (2003 and 2006). The dependent variable is the difference of innovation. $EXP04_f$ = 1, exporter in 2004. $EXP04_f$ = 0, non-exporter in 2004. Firm-level controls include log employment, log fixed capital, TFP. Industry-level controls include industry import penetration ratio, log industry total exports, log industry total domestic sales. t-values in parentheses. *,**,*** indicate significance at 10%, 5% and 1% level, respectively.

5.2 | Control for other confounding polices

Although using one year before and after the shock may alleviate the effect of the confounding policies long before and after the shock, it will not be able to exclude the effect of policies that took effect contemporaneously with the exchange rate shock. Here we consider two highly relevant policies. The first is the expiration of the Multi-Fiber Arrangement (MFA) in January 2005, as documented in Brambilla, Khandelwal, and Schott (2010). The quota elimination on textile and apparel products led to a surge in exports to the USA and Europe. This may have promoted the innovation of textile exporters through market size effects. To rule out the effect of the MFA, we repeat the DID regression but excluding textile related industries. Results are reported in Table 6(a). The second possible confounding factor is the rise of labor costs in China after 2005 (Zhang, Yang, & Wang, 2011), which might have induced firms to adopt more skill-intensive techniques. We control for this factor by including the change in log average wage as the additional control variable. Results are reported in Table 6(b). In both cases, the main result in the previous section holds very well.

5.3 | Placebo tests

One of the critical assumptions in applying the DID is that the outcome variable for the treatment group should be identical with the control group in the absence of the treatment. In our case, this

TABLE 6 Excluding the Influence of Other Confounding Policies

Dependent variable	(1) Δlog R&D	(2) ΔR&D dummy	(3) Δnew product revenue share	(4) Δnew product dummy
(a) Excluding textile sectors				
$EXP04_f$	0.138***	0.019***	0.011***	0.016***
	(5.57)	(4.80)	(5.89)	(4.07)
Firm-level controls	Yes	Yes	Yes	Yes
Industry-level controls	Yes	Yes	Yes	Yes
Observations	48,406	48,406	48,121	48,121
R-squared	.020	.005	.004	.005
(b) Including wage growth				
$EXP04_f$	0.113***	0.016***	0.010***	0.014***
	(4.78)	(4.57)	(5.97)	(4.04)
Δlog wage	0.053***	0.007***	0.001	–0.002
	(3.69)	(2.92)	(0.77)	(–0.88)
Firm-level controls	Yes	Yes	Yes	Yes
Industry-level controls	Yes	Yes	Yes	Yes
Observations	57,322	57,322	57,001	57,001
R-squared	.019	.005	.004	.004

Notes: This table reports the regression results of equation (5). Part (a) excludes textile industries. Part (b) includes change in log wage as an additional control. The dependent variable is the difference of average innovation between the appreciation period and pre-appreciation period. $EXP04_f = 1$, exporter in 2004. $EXP04_f = 0$, non-exporter in 2004. Firm-level controls include log employment, log fixed capital, TFP. Industry-level controls include industry import penetration ratio, log industry total exports, log industry total domestic sales. t-values in parentheses. *,**,*** indicate significance at 10%, 5% and 1% level, respectively.

assumption means that the innovation of exporters and non-exporters should have a statistically identical trend before the exchange rate appreciation. If not, the impact we find in the previous section may just be spurious. We test this hypothesis by picking some year *before* the appreciation to conduct a DID regression. The results using 2002 and 2004 as the dividing years are reported in Table 7.[17] In both cases, none of the export dummy coefficients is positively significant. Thus, it is not likely that our previous result is driven by the innately different innovation trend between exporters and non-exporters.

5.4 | Firm entry and exit

All the previous results are based on a balanced panel and therefore do not take into account firm entry and exit. However, it is well documented in the literature that entry and exit of firms are not random. Less productive firms are more likely to exit the sample (Pavcnik, 2002) and are thus more likely to be excluded in the previous analysis. These firms might have different innovation response compared with firms that stay throughout the sample period. To ensure that our previous result is not driven by sample selection, we repeat the DID exercise using the full unbalanced sample and report the results in Table 8. It is clear that the benchmark results still qualitatively hold.

5.5 | Imported inputs

Another possible channel of the exchange rate effect is that home currency appreciation may lower the price of imported intermediate inputs. We expect this effect to benefit innovation in

TABLE 7 Placebo Test

Dependent variable	(1) Δlog R&D	(2) ΔR&D dummy	(3) Δnew product revenue share	(4) Δnew product dummy
(a) Dividing year: 2002				
$EXP01_f$	–0.023	–0.003	–0.001	–0.015***
	(–0.95)	(–0.68)	(–0.92)	(–4.38)
Firm-level controls	Yes	Yes	Yes	Yes
Industry-level controls	Yes	Yes	Yes	Yes
Observations	55,987	55,987	55,885	55,885
R-squared	.003	.001	.001	.001
(b) Dividing year: 2004				
$EXP03_f$	0.040*	0.006*	–0.001	–0.015***
	(1.87)	(1.67)	(–0.15)	(–4.02)
Firm level controls	Yes	Yes	Yes	Yes
Industry-level controls	Yes	Yes	Yes	Yes
Observations	57,536	57,536	57,428	57,428
R-squared	.001	.001	.001	.001

Notes: This table reports the regression results of equation (5), using years before the appreciation as dividing year. Part (a) uses 2002, part (b) uses 2004. The dependent variable is the difference of innovation. Only one year before and after the dividing year are included. Firm-level controls include log employment, log fixed capital, TFP. Industry-level controls include industry import penetration ratio, log industry total exports, log industry total domestic sales. *t*-values in parentheses. *,**,*** indicate significance at 10%, 5% and 1% level, respectively.

TABLE 8 Unbalanced Sample Regressions

Dependent variable	(1) Δlog R&D	(2) ΔR&D dummy	(3) Δnew product revenue share	(4) Δnew product dummy
$EXP04_f$	0.193***	0.0258***	0.00977***	0.0148***
	(5.11)	(8.41)	(7.32)	(5.01)
Firm-level controls	Yes	Yes	Yes	Yes
Industry-level controls	Yes	Yes	Yes	Yes
Observations	122,629	122,629	121,952	121,952
R-squared	.042	.025	.004	.004

Note: This table reports the regression results of equation (5), using the unbalanced sample. Dependent variable is the period difference of average innovation. $EXP04_f = 1$, exporter in 2004. $EXP04_f = 0$, non-exporter in 2004. Firm-level controls include log employment, log fixed capital, TFP. Industry-level controls include industry import penetration ratio, log industry total exports, log industry total domestic sales. *t*-values in parentheses. *,**,*** indicate significance at 10%, 5% and 1% level, respectively.

several ways. First, cheaper imported inputs yield higher operating profits, leaving more room for the firm to pay for the fixed costs of innovation. Second, firms may import new input varieties or higher-quality inputs, which are usually considered to be complementary to innovation.

In order to control for this alternative channel of the exchange rate effect, we include in the regression the firm's import intensity, defined as the ratio of imported material costs to total variable costs (wage bill plus material costs).[18] Intuitively, the cost-saving effect of the appreciation should be larger for firms that are more reliant on imported intermediate inputs. Therefore, we expect a positive coefficient before the import intensity variable. Table 9 shows that that it is what we find in the data. In any case, the coefficient before the export status variable remains positive and significant, suggesting that the effect of export market competitive pressure on innovation is still present even when controlling for the imported input cost channel.

TABLE 9 Imported Intermediate Inputs

Dependent variable	(1) Δlog R&D	(2) ΔR&D dummy	(3) Δnew product revenue share	(4) Δnew product dummy
$EXP04_f$	0.110***	0.0139***	0.0117***	0.0182***
	(5.88)	(4.25)	(7.85)	(6.21)
Import intensity$_f$	0.0221	0.0216***	0.0126***	0.0368***
	(0.50)	(3.22)	(3.63)	(6.59)
Firm-level controls	Yes	Yes	Yes	Yes
Industry-level controls	Yes	Yes	Yes	Yes
Observations	52,456	52,456	52,161	52,161
R-squared	.019	.006	.004	.005

Notes: This table reports the regression results of equation (5), controlling for firm-level import intensity. Dependent variable is the period difference of average innovation. $EXP04_f = 1$, exporter in 2004. $EXP04_f = 0$, non-exporter in 2004. Import intensity$_f$ is the share of imported intermediate inputs in total costs in 2004. Firm-level controls include log employment, log fixed capital, TFP. Industry-level controls include industry import penetration ratio, log industry total exports, log industry total domestic sales. *t*-values in parentheses. *,**,*** indicate significance at 10%, 5% and 1% level, respectively.

6 | INDUSTRY AND FIRM HETEROGENEITY

6.1 | Industry heterogeneity

In Section 4 we saw that the increased competitive pressure imposed by the appreciation induced more innovations from exporters than from non-exporters. In this section we examine whether such effects vary across industries and firms. Intuitively, R&D is more critical for competitiveness in industries that are more R&D-intensive. Therefore, firms in R&D-intensive industries should be more likely to respond to the competitive pressure by increasing innovation. To test whether this is true in the data, we include in equation (4) an interaction term for the export dummy and the R&D intensity (defined as R&D expenditure over total sales) of each 4-digit industry. In Table 10, all the coefficients before the interaction term are positively significant. Therefore, while in general exporters respond to increased competitive pressure with more innovation, such response is larger in industries with greater reliance on research and development.

6.2 | Response across firms with different export dynamics

Although we had the general finding that the appreciation encouraged R&D and new product development for exporters, the effects could be heterogeneous among firms with different export dynamics. Some exporters may have been driven out of the foreign market due to the appreciation, while other firms survived. We might expect the quitters and the continuing exporters to have different responses in terms of innovation. First, the appreciation implied tougher competition in the foreign market only for the continuing exporters but not for the quitters. For the quitters, competitive stance in the export market no longer matters. Second, exiting the export market will further discourage innovation through the market size effects if it leads to a contraction of firm size. In sum, we expect the appreciation to induce relatively more innovation for continuing exporters than the quitters.

In order to investigate this heterogeneity, we divide exporters in our data into two subgroups: continuing exporters and export quitters. We define continuing exporters to be firms that exported

TABLE 10 Industry Heterogeneity

Dependent variable	(1) Δlog R&D	(2) ΔR&D dummy	(3) Δnew product revenue share	(4) Δnew product dummy
$EXP04_f$	0.034	0.010***	0.008***	0.012***
	(1.33)	(2.70)	(4.42)	(3.21)
$EXP04_f \times RDint_i$	0.388***	0.030***	0.011**	0.012
	(5.13)	(4.41)	(2.17)	(1.54)
Firm-level controls	Yes	Yes	Yes	Yes
Industry-level controls	Yes	Yes	Yes	Yes
Observations	57,328	57,328	57,004	57,004
R-squared	.020	.005	.004	.004

Notes: This table reports the regression results of equation (5). The interaction term of the exporter dummy and industry R&D intensity is added to investigate the different response across industry. The dependent variable is the period difference of average innovation. Firm-level controls include log employment, log fixed capital, TFP. Industry-level controls include industry import penetration ratio, log industry total exports, log industry total domestic sales. t-values in parentheses. *,**,*** indicate significance at 10%, 5% and 1% level, respectively.

in 2004 and continued exporting during 2005–2007. Export quitters are firms that exported in 2004 but quitted the export market during 2005–2007 and never exported afterwards.[19] We rerun the DID regression in equation (4), but now restrict the treatment group to continuing exporters or export quitters.[20] The results are reported in Table 11. The results show that the exporter dummy coefficient in the continuing exporter sample is still positively significant, and the magnitude is larger than what we found in Section 4 using exporters in general as the treatment group. However, for export quitters, the coefficient are all negative, though most of them nonsignificant. Therefore, although exporters in general increased innovation in response to the appreciation, such effects are restricted to firms that managed to survive in the export market.[21]

6.3 | Processing versus non-processing exporters

Processing accounts for nearly 50% of China's exports. The recent literature has found that processing firms perform quite differently than non-processing exporters (Dai *et al.*, 2016; Yu, 2015). These firms import foreign intermediate inputs for assembly and re-export, and are associated with low-end, labor-intensive tasks. We expect less innovation response from these firms for two reasons. First, processing firms usually receive patents and blueprints from foreign suppliers, and do not have their own brands or products. Therefore, their competitiveness depends little on in-house innovation. Second, processing firms are usually associated with high import intensity because they need to import foreign materials for assembly. As a result, the appreciation may increase the competitiveness of processing firms by making the imported inputs less expensive. Thus, the

TABLE 11 Firm Heterogeneity: Continuing Exporters and Export Quitters

Dependent variable	(1) Δlog R&D	(2) ΔR&D dummy	(3) Δnew product revenue share	(4) Δnew product dummy
(A) Continuing Exporters				
Continuing exporter	0.185***	0.023***	0.016***	0.043***
	(6.36)	(5.35)	(7.97)	(10.20)
Firm-level controls	Yes	Yes	Yes	Yes
Industry-level controls	Yes	Yes	Yes	Yes
Observations	48,063	44,768	44,539	44,539
R-squared	.021	.006	.007	.012
(B) Export Quitters				
Export quitter	–0.042	–0.003	–0.007**	–0.021***
	(–1.02)	(–0.48)	(–2.42)	(–3.52)
Firm-level controls	Yes	Yes	Yes	Yes
Industry-level controls	Yes	Yes	Yes	Yes
Observations	31,725	31,725	31,459	31,459
R-squared	.005	.001	.001	.002

Notes: This table reports the regression results of equation (5). Part (a) uses the sample of continuing exporters as treatment group, panel (b) uses the sample of export quitters as treatment group. Continuing exporters: firms exporting in 2004 and continue exporting during 2005–2007. Export quitters: firms that export in 2004 but quit the export market during 2005–2007 and never export afterwards. The comparison group is the firms that do not export in 2004 and afterwards. Firm-level controls include log employment, log fixed capital, TFP. Industry-level controls include industry import penetration ratio, log industry total exports, log industry total domestic sales. *t*-values in parentheses. *,**,*** indicate significance at 10%, 5% and 1% level, respectively.

competitive pressure imposed on processing exporters is expected to be less than that on non-processing exporters.

Following Dai *et al.* (2016), we directly identified processing trade firms using the information in the firm-level trade data provided by China Customs. We define processing exporters as firms with at least half of their total exports coming from processing trade. We then create categorical variables splitting all firms into three groups: processing exporters, non-processing exporters, and non-exporters. We regress the growth of innovation on a processing exporter dummy and a non-processing exporter dummy, omitting the non-exporter. The regression results in Table 12 show that, consistent with our expectations, the non-processing firms have higher innovation growth than non-exporters, as we documented for exporters in general. However, processing exporters do not exhibit higher innovation growth in most of the specifications.

7 | CONCLUSIONS

The aim of this paper has been to investigate a new channel linking trade and innovation: changes in competitive pressure in firms' export markets. We use China's exchange rate regime reform and the subsequent gradual appreciation of its currency as a natural experiment and exploit its differential impact on exporters and non-exporters. The appreciation reduced exports and imposed greater competitive pressure on exporters than on non-exporters. Exporters responded to this competitive pressure by increasing innovation. Our benchmark results show that the appreciation caused the R&D expenditure of *ex ante* exporters to increase by 11% more than that of non-exporters, and new product development to increase by nearly 1.5 times more than that of non-exporters. We also show these effects exhibit variations across industries with different R&D intensities, and across firms with different export dynamics and export types.

Governments in many countries are often reluctant to appreciate their currencies for fear of the potential negative impact on employment and growth. While these concerns are reasonable in the short run, our results suggest that the competitive pressure induced by the appreciation may benefit productivity and growth in the long run by creating incentives for innovation. In this regard, a

TABLE 12 Processing versus Non-processing Exporters

Dependent variable	(1) Δlog R&D	(2) ΔR&D dummy	(3) Δnew product revenue share	(4) Δnew product dummy
$Proc04_f$	–0.019	0.013*	–0.001	–0.006
	(0.45)	(1.88)	(0.32)	(1.07)
$Nonproc04_f$	0.169***	0.020***	0.019***	0.035***
	(6.53)	(4.62)	(9.04)	(8.69)
Firm-level controls	Yes	Yes	Yes	Yes
Industry-level controls	Yes	Yes	Yes	Yes
Observations	43,008	43,008	42,734	42,734
R-squared	.018	.006	.006	.007

Note: $Proc04_f$ = 1, processing exporter in 2004 (processing exports/total exports > 0.5). $Nonproc04_f$ = 1, non-processing exporter in 2004 (processing exports/total exports < 0.5). Omitted category is non-exporter. Firm-level controls include log employment, log fixed capital, TFP. Industry-level controls include industry import penetration ratio, log industry total exports, log industry total domestic sales. *t*-values in parentheses. *,**,*** indicate significance at 10%, 5% and 1% level, respectively.

gradual appreciation is more favorable than a drastic appreciation, because the former allows firms to adjust to the competitive pressure over time and is therefore more effective in inducing productivity-enhancing activities. These considerations should be taken into account in the making of monetary and exchange rate policies.

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ENDNOTES

[1] See Bustos (2011), Lileeva and Trefler (2010), Aw, Roberts, and Winston (2007), Aw, Roberts, and Xu (2011), Costantini and Melitz (2008), and Verhoogen (2008).

[2] See Bloom, Draca, and Reenen (2016), Teshima (2008), and Iacovone, Keller, and Rauch (2011).

[3] Increased competitive pressure can also reduce innovation through the Schumpeter force that leads to lower price-cost margins, thereby reducing the quasi-rents from innovation (Aghion *et al*., 2005).

[4] According to the definition provided by the National Bureau of Statistics of China, new products are products that are made using new technology or new design, or that significantly improve the function or quality of the original products. In order to be officially recognized as new products, the firm should deliver applications and receive assessment from the relevant government authorities. There are three levels of new products: national, provincial, and sub-provincial. New products at different levels are authorized by the government authority at the corresponding level, and are given different periods of validity. The validity period for national, provincial, and sub-national level new product is 3 years, 2 years, and 1 year, respectively. The new product revenue variable in our data includes the sales revenue from all authorized new products that are in the period of validity. For example, the 2007 value will include the following: national-level new products authorized in either 2005, 2006, or 2007, provincial-level new product authorized in 2006 or 2007, or sub-provincial-level new product authorized in 2007. Unfortunately, we do not have information about the level of the new product.

[5] The original data set includes 526,612 firms and 1,733,848 observations. In order to ensure our results are not purely driven by firm entry and exit, we also repeat the benchmark regression using the unbalanced sample which includes all firms in Section 5.

[6] In 2007 the fluctuating band against the dollar was enlarged to 0.5%, with the band against other currencies unchanged.

[7] http://usa.chinadaily.com.cn/china/2011-03/14/content_12167195.htm

[8] In Appendix Table 1C we show that among exporters, the negative shock of the appreciation is stronger for firms with higher export intensity. However, firms with export intensity equal to 1 (i.e. pure exporters) are less affected. As mentioned in Dai *et al*. (2016), a large proportion of pure exporters in China are processing exporters, which import foreign intermediate inputs for assembly and re-export. As processing firms import a large share of inputs, the appreciation may reduce their total cost by making the imported inputs less expensive. This cost-saving effect on the import side may offset the revenue-reducing effect on the export side.

[9] Although the appreciation began only in July 2005, and the actual appreciation during 2005 is modest, we still choose 2005 as the first year of the appreciation period. As mentioned, the innovation response may result from not only the actual appreciation, but also the expectation of future appreciation. In this sense, although the actual appreciation in 2005 is not drastic, the exchange rate regime reform has already changed firms’ behavior by

altering their expectations for the future exchange rate movement. For robustness, we have also used year 2006 as the first year of the appreciation period. The results are quite similar.

[10] We use the exporting status one year before the exchange rate shock to avoid potential endogeneity. Results using exporting status in 2005 show similar results (results available upon request)

[11] TFP is estimated using the Olley and Pakes (1996) approach. Detailed estimation procedures are described in Appendix A.

[12] The industry import penetration ratio is defined as the value of imports over total absorption. For the detailed calculation procedure, see Appendix B.

[13] All control variables taking the value of the initial year (i.e., 2001) yield similar results.

[14] Considering that firm R&D and new product share have lots of zeros, it is tempting to run a Tobit regression instead of simple OLS. However, since our main estimation equation is in the first-difference form, the dependent variable is no longer left or right censored. Therefore the usual Tobit approach will not apply. But we indeed tried a Tobit model in levels, as in equation (3). The results are qualitatively similar to the benchmark results and are available upon request.

[15] TFP_OP refers to total factor productivity estimated using the Olley-Pakes (1996) method.

[16] In Appendix Table 2C we also investigate whether the innovation response is larger for firms with higher export intensity. We replace the export dummy in equation (4) with export intensity and then rerun the regression. The results show that when pure exporters are excluded, firms with higher export intensity have a larger increase in innovation. However, the coefficients become nonsignificant when pure exporters are included. We discuss the role of pure exporters in Section 6.

[17] We cannot do the test using 2003 as the dividing year because the innovation for 2004 is missing.

[18] The ASIF does not have firms' import information. We obtain the import value of each firm by combining the ASIF with firm-level trade data provided by China Customs. The specific matching procedure is described in Dai, Maitra, and Yu (2016). Wage bill and total material costs data are from the ASIF.

[19] Table 1D in Appendix D compares the productivity (measured by TFP), firm size (log employment) and log sales of continuing exporters and export quitters. Consistent with the literature (e.g., Pavcnik, 2002), continuing exporters are larger and more productive.

[20] The comparison group is firms that did not export in 2004 and afterwards. Results are similar using firms that never exported during the whole sample period as the comparison group.

[21] One might worry that export markets may not actually tighten for continuing exporters, so their increase in innovation might simply reflect the effect of expanding market size instead of competition. To check this possibility, we calculate the average export growth and export intensity for continuing exporters for each year in the sample period in Appendix Table 2D. It is quite obvious that continuing exporters also experienced certain degrees of market contraction. While their export growth was over 60% in the pre-appreciation period, it fell to around 10% in the appreciation period. Export intensity also fell. Therefore, the increased innovation by continuing exporters cannot be the result of market size effects. It is driven by the competitive pressure from the foreign markets.

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APPENDIX A: AUGMENTED OLLEY–PAKES TFP MEASURES

Here we describe in detail the Olley–Pakes approach to estimating firms' TFP with some extensions. First, we adopt different price deflators for inputs and outputs. Data on input deflators and output deflators are from Brandt, Van Biesebroeck, and Zhang (2012) in which the output deflators are constructed using *reference price* information from China's statistical yearbooks, whereas input deflators are constructed based on output deflators and China's national input–output table (2002).

Next, we construct the real investment variable using the perpetual inventory method. Rather than assigning an arbitrary number for the depreciation ratio, we use the firms' real depreciation rate provided by the Chinese firm-level dataset.

We work with the standard Cobb–Douglas production function

$$Y_{it} = \pi_{it} L_{it}^{\beta_l} K_{it}^{\beta_k} M_{it}^{\beta_m}, \tag{A1}$$

where Y_{it} is the output of firm i in year t, and K_{it}, L_{it}, and M_{it} denote labor, capital, and intermediate inputs, respectively. By assuming that the expectation of future realization of the unobserved productivity shock, v_{it}, relies on its contemporaneous value, firm i's investment is modeled as an increasing function of both unobserved productivity and log capital, $k_{it} = \ln K_{it}$. Following previous work, such as Van Biesebroeck (2005) and Amiti and Konings (2007), we add the firm's export decision as an extra argument of the investment function since most firms' export decisions are determined in the previous period:

$$I_{it} = \tilde{I}(k_{it}, v_{it}, X_{it}), \tag{A2}$$

where X_{it} is a dummy measuring whether firm i exports in year t. Therefore, the inverse function of I_{it} is

$$v_{it} = \tilde{I}^{-1}(k_{it}, I_{it}, X_{it}). \tag{A3}$$

The unobserved productivity also depends on log capital and the firm's export decisions. Accordingly, the estimation specification can now be written as:

$$y_{it} = \beta_0 + \beta_m m_{it} + \beta_l l_{it} + g(k_{it}, I_{it}, X_{it}) + \varepsilon_{it}, \tag{A4}$$

where $g(k_{it}, I_{it}, X_{it})$ is defined as $\beta_k k_{it} + \tilde{I}^{-1}(k_{it}, I_{it}, X_{it})$. Following Olley and Pakes (1996) and Amiti and Konings (2007), fourth-order polynomials are used in log capital, log investment and firm's export dummies to approximate $g(.)$. In addition, we also include a World Trade Organization dummy (i.e., 1 for a year after 2001 and 0 for before) to characterize the function $g(.)$ as follows:

$$g(k_{it}, I_{it}, X_{it}, WTO_t) = (1 + WTO_t + X_{it}) \sum_{h=0}^{4} \sum_{q=0}^{4} \delta_{hq} k_{it}^h I_{it}^q. \tag{A5}$$

After finding the estimated coefficients $\hat{\beta}_m$ and $\hat{\beta}_l$, we calculate the residual R_{it} which is defined as

$$R_{it} \equiv y_{it} - \hat{\beta}_m m_{it} - \hat{\beta}_l l_{it}. \tag{6}$$

The next step is to obtain an unbiased estimated coefficient of β_k. We assume that firms' productivity follows an exogenous Markov process, $v_{it} = h(v_{it} - 1) + \eta_{it}$. To correct the selection bias due to firm exit, Amiti and Konings (2007) suggested regressing a firm exit dummy on a high-order polynomial in log capital and log investment. One can then accurately estimate the following specification:

$$R_{it} = \beta_k k_{it} + h(\hat{g}_{it} - 1 - \beta_k k_{it} - 1, \hat{pr}_{it} - 1) + \varepsilon_{it}^*, \tag{A7}$$

where $\hat{pr}_{i,t-1}$ denotes the fitted value for the probability of the firm's exit in the next year, and $\varepsilon_{it}^* = \varepsilon_{it} + \eta_{it}$ denotes the composite error. Since the specific *true* functional form of the inverse function h is unknown, it is appropriate to use fourth-order polynomials in $g_{i,t\text{-}1}$ and $k_{i,t\text{-}1}$ to approximate that. In addition, (A6) also requires the estimated coefficients of the log capital in the first and second term to be identical. Therefore, nonlinear least squares is used (Pavcnik, 2002). Finally, the Olley–Pakes type of TFP for each firm i in industry j is obtained once the estimated coefficient $\hat{\beta}_k$ is obtained:

$$TFP_{ijt}^{\mathrm{OP}} = y_{it} - \hat{\beta}_m m_{it} - \hat{\beta}_k k_{it} - \hat{\beta}_l l_{it}. \tag{A8}$$

APPENDIX B: CONSTRUCTION OF INDUSTRY IMPORT PENETRATION RATIO

We control for industry-level import competition by means of the industry import penetration ratio. The import penetration ratio is defined as industry import value over industry total absorption. Total absorption is measured as production minus exports plus imports – in symbols,

$$IMP\_PEN_{it} = \frac{IM_{it}}{Y_{it} - EX_{it} + IM_{it}}, \tag{B1}$$

where IMP_PEN_{it} is the import penetration ratio of industry i in year t, IM_{it} is China's imports from the world, EX_{it} is China's exports to the world, and Y_{it} is domestic gross output. Import and export data are taken from COMTRADE at the 6-digit HS level. We map the HS6 products to 2-digit Chinese Industry Classifications (GB/T 4754-2002), and aggregate the import and export value to 2-digit CIC industry level. Finally, we calculate the import penetration ratio in each 2-digit CIC industry over 2001–2007, using (B1). The domestic gross output data are taken from China statistical yearbooks.

APPENDIX C: THE IMPACT OF THE APPRECIATION ON FIRMS WITH DIFFERENT EXPORT INTENSITIES

TABLE C1 Growth Difference of Employment, Profit and Total Sales (%), by Export Intensity

Export intensity	Employment	Profit	Sales
0<expint<0.1	–7.501	–18.609	–18.608
0.1< expint <0.4	–8.842	–37.040	–16.482
0.4< expint <1	–11.258	–42.231	–18.191
expint =1	–13.562	–14.354	–13.390

Note: This table reports the growth difference of employment, profit and sales between the appreciation period and pre-appreciation period by export intensity. Each entry is given by the growth rate in the appreciation period minus the growth rate in the pre-appreciation period.

TABLE C2 Regression Results of Equation (5), by Export Intensity

	(1) Δlog R&D	(2) ΔR&D dummy	(3) Δnew product revenue share	(4) Δnew product dummy
$EXPINT04_f$	0.032*	0.017***	0.008***	0.018***
	(1.85)	(3.07)	(3.75)	(3.33)
TFP	0.091***	0.011***	0.003***	0.010***
	(8.84)	(6.63)	(4.63)	(6.73)
Log employment	0.098***	0.005***	0.001**	0.004**
	(7.72)	(2.66)	(2.00)	(2.35)
Log capital	0.065***	0.006***	0.001***	0.002**
	(9.96)	(5.90)	(3.69)	(2.06)
Import penetration	0.092***	0.004	0.003***	0.001
	(4.57)	(1.42)	(2.92)	(0.49)
Industry export	0.017	0.003*	0.002***	0.003**
	(1.51)	(1.93)	(5.00)	(2.33)
Industry domestic sales	–0.019	–0.002	–0.001**	–0.003**
	(–1.22)	(–1.16)	(–2.52)	(–2.04)
Constant	–1.296***	–0.138***	–0.028***	–0.033
	(–6.23)	(–6.17)	(–3.25)	(–1.59)
Observations	51,510	51,510	51,249	51,249
R-squared	.019	.005	.003	.004

Note: This table reports the estimation results for firms with different export intensity in 2004. The dependent variable is the difference of average innovation between the appreciation period and pre-appreciation period. $EXPINT04_f$ is export intensity in 2004. *t*-values in parentheses.

*,**,*** indicate significance at 10%, 5%, and 1% level, respectively.

APPENDIX D FIRM HETEROGENEITY

TABLE D1 Firm Characteristics of Continuing Exporters and Export Quitters

Firm characteristics	Continuing exporters	Export quitters
TFP	4.132	4.019
Log employment	5.721	5.250
Log sales	10.963	10.591

Note: This table compares firm characteristics for continuing exporters and export quitters in 2004. Continuing exporters: firms that export in 2004 and continue to export during 2005–2007. Quitters: firms that export in 2004 but quit the export market during 2005–2007 and never export again.

TABLE D2 Export Growth and Export Intensity for Continuing Exporters in 2005

Year	Export growth	Export intensity
2001	–	59.293
2002	59.012	60.131
2003	44.994	63.909
2004	81.987	63.912
2005	20.198	64.273
2006	9.072	63.966
2007	3.143	63.128