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Firm Innovation under Import Competition from Low-Wage Countries

Abstract

In recent years, manufacturing firms in the United States have faced increasing import competition from low-wage countries, especially China. Does this competition hurt or help innovation by firms? This paper studies the effect of the surge in imports from China on innovation in the US manufacturing sector. We combine patent, firm and trade data during 1990-2006 for US publicly-listed firms in the Compustat dataset. We find consistent evidence that Chinese import competition had a positive effect on firm innovation, as measured by citation-weighted patent applications. This positive effect persists when we instrument import competition in the US by using Chinese import penetration in the United Kingdom. Next we investigate this relationship between import competition and innovation by considering industry and firm heterogeneity. We find that firms in low-tech industries and those with a lower degree of product differentiation show a significant positive response to import competition. Firms with a higher capital intensity and lower labor productivity also exhibit a greater response. These results are shown to be robust to a variety of measures for import penetration and innovation.

JEL-Codes: F100, F140, O310, O320.

Keywords: import competition, innovation, international trade, manufacturing firms, patents.

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1 Introduction

Innovation is considered a fundamental driving force for economic growth (Romer, 1990; Aghion and Howitt, 1992). While manufacturing firms only account for less than 10% of US private sector employment, they generate more than two-thirds of both research and development (R&D) spending and corporate patents. In recent decades, manufacturing firms in the United States (as well as those located in other advanced economies) have experienced dramatically increasing import competition from low-wage countries. China has led this wave of expansion in international merchandise markets, with an annual increase in manufacturing exports of more than 18% during the past two decades. Figure 1 shows that the rising share of manufacturing imports into the US from low-wage countries increased from 4.6% in 1990 to 12.2% in 2001, thanks to a substantial contribution by products made in China.[1] Note that China has been the major contributor behind this surge in imports. As this trend has continued in more recent years, it is important to understand its impact on innovative activities of US firms.

Figure 1: Share of Manufacturing Imports in the US from China and All Low-wage Countries

There is a large theoretical literature on whether competition spurs or hinders innovation. Arrow (1962) originally suggested that competitive firms may have a higher incentive to innovate relative to an incumbent monopolist. More recent research by Aghion et al. (2005) suggest an inverted-U shaped relationship between innovation and competition. In their model, initially competition increases innovation because post-innovation rents are larger than pre-innovation rents. Firms use R&D investments to "escape" competition. However, the relationship is reversed if product market competition is intense and innovation is mainly

[1]Bernard et al. (2006) define low-wage countries as those with a per capita GDP which is lower than 5% of that of the United States during the period of 1972 to 1992. This approach has also been adopted by Mion and Zhu (2013) and Bloom et al. (2016) to calculate the share of imports from low-wage countries.

performed by laggard firms with low initial profits. Bloom et al. (2014) propose another mechanism through which competition can promote innovation. They assume that the manufacture of old products requires specific know-how that is difficult to transfer to other products. This high adjustment cost prevents firms from reallocating factors to new product development. However, if the old products become unprofitable due to import competition, firms will be more willing to shift resources into developing and producing new products.[2]

Our paper makes two distinct contributions. We first provide a simple model of imitation and innovation in which domestic firms engaged in imperfect competition respond to import competition by deciding whether to invest in a higher quality product. We show that our model also generates an inverted-U shaped response to competition: at low levels of imitation, domestic firms make higher profits and a rise in imitation triggers innovation. However when import penetration is high, the effect of innovation on profits is weak and imitation reduces innovation.

Second, we take the theoretical predictions to the data by empirically studying the effect of imports from low-wage countries, especially China, on innovation activities of US manufacturing firms. Given that Chinese import penetration in the US is "small" (of the order of 5%), we test whether a linear positive relationship between innovation and import competition exists, the upward-sloping part of the U-shaped relationship. We combine patent, firm and trade data for all US public firms in the Compustat dataset for the period 1990-2006. In our baseline, we focus on using firm patent applications (both with and without adjusting for citations) as measures of innovation (Griliches, 1990; Cohen, 2010). We find a robust positive relationship between exposure to imports from China and innovation activities of US manufacturing firms when we measure innovation by the number of citation-weighted patent applications. Without adjusting for citations, we do not find this positive relationship to be significant. These results indicate that US manufacturing firms do not produce more patents, instead they produce more "valuable" patents in response to low-wage import competition.[3]

We instrument for the change in US industry dynamics by using Chinese import penetration ratios in another developed economy other than the US, namely the United Kingdom, as suggested by Autor et al. (2014, 2016). While Chinese exports to the US and the UK both reflect Chinese producers' competitiveness in any given industry and are likely to be strongly correlated with each other, unobserved technology or policy shocks that affect demand in the US are unlikely to be correlated with demand shocks in another country, namely the United Kingdom. This IV estimation yields similar results – Chinese import competition has a positive and significant effect on the number of citation-weighted patent applications by US manufacturing firms.

Next we study the heterogeneous impact of Chinese import competition across industries and firms. We find that US firms in low-tech and less-differentiated industries innovate more under import competition from China. These companies cannot easily differentiate their products from their competitors with lower

[2]Their calibration exercise with OECD countries suggests that integration with low-wage countries that occurred in the decade around China's accession to the WTO contributed an additional 0.4 percent to the annual growth rate in the OECD, about half of which they attribute to Chinese import competition.

[3]As a robustness check we replace patents by firm R&D as a measure of innovation and find that Chinese import competition also leads to an increase in firm R&D.

wage costs, and thus face more intense competition than those operating in high-tech or highly differentiated industries, even if the *measured* import penetration ratios are similar (Amiti and Khandelwal, 2013). We show that US firms with high capital intensity and low labor productivity innovate more when facing Chinese import competition. These companies may react faster to rising imports from low-wage countries, either due to their advantage in reallocating resources towards innovation, or because they are hit harder than more efficient domestic producers (Bloom et al., 2014).

This paper is closely related to a growing literature that tries to understand the within-firm impact of import competition, especially from low-wage countries, on innovation activities of firms in developed countries (see Liu and Rosell, 2013; Bloom et al., 2016; Autor et al., 2016; Kueng et al., 2016). In particular, Bloom et al. (2016) employ a broad range of indicators including patents, total factor productivity, R&D expenses, computers per worker and management practices, to capture firm innovation in Europe and find that increased import competition from China contributes to the rise of innovation within surviving firms between 2000 and 2007.[4] In contrast, Autor et al. (2016) match Compustat firm data with US patent data between 1975 and 2013 and find that the impact of Chinese import competition on patent counts is strongly negative.

Our paper contributes to this debate by examining the impact of low-wage import competition on firm patents during 1990-2006 using the linked Compustat firm and patent data provided by the NBER Patent Data Project. As in Autor et al. (2016), we combine several widely recognized data sets covering firms in the United States, while other studies are based on either non-US or more aggregated data. Our analysis is different from Autor et al. (2016) in the sense that we fully incorporate citation statistics into the computation of innovation measures. Our focus on measuring innovation through weighting patent applications by citations received in subsequent years recognizes that not all innovation is equally valuable, and thus offers a richer perspective on the correlation between Chinese import competition and firm innovation. It turns out from our analysis that this quality-based measure of innovation is indeed profoundly important, because the relationship between Chinese imports and citation-weighted patent counts is positive and significant, but becomes insignificant when the estimation is performed with a simple count of patent applications. The takeaway is that in response to low-wage import competition, US firms are induced to produce patents that have greater "impact," as measured by their citations.

This paper complements the literature that examines the between-firm reallocation effects of import competition pioneered by Melitz (2003). Bernard et al. (2006) find that US firms in labor-intensive industries have a lower likelihood of survival than those in capital- and technology-intensive industries in response to import competition from low-wage countries. Due to the fact that capital- and technology-intensive industries generally have a greater R&D intensity, expansion of these industries can result in a higher overall level of innovation in developed economies. For example, Iacovone et al. (2013) find that more productive Mexican firms face less pressure to shrink under import competition from China, and are less likely to discontinue production of their core products. Proxying innovation by the adoption of key operations management techniques, Iacovone et al. (2011) provides evidence on the intra-industry reallocation effect of Chinese

[4]Their paper also provides evidence for the between-firm reallocation effect of Chinese import competition that favors high-tech firms.

import competition. They show that innovation by more productive firms has risen in response to the "China trade shock," while less productive firms innovate less.

Lastly, this paper is related to a large literature suggesting that trade liberalization bolsters innovation for exporting firms (see Costantini and Melitz, 2008; Atkeson and Burstein, 2010; Lileeva and Trefler, 2010; Bustos, 2011; Dhingra, 2013). This literature examines the impact of trade liberalization, particularly the export opportunity, on firm incentives to engage in technology upgrading or innovation.[5]

In Section 2 we propose a simple theoretical model that illustrates the impact of imitation (as proxied by import competition from low-wage countries) on firm innovation in high-wage countries. Next we introduce the variables and describe the data in Section 3. Section 4 presents our empirical strategy and reports the main result, the positive relationship between low-wage import competition and the citation-weighted patent count. Section 5 explores the heterogeneous effects of low-wage import competition on innovation. Section 6 concludes the paper.

2 A Simple Model of Imitation and Innovation

The goal of this section is to provide a simple model to illustrate the effect of imitation on innovation. The model we present is by no means comprehensive in terms of specifying the full equilibrium but serves to highlight the choices firms must make in the face of foreign competition in the domestic sector. We consider a representative consumer who consumes both a domestic good x and an imported good y which are assumed to be perfect substitutes. Let the utility function of the consumer be given by $U(x) = x^{\alpha}$, $0 < \alpha < 1$. The prices of the two goods are given by p_x and p_y, respectively. The consumer maximizes utility as follows:

$$\max_{x,y}(x+y)^{\alpha} - p_x x - p_y y. \tag{1}$$

The first order conditions imply that

$$p_x = p_y = \alpha(x+y)^{\alpha-1}. \tag{2}$$

Now let us assume that there is one domestic firm that plays a Cournot game with the foreign firm which imitates the product and sells it in this market. We do not worry about the foreign firm selling in the foreign market. The quantity of imitation goods sold in the domestic market is given by y which is assumed to be a perfect substitute for the good x. The domestic firm takes the quantity y sold by the foreign firm as given and solves the following problem:

$$\max_{x} \Pi(x) = x p_x(x+y) - cx \tag{3}$$

where c is the unit cost of producing the good, assumed equal for both the domestic and imported firms. This yields the necessary condition

$$x p'_x(x+y) + p_x = c. \tag{4}$$

[5] See Melitz and Trefler (2012) for a comprehensive survey.

Now differentiating (2) with respect to x gives us the relation $p'_x = x\alpha(\alpha - 1)(x + y)^{(\alpha-2)}$ which can be used to rewrite (4) as

$$\alpha(x + y)^{(\alpha-2)}(\alpha x + y) = c. \tag{5}$$

Let us introduce innovation in this simple model. Later we compare the equilibria in the two models, with and without innovation. To simplify matters, we only consider the case when the lower quality imitation good competes with only the lower quality product in the domestic market. That is, the domestic firm sells the higher quality product while the foreign imitator sells the lower quality product.[6]

Again consumers in this case, can choose between the inferior foreign good and the higher quality domestic good. Let the higher quality domestic product be denoted by z. Consumers derive strictly greater utility from consuming this good, given by q where $q > 1$. We can now rewrite the consumer's utility maximization problem as

$$\max_{z,y}(qz + y)^{\alpha} - p_z z - p_y y \tag{6}$$

where p_z denotes the price of the higher quality good denoted by z. The first order conditions imply that

$$q\alpha(qz + y)^{\alpha-1} = p_z \tag{7}$$

$$\alpha(qz + y)^{\alpha-1} = p_y. \tag{8}$$

Note that the above two conditions yield the relation $p_z = qp_y$ when products of both qualities are sold in the market. We can rewrite the domestic firm's maximization problem when it produces the higher quality good and competes with the imitator. The marginal cost for producing the two goods of high and low quality, are both assumed to be c but firms must incur a fixed cost F to produce the high quality good. This yields

$$\max_{z} \Pi(z) = zp_z(z + y) - cz - F \tag{9}$$

$$\Pi(z) \geq F \tag{10}$$

which gives us the condition

$$zp'_z(z + y) + p_z = c. \tag{11}$$

if the firm is able to cover the fixed cost of innovation. Again, substituting from the consumer's first order condition (7), we get

[6] We refrain from considering the more complicated case when the domestic firm sells both the lower and higher quality products. This will mean an explicit modeling of the domestic sector with multiple firms, choosing between selling the lower or higher quality product, and is beyond the scope of this simple model. It can be shown that with multiple firms with variable costs that do not vary for the production of high and low quality goods, each firm will specialize in producing either the high or low quality good.

$$q\alpha(qz+y)^{(\alpha-2)}[q\alpha z+y]=c. \tag{12}$$

Our goal is to investigate under what conditions increased imitation leads to greater innovation by the domestic firm. That is, is the magnitude of the derivative $d\Pi/dy$ greater with or without imitation? Consider the optimized profit function of the domestic firm for a given level of imports y:

$$\Pi(y)=xp_x(x+y)-cx.$$

By the envelope theorem, we get

$$d\Pi/dy=\partial\Pi/\partial y=x\partial p/\partial y=xp'_x(x+y) \tag{13}$$

with an analogous condition when x is replaced by z. We want to show that $d\Pi(q)/dy > d\Pi(1)/dy$ where $q=1$ represents the case without innovation. Because the right hand side of (13) is negative, we need to show that $zp'_z(z+y) < xp'_x(x+y)$. After cancelling terms, this inequality can be written as

$$\frac{zq}{(qz+y)^{(2-\alpha)}} > \frac{x}{(x+y)^{(2-\alpha)}}. \tag{14}$$

Rewriting (12) we obtain

$$\alpha(qz+y)^{(\alpha-2)}[q\alpha z+y]=c/q. \tag{15}$$

Note that the left hand side of (5) and (15) represent the domestic firm's marginal revenue curve and are similar expressions in x and qz. Since these curves are downward sloping, and $c > c/q$ because $q > 1$, the equilibrium quantity x must be lower than qz. Both sides of the inequality in (14) are of the form $f(k)=\frac{k}{(k+y)^{(2-\alpha)}}$, where k denotes either x or qz. Since $x < qz$, condition (14) will hold if $f(k)$ is decreasing in k. Taking logs for $f(k)$ and differentiating with respect to k, we get

$$\frac{f'(k)}{f(k)}=\frac{1}{k}-\frac{2-\alpha}{k+y}. \tag{16}$$

From the above, $f'(k) < 0$ if $y < k(1-\alpha)$. This is indeed the case when imitation is low, and in the polar case, when $y=0$, that is, there is no imitation. Then the inequality is automatically satisfied because $\alpha < 1$. We obtain that $f(k)$ is decreasing and (14) holds. At low levels of imitation, imitation spurs innovation. However, when y is large, $f(k)$ is increasing and condition (14) is unlikely to hold. In that case imitation may lower imitation. We can thus summarize these results in the following proposition:

Proposition. *When imitation is low, it has a positive effect on innovation. However, when imitation is high, the effect is negative.*

The graph of innovation as a function of imitation is shown in Figure 2. Innovation rises with imitation at low levels of imitation but declines at higher levels. The intuition is that when import penetration is low, domestic firms make higher profits, and a rise in imitation triggers an increase in innovation. However,

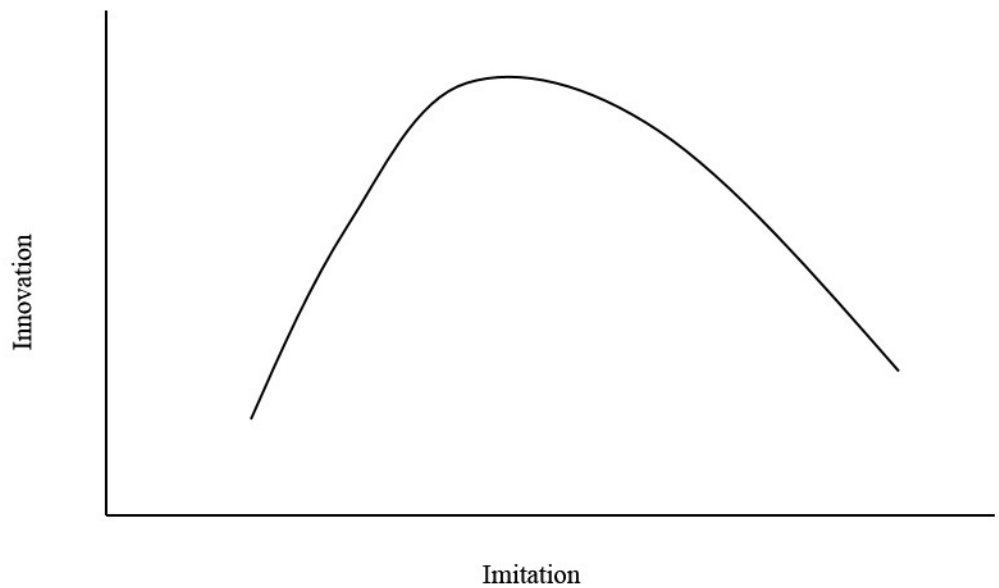

Figure 2: Inverted U-shaped relationship between Innovation and Imitation

when import penetration is higher, the effect of increased imitation is muted. Innovation falls with increased competition. Of course, implicit in this analysis is that the domestic firm is able to cover the fixed cost of innovation.

3 Data and Variables

In this section, we describe the construction of our key variables measuring firm innovation and import competition from China as well as the underlying data.

Innovation

In our baseline analysis, we use the annual number of patent applications as the main measure of firm innovation. Following Bloom et al. (2016), we create the unweighted patent application count as one indicator of firm innovation. Second, to reflect the heterogeneity in the significance (or "quality") of the innovation, we weight every patent by the number of citations it receives within three years after the patent is granted (Griliches, 1990; Mowery et al., 2004). We use this citation-weighted patent application count as another measure of firm innovation.

For each recorded patent, the NBER patent and citation dataset (see Hall et al., 2002) provides detailed information including application and grant year, Compustat identifier(s) of the assignee(s), as well as citations made and received. By employing the NBER dataset, we can compute the citation-weighted and unweighted counts of patent applications by each patent assignee, for every year during the 1990-2001 period.[7]

[7]Note that we set 1990 as the start year due to the availability of data on the import penetration ratio of China in the United Kingdom, which is used to construct our instrumental variable, discussed later in the paper. We set 2001 as the end year because the NBER patent citation data ends in 2006. Assuming a two-year lag between application year and granting year and using a three-year citation window, the last year we can get all the citation information for a patent is 2001.

Import Competition from China

To measure import competition from China faced by US firms, we follow the widely used approach from Bernard et al. (2006), and construct an import penetration index $ImportPen_{j,t}$ for imports from China faced by firm i in industry j in year t as

$$ImportPen_{j,t} = \frac{M^{C}_{j,t}}{Q_{j,t} + M_{j,t} - X_{j,t}},$$

where $M^{C}_{j,t}$ represents the value of imports from China to the US in industry j in year t, $M_{j,t}$ denotes the value of imports from all countries including China, $Q_{j,t}$ is the value of shipments produced domestically, and $X_{j,t}$ is the value of exports in industry j in year t.

We extract data on imports, exports and shipments from the US Manufacturing Exports and Imports dataset (see Schott, 2010). The latest version of this dataset tracks US bilateral trade statistics between 1972 and 2005. The export and import data are available for each partner country at the four-digit 1987-version US Standard Industry Classification (SIC87 codes 2011 through 3999). The dataset also includes the value of domestic shipments for each industry and GDP per capita for each trading partner during the same period. Since each firm in the Compustat database is assigned a four-digit US SIC87 industry code, our baseline measure of import competition is accordingly defined at the four-digit SIC87 level.

As shown in Figure 3, import competition from China increased sharply from 1990 to 2001. The average import penetration ratio across all 4-digit SIC87 US manufacturing industries was less than 1.3% in 1990, but by 2001 this figure had almost quadrupled to exceed 5.0%. The three industries with the most intensive import competition from China in 2001 were dolls and stuffed toys (with an import penetration ratio of 89%), footwear except rubber (78%), and rubber and plastic footwear (68%). In contrast, these figures were close to zero in other industries, such as natural, processed and imitation cheese, wood pellets and skids, truck and bus bodies, etc. The three industries with the largest increase in the indicator from 1990 to 2001 are footwear except rubber (72 percentage-point increase), leather and sheep-lined clothing (62 percentage-point increase) and waterproof outerwear (48 percentage-points). More generally, ten out of eleven industries that have experienced more than a 30 percentage-point increase in Chinese import penetration fall within the textile and toy sectors. These industry-level differences in import competition provide us the variation needed to identify the impact of rising import competition on firm innovation.

Descriptive Statistics

We link firms in the Compustat database to the NBER patent data, following the procedures described in the NBER Patent Data Project.[8] We match patent assignee numbers in the NBER patent and citation dataset with firm identifiers in the Compustat database. We then compute the citation-weighted and un-weighted patent application counts for each Compustat firm. In our empirical analysis, we consider two samples of Compustat firms. The *narrow* sample contains firms that applied for at least one patent between 1990 and 2006. This sample drops firms that never applied for any patent during the sample period. To avoid a potential sample selection issue, we also construct another sample of Compustat firms. This *main* sample

[8]See details for the NBER Patent Data Project at https://sites.google.com/site/patentdataproject/Home.

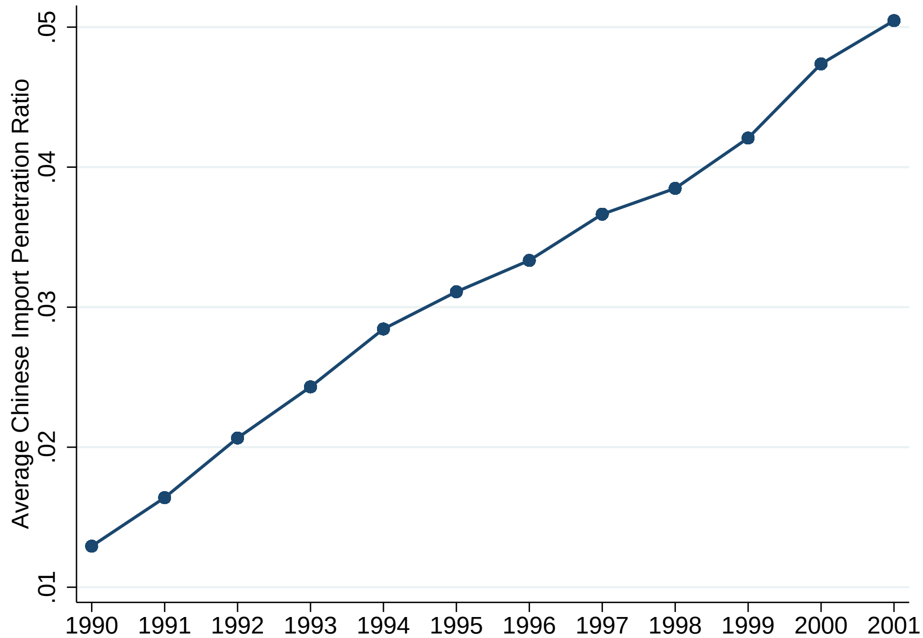

Figure 3: Average Import Penetration Ratio of China across US Manufacturing Industries

includes firms in the narrow sample, and those identified as not applying for any patent during the sample period by the NBER Patent Data Project.

On average, in our main sample we have over 1000 Compustat firms that applied for about 18,000 patents each year during 1990-2001. The number of unweighted patent applications increased steadily from 14,393 in 1990 to 26,087 in 2001, while the number of citation-weighted patent applications in 2001 also peaked at 21,919 – more than twice as many as in 1990.

Table 1 presents the descriptive statistics for our main sample. Our matched firms are large public US firms. The size of these firms is indicated by their average number of employees and profits. These firms make large investments in R&D and on average they applied for about 23 patents per year during 1990-2001. The mean and standard error of the key variables shown in the table indicate that these firms exhibit considerable heterogeneity in innovation performance and financial statistics.

Given the characteristics of these firms it is clear that we can only speak to how imports affect the innovation activity of typically large, publicly traded firms in the US. This has been a common caveat of studies using the Compustat/NBER dataset (e.g. Bloom et al., 2013). However, because these firms are active innovators, this data allow us to infer what happens to a large segment of innovation activity and the majority of patent applications in response to low-wage import competition.

4 Empirical Results

In this section, we present our estimation regressions and baseline results. Later we discuss our instrumental variable strategy and provide robustness checks.

Table 1: Descriptive Statistics

Variable	Obs	Mean	S.D.	Min	Max
Innovation					
Patent Applications	10,419	22.84	94.42	0	2350
Citation-weighted Patent Applications	10,419	18.28	75.77	0	1376
Import Competition					
Import Penetration from China	10,419	0.02	0.05	0	0.89
Firm Characteristics					
R&D Intensity	10,419	0.05	0.06	0	1.45
Patent Stock	10,419	96.63	381.05	0	6406
Number of Employees (thousand)	10,419	9.38	32.57	0	761.4
Capital Intensity (US$ million)	10,419	50.25	87.39	0.2	3277
Net Operating Income (US$ million)	10,419	243.67	1,007.55	0	21658

Estimation Equation and Baseline Results

The level of innovative activity conducted by firm i in industry j in year t is given by

$$\ln Innovation_{i,j,t} = \alpha + \beta\, ImportPen_{j,t-1} + \gamma X_{i,t-1} + \sum_{Firm} \phi_{Firm}\, I(Firm) + \sum_{Year} \phi_{Year}\, I(Year) + \varepsilon_{i,j,t}. \quad (17)$$

In our baseline regressions we use the number of unweighted and citation-weighted patent applications to index *Innovation*.[9] The variable $ImportPen_{j,t-1}$ represents Chinese import penetration ratio in industry j in year $t-1$, and thus measures the level of import competition from China that firm i faces in year $t-1$. We lag the independent variables by one year to account for the fact that import competition from China may have a lagged effect on firm innovation.[10]

The coefficient of interest in Equation (17) is the variable β. Our illustrative model predicts an inverted-U relationship between imitation from the South and innovation in the North. Given that the average level of import competition from China is still small (about 5%), we expect a positive impact of import competition from China on innovation activities of US firms.

To eliminate any potential impacts of firm-specific characteristics on innovation, we add a set of dummy variables $\{I(Firm)\}$ to our baseline equation. Consequently, we only explore within-firm variation to examine the relationship between Chinese import competition and innovation. We also control for year-specific effects that are homogeneous across firms, for example, macro changes in the economy or the patent system that affects measured innovative activities, by adding the set of dummy variables $\{I(Year)\}$.

As summarized in Cohen (2010), empirical studies on innovation usually link innovation performance with size and other firm-specific characteristics. Following Link and Long (1981), Link (1982), Hall and

[9]Since the two patent application count variables may have zeros, we add one to each variable before taking the natural log following Bloom et al. (2016).

[10]We experiment with alternative lag-lengths, such as using contemporaneous and two-year lagged independent variables. The results are presented in the robustness section and are consistent with our main findings.

Ziedonis (2001), and Yanadori and Cui (2013), the firm's R&D intensity, prior innovation performance, size, capital intensity and profitability are factors other than import competition that affect firm innovation. We include this set of control variables in $X_{i,t-1}$ as well as $R\&D\ Intensity_{i,t-1}$, the log levels of $Patent\ Stock_{i,t-1}$, $Number\ of\ Employees_{i,t-1}$, $Capital\ Intensity_{i,t-1}$, and $Net\ Operating\ Income_{i,t-1}$. We extract R&D expenditure for each firm directly from the Compustat North America database, then divide it by annual net sales to compute R&D intensity. Firms' prior innovation performance is represented by their patent stocks, computed by summing up their patent applications in the past five years in the NBER patent dataset. Firm size and profitability are proxied by the number of employees and net operating income, respectively. We define capital intensity as the ratio of the value of plants, property and equipment to the number of employees. The last three firm-specific variables are constructed by using financial statistics from the Compustat database.

Table 2 presents the ordinary least square (OLS) estimates for coefficients in Equation (17), with all columns controlling for firm and year fixed effects. To correct for industry-wide and year-specific shocks uncorrelated with the error term $\varepsilon_{i,j,t}$ and other right-hand-side (RHS) variables, the standard errors in Table 2 are two-way clustered by 4-digit SIC87 industry and year. Coefficient estimates with unweighted patent applications as the dependent variable are shown in columns (1) and (2), while citation-weighted patent counts are used as the dependent variable in columns (3) and (4). The results can also be grouped according to sample type: columns (1) and (3) show results for the narrow sample, which only includes firms awarded at least one patent between 1976 and 2006; results for the main sample, which covers firms with and without successful patent applications during the same period, are listed in columns (2) and (4).

When all patents are viewed as equally valuable, as in columns (1) and (2), the coefficient estimates suggest that Chinese import competition seems to have a positive but insignificant impact on firm innovation. However, the coefficients for import penetration ratios turn positive and significant at the 5% level, once patents are weighted by the number of citations received. In particular, the coefficients for the main sample suggest that a one percentage point increase in import penetration from China raises citation-weighted patent applications for a firm by 1.35%, and this effect increases to 1.56% if only patenters between 1976 and 2006 are included in the analysis. Overall, these baseline results provide support to the argument that import competition from China fosters innovation by US manufacturing firms, when innovation is adjusted by quality.

These results are different from those reported by Bloom et al. (2016), who find a positive relationship between Chinese import penetration and firm innovation as measured by patent counts. Our baseline results indicate that the import competition from China induces US firms to produce patents with a "higher impact," not simply a larger number of patents.

Endogeneity

A potential problem with using Chinese import penetration to measure imitation pressure is its potential endogeneity. For example, an unobserved positive technology or policy shock can simultaneously affect firm innovative activities and their demand for imports from China. This would bias the coefficient estimates from the OLS regressions.

We consider an Instrumental Variables (IV) approach to deal with this problem and choose Chinese import penetration to the United Kingdom as an instrument following Lu and Ng (2013) and Autor et al.

Table 2: Baseline Estimation: Patent Counts and Import Penetration from China

	Unweighted		Citation-weighted	
Independent Variables	(1) Narrow Sample	(2) Main Sample	(3) Narrow Sample	(4) Main Sample
Import Penetration	0.912	0.755	1.563**	1.351**
	(0.711)	(0.611)	(0.774)	(0.669)
R&D Intensity	0.804***	0.784***	0.777**	0.669**
	(0.298)	(0.285)	(0.342)	(0.298)
Patent Stock	0.160***	0.163***	0.133**	0.136**
	(0.061)	(0.061)	(0.056)	(0.056)
ln(*No. of Employees*)	0.159***	0.149***	0.172***	0.151***
	(0.052)	(0.049)	(0.055)	(0.049)
ln(*Capital Intensity*)	0.130***	0.118***	0.134***	0.122***
	(0.046)	(0.043)	(0.048)	(0.045)
ln(*Net Operating Income*)	0.057***	0.055***	0.062***	0.058***
	(0.017)	(0.015)	(0.016)	(0.015)
Number of Firms	1,136	1,228	1,104	1,228
Observations	7,435	7,844	7,248	7,844

Notes: *** denotes 1%, ** 5%, and * 10% significance, respectively. All regressions include firm and year fixed effects. Standard errors are clustered by industry and year, 'ln' denotes natural log of the variable.

(2013). The idea is that import penetration ratios for China in the US and the UK in a similar industry tend to fluctuate in the same direction, since they both reflect the commercial competitiveness of Chinese producers in that particular sector. However, the unobserved factors correlated with the market share for Chinese goods in the US market, such as unobserved technology and policy shocks in the US, are unlikely to be related to Chinese imports in the UK market.

We denote the import penetration ratio for China in UK industry j in year t as $ImpUK_{j,t}$ and construct it as

$$ImpUK_{j,t} = \frac{M_{j,t}^{UK,C}}{Q_{j,t}^{UK} + M_{j,t}^{UK} - X_{j,t}^{UK}}.$$

Analogous to $ImportPen_{j,t}$, $M_{j,t}^{UK,C}$ represents the value of imports from mainland China to the UK in industry j and year t, while $M_{j,t}^{UK}$, $Q_{j,t}^{UK}$ and $X_{j,t}^{UK}$ represent the value of overall imports, domestic production and exports of UK in industry i in year t. We construct $ImpUK_{j,t}$ for each 2-digit US SIC87 industry between 1990 and 2001, by substituting export, import and domestic production data from the Structural Analysis (STAN) database into the above equation. Note that the simple correlation between $Import\ pen_{j,t}$ and $Imp\ UK_{j,t}$ is 0.41, statistically significant at the 1% level.

The coefficient estimates generated by the two-stage least squares (2SLS) approach are shown in Table 3. Results presented in columns (1) and (2) indicate that Chinese import penetration has a insignificant impact on the simple count of firms' patent applications, once the potential endogeneity issue is addressed. Columns

(3) and (4) show that the coefficients on the import penetration ratio for China are positive and significant at the 10% level, when citation-weighted patent counts are employed as the measure of firm innovation. These results are consistent with the earlier OLS results, and also imply that import competition from China stimulates firms to produce patents of greater influence and market value.

The coefficient for the main sample shown in column (4) suggests that a one percentage point increase in import penetration from China raises citation-weighted patent applications for a representative firm by 6.71%. Compared with the baseline OLS results, the coefficients on import penetration turn to be significantly larger under the IV specification. This increase in magnitude for the IV coefficient estimates has been noted by Lu and Ng (2013) and Autor et al. (2013). They suggest that OLS estimates may suffer from attenuation bias led by measurement errors in disaggregated trade data. Although the US Manufacturing Exports and Imports dataset is comprehensive and carefully constructed, it is unlikely that the data is completely free of measurement error, especially given the fact that "the aggregation of import values at the ten-digit HS product level to the industry level is fundamentally tricky" (Lu and Ng, 2013, p. 1409). In addition, the omitted variable and reverse causality issues discussed earlier may also lead to a downward bias in the OLS estimates of β. For example, if both firm innovation and imports from China are positively correlated with unobserved shocks to the US market, the OLS estimate of the effect of rising Chinese import penetration on innovation of US manufacturing firms may understate the true impact. Thus, the increase in the estimated magnitude of the positive effect is in line with predictions from theory and consistent with previous studies.

Based on the "rule of thumb" indicated in Staiger and Stock (1997) and Baum et al. (2007), weak identification should not be considered a problem in the IV specification, when the F statistics of first-stage regressions are larger than 10. The weak identification test statistics for all specifications in Table 3 satisfy this constraint. Based on the detailed first-stage estimation results presented in Table 4, the correlation between import penetration ratios of China in the US and the UK markets is significant and positive, suggesting that Chinese import penetration to the UK is a reasonably strong instrument.

Robustness of Baseline Results

In this section we perform several robustness checks and show that our main results are robust to using (1) import competition from *all* low-wage countries (2) estimation of a negative binomial specification, (3) different lag structures for import penetration and (4) R&D as a proxy for firm innovation.

Import competition from low-wage countries Because a major share of the increase in imports from low-wage countries to the US is driven by Chinese imports, we have used Chinese import penetration in our baseline to proxy for low-wage imitation into the US. However, as indicated in Figure 1 the share of imports into the US from non-Chinese low-wage countries has also increased between 1990-2001. We now consider import competition from *all* low-wage countries, as defined by Bernard et al. (2006). Table 5 shows the estimation of Equation (17) by employing import penetration by China and all low-wage countries, respectively.[11] All of the coefficients for the import penetration ratio for the aggregated group of countries are positive and significant at the 5% level, when innovation is proxied by citations-weighted patent counts.

Negative binomial estimation In our baseline estimation, we follow Bloom et al. (2016) to use ln(1 +

[11]We ran a sensitivity test by adding import penetration ratios of OECD members as an additional control variable. The results are consistent with those shown in Table 5.

Table 3: Endogeneity: Chinese Import Penetration in the UK as an IV

	Unweighted		Citation-weighted	
	(1)	(2)	(3)	(4)
	Narrow	Main	Narrow	Main
Independent Variables	Sample	Sample	Sample	Sample
Import Penetration	4.495	4.039	7.675*	6.713*
	(3.509)	(3.157)	(4.075)	(3.705)
R&D Intensity	0.785***	0.769***	0.747**	0.645**
	(0.289)	(0.279)	(0.336)	(0.292)
Patent Stock	0.160***	0.163***	0.131**	0.134**
	(0.061)	(0.061)	(0.056)	(0.055)
ln(*No. of Employees*)	0.150***	0.142***	0.156***	0.140***
	(0.052)	(0.049)	(0.055)	(0.050)
ln(*Capital Intensity*)	0.138***	0.125***	0.148***	0.134***
	(0.049)	(0.045)	(0.053)	(0.049)
ln(*Net Operating Income*)	0.060***	0.058***	0.067***	0.063***
	(0.019)	(0.017)	(0.019)	(0.017)
Endogeneity C Statistic	1.077	1.204	2.066	2.187
p-value	0.299	0.273	0.151	0.139
K-P Weak ID F Statistic	20.40	16.58	19.83	16.55
Number of Firms	1,136	1,228	1,104	1,228
Observations	7,435	7,844	7,248	7,844

Notes: *** denotes 1%, ** 5%, and * 10% significance, respectively. All regressions include firm and year fixed effects. Standard errors are clustered by industry and year, 'ln' denotes natural log of the variable.

Table 4: First-Stage: Chinese Import Penetration in the UK as an IV

	Import Penetration in the US			
	(1)	(2)	(3)	(4)
	Narrow	Main	Narrow	Main
Independent Variables	Sample	Sample	Sample	Sample
Import Penetration in UK	0.523***	0.579***	0.528***	0.578***
	(0.116)	(0.142)	(0.119)	(0.142)
K-P Weak ID F Statistic	20.39	16.58	19.83	16.55
Number of Firms	1,136	1,228	1,104	1,228
Observations	7,435	7,844	7,248	7,844

Notes: *** denotes 1%, ** 5%, and * 10% significance, respectively. All regressions include firm and year fixed effects. Standard errors are clustered by industry and year.

Table 5: Robustness: Patent Applications and Imports from All Low-wage Countries

Independent Variables	Unweighted (1) Narrow Sample	Unweighted (2) Main Sample	Citation-weighted (3) Narrow Sample	Citation-weighted (4) Main Sample
	China			
Import Penetration	0.912	0.755	1.563**	1.351**
	(0.711)	(0.611)	(0.774)	(0.669)
Number of Firms	1,136	1,228	1,104	1,228
Observations	7,435	7,844	7,248	7,844
	All Low-Wage Countries			
Import Penetration	0.954	0.789	1.605**	1.385**
	(0.711)	(0.606)	(0.773)	(0.664)
Number of Firms	1,136	1,229	1,104	1,229
Observations	7,446	7,858	7,259	7,858

Notes: *** denotes 1%, ** 5%, and * 10% significance, respectively. All regressions include firm and year fixed effects. Standard errors are clustered by industry and year.

$PatentCounts$) as the dependent variable. Given that the patent count for each firm is a non-negative count variable, we check the robustness of our baseline results by re-estimating a negative binomial fixed effects model with the number of patent applications as the dependent variable. Results presented in Table 6 show that all coefficients on Chinese import penetration ratios are positive and significant at the 1% level. Coefficients in column (4) indicate that a one percentage point increase in import penetration from China leads to a representative firm obtaining 2.5 more citation-weighted patents. This measured effect is larger than in the baseline estimation.

Alternative lag structures for import penetration In the baseline, we consider the lagged impact of import competition on firm innovation by using a one-year lagged import penetration ratio of China. However, in the data, we do not observe the exact timing of the impact of import penetration on firm innovation activities. In order to check the effect of alternate lag structures for import penetration, we use shorter (contemporaneous) and longer (two-year) lags as shown in Table 7. The signs and significance of the coefficients confirm our baseline findings. The coefficients for Chinese import penetration ratios are positive and significant at the 5% level in columns (3) and (4), while those in columns (1) and (2) are positive but insignificant.

R&D expenditure as an alternative measure of innovation In our baseline, we use patent count as an indicator of firm innovation. Patents may be considered as an output of the innovation process while firm R&D expenditure may be considered as an input. We now use firm R&D expenditure as an alternative dependent variable and re-estimate the main equations with the same set of right hand side variables except $R\&D\ intensity_{i,t-1}$ which must now be excluded. Columns (1) and (2) in Table 8 contain the OLS results for the narrow and main samples respectively, while IV results are shown in columns (3) and (4). All of the

Table 6: Robustness: Negative Binomial Estimation

	Unweighted		Citation-weighted	
	(1)	(2)	(3)	(4)
	Narrow	Main	Narrow	Main
Independent Variables	Sample	Sample	Sample	Sample
Import Penetration	2.204***	2.204***	2.481***	2.481***
	(0.836)	(0.836)	(0.902)	(0.902)
R&D Intensity	–0.020	–0.020	–0.256	–0.256
	(0.699)	(0.699)	(0.725)	(0.725)
Patent Stock	0.262***	0.262***	0.239***	0.239***
	(0.046)	(0.046)	(0.050)	(0.050)
ln(*No. of Employees*)	–0.111**	–0.111**	–0.080	–0.080
	(0.050)	(0.050)	(0.050)	(0.050)
ln(*Capital Intensity*)	0.018	0.018	0.018	0.018
	(0.068)	(0.068)	(0.065)	(0.065)
ln(*Net Operating Income*)	0.062**	0.062**	0.073***	0.073***
	(0.024)	(0.024)	(0.025)	(0.025)
Number of Firms	976	976	947	947
Observations	6,704	6,704	6,556	6,556

Notes: *** denotes 1%, ** 5%, and * 10% significance, respectively. All regressions include firm and year fixed effects. Standard errors are clustered by industry, 'ln' denotes natural log of the variable.

Table 7: Robustness: Different Lag Lengths for Import Penetration

	Unweighted		Citation-weighted	
	(1)	(2)	(3)	(4)
	Narrow	Main	Narrow	Main
Independent Variables	Sample	Sample	Sample	Sample
	Using Contemporaneous RHS Variables			
Import Penetration	1.012*	0.861*	1.447**	1.252**
	(0.576)	(0.495)	(0.643)	(0.551)
Observations	9,518	10,151	9,243	10,151
	Using 2-year Lagged RHS Variables			
Import Penetration	1.165	1.005	2.063**	1.826**
	(0.828)	(0.729)	(0.957)	(0.852)
Observations	6,232	6,526	6,079	6,526

Notes: *** denotes 1%, ** 5%, and * 10% significance, respectively. All regressions include firm and year fixed effects. Standard errors are clustered by industry and year.

coefficients on import penetration ratios for China are positive and significant at the 5% level. In addition, the instrumental variable – import penetration ratio for China in the UK is not weak and leads to results similar to baseline, shown in columns (3) and (4) in the Table.

Table 8: Robustness: R&D Expenditure as an Alternative Measure of Innovation

	OLS Results		IV Results	
Independent Variables	(1) Narrow Sample	(2) Main Sample	(3) Narrow Sample	(4) Main Sample
Import Penetration	1.162**	1.070**	6.925**	6.099**
	(0.569)	(0.473)	(3.491)	(2.960)
Patent Stock	0.083***	0.084***	0.082***	0.084***
	(0.018)	(0.019)	(0.018)	(0.018)
ln(*No. of Employees*)	0.556***	0.557***	0.544***	0.546***
	(0.044)	(0.043)	(0.044)	(0.043)
ln(*Capital Intensity*)	0.195***	0.199***	0.210***	0.213***
	(0.040)	(0.039)	(0.045)	(0.043)
ln(*Net Operating Income*)	0.095***	0.093***	0.100***	0.097***
	(0.015)	(0.014)	(0.015)	(0.014)
Endogeneity C Statistic			2.893	3.019
p-value			0.089	0.082
K-P Weak ID F Statistic			19.89	15.38
Number of Firms	1,135	1,221	1,135	1,221
Observations	7,447	7,839	7,447	7,839

Notes: *** denotes 1%, ** 5%, and * 10% significance, respectively. All regressions include firm and year fixed effects. Standard errors are clustered by industry and year, 'ln' denotes natural log of the variable.

5 Heterogeneity in the Impacts of Chinese Import Competition on US Manufacturing

We have so far shown a positive and significant impact of Chinese import penetration on firm innovation, especially when patents are weighted by the number of citations. In this section, we investigate if the effect varies across industries and firms as suggested by other studies. We start by comparing firm response to import competition from China in sectors differing in technology intensity and in the scope for quality differentiation. Then we discuss if firm characteristics, such as capital intensity and labor productivity affect how firms respond to import competition.

Industry Characteristics and the Effect of Chinese Import Competition

Given the low technology intensity of products in labor-intensive industries, goods produced by domestic firms can be easily substituted by those shipped from low-wage countries. Therefore, when imports from low-wage producers increase, firms operating in these low-tech industries may experience more intensive competition than those in high-tech sectors. Therefore, firms in low-tech industries are more likely to innovate, and upgrade their product quality to insulate themselves from import competition.

We classify all the 4-digit SIC87 manufacturing industries into low- and high-tech sectors following the industry classification proposed by Chandler (1994) and Hall and Vopel (1997), and estimate our baseline model on firms in each sector separately. The high-tech sector in our study includes the same list of industries as in Hall and Vopel (1997), whereas the low-tech sector contains low-tech industries, in which average R&D intensities of firms are substantially lower than in the high-tech sector. Estimation results for Equation (17) for the two sub-samples are given in Table 9. The coefficients for Chinese import competition are positive and significant at the 5% level for the sample of firms in the low-tech sector for citation-weighted patents. None of the corresponding coefficients are significant for firms in the high-tech industries. Innovation effort of firms in high-tech industries seems to be unaffected by the surge in imports from China, while firms in low-tech industries innovate more.

Table 9: Heterogeneous Effects across Low- and High-tech Industries

	Unweighted		Citation-weighted	
Independent Variables	(1) Narrow Sample	(2) Main Sample	(3) Narrow Sample	(4) Main Sample
	Panel A: Firms in the Low-Tech Sector			
Import Penetration	1.112	0.867	1.660**	1.390**
	(0.751)	(0.617)	(0.802)	(0.662)
Number of Firms	495	534	481	534
Observations	3,454	3,627	3,346	3,627
	Panel B: Firms in the High-Tech Sector			
Import Penetration	0.288	0.341	1.160	1.151
	(1.825)	(1.773)	(1.945)	(1.849)
Number of Firms	641	694	623	694
Observations	3,981	4,217	3,902	4,217

Notes: *** denotes 1%, ** 5%, and * 10% significance, respectively. All regressions include firm and year fixed effects. Standard errors are clustered by industry and year. High tech industries are those defined in Hall and Vopel (1997), rest grouped into low-tech.

Besides technology intensity, manufacturing industries also differ along other dimensions that can affect how firms respond to import competition from low-wage countries. One important characteristic proposed by Khandelwal (2010) is the scope of quality differentiation, or "quality ladders". In industries with a short quality ladder, i.e, a smaller scope for product differentiation, firms are vulnerable to competition from low-wage countries, since they are unable to differentiate their products from the competition. Therefore, firms in less-differentiated industries are more likely to innovate, and upgrade their product quality to insulate themselves from import competition.[12]

Here we classify all the 4-digit SIC87 manufacturing industries into two groups based on quality ladder measures proposed by Khandelwal (2010). We classify industries with a lower than the median Khandelwal quality ladder measure as the short-ladder group, and the rest are grouped into the long-ladder category. The estimation results for Equation (17) are reported in Table 10. The coefficients on import penetration are positive and significant at the 5% level for the sub-sample of firms in short-ladder industries, when citation-weighted patents are considered. Firms in the short-ladder industries respond positively to import competition through innovation into higher quality products. Firms in the long-ladder class enjoy a higher degree of product differentiation and hence do not innovate to a significant degree in response to low-wage competition.

Table 10: Heterogeneous Effects across Short and Long-ladder Industries

	Unweighted		Citation-weighted	
Independent Variables	(1) Narrow Sample	(2) Main Sample	(3) Narrow Sample	(4) Main Sample
	Panel A: Firms in the Short-Ladder Sector			
Import Penetration	1.170*	0.931	1.808**	1.517**
	(0.709)	(0.604)	(0.867)	(0.736)
Number of Firms	597	633	578	633
Observations	3,855	4,035	3,746	4,035
	Panel B: Firms in the Long-Ladder Sector			
Import Penetration	0.255	0.315	0.927	0.909
	(1.926)	(1.900)	(1.850)	(1.812)
Number of Firms	517	567	505	567
Observations	3,427	3,628	3,353	3,628

Notes: *** denotes 1%, ** 5%, and * 10% significance, respectively. All regressions include firm and year fixed effects. Standard errors are clustered by industry and year. Median value for the quality ladder measure (Khandelwal (2010)) is used to classify firms into short and long ladder categories.

In summary, the positive impact from direct competition from low-wage countries on firm innovation is more pronounced in industries with low technology intensity or with a lower potential for quality differentiation.

Heterogeneity in Firm Characteristics

Differential firm characteristics may also affect the response to import competition. For instance, if factors are "trapped" in production of old products as discussed in Bloom et al. (2014), and the adjustment cost of within-firm reallocation is higher for labor than for capital, firms with higher capital intensity may

[12]There may be other channels that affect the way firms in developed countries respond to low-wage import competition. For example, they may alter their product mix and switch to less affected industries, as shown by Bernard et al. (2006) and Bernard et al. (2011).

experience less friction in shifting resources towards development and production of new products. However, firms with lower labor productivity may be hit harder by increasing imports from low-wage countries, as these less efficient producers may be more vulnerable to potential losses in revenue from overseas competition. Hence capital-intensive producers and less productive firms may have a greater incentive to innovate under import competition.

To examine the effect on capital intensity, we use the median value for the capital intensity to split the firms into two groups, with low and high capital intensities. As shown in Table 11, the coefficients for firms in the group with high capital intensity exhibit a positive and significant effect on citation-weighted as well as unweighted patents. The effect on firms with low capital intensity is not significant, as one would expect.

Table 11: Heterogeneous Effects across Firms with Low and High-Capital Intensity

	Unweighted		Citation-weighted	
Independent Variables	(1) Narrow Sample	(2) Main Sample	(3) Narrow Sample	(4) Main Sample
	Panel A: Firms with Low Capital Intensity			
Import Penetration	0.875	0.613	1.186	0.921
	(0.847)	(0.690)	(0.836)	(0.676)
Number of Firms	642	697	625	697
Observations	3,384	3,608	3,294	3,608
	Panel B: Firms with High Capital Intensity			
Import Penetration	2.407*	2.488**	3.429**	3.378**
	(1.283)	(1.265)	(1.471)	(1.407)
Number of Firms	658	697	640	697
Observations	3,920	4,094	3,826	4,094

Notes: *** denotes 1%, ** 5%, and * 10% significance, respectively. All regressions include firm and year fixed effects. Standard errors are clustered by industry and year. Median value for capital intensity is used to classify firms into low and high categories.

Finally we examine the effect of import competition on firm productivity. Labor productivity is defined as the ratio of net sales to number of employees, and as before, we divide our data into two sub-samples based on the median value for this variable in the entire sample. Results are shown in Table 12. Import competition has a positive and significant effect only on firms with low labor productivity, when patents are citation-weighted.

6 Concluding Remarks

Using matched US firm and patent data provided by the NBER Patent Data Project during 1990-2006, we have studied the effect of low-wage import competition from China, on innovation by US manufacturing firms. We find a positive and significant impact of low-wage imports on innovation when using citation-weighted

Table 12: Heterogeneous Effects across Firms with Differences in Labor Productivity

	Unweighted		Citation-weighted	
	(1)	(2)	(3)	(4)
	Narrow	Main	Narrow	Main
Independent Variables	Sample	Sample	Sample	Sample
	Panel A: Firms with Low Labor Productivity			
Import Penetration	1.187	0.833	1.746**	1.301**
	(0.790)	(0.634)	(0.753)	(0.643)
Number of Firms	645	696	626	696
Observations	3,503	3,704	3,401	3,704
	Panel B: Firms with High Labor Productivity			
Import Penetration	0.810	0.783	1.426	1.402
	(0.945)	(0.868)	(1.212)	(1.115)
Number of Firms	696	743	681	743
Observations	3,723	3,916	3,648	3,916

Notes: *** denotes 1%, ** 5%, and * 10% significance, respectively. All regressions include firm and year fixed effects. Standard errors are clustered by industry and year. Median value for labor productivity is used to classify firms into low and high categories.

patent counts, but an insignificant impact when using a simple count of patent applications. This positive relationship is stronger for firms in low-tech industries and in those with lower product differentiation. It is also stronger for firms with higher capital intensity and lower labor productivity. Our results support earlier findings on the positive relationship between import competition and innovation. However, distinct from earlier research, we find this positive relationship to be significant only for quality-adjusted patent counts, and not for patent applications. Import competition affects the quality of patent production, not the volume.

In this paper we use publicly available matched firm and patent data for US public firms. Therefore, our findings only speak to the within-firm responses to import competition from low-wage countries. To gain a more complete understanding of the impact of import competition on firm innovation, future work needs to focus on both within-firm and between-firm responses using data on a bigger sample of US manufacturing firms, such as the Annual Survey of Manufactures from the US Census Bureau.

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