Minimum Wages, Import Status, and Firms' Innovation: Theory and Evidence from China

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Abstract

This study explores the heterogeneous effects of minimum wage on innovation of different types of firms. We develop an open-economy R&D-based growth model and obtain the following result: raising the minimum wage reduces innovation of firms that use domestic inputs but increases innovation of firms that import foreign inputs. Intuitively, when the minimum wage increases, importing firms substitute labor with imported inputs, which have technology spillovers and enhance their innovation. We test this result using city-level data on minimum wages and firm-level patent data in China. Finally, we find that in accordance with our theory, raising the minimum wage is associated with more innovation by importing firms and less by non-importing firms. This result survives a battery of robustness checks.

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1 Introduction

In the latest 40 years, China achieved and maintained a high rate of economic growth and a rapid expansion in international trade. Now, China has become the largest country in the world in terms of bilateral trade. Meanwhile, labor costs in China have increased dramatically. An important contributing factor is the rising minimum wages in China. Does a rise in minimum wages affect firms' innovation? If so, does this effect vary across firms' trade status?

This study explores the effects of minimum wage on innovation. The novelty of our analysis is that we consider the heterogeneous effects of minimum wage on different types of firms. First, we develop an open-economy R&D-based growth model in which some firms import inputs from abroad and others use domestic inputs. Then, we apply this growth-theoretic framework to explore the different effects of minimum wage on the innovation of the two types of firms. Finally, we test our theoretical results using firm-level patent data and city-level data on minimum wages in China.

Within our growth-theoretic framework, raising the minimum wage reduces innovation of firms that use domestic inputs but increases innovation of firms that import foreign inputs. Intuitively, when a higher minimum wage reduces employment, importing firms respond by importing a larger amount of inputs. Following empirical evidence such as Amiti and Konings (2007), Goldberg *et al.* (2010), Bloom *et al.* (2016), Chen *et al.* (2017), and Mo *et al.* (2019), we assume that imported inputs give rise to technology spillovers from abroad. As a result, the increase in imported inputs enhances research efficiency of importing firms and leads to a reallocation of research labor from non-importing firms to importing firms. Consequently, innovation of non-importing firms decreases, whereas innovation of importing firms increases.

In our empirical analysis, we construct a merged dataset from the following data sources: annual firm-level manufacturing survey data from the National Bureau of Statistics of China (NBSC); firm-level patent applications from China National Intellectual Property Administration (CNIPA); firm-product-level trade data from China's General Administration of Customs (CGAC); and city-level minimum-wage and economic data. We find that the impacts of minimum wage vary across importing firms and non-importing firms. Consistent with our theoretical predictions, a higher minimum wage is associated with a lower level of innovation (measured by patents) by non-importing firms but a higher level of innovation by importing firms. We then conduct additional tests to address potential endogeneity issues. Following the approach of Dube *et al.* (2010) and Fan *et al.* (2018), we construct a dataset of all city pairs across province borders to identify the effects of minimum wage on patent applications. In addition, we also employ instrumental variables for both the minimum wage and the import status to solve the endogeneity issue. Moreover, we study the heterogeneous effects across different capital intensity and find that the impact of minimum wage is higher for firms with lower capital intensity.[1] Finally, the impacts of minimum wage on patent citations, firm's product scope, TFP and labor employment are also consistent with our theoretical predictions.

[1]This is consistent with Bai *et al.* (2018) and Fan *et al.* (2018), who show a greater effect of minimum wage on export performances and FDI in industries with higher labor intensity, respectively.

This study relates to the theoretical literature on innovation and economic growth. Seminal studies by Romer (1990), Segerstrom *et al.* (1990), Grossman and Helpman (1991a), and Aghion and Howitt (1992) develop the R&D-based growth model. While all of these early studies feature full employment, some subsequent studies use different approaches to incorporate equilibrium unemployment into the R&D-based growth model.[2] A branch of this literature uses variants of the R&D-based growth model to explore the effects of minimum wage on unemployment and innovation; see Askenazy (2003), Meckl (2004), Agenor and Lim (2018), Chu, Cozzi, Fan, Furukawa, and Liao (2020), and Chu, Kou, and Wang (2020). This study contributes to this literature by showing that minimum wage has heterogeneous effects on innovation of different firms, and by testing these heterogeneous effects using firm-level data.

This study also relates to the empirical literature on the determinants of innovation and productivity. Within this literature, our paper is most closely related to Amiti and Konings (2007), Goldberg *et al.* (2010), Bloom *et al.* (2016), Chen *et al.* (2017) and Mo *et al.* (2019), who use firm-level data to show that imported inputs enhance innovation and productivity.[3] Complementing these interesting studies, our study examines the effects of minimum wage on firms' innovation by using the dataset of patent applications and shows that minimum wage affects non-importing firms and importing firms differently via imported inputs and their spillover effects on technologies.[4]

This paper also belongs to the vast literature on the economic effects of minimum wage regulations in China. Among them, Wang and Gunderson (2011), Huang *et al.* (2014), Fang and Lin (2015), Long and Yang (2016) and Bai *et al.* (2018) study the effects of minimum wages on labor employment. Mayneris *et al.* (2018) and Hau *et al.* (2020) examine the impacts of minimum wages on firms' input-substitution, management practice and productivity. Gan *et al.* (2016) and Fan *et al.* (2018) study the relationship between changes in the minimum wage and firms' export and FDI, respectively.[5] However, none of these papers analyze the differentiated effects of minimum wage on innovation for importing firms and non-importing firms. We aim to fill this gap in the literature.

The rest of this study is organized as follows. Section 2 describes the theoretical model. Section 3 presents our theoretical results. Section 4 describes the institutional background, data and empirical specification. Section 5 presents our empirical analysis. We provide concluding remarks in section 6.

2 An open-economy R&D-based growth model

In this section, we develop an innovation-driven growth model. The open-economy R&D-based growth model is based on Grossman and Helpman (1991b). We follow Chu, Fan, Shen,

[2] See for example Mortensen and Pissarides (1998) for search frictions, Parello (2010) for efficiency wage, Peretto (2011) for wage bargaining, and Chu, Cozzi, and Furukawa (2016), Ji *et al.* (2016), and Chu, Kou, and Liu (2018) for trade unions.

[3] Lu and Ng (2012) also use firm-level data to show that imports spur incremental innovation in China.

[4] Liu *et al.* (2015) and Liu and Qiu (2016) find that trade policies also have multiple effects on innovation.

[5] Chan (2019) studies how Chinese import competition affects US local labor market and finds that US regions with higher minimum wages are less affected by import competition from China.

and Zhang (2018) to extend the Grossman-Helpman model to multiple sectors. Specifically, firms in one sector use domestic inputs for the production of differentiated products, whereas those in the other sector use foreign inputs. Furthermore, we generalize the model in Chu, Fan, Shen, and Zhang (2018) by introducing minimum wage and allowing for a nonunitary elasticity of substitution between labor and imported inputs in production. For simplicity, we assume that the terms of trade are exogenous, as in Grossman and Helpman (1991b).

2.1 Household

In the economy, there is a representative household, whose utility function is

$$U = \int_0^\infty e^{-\rho t}(\ln C_{y,t} + \gamma \ln C_{z,t})dt. \tag{1}$$

The parameter $\rho > 0$ is the subjective discount rate. $C_{y,t}$ is the consumption of a domestic final good, which is chosen as the numeraire.[6] The parameter $\gamma \geq 0$ determines the importance of the consumption of a foreign final good $C_{z,t}$ imported from abroad.[7] p_z is the price of this foreign good, and also the terms of trade, which is exogenous for simplicity.

The household maximizes utility subject to the following asset-accumulation equation:

$$\dot{a}_t = r_t a_t + w_{h,t} + \overline{w}_{l,t}(L_t^d + L_t^f) + b_t(l - L_t^d - L_t^f) - \tau_t - C_{y,t} - p_z C_{z,t}, \tag{2}$$

where a_t is the amount of assets, and r_t is the interest rate.[8] The household supplies one unit of high-skill research labor to earn the high-skill wage rate $w_{h,t}$, which is higher than the minimum wage. The household also supplies l units of low-skill production labor, among which $L_t^d + L_t^f$ units work in the two production sectors $\{d, f\}$ and earn the minimum wage $\overline{w}_{l,t}$. The unemployed low-skill labor $l - L_t^d - L_t^f$ receives unemployment benefit $b_t < \overline{w}_{l,t}$. τ_t is a lump-sum tax collected by the government. Standard dynamic optimization yields the following optimality conditions:

$$\frac{\dot{C}_{y,t}}{C_{y,t}} = r_t - \rho, \tag{3}$$

$$C_{z,t} = \gamma C_{y,t}/p_z. \tag{4}$$

2.2 Domestic final good

Competitive firms produce domestic final good Y_t. The production function is

$$Y_t = (X_t^d)^{0.5}(X_t^f)^{0.5}, \tag{5}$$

[6]Domestic final goods can be consumed by the household, used to produce intermediate inputs, or exported.

[7]Imported foreign final goods can be consumed by the household or used to produce intermediate inputs.

[8]Here, we assume financial autarky under which the domestic financial market is not integrated to the global financial market. This assumption is reasonable given capital control in China. Under the assumption of financial autarky, it can be shown that the asset-accumulation equation ensures balanced trade.

where X_t^d is the intermediate good that uses domestic inputs, and X_t^f is the intermediate good that uses foreign inputs. From profit maximization, we derive the conditional demand functions for X_t^d and X_t^f as

$$X_t^d = \frac{Y_t}{2P_t^d}, \tag{6}$$

$$X_t^f = \frac{Y_t}{2P_t^f}, \tag{7}$$

where P_t^d is the price of X_t^d and P_t^f is the price of X_t^f.

2.3 Intermediate goods

Competitive firms produce intermediate good $i \in \{d, f\}$. The production function for X_t^d is:

$$X_t^d = \left\{ (1-\alpha)(L_t^d)^{\frac{\varepsilon-1}{\varepsilon}} + \alpha \left[\int_0^{n_t^d} [x_t^d(\omega)]^\alpha d\omega \right]^{\frac{\varepsilon-1}{\alpha\varepsilon}} \right\}^{\frac{\varepsilon}{\varepsilon-1}}, \tag{8a}$$

where $\varepsilon > 1$ is the elasticity of substitution between domestic production labor L_t^d and domestic capital goods $x_t^d(\omega)$ for $\omega \in [0, n_t^d]$. Similarly, the production function for X_t^f is:

$$X_t^f = \left\{ (1-\alpha)(L_t^f)^{\frac{\varepsilon-1}{\varepsilon}} + \alpha \left[\int_0^{n_t^f} [x_t^f(\omega)]^\alpha d\omega \right]^{\frac{\varepsilon-1}{\alpha\varepsilon}} \right\}^{\frac{\varepsilon}{\varepsilon-1}}, \tag{8b}$$

where $\varepsilon > 1$ is the elasticity of substitution between domestic production labor L_t^f and foreign capital goods $x_t^f(\omega)$ for $\omega \in [0, n_t^f]$.[9] This nonunitary elasticity of substitution between labor and imported capital goods will interact with the technology spillovers of imported capital goods to affect innovation. From profit maximization, we derive the conditional demand functions for L_t^i and $x_t^i(\omega)$ as

$$\overline{w}_{l,t} = (1-\Phi_t^d)\frac{P_t^d X_t^d}{L_t^d} = (1-\Phi_t^f)\frac{P_t^f X_t^f}{L_t^f}, \tag{9}$$

$$p_t^d(\omega) = \Phi_t^d \frac{P_t^d X_t^d}{\int_0^{n_t^d} [x_t^d(\omega)]^\alpha d\omega} [x_t^d(\omega)]^{\alpha-1}, \tag{10a}$$

$$p_t^f(\omega) = \Phi_t^f \frac{P_t^f X_t^f}{\int_0^{n_t^f} [x_t^f(\omega)]^\alpha d\omega} [x_t^f(\omega)]^{\alpha-1}, \tag{10b}$$

where

$$\Phi_t^i \equiv \frac{\alpha \left[\int_0^{n_t^i} [x_t^i(\omega)]^\alpha d\omega \right]^{\frac{\varepsilon-1}{\alpha\varepsilon}}}{(1-\alpha)(L_t^i)^{\frac{\varepsilon-1}{\varepsilon}} + \alpha \left[\int_0^{n_t^i} [x_t^i(\omega)]^\alpha d\omega \right]^{\frac{\varepsilon-1}{\alpha\varepsilon}}},$$

[9] It is useful to note that X_t^f is produced by combining domestic labor L_t^f and foreign input $x_t^f(\omega)$ imported from abroad. So, X_t^f is not a foreign good but a domestically produced good that uses some foreign inputs.

and $p_t^i(\omega)$ is the price of $x_t^i(\omega)$ for $i \in \{d, f\}$.

2.4 Domestic capital goods

A monopolistic firm uses $x_t^d(\omega)$ units of domestic final goods to produce $x_t^d(\omega)$ units of domestic capital good $\omega \in [0, n_t^d]$.[10] Therefore, the profit function for producing $x_t^d(\omega)$ units of domestic capital good ω is

$$\pi_t^d(\omega) = p_t^d(\omega) x_t^d(\omega) - x_t^d(\omega) = \Phi_t^d \frac{P_t^d X_t^d}{\int_0^{n_t^d} [x_t^d(\omega)]^\alpha d\omega} [x_t^d(\omega)]^\alpha - x_t^d(\omega). \tag{11}$$

The monopolistic price is $p_t^d(\omega) = 1/\alpha$, and the amount of profit for $\omega \in [0, n_t^d]$ is

$$\pi_t^d(\omega) = \frac{1-\alpha}{\alpha} x_t^d(\omega) = (1-\alpha)\, \Phi_t^d \frac{P_t^d X_t^d}{n_t^d} = (1-\alpha)\, \Phi_t^d \frac{Y_t}{2n_t^d} \equiv \pi_t^d, \tag{12}$$

where the second equality uses symmetry in (10a), and $p_t^d(\omega) = 1/\alpha$. Later on, we will show that the economy features a steady state (instead of a balanced growth path) due to the obsolescence of products.[11] The steady-state value of an invention is:

$$v_t^d(\omega) = \frac{\pi_t^d(\omega)}{r+\delta} = (1-\alpha)\, \Phi_t^d \frac{Y_t}{2n_t^d} \frac{1}{\rho+\delta} \equiv v_t^d, \tag{13}$$

where the parameter $\delta > 0$ is the probability that a product becomes obsolete.

2.5 Foreign capital goods

A monopolistic firm imports $x_t^f(\omega)$ units of foreign final good to produce $x_t^f(\omega)$ units of foreign capital good $\omega \in [0, n_t^f]$.[12] Therefore, the profit function for producing $x_t^f(\omega)$ units of foreign capital good ω is

$$\pi_t^f(\omega) = p_t^f(\omega) x_t^f(\omega) - p_z x_t^f(\omega) = \Phi_t^f \frac{P_t^f X_t^f}{\int_0^{n_t^f} [x_t^f(\omega)]^\alpha d\omega} [x_t^f(\omega)]^\alpha - p_z x_t^f(\omega). \tag{14}$$

The monopolistic price is $p_t^f(\omega) = p_z/\alpha$, and the amount of profit for $\omega \in [0, n_t^f]$ is

$$\pi_t^f(\omega) = \frac{1-\alpha}{\alpha} p_z x_t^f(\omega) = (1-\alpha)\, \Phi_t^f \frac{P_t^f X_t^f}{n_t^f} = (1-\alpha)\, \Phi_t^f \frac{Y_t}{2n_t^f} \equiv \pi_t^f, \tag{15}$$

where the second equality uses symmetry in (10b), and $p_t^f(\omega) = p_z/\alpha$. The steady-state value of an invention is

$$v_t^f(\omega) = \frac{\pi_t^f(\omega)}{r+\delta} = (1-\alpha)\, \Phi_t^f \frac{Y_t}{2n_t^f} \frac{1}{\rho+\delta} \equiv v_t^f, \tag{16}$$

where $\delta > 0$ is once again the probability that a product becomes obsolete.

[10] A firm may own the patents for producing multiple varieties of domestic capital goods.
[11] See also Grossman and Lai (2004).
[12] An importing firm may own the patents to produce multiple varieties of foreign capital goods.

2.6 R&D for non-importing firms

We refer to firms in the sector that uses only domestic capital goods as non-importing firms. Firms in this sector d devote one unit of domestic high-skill research labor to invent a new variety of differentiated products. The zero-profit condition of R&D in sector d is given by:

$$v_t^d = w_t^h. \tag{17}$$

Together with the obsolescence δ of existing products, the law of motion for n_t^d is given by:

$$\dot{n}_t^d = R_t^d - \delta n_t^d, \tag{18}$$

where R_t^d denotes domestic R&D labor in sector d. Therefore, the steady-state level of n_t^d is given by $n^d = R^d/\delta$, which is increasing in R&D labor in the sector.

2.7 R&D for importing firms

We refer to firms in the sector that uses foreign capital goods as importing firms. Firms in this sector f devote $1/(1+\overline{\lambda}I_t)$ units of domestic high-skill research labor to inventing a new variety of differentiated products. The zero-profit condition of R&D in sector f is given by $v_t^f = w_t^h/(1+\overline{\lambda}I_t)$. Together with the obsolescence δ of existing products, the law of motion for n_t^f is given by:

$$\dot{n}_t^f = (1+\overline{\lambda}I_t)R_t^f - \delta n_t^f, \tag{19}$$

where R_t^f denotes domestic R&D labor in sector f. Therefore, the steady-state level of n_t^f is given by $n^f = (1+\overline{\lambda}I)R^f/\delta$, where $\overline{\lambda} > 0$ is an import-spillover parameter. We assume that the productivity of R_t^f depends on the intensity I_t of imported inputs. Specifically, the value of imported inputs as a ratio of output is:

$$I_t \equiv p_{z,t} \int_0^{n_t^f} x_t^f(\omega) d\omega / Y_t.$$

We adapt this specification from Grossman and Helpman (1991b), who also assume that knowledge spillovers arise from trade.[13] Imposing symmetry and using (7) and (15), one can show that $I_t = \alpha\Phi_t^f/2$. If we define $\lambda \equiv \overline{\lambda}\alpha/2$, then the zero-profit condition of R&D in sector f can be expressed as:

$$(1+\lambda\Phi_t^f)v_t^f = w_t^h, \tag{20}$$

where $\lambda\Phi_t^f = \overline{\lambda}I_t$ captures the spillover effects of imported inputs.

[13]See Coe and Helpman (1995) for empirical evidence that trade stimulates international spillovers, and Chen *et al.* (2017) and Mo *et al.* (2019) for evidence that imported inputs stimulate innovation.

2.8 Government

The government sets a minimum wage that is binding in the production sectors. The total supply of low-skill production labor is l, and unemployment is $l - L_t^d - L_t^f$. The government sets the minimum wage as:

$$\overline{w}_{l,t} = \mu. \tag{21}$$

Combining (6), (7), (9), and (21) yields the level of low-skill employment in the two sectors:

$$L_t^d = (1 - \Phi_t^d)\frac{Y_t}{2\mu}, \tag{22a}$$

$$L_t^f = (1 - \Phi_t^f)\frac{Y_t}{2\mu}. \tag{22b}$$

For a sufficiently large μ, the minimum wage is binding such that $L_t^d + L_t^f < l$. Finally, the government levies a lump-sum tax τ_t on the household to pay for the unemployment benefit b_t subject to

$$\tau_t = b_t(l - L_t^d - L_t^f). \tag{23}$$

2.9 Decentralized equilibrium

The equilibrium is a time path of allocations $\{C_{z,t}, C_{y,t}, Y_t, X_t^d, X_t^f, x_t^d(\omega), x_t^f(\omega), L_t^d, L_t^f, R_t^d, R_t^f\}_{t=0}^{\infty}$ and prices $\{p_z, r_t, w_t^h, \overline{w}_t^l, P_t^d, P_t^f, p_t^d(\omega), p_t^f(\omega), v_t^d, v_t^f\}_{t=0}^{\infty}$. At each instance of time, the following is true.

- the representative household chooses $\{C_{z,t}, C_{y,t}\}$ to maximize lifetime utility, given $\{p_z, r_t, w_t^h, \overline{w}_t^l\}$;
- competitive firms produce Y_t to maximize profit, given $\{P_t^d, P_t^f\}$;
- competitive firms produce X_t^d to maximize profit, given $\{\overline{w}_t^l, P_t^d, p_t^d(\omega)\}$;
- competitive firms produce X_t^f to maximize profit, given $\{\overline{w}_t^l, P_t^f, p_t^f(\omega)\}$;
- a monopolistic firm produces $x_t^d(\omega)$ and sets $p_t^d(\omega)$ to maximize profit;
- a monopolistic firm produces $x_t^f(\omega)$ and sets $p_t^f(\omega)$ to maximize profit, given p_z;
- R&D labor R_t^d performs innovation to maximize profit, given $\{w_t^h, v_t^d\}$;
- R&D labor R_t^f performs innovation to maximize profit, given $\{w_t^h, v_t^f\}$;
- the market-clearing condition for high-skill labor holds such that $R_t^d + R_t^f = 1$;
- the minimum wage in the low-skill labor market implies $L_t^d + L_t^f < l$;
- the trade account is balanced such that $Y_t - C_{y,t} - \int_0^{n_t^d} x_t^d(\omega)d\omega = p_z C_{z,t} + p_z \int_0^{n_t^f} x_t^f(\omega)d\omega$.

3 Effects of minimum wage on innovation

We now examine the steady-state effects of minimum wage. From (22a), production labor L_t^d in sector d is decreasing in the minimum-wage parameter μ for a given Φ^d and Y_t. From (22b), production labor L_t^f in sector f is also decreasing in μ for a given Φ^f and Y_t. Intuitively, an increase in the minimum wage reduces labor demand and the employment level. From (10b), the income share Φ^f of imported capital goods in sector f is:

$$\Phi^f = \frac{\alpha \left[(n^f)^{1/\alpha} x^f\right]^{(\varepsilon-1)/\varepsilon}}{(1-\alpha)(L^f)^{(\varepsilon-1)/\varepsilon} + \alpha \left[(n^f)^{1/\alpha} x^f\right]^{(\varepsilon-1)/\varepsilon}}, \tag{24}$$

which is decreasing in L^f for a given $(n^f)^{1/\alpha} x^f$. In other words, for a given $(n^f)^{1/\alpha} x^f$, a higher minimum wage μ leads to an increase in the income share Φ^f of imported capital goods by decreasing L^f due to the substitutability between labor and imported inputs.

Combining (13), (16), (17), and (20) yields the steady-state ratio of relative technology between the two sectors as

$$\frac{n^f}{n^d} = \frac{(1+\lambda\Phi^f)\Phi^f}{\Phi^d}, \tag{25}$$

which is increasing in Φ^f due to the technology spillovers $\lambda\Phi^f$ of imported capital goods in sector f. Substituting $n^f = (1+\lambda\Phi^f)R^f/\delta$ and $n^d = R^d/\delta$ in (25) yields the relative level of R&D labor between the two sectors as:

$$\frac{R^f}{R^d} = \frac{R^f}{1-R^f} = \frac{\Phi^f}{\Phi^d}, \tag{26}$$

where the first equality uses the resource constraint on high-skill labor, $R^d + R^f = 1$. In the proof of Proposition 1, we show that Φ^f is increasing in minimum wage μ and that the ratio Φ^f/Φ^d is increasing in μ if and only if $\lambda > 0$. In this case, R&D labor R^f in sector f is increasing in minimum wage μ, whereas R&D labor R^d in sector d is decreasing in μ. Intuitively, when a higher minimum wage reduces employment, importing firms respond by importing more capital goods,[14] which have technology spillovers and improve research efficiency in sector f. This leads to a reallocation of research labor from sector d to sector f. As a result, the level of innovation $n^f = (1+\lambda\Phi^f)R^f/\delta$ in sector f increases, whereas the level of innovation $n^d = R^d/\delta$ in sector d decreases. Finally, from (22), we can derive that $L^f/L^d = (1-\Phi^f)/(1-\Phi^d)$, which is decreasing in the minimum wage parameter μ.

The above results can be summarized as follows. First, raising the minimum wage has a negative effect on non-importing firms' innovation. Second, raising the minimum wage has a positive effect on importing firms' innovation. Third, raising the minimum wage causes a fall in the production labor of importing firms relative to non-importing firms (i.e., L^f/L^d). Proposition 1 summarizes these results.

Proposition 1 *If the elasticity of substitution is not excessively large, such that $\varepsilon < (1-\alpha/2)/(1-\alpha)$, then the economy features a unique steady-state equilibrium. In this case,*

[14] In Table C1, we empirically show that a rise in minimum wage increases firms' imported capital goods, capital, and capital-labor ratio.

raising the minimum wage causes the following effects: (1) a decrease in innovation of non-importing firms; (2) an increase in innovation of importing firms; and (3) a decrease in the production labor of importing firms relative to non-importing firms.

Proof. See Appendix A. ■

3.1 An extension

In our benchmark model, we assume that a monopolistic firm either uses domestic or foreign inputs. We consider an extension of our model in which all of the monopolistic firms use domestic and foreign inputs, but the intensity differs across firms. Suppose a monopolistic firm uses $\psi x_t^d(\omega)$ units of domestic final good and imports $(1-\psi)\, x_t^d(\omega)$ units of foreign final good to produce $x_t^d(\omega)$ units of domestic-input-intensive capital good $\omega \in [0, n_t^d]$, where $\psi \in (0.5, 1]$ denotes the factor intensity of domestic inputs in the production of domestic-input-intensive capital goods. Similarly, a monopolistic firm uses $(1-\psi)x_t^f(\omega)$ units of domestic final good and imports $\psi x_t^f(\omega)$ units of foreign final good to produce $x_t^f(\omega)$ units of foreign-input-intensive capital goods $\omega \in [0, n_t^f]$, where $\psi \in (0.5, 1]$ again denotes the factor intensity of foreign input in the production of foreign-input-intensive capital goods.[15] Hence, our benchmark model is a special case with $\psi = 1$. In Appendix B, we show that there exists a range of $\psi \in [\hat{\psi}, 1]$ in which our results hold.

4 Institutional background, data, and empirical specification

In this section, we first introduce the minimum-wage system and the patent system in China. Then, we describe the data employed in our empirical analysis. Finally, we specify our main regression and describe the key components of the econometric model.

4.1 China's minimum-wage system

In November 1993, the former Ministry of Labor of China issued the first national minimum wage regulations, which were written into the Labor Law in 1994. All of the provincial, autonomous-region, and municipal governments are authorized to set their local minimum wages according to their economic development levels, which can vary across cities within a province. When setting their minimum wages, governments are required to consider local factors such as the living expenses of urban residents, average wages, unemployment rate, and level of economic development.

Due to weak supervision, the minimum wage regulations were not well implemented in the 1990s and early 2000s. In 2004, the Chinese Ministry of Labor and Social Security (restructured from the Chinese Ministry of Labor) passed and reinforced the Minimum Wage

[15] In general, we can allow ψ to be different in the production of the two types of capital goods.

Regulations (Gan *et al.*, 2016; Fan *et al.*, 2018), which were more strongly enforced than the original regulations. Article 4 in the new minimum wage regulations emphasizes that "Labor unions at all levels shall supervise the implementation of these regulations in accordance with the law, and when discovering wages paid by employers in violation of these regulations, they are obliged to require the local labor security administrative department to handle it." Moreover, the new regulations expanded the scope of the original minimum wage standards. In addition to the monthly minimum wage standards for full-time employed workers, they required the hourly minimum wage to be paid to part-time workers. The new regulations significantly increased the compensation that firms in violation of the minimum wage system should pay to workers, from 10%-20% of the owed wages to 100%-500%. Finally, provincial governments were required to renew the minimum wage standard at least once every two years after 2004, and local governments were required to publish the minimum wage rates in government bulletins and newspapers within a week after a change.

We collect the minimum wage data of Chinese cities from 2000 to 2012 from government websites of cities. Figure 1 shows the changes in China's minimum wage during this period. From 2000 to 2012, the average monthly minimum wage in Chinese cities rose from 267 Yuan to 1,006 Yuan, and its standard deviation gradually increased as well. Compared to 2000, the city with the highest minimum wage increase in 2012 was Ordos in Inner Mongolia, where the minimum wage in 2012 was 7.06 times that in 2000. The cities with the lowest increase were Qingyuan and Yangjiang from Guangdong Province, where the minimum wage in 2012 was 2.36 times that in 2000.[16] We also calculate the ratio of the firms' average wage to the city level minimum wage to see how binding minimum wages in China are. A lower ratio implies that the local minimum wage is more likely to be binding. The mean of this ratio in our sample is 2.31.

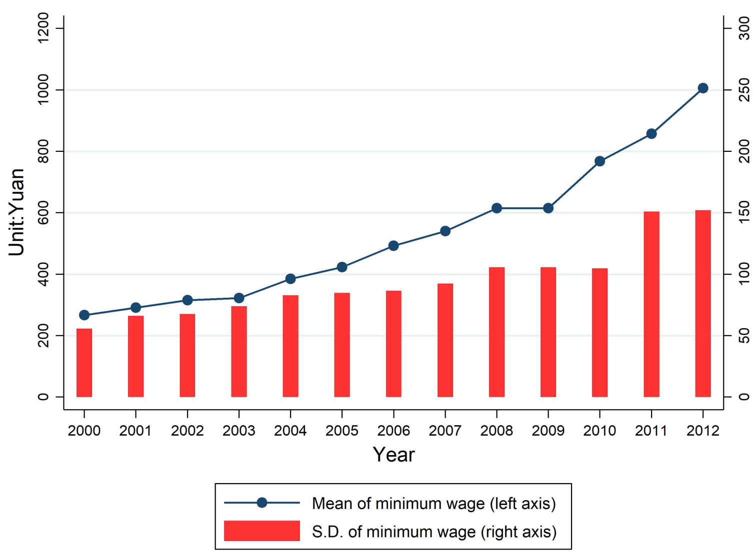

Figure 1: China's minimum wage: 2000-2012

[16]The city with the highest minimum wage in 2000 and 2012 was Shenzhen in Guangdong Province, at 547 yuan and 1500 yuan, respectively.

4.2 China's patent system

After the patent law was enacted in April 1985, the China National Intellectual Property Administration (CNIPA) started to receive and examine patent applications. Patents in CNIPA fall in three categories: invention, utility model, and design. Invention patents represent core technological progress, necessitating substantive examination of novelty and non-obviousness. Utility models and designs are treated as trivial patents, only requiring formative examination. China's patent law has experienced three amendments. The first, in 1992, mainly extended the statutory life of invention patents from 15 years to 20 years. The second, in 2001, mainly prepared for China to join the WTO by satisfying the minimum requirements of the Agreement on Trade-related Aspects of Intellectual Property Rights (TRIPs) on intellectual property protection. This amendment extended 20-year protection to inventions with patents applied for before the end of 1992 and still valid on December 11, 2001. The third, in 2009, mainly increased the patentability requirement, changing "relative novelty" to "absolute novelty." China is undertaking a fourth amendment, whose draft has recently been circulated for public feedback.

From 2001 to 2013, the number of patent applications in CNIPA increased dramatically from 203,573 to 2,377,061 with an average annual growth rate of 22.73%. As shown in Figure 2, China's domestic firms had became the main driving force of invention patent applications, while among 68,137 invention patents in 2001, domestic firms accounted for 9.08%, but among 726,961 invention patents in 2013, domestic firms accounted for 50.71%. Furthermore, as shown in Figure 3, the average number of patent applications of importing firms is much larger than non-importing firms from 2001 to 2013, and the comparative advantage of importing firms to non-importing ones became larger since the minimum wage was strictly enforced in 2004.

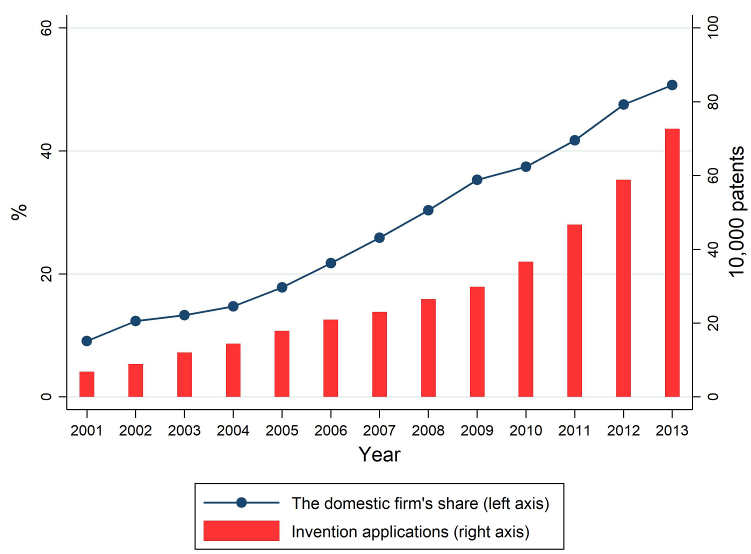

Figure 2: China's invention applications and domestic firms' share: 2001-2013

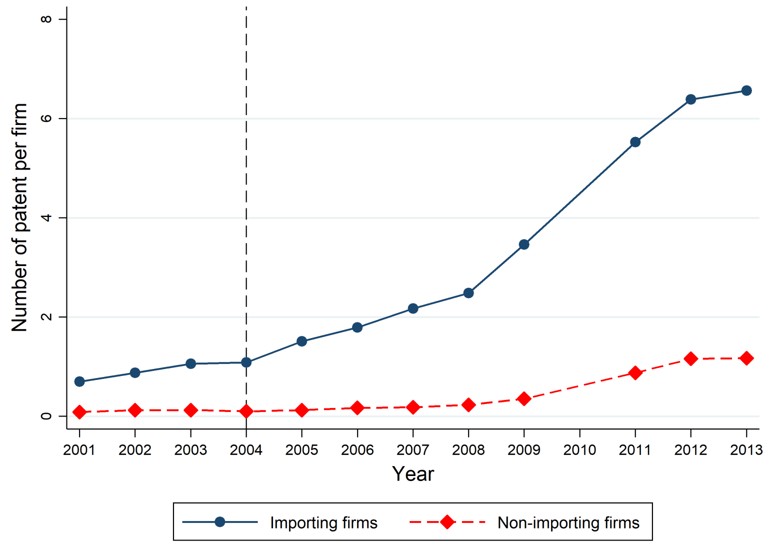

Figure 3: Importing and non-importing firms' patent applications per firm: 2001-2013

4.3 Data

This paper uses four datasets: (1) annual firm-level manufacturing survey data from the National Bureau of Statistics of China (NBSC); (2) firm-level patent applications from the China National Intellectual Property Administration (CNIPA); (3) firm-product-level trade data from China's General Administration of Customs (CGAC); and (4) city-level minimum wage and economic data.

First, we use the firm-level data from the Annual Survey of Industrial Firms (ASIF), which have been widely used in literature on the Chinese economy (Brandt *et al.*, 2012; Fan *et al.*, 2018; Gan *et al.*, 2016). This dataset contains rich firm-level information from 1998 to 2013, including basic firm information (e.g., firm name, address, age, ownership structure, employment, capital stock, gross output,and value added), and complete information on the three major accounting statements (balance sheet, profit and loss account, and cash flow statement). Until 2006, this dataset covers all of the state-owned firms and non-state-owned firms with annual sales income of more than 5 million yuan. After 2006, it covers all of the firms with annual sales income of more than 5 million yuan. From 2011 to 2013, it covers all of the firms with annual sales income of more than 20 million yuan.[17]

The second dataset is transaction-level import and export data from the China General Administration of Customs (CGAC). This dataset includes information on each import and export transaction of Chinese firms from 2000 to 2013, including firm name, product codes, value, and quantity. According to product classification by broad economic categories (BEC), we determine whether the imported products are capital goods.[18]

[17]Following Brandt *et al.* (2012), we delete problematic observations resulting from misreporting, as follows: (1) annual revenue missing or less than 5 million yuan; (2) total asset data missing; (3) liquid assets surpassing total assets; (4) fixed assets surpassing total assets; and (5) labor missing or less than 8.

[18]Capital goods are those with BEC classification codes of 41 and 521 as provided by the United Nations; see BEC classification at https://unstats.un.org/unsd/trade/classifications/bec.asp.

The third dataset is patent data from the China National Intellectual Property Administration (CNIPA). This dataset includes information on each patent application in China since 1985, including the applicant name, address, patent name, and patent category (i.e., invention patent, utility model, or design). We obtain the citation information of each invention patent from Google Patent.

We match the above three firm-level datasets by firms' name. The matching methods and results are shown in Table C2. The last dataset is the minimum wage and economic data at the city level. Since there is no uniform data source for minimum wage by city, we manually collect this information from 2000-2012 from the official websites of local governments. In addition, we obtain per capita GDP and total population data for each city over 2000-2012 from the China City Statistical Yearbook (CCSY). We match a city's minimum wage and economic data to firm-level data based on firms' address information (city identification). For descriptive statistics and data sources, see Table C3 and Table C4.

4.4 Empirical specification

We explore the heterogeneous effects of minimum wage on importing and non-importing firms' innovation using manufacturing firm-level data in China from 2001 to 2013. Specifically, we estimate the effects of minimum wage using the following regression model:

$$\begin{aligned} y_{it} = \beta_0 + \beta_1 min\_wage_{c,t-1} \times import_{i,t-1} + \beta_2 min\_wage_{c,t-1} + \beta_3 import_{i,t-1} \\ + \gamma C_{i,t-1} + \varphi_i + \varphi_t + \epsilon_{it}, \end{aligned} \tag{27}$$

where y_{it} is the log value of the number of all types of patent applications or invention applications by firm i in year t.[19] $min\_wage_{c,t-1}$ is the log value of minimum wage in city c in year $t-1$. If firm i imports capital goods in year $t-1$, then $import_{i,t-1}$ is equal to 1; otherwise, $import_{i,t-1}$ is equal to 0. The interaction term $min\_wage_{c,t-1} \times import_{i,t-1}$ captures the additional effect of minimum wage on importing firms. $C_{i,t-1}$ is a vector of firm- and city-level control variables, including firm size as measured by total assets, firm age, city GDP per capita, and city population size. φ_i denotes firm fixed effects, and φ_t denotes year fixed effects. The standard errors ϵ_{it} are clustered at city level. According to our theory, we expect that $\beta_1 > 0$ and $\beta_2 < 0$. Here, $\beta_1 + \beta_2$ captures the effects of minimum wage on importing firms' innovation, β_2 captures the effects of minimum wage on non-importing firms' innovation, and β_1 reflects the differentiation between importing firms and non-importing firms.

5 Empirical results

We report our empirical results to test the theoretical predictions of the heterogeneous effects of minimum wage on firms' innovation.

[19] Given that some firms have zero patent applications, we add 1 to the number of patent applications.

5.1 Baseline results

Table 1 reports the impact of minimum wage on patent applications using the baseline regression equation (27). The dependent variables are the number of all of the patent applications (see columns 1-2) and the number of invention patent applications (see columns 3-4).[20] In columns 1 and 3, we include only firm fixed effects and year fixed effects. In columns 2 and 4, we add the firm- and city-level controls, including firm size, firm age, city-level GDP per capita, and city-level population size. In column 2, the estimated coefficient on the interaction term ($min\_wage \times import$) is 0.241, which is statistically significant at the 1% level. The positive and statistically significant coefficients on the interaction term suggest differentiation effects for importing firms and non-importing firms. Specifically, the estimated coefficient on the minimum wage is -0.101, which is statistically significant at the 1% level. The sum of these two coefficients ($\beta_1 + \beta_2 = 0.140$) is positive and statistically significant. Hence a rise in minimum wage increases the importing firms' number of all of the patent applications, but decreases the non-importing firms' number of all of the patent applications. When we move to columns 3-4 for the number of invention patent applications, we see similar results: there exists a differentiated impact for importing firms and non-importing firms. As the minimum wage rises, the number of invention patent applications increases for importing firms and decreases for non-importing firms.

[20]Patents in CNIPA fall in three categories: invention, utility model, and design. Only invention patents represent core technological progress, necessitating substantive examination of novelty and non-obviousness. When we use utility patent applications and design patent applications, we also find the differentiated effects for importing firms and non-importing firms (see Table C5 in the appendix). However, a minimum wage increase has no positive impact on design patent applications.

Table 1: Baseline results

	all patents		invention	
	(1)	(2)	(3)	(4)
min_wage × *import*	0.232***	0.241***	0.158***	0.162***
	(0.021)	(0.020)	(0.012)	(0.012)
min_wage	-0.085***	-0.101***	-0.030***	-0.041***
	(0.020)	(0.019)	(0.010)	(0.010)
import	-1.419***	-1.489***	-0.980***	-1.007***
	(0.133)	(0.127)	(0.077)	(0.074)
Controls	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
F-test $\beta_1 + \beta_2 = 0$	34.635	32.660	66.239	63.588
Prob > F	0.000	0.000	0.000	0.000
Observations	2,234,545	2,234,545	2,234,545	2,234,545
Adj R-Squared	0.446	0.449	0.428	0.431

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. The dependent variable in specifications 1 and 2 is the (log) number of all patent applications (after adding 1); the dependent variable in specifications 3 to 4 is the (log) number of invention patent applications (after adding 1). Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and year fixed effects in all specifications. The F-test of all of the columns test the sum of the estimated coefficients on *min_wage* and *min_wage* × *import*. Probabilities (below 0.05) indicate that this equality is rejected at the 5% confidence level.

It is natural to believe that spillover effects of importing goods to increase firms' innovation are more prominent for capital goods and differentiated goods (Fan *et al.*, 2015, 2018; Kruger and Verhoogen, 2009).[21] Here, we adopt Rauch's classification (Rauch, 1999) to distinguish differentiated goods and homogeneous goods. In Table C6, we further divide our sample into two subsamples: importing firms and non-importing firms. The dependent variables are the number of all of the patent applications (see columns 1-4) and the number of invention patent applications (see columns 5-8). As Table C6 shows, the increase of minimum wage decreases the non-importing firms' patent applications. For importing firms, it only improves the innovation level of firms importing capital goods or differentiated goods.

We consider several robustness checks to further examine our main results. First, we alternatively define firms as importing firms according to whether they import capital goods at the time they first appeared in the sample (see Table C7 in the appendix). Second, we add industry-year fixed effects to capture time-varying industry characteristics, such as industrial policies, that may influence firms' innovation activities (see Table C8 in the appendix). In these two tables, the estimated coefficients of minimum wage are significantly negative, and those of the interaction term are significantly positive. This further supports our theoretical predictions.

[21]This finding is consistent with the literature in that imports of capital goods increase economic growth, TFP, and R&D (Cavallo and Landry, 2010; Mo *et al.*, 2019).

5.2 Endogeneity issue

This paper mainly investigates the heterogeneous effects of minimum wage on firms' innovation. However, cities with higher levels of development may set higher minimum wage levels, and these cities may also have relatively higher levels of innovation. To solve this potential missing variable problem, we control the city's per capita GDP level and firm fixed effects in the benchmark regression, which can alleviate the endogenous problem to a certain extent. However, other confounding factors may affect the association between minimum wage and a firm's patent applications. To solve potential endogenous problems, we adopt a variety of methods for causal identification.

First, we use the approach developed by Dube *et al.* (2010) and adapted to China by Fan *et al.* (2018) and Huang *et al.* (2014) to consider city pairs located near borders of different provinces in order to exploit policy discontinuities at provincial borders. Specifically, we consider two cities to be a pair if they share a border and belong to different provinces, and assign the same ID to cities within a pair. If a city belongs to multiple city pairs, it has multiple replicates in the city pair dataset.[22] Then we match our baseline regression data with the city pair data to obtain a firm-level city pair regression dataset including 2,172,545 observations. This new regression dataset can solve potential endogenous problems in two ways. First, since neighboring cities may have similar economic characteristics (Dube *et al.*, 2010), we can solve the problem of time-varying unobserved factors by controlling the city-pair-year fixed effects. Second, the minimum wage in border cities is often less affected by the local economic situation. This is because the provincial government setting the minimum wage standard is generally far from cities on its boundary.[23]

We add the city-pair-year fixed effects φ_{pt} to the benchmark regression (27) to control city-pair time-varying shocks that may affect firms' innovation, where p is the city pair ID. After controlling city-pair-year fixed effects, we exploit the relative impact of the changes in the minimum wage between the two cities. Following Dube *et al.* (2010) and Fan *et al.* (2018), we use the high-dimensional robust standard error of clustering at the city and city-pair-year levels. Table 2 shows the corresponding regression results. Odd columns correspond to the regression result without weighting, and even columns to the regression weighting by the inverse of the number of duplicates in the city pair firm-level sample. The dependent variables are the number of all of the patent applications in the first two columns and the number of invention patent applications in the last two columns. The estimated coefficients on the interaction term ($min\_wage \times import$) are significantly positive with the similar value as them in the baseline regression. The estimated coefficients on the minimum wage are significantly negative. Moreover, the absolute values of estimated coefficients on the minimum wage are less than that on the interaction term. Therefore, we still find the differentiated impact for importing firms and non-importing firms when using the city-pair-year regression dataset. Specifically, a rise in the minimum wage increases the importing firms' number of patent applications but decreases that of non-importing firms.

[22] For example, Nanjing City in Jiangsu Province is adjacent to the borders of Ma'anshan City, Chuzhou City, and Xuancheng City in Anhui Province. Therefore, in the city-pair data, Nanjing City will appear three times.

[23] Since the minimum wages of the four municipalities of Beijing, Tianjin, Shanghai, and Chongqing are directly determined by the government at the same level, we eliminated them in the city pair data.

Table 2: Results by considering city pairs located near borders of different provinces

	all patents		invention	
	(1)	(2)	(3)	(4)
	unweighted	weighted	unweighted	weighted
min_wage × *import*	0.259***	0.259***	0.183***	0.182***
	(0.028)	(0.025)	(0.019)	(0.016)
min_wage	-0.073***	-0.073***	-0.046***	-0.045***
	(0.013)	(0.013)	(0.008)	(0.009)
import	-1.586***	-1.590***	-1.131***	-1.130***
	(0.163)	(0.145)	(0.111)	(0.096)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
City-pair-year FE	Yes	Yes	Yes	Yes
Observations	2,172,545	2,172,545	2,172,545	2,172,545
Adj R-Squared	0.489	0.486	0.461	0.458

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors corrected by two-way clustering at the city and city-pair-year levels are reported in parentheses. The dependent variable in specifications 1 to 2 is the (log) number of all patent applications (after adding 1); the dependent variable in specifications 3 to 4 is the (log) number of invention patent applications (after adding 1). Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and city-pair-year fixed effects in all specifications. Regressions in specifications 1 and 3 are unweighted, and those in specifications 2 and 4 are weighted by the inverse of the number of duplicates in the city pair firm-level sample.

Second, we use instrumental variables (IV) to solve the problem of missing variables. Specifically, we use the average minimum wage of similar cities in the same year as the instrumental variable of the minimum wage. Because the economic characteristics of neighboring cities are generally similar, we use the average minimum wage level of neighboring cities in the same province as an IV for each city's minimum wage. The regression results are shown in columns 1 and 3 of Table 3. We refer to the method of Bai *et al.* (2018), and rank cities by GDP per capita every year. We divide all of the cities from small to large into 20 groups, and use the average minimum wage of other cities in the same group as an IV for the minimum wage of each city. The regression results are shown in columns 2 and 4 of Table 3. Similar to baseline results, we find that the estimated coefficients on the interaction term (*min_wage* × *import*) are significantly positive, and that the estimated coefficients on the minimum wage are significantly negative.[24]

[24] One concern with the instrumental variable approach is the weak instrument. Kleibergen-Paap rk Wald F statistics reject the null hypothesis that the first stage is weakly identified.

Table 3: Results by using instrumental variables for minimum wage

	all patents		invention	
	(1)	(2)	(3)	(4)
	IV1	IV2	IV1	IV2
min_wage × *import*	0.267***	0.251***	0.177***	0.174***
	(0.020)	(0.022)	(0.013)	(0.014)
min_wage	-0.117***	-0.201	-0.036***	-0.063
	(0.030)	(0.135)	(0.011)	(0.072)
import	-1.650***	-1.553***	-1.100***	-1.083***
	(0.127)	(0.139)	(0.081)	(0.086)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2,004,530	2,234,545	2,004,530	2,234,545

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. The dependent variable in specifications 1 to 2 is the (log) number of all of the patent applications (after adding 1); the dependent variable in specifications 3 to 4 is the (log) number of invention patent applications (after adding 1). Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and year fixed effects in all of the specifications. The weak identification test (Kleibergen-Paap rk Wald F statistic) of specifications 1 and 3 is 515.488, and 13.099 for specifications 2 and 4.

Another concern about our baseline results is the endogeneity of firm import status. To solve this potential endogenous problem, we follow Brandt, Van Biesebroeck, Wang, and Zhang (2017) and calculate the input tariff and output tariff of each 4-digit CIC industry in China during the sample period.[25] We use the input tariff as an IV for a firm's import status. The regression results are shown in columns 1 and 3 of Table 4. Then we use both input tariff and output as IVs for a firm's import status. The regression results are shown in columns 2 and 4 of Table 4. In Table 4, we also find that the estimated coefficients on the interaction term (*min_wage* × *import*) are significantly positive, and the estimated coefficients on the minimum wage are significantly negative.

[25]HS 6-digit tariff data come from the World Integrated Trade Solution database (WITS) maintained by the World Bank. Then we use Chinese input-output tables to calculate 4-digit CIC industry level input and output tariffs.

Table 4: Results by using instrument variables for import status

	all patents		invention	
	(1)	(2)	(3)	(4)
	IV3	IV4	IV3	IV4
min_wage × *import*	1.286***	1.319***	0.645***	0.760***
	(0.166)	(0.132)	(0.080)	(0.074)
min_wage	-0.122***	-0.119***	-0.060***	-0.056***
	(0.024)	(0.024)	(0.011)	(0.012)
import	-6.403***	-6.711***	-2.858***	-3.705***
	(0.882)	(0.719)	(0.483)	(0.443)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2,234,545	2,234,545	2,234,545	2,234,545

Notes: *** p < 0.01, ** p < 0.05, * p < 0.1. Robust standard errors clustered at the city level are reported in parentheses. The dependent variable in specifications 1 to 2 is the (log) number of all of the patent applications (after adding 1); the dependent variable in specifications 3 to 4 is the (log) number of invention patent applications (after adding 1). Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and year fixed effects in all of the specifications. The weak identification test (Kleibergen-Paap rk Wald F statistic) of specifications 1 and 3 is 44.950, and it is 26.709 for specifications 2 and 4.

5.3 Heterogeneous effects by sectoral capital intensity

We examine whether the effects of minimum wage on the innovation of importing and non-importing firms differ by industry type. Intuitively, when the minimum wage rises by the same amount, it has a relatively smaller effect on the marginal cost of production in capital-intensive industries, and thus has a relatively smaller impact on a firm's innovation in those industries. We use the capital-labor ratio $ln(K/L)$ of each 4-digit CIC industry in the early 2001 period to measure the capital intensity of an industry, and we use this variable to interact with the explanatory variables in the benchmark equation (27). The regression results are shown in Table 5, where columns 2 and 4 further control the industry-year and city-year fixed effects. The coefficients of the triple term are significantly negative in all of the columns of Table 5, indicating that the differentiated effect of the minimum wage on the innovation of importing and non-importing firms is relatively small in capital-intensive industries.

In all 4-digit CIC industries, the industry capital-labor ratio is 2.744 in the 5% quantile and 4.675 in the 95% quantile. Taking column 1 as an example, for every 1% increase in the minimum wage in an industry at the 5% quantile, the differentiated effects for importing and non-importing firms are 0.302%.[26] For every 1% increase in the minimum wage in an

[26]For every 1% increase in the minimum wage in an industry at the 5% quantile, importing firms' all of the patent applications increase by 0.193% (-0.054% * 2.744 + 0.450% + 0.009% * 2.744 - 0.134%), vs. a decrease of 0.109% (0.009% * 2.744 - 0.134%) for all non-importing firms.

industry at the 95% quantile, the differentiated effects for importing and non-importing firms are 0.198%.[27] Therefore, the minimum wage on firms' innovation has a greater differentiated impact on labor-intensive industries than on capital-intensive industries. This is consistent with the findings of Bai *et al.* (2018) and Fan *et al.* (2018). We also examined the heterogeneous effects for firms with lower capital-labor ratios and for firms paying lower average wages, with regression results as shown in Table C9 and Table C10. Consistent with Table 8, we also find that the impact of minimum wage is more prominent for firms with lower capital-intensity and average wages.

Table 5: Results by sectoral capital intensity

	all patents		invention	
	(1)	(2)	(3)	(4)
min_wage × *import* × *sector K/L*	-0.054**	-0.028*	-0.055***	-0.033***
	(0.021)	(0.015)	(0.014)	(0.011)
min_wage × *import*	0.450***	0.276***	0.374***	0.243***
	(0.086)	(0.064)	(0.059)	(0.045)
min_wage × *sector K/L*	0.009	-0.010	0.017***	-0.011*
	(0.006)	(0.011)	(0.004)	(0.007)
import × *sector K/L*	0.333**	0.176*	0.341***	0.206***
	(0.136)	(0.095)	(0.089)	(0.068)
min_wage	-0.134***		-0.106***	
	(0.032)		(0.017)	
import	-2.771***	-1.713***	-2.321***	-1.515***
	(0.544)	(0.403)	(0.366)	(0.283)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	-	Yes	-
Industry-year FE	No	Yes	No	Yes
City-year FE	No	Yes	No	Yes
Observations	2,234,530	2,234,518	2,234,530	2,234,518
Adj R-Squared	0.449	0.463	0.432	0.446

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. The dependent variable in specifications 1 to 2 is the (log) number of all of the patent applications (after adding 1); the dependent variable in specifications 3 to 4 is the (log) number of invention patent applications (after adding 1). *Sector K/L* is the capital-labor ratio of each 4-digit CIC industry in the early 2001 period. Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and year fixed effects in specifications 1 and 3. We control the firm fixed effects, 4-digit CIC industry-year fixed effects, and city-year fixed effects in specifications 2 and 4.

5.4 Other firm-level responses

We analyze the heterogeneous effect of the minimum wage on firms' other performance, including patent citations, export products, total factor productivity (TFP), and labor em-

[27] For every 1% increase in minimum wage in an industry at the 95% quantile, importing firms' all of the patent applications increase by 0.106% (0.054% * 4.675 + 0.450 % + 0.009% * 4.675 - 0.134%), vs. a decrease of 0.092% (0.009% * 4.675 - 0.134%) for non-importing firms.

ployment. The regression results are shown in Table 6.

In column 1, we examine the impact of the minimum wage on the quality of a firm's patents. Taking the number of citations of invention patents as the dependent variable, we find that for every 1% increase in minimum wage, the differentiated impact of minimum wage on the number of citations of invention patents for importing and non-importing firms is 0.145%. Similar to patent citations, the number of products also can portray a firm's innovation. In column 2, we use the number of HS 8-digit export products for each firm as the dependent variable. As shown in column 2, there exists a heterogeneous effect of the minimum wage on a firm's number of export products. The increase in minimum wage increases the number of products exported by importing firms, and reduces the number of products exported by non-importing firms. We examine the heterogeneous effect of minimum wage on a firm's total factor productivity in column 3. We use the method of Olley and Pakes (1996) to calculate the TFP level. The result shows that compared to non-importing firms, the increase in minimum wage increases the importing firms' TFP by 0.149% after a 1% increase in minimum wage.[28]

Finally, we examine the heterogeneous effect of minimum wage on labor employment. According to our theory, comparing the non-importing firms, the labor used by importing firms decreases more after the minimum wage increase, due to the higher spillover effect for importing firms. In column 4, labor employment is the dependent variable. Consistent with our predictions, we find that the heterogeneous effect of minimum wage on labor employment for importing firms and non-importing firms. This is to say, the employed labor decreases more for importing firms after the minimum wage rises.[29]

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[28]Because the value-added and intermediate input are no longer reported in ASIF form 2011 to 2013, we follow Brandt, Wang, and Zhang (2017) to estimate them as follows. We use the ASIF data from 2004-2007 to construct a 4-digit CIC industry-level multiplier, which is equal to the average of the ratio of firms' total labor cost (the sum of wage bills, employment insurance, welfare, pension, and housing funds) over the wage bill, and apply it to the value of the wage bill from 2011 to 2013 to get their total labor cost. Then we estimate the total production cost of each firm as $total\,production\,cost = total\,output * (sales\,cost/sales\,revenue)$. We calculate intermediate input, which is $total\,production\,cost - total\,labor\,cost - depreciation$, and value-added, which is $total\,output - intermediate\,input + value\,added\,tax$. Then we use sector-level price deflators (output, input, and capital) from Brandt *et al.* (2012) to deflate to real output, input, and capital. Finally, we use the method of Olley and Pakes (1996) to calculate the TFP level. Many variables are missing in the ASIF data of 2009. We cannot estimate the firms' TFP level in 2009, so the sample number in column 3 of Table 6 is reduced by a part.

[29]It is even better if we can test how a rise in minimum wage affects the R&D labor employment of importing and non-importing firms. However, we cannot obtain firm- , city-, or city-industry-level R&D labor employment data.

Table 6: Results by other firm-level responses

	(1) citations	(2) products	(3) TFP	(4) labor
min_wage × *import*	0.145***	4.169***	0.149***	-0.097***
	(0.013)	(0.410)	(0.018)	(0.032)
min_wage	-0.039***	-0.742***	-0.024	-0.020
	(0.010)	(0.137)	(0.041)	(0.040)
import	-0.897***	-25.857***	-0.941***	0.694***
	(0.082)	(2.707)	(0.119)	(0.206)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2,234,545	2,234,545	1,820,071	2,234,545
Adj R-Squared	0.392	0.717	0.641	0.809

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. The dependent variable in specification 1 is the (log) number of firms' invention patents cited (after adding 1); the dependent variable in specification 2 is the number of firms' HS 8-digit export products; the dependent variable in specification 3 is the TFP level calculated by the method of Olley and Pakes (1996); the dependent variable in specification 4 is the (log) number of labor employment. Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and year fixed effects in all of the specifications.

6 Conclusion

In this study, we have explored the heterogeneous effects of minimum wage on innovation of different types of firms. Using an open-economy R&D-based growth model, we have shown that raising the minimum wage reduces innovation of firms that use domestic inputs but increases innovation of firms that import foreign inputs. These heterogeneous effects of minimum wage on the innovation of the two types of firms are consistent with the empirical results that we have estimated using city-level data on minimum wages and firm-level patent data in China. Previous studies that explore the overall effect of minimum wage on firm-level innovation may have neglected the heterogeneous responses of different types of firms. Our paper fills this gap in the literature.

The results of our study have important implications for policy makers. As the labor costs increase in China, policy makers should further open up the economy for international trade, especially trade on capital goods. Tariff cuts on capital goods would induce more firms to import capital goods. Such a policy would stimulate innovation in China due to the positive impacts of minimum wage on innovation of firms importing capital goods.

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Appendix A

Proof of Proposition 1. We first derive the steady-state equilibrium condition that determines Φ_t^f. Using (7), (10b), and the equation $p_t^f(\omega) = p_z/\alpha$, we obtain

$$(n_t^f)^{\frac{1}{\alpha}} x_t^f = \frac{\alpha \Phi_t^f}{2p_z} (n_t^f)^{\frac{1-\alpha}{\alpha}} Y_t. \tag{A1}$$

Substituting (A1) and (22b) in (24), we have

$$\Phi_t^f = \frac{\alpha \left[\alpha\mu\Phi_t^f (n_t^f)^{\frac{1-\alpha}{\alpha}}\right]^{(\varepsilon-1)/\varepsilon}}{(1-\alpha)\left[p_z(1-\Phi_t^f)\right]^{(\varepsilon-1)/\varepsilon} + \alpha\left[\alpha\mu\Phi_t^f (n_t^f)^{\frac{1-\alpha}{\alpha}}\right]^{(\varepsilon-1)/\varepsilon}}, \tag{A2}$$

which can be expressed as

$$\Phi_t^f = \frac{(n_t^f)^{\frac{(1-\alpha)(\varepsilon-1)}{\alpha}}}{(1-\alpha)^{\varepsilon}(p_z)^{\varepsilon-1}/(\alpha^{2\varepsilon-1}\mu^{\varepsilon-1}) + (n_t^f)^{\frac{(1-\alpha)(\varepsilon-1)}{\alpha}}} \equiv f(n_t^f) \in (0,1). \tag{A3}$$

It is useful to note that $f'(n_t^f) > 0$ and $f''(n_t^f) < 0$ because $\varepsilon > 1$. From (26), the steady-state levels of R&D spending must satisfy $R^d = \Phi_t^d/(\Phi_t^d + \Phi_t^f) \in (0,1)$ and $R^f = \Phi_t^f/(\Phi_t^d + \Phi_t^f) \in (0,1)$, where $\Phi_t^f \in (0,1)$ from (A3). Then we combine $n^f = (1+\lambda\Phi^f)R^f/\delta$ and $R^f = \Phi_t^f/(\Phi_t^d + \Phi_t^f)$ in the following expression:

$$\frac{\delta n^f}{1+\lambda\Phi^f} = R^f = \frac{\Phi^f}{\Phi^d + \Phi^f},$$

which can be expressed as:

$$n^f = \frac{1}{\delta}\frac{\Phi^f\left(1+\lambda\Phi^f\right)}{\Phi^d + \Phi^f}. \tag{A4}$$

Finally, substituting (A3) in (A4) yields:

$$\Psi(\mu)\frac{1}{\Phi^f}\left(\frac{\Phi^f}{1-\Phi^f}\right)^{\frac{\alpha}{(1-\alpha)(\varepsilon-1)}} = \frac{1+\lambda\Phi^f}{\Phi^d + \Phi^f}, \tag{A5a}$$

where

$$\Psi(\mu) \equiv \delta\left(\frac{1-\alpha}{\alpha^{2-1/\varepsilon}}\right)^{\frac{\alpha\varepsilon}{(1-\alpha)(\varepsilon-1)}}\left(\frac{p_z}{\mu}\right)^{\frac{\alpha}{1-\alpha}},$$

which is decreasing in μ. Due to symmetry between f and d, we can derive the condition that determines Φ^d in a similar way to the above:

$$\Gamma(\mu)\frac{1}{\Phi^d}\left(\frac{\Phi^d}{1-\Phi^d}\right)^{\frac{\alpha}{(1-\alpha)(\varepsilon-1)}} = \frac{1}{\Phi^d + \Phi^f}, \tag{A5b}$$

where

$$\Gamma(\mu) \equiv \delta\left(\frac{1-\alpha}{\alpha^{2-1/\varepsilon}}\right)^{\frac{\alpha\varepsilon}{(1-\alpha)(\varepsilon-1)}}\left(\frac{1}{\mu}\right)^{\frac{\alpha}{1-\alpha}}.$$

Note that the two equations in (A5) determine $\left(\Phi^d, \Phi^f\right)$ in equilibrium. Then we have the following lemmas.

Lemma 1 *If $\varepsilon < (1-\alpha/2)/(1-\alpha)$, then the equilibrium is unique.*

Proof. We express (A5) as:

$$\Phi^d = \left[\zeta(\Phi^f) - 1\right]\Phi^f, \tag{A6a}$$

$$\Phi^f = \left[\frac{1}{\Gamma(\mu)}\left(\frac{1-\Phi^d}{\Phi^d}\right)^{\Omega} - 1\right]\Phi^d, \tag{A6b}$$

where we have defined

$$\Omega \equiv \frac{\alpha}{(1-\alpha)(\varepsilon-1)},$$

$$\zeta(\Phi^f) \equiv \frac{1+\lambda\Phi^f}{\Psi(\mu)}\left(\frac{1-\Phi^f}{\Phi^f}\right)^{\Omega}.$$

Substituting (A6a) in (A6b) and rearranging some terms yields:

$$\left[\Gamma(\mu)\frac{\zeta(\Phi^f)}{\zeta(\Phi^f)-1}\right]^{1/\Omega} = \frac{1}{[\zeta(\Phi^f)-1]\,\Phi^f} - 1. \tag{A7}$$

Multiplying both sides of (A7) by $[\zeta(\Phi^f)-1]/\zeta(\Phi^f)$, we obtain

$$\left[\frac{\zeta(\Phi^f)-1}{\zeta(\Phi^f)}\right]^{(\Omega-1)/\Omega} = \frac{1}{[\Gamma(\mu)]^{1/\Omega}}\left[\frac{1+\Phi^f}{\zeta(\Phi^f)\Phi^f} - 1\right]. \tag{A8}$$

Suppose $\varepsilon < (1-\alpha/2)/(1-\alpha)$, which is equivalent to $\Omega > 2$. Then, as Φ^f increases from 0 to 1, both $\zeta(\Phi^f)$ and $\zeta(\Phi^f)\Phi^f$ decrease from infinity to 0.[30] Therefore, we can define two threshold values of Φ^f, denoted as $\{\Phi^f_-, \Phi^f_+\} \in (0,1)$ such that $\zeta(\Phi^f_+) = 1$ and $\Phi^f_-\zeta(\Phi^f_-) = 1 + \Phi^f_-$. It is useful to note that $\Phi^f_- < \Phi^f_+$ because $\zeta(\Phi^f_+) < \zeta(\Phi^f_-) = 1 + 1/\Phi^f_-$.[31]

As shown in Figure A1, the left side of (A8) decreases from 1 to 0 as Φ^f increases from 0 to Φ^f_+, whereas the right side increases from 0 to infinity as Φ^f increases from Φ^f_- to 1. Given $\Phi^f_- < \Phi^f_+$, (A8) uniquely determines the equilibrium value of $\Phi^f \in (0,1)$, which then determines the equilibrium value of $\Phi^d \in (0,1)$ in (A6a). ■

Lemma 2 *Φ^f is increasing in μ.*

Proof. Given that the left-hand side (LHS) of (A8) is increasing in $\zeta(\Phi^f)$ and that $\zeta(\Phi^f)$ is also increasing in μ,[32] an increase in μ shifts up the LHS to the right in Figure A1. Then the right-hand side (RHS) of (A8) can be divided into two parts, as follows:

$$RHS = \frac{1+\Phi^f}{\Phi^f}\frac{1}{\Gamma(\mu)^{1/\Omega}\zeta(\Phi^f)} - \frac{1}{\Gamma(\mu)^{1/\Omega}}.$$

$\Gamma(\mu)^{1/\Omega}$ is decreasing in μ and $\zeta(\Phi^f)$ is increasing in μ; however, it can be shown that $\Gamma(\mu)^{1/\Omega}\zeta(\Phi^f)$ is increasing in μ given $\Omega > 1$. Therefore, the first term in the RHS is decreasing in μ. In addition, the second term, $-1/\Gamma(\mu)^{1/\Omega}$, is also decreasing in μ. As a result, an increase in μ shifts down the RHS also to the right in Figure A1. Finally, the shifts in the LHS and RHS give rise to an increase in Φ^f. ■

[30]It can be shown that $\zeta(\Phi^f)\Phi^f$ is decreasing in Φ^f if $\Omega > \max\{2 - 1/\lambda, 1\}$.
[31]Recall that $\zeta(\Phi^f)$ is decreasing in Φ^f.
[32]Note that $\zeta(\Phi^f)$ is decreasing in $\Psi(\mu)$, which in turn is decreasing in μ.

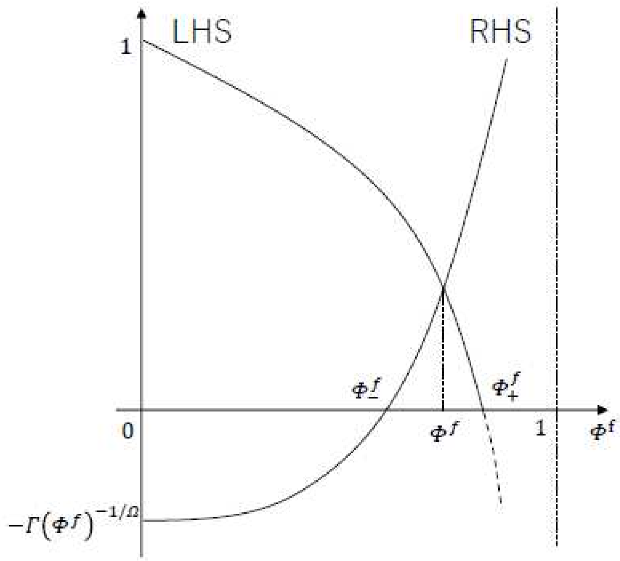

Figure A1: Equilibrium uniqueness

Lemma 3 *Φ^f/Φ^d is increasing in μ if and only if $\lambda > 0$.*

Proof. Given the unique equilibrium in Lemma 1, we combine (A5a) and (A5b) and apply the approximation $\ln(1+\Phi^i) \approx \Phi^i$ to derive

$$\Phi^f - \Phi^d = \frac{1}{2\Omega - 1}\left[-\frac{\alpha}{1-\alpha}\ln p_z + \lambda\Phi^f\underset{+}{(\mu)}\right], \tag{A9}$$

which shows that $\ln(\Phi^f/\Phi^d) = \ln\Phi^f - \ln\Phi^d \approx \Phi^f - \Phi^d$ is increasing in μ if and only if $\lambda > 0$. ■

Lemma 4 *L^f/L^d is decreasing in μ if and only if $\lambda > 0$.*

Proof. From (22), we have $L^f/L^d = (1-\Phi^f)/(1-\Phi^d)$. Then, applying the approximation $\ln(1+\Phi^i) \approx \Phi^i$ yields[33]

$$\ln(L^f/L^d) \approx \Phi^d - \Phi^f = \frac{1}{2\Omega - 1}\left[\frac{\alpha}{1-\alpha}\ln p_z - \lambda\Phi^f\underset{+}{(\mu)}\right], \tag{A10}$$

which is decreasing in μ if and only if $\lambda > 0$. ■

Given $\overline{\lambda}I = \lambda\Phi^f$ and $R^f/R^d = \Phi^f/\Phi^d$, Lemmas 1–4 give a complete proof of all the results in Proposition 1.

[33]We can also prove this result without using the approximation. Derivations are available upon request.

Appendix B

According to the extension in Section 3.1, we have to make the following changes. The profit for domestic capital goods becomes

$$\pi_t^d(\omega) = p_t^d(\omega)x_t^d(\omega) - \left[\psi^d + p_z\left(1-\psi^d\right)\right]x_t^d(\omega) = \Phi_t^d \frac{P_t^d X_t^d}{\int_0^{n_t^d}[x_t^d(\omega)]^\alpha d\omega}[x_t^d(\omega)]^\alpha - \tilde{\psi}^d x_t^d(\omega), \tag{11'}$$

where $\tilde{\psi}^d \equiv \psi + p_z(1-\psi)$. Given that the monopolistic price is now $p_t^d(\omega) = \tilde{\psi}^d/\alpha$,

$$\pi_t^d(\omega) = \frac{1-\alpha}{\alpha}\tilde{\psi}x_t^d(\omega) = (1-\alpha)\,\Phi_t^d\frac{P_t^d X_t^d}{n_t^d} = (1-\alpha)\,\Phi_t^d\frac{Y_t}{2n_t^d} \equiv \pi_t^d. \tag{12'}$$

Note that π_t^d itself does not change, and so neither does (13). The profit for foreign capital goods also becomes:

$$\pi_t^f(\omega) = p_t^f(\omega)x_t^f(\omega) - [(1-\psi)+p_z\psi]x_t^f(\omega) = \Phi_t^f\frac{P_t^f X_t^f}{\int_0^{n_t^f}[x_t^f(\omega)]^\alpha d\omega}[x_t^f(\omega)]^\alpha - \tilde{\psi}^f x_t^f(\omega), \tag{14'}$$

where $\tilde{\psi}^f \equiv 1-\psi+p_z\psi$. Given $p_t^f(\omega) = \tilde{\psi}^f/\alpha$,

$$\pi_t^f(\omega) = \frac{1-\alpha}{\alpha}\tilde{\psi}^f x_t^f(\omega) = (1-\alpha)\,\Phi_t^f\frac{P_t^f X_t^f}{n_t^f} = (1-\alpha)\,\Phi_t^f\frac{Y_t}{2n_t^f} \equiv \pi_t^f. \tag{15'}$$

Like π_t^d, π_t^f (16) do not alter.

We should reconsider the structure of R&D externalities. Firms in this sector d devote $1/(1+\overline{\lambda}_d I_t)$ units of domestic high-skill research labor to invent a new variety of differentiated products. The zero-profit condition is: $v_t^d = w_t^h/(1+\overline{\lambda}_d I_t^d)$. The law of motion for n_t^d is

$$\dot{n}_t^d = (1+\overline{\lambda}_d I_t)R_t^d - \delta n_t^d, \tag{18'}$$

where

$$I_t \equiv \frac{p_{z,t}\,(1-\psi)\int_0^{n_t^d}x_t^d(\omega)d\omega + p_{z,t}\psi\int_0^{n_t^f}x_t^f(\omega)d\omega}{Y_t} \equiv \frac{\alpha}{2}\tilde{\Phi}_t$$

and

$$\tilde{\Phi}_t \equiv \frac{p_z(1-\psi)}{\psi+p_z(1-\psi)}\Phi_t^d + \frac{p_z\psi}{1-\psi+p_z\psi}\Phi_t^f.$$

Defining $\lambda^d \equiv \overline{\lambda}_d\alpha/2$, the zero-profit condition becomes

$$(1+\lambda^d\tilde{\Phi}_t)v_t^d = w_t^h. \tag{17'}$$

Accordingly, we need to make revisions such that

$$\dot{n}_t^f = (1+\overline{\lambda}_f I_t)R_t^f - \delta n_t^f, \tag{19'}$$

$$(1+\lambda^f\tilde{\Phi}_t)v_t^f = w_t^h, \tag{20'}$$

and

$$\frac{n^f}{n^d} = \frac{(1+\lambda^f\tilde{\Phi})\Phi^f}{(1+\lambda^d\tilde{\Phi})\Phi^d}. \tag{25'}$$

There is no change on (26).

Using the above revised equations, we will check the robustness of the results in Proposition 1, basically following the method in Appendix A. Using (7) and (10b), and noting that $p_t^f(\omega) = \tilde{\psi}^f/\alpha$, we obtain

$$(n_t^f)^{\frac{1}{\alpha}} x_t^f = \frac{\alpha\Phi_t^f}{2\tilde{\psi}^f}(n_t^f)^{\frac{1-\alpha}{\alpha}} Y_t. \tag{B1}$$

Substituting (B1) and (22b) in (24), we have

$$\Phi_t^f = \frac{\alpha\left[\alpha\mu\Phi_t^f(n_t^f)^{\frac{1-\alpha}{\alpha}}\right]^{(\varepsilon-1)/\varepsilon}}{(1-\alpha)\left[\tilde{\psi}^f(1-\Phi_t^f)\right]^{(\varepsilon-1)/\varepsilon} + \alpha\left[\alpha\mu\Phi_t^f(n_t^f)^{\frac{1-\alpha}{\alpha}}\right]^{(\varepsilon-1)/\varepsilon}}, \tag{B2}$$

which can be expressed as:

$$\Phi_t^f = \frac{(n_t^f)^{\frac{(1-\alpha)(\varepsilon-1)}{\alpha}}}{(1-\alpha)^\varepsilon(\tilde{\psi}^f)^{\varepsilon-1}/(\alpha^{2\varepsilon-1}\mu^{\varepsilon-1}) + (n_t^f)^{\frac{(1-\alpha)(\varepsilon-1)}{\alpha}}} \equiv \tilde{f}(n_t^f) \in (0,1). \tag{B3}$$

Noting that $n^f = (1+\lambda^f\tilde{\Phi})R^f/\delta$ and $R^f = \Phi_t^f/(\Phi_t^d + \Phi_t^f)$ into the following expression:

$$\frac{\delta n^f}{1+\lambda^f\tilde{\Phi}} = R^f = \frac{\Phi^f}{\Phi^d + \Phi^f},$$

which can be expressed as

$$n^f = \frac{1}{\delta}\frac{\Phi^f\left(1+\lambda^f\tilde{\Phi}\right)}{\Phi^d+\Phi^f}. \tag{B4}$$

Then we have

$$\tilde{\Psi}(\mu)\frac{1}{\Phi^f}\left(\frac{\Phi^f}{1-\Phi^f}\right)^{\frac{\alpha}{(1-\alpha)(\varepsilon-1)}} = \frac{1+\lambda^f\tilde{\Phi}}{\Phi^d+\Phi^f}, \tag{B5a}$$

where

$$\tilde{\Psi}(\mu) \equiv \delta\left(\frac{1-\alpha}{\alpha^{2-1/\varepsilon}}\right)^{\frac{\alpha\varepsilon}{(1-\alpha)(\varepsilon-1)}}\left(\frac{\tilde{\psi}^f}{\mu}\right)^{\frac{\alpha}{1-\alpha}},$$

which is decreasing in μ. Due to symmetry between f and d, we can derive the condition that determines Φ^d in a similar way to the above:

$$\tilde{\Gamma}(\mu)\frac{1}{\Phi^d}\left(\frac{\Phi^d}{1-\Phi^d}\right)^{\frac{\alpha}{(1-\alpha)(\varepsilon-1)}} = \frac{1+\lambda^d\tilde{\Phi}}{\Phi^d+\Phi^f}, \tag{B5b}$$

where

$$\tilde{\Gamma}(\mu) \equiv \delta\left(\frac{1-\alpha}{\alpha^{2-1/\varepsilon}}\right)^{\frac{\alpha\varepsilon}{(1-\alpha)(\varepsilon-1)}}\left(\frac{\tilde{\psi}^d}{\mu}\right)^{\frac{\alpha}{1-\alpha}}.$$

The two equations in (B5) determine $\left(\Phi^d, \Phi^f\right)$ in equilibrium, which can be rewritten as:

$$\Phi^d = \frac{\left[\frac{1}{\tilde{\Psi}(\mu)}\left(1+\frac{p_z\psi}{1-\psi+p_z\psi}\lambda^f\Phi^f\right)\left(\frac{1-\Phi^f}{\Phi^f}\right)^\Omega - 1\right]\Phi^f}{1-\frac{1}{\tilde{\Psi}(\mu)}\frac{p_z(1-\psi)}{\psi+p_z(1-\psi)}\lambda^f\Phi^f\left(\frac{1-\Phi^f}{\Phi^f}\right)^\Omega} \equiv \frac{\vartheta_1(\Phi^f)}{\vartheta_2(\Phi^f)} \tag{B6a}$$

$$\Phi^f = \frac{\left[\frac{1}{\tilde{\Gamma}(\mu)}\left(1+\frac{p_z(1-\psi)}{\psi+p_z(1-\psi)}\lambda^d\Phi^d\right)\left(\frac{1-\Phi^d}{\Phi^d}\right)^\Omega - 1\right]\Phi^d}{1-\frac{1}{\tilde{\Gamma}(\mu)}\frac{p_z\psi}{1-\psi+p_z\psi}\lambda^d\Phi^d\left(\frac{1-\Phi^d}{\Phi^d}\right)^\Omega}. \tag{B6b}$$

Under $\Omega > 2$, as Φ^f increases from 0 to 1, $\vartheta_1(\Phi^f)$ decreases from $+\infty$ to -1, and $\vartheta_2(\Phi^f)$ increases from $-\infty$ to $+1$. In addition, $\vartheta_1(z) > 0$ holds when z satisfies $\vartheta_2(z) = 0$. Thus Φ^f has a lower (upper) bound that is strictly higher (lower) than 0 (1), such that $\Phi^f \in (\Phi^f_{--}, \Phi^f_{++}) \subset (0, 1)$. We can also show that Φ^d is bounded in a similar way.

When $\psi \to 1$, λ^f in the extension model converges to λ in the original model. Noting this, we have the following lemma.

Lemma 5 *When $\psi \to 1$, (B6) uniformly converges to (A6).*

Proof. First, we prove uniform convergence of (B6a) to (A6a). Taking $\psi \to 1$, for any $\left(\Phi^d, \Phi^f\right)$, we have

$$\Phi^d\big|_{\psi\to 1} = \left[\frac{1}{\tilde{\Psi}(\mu)}\left(1+\lambda^f\Phi^f\right)\left(\frac{1-\Phi^f}{\Phi^f}\right)^\Omega - 1\right]\Phi^f \equiv \Phi^{d*}. \tag{B7}$$

Given that (B7) is equivalent to (A6a), there is a pointwise convergence of (B6a) to (A6a). To prove the convergence is also uniform, we use the following well-known property. In general, a real-valued function defined on X, denoted as $h(x;n)$, uniformly converges to h^* if and only if $\sup_{x\in X}(h(x;n) - h^*) \to 0$ as $n \to \infty$. Applying this to our case, we first define:

$$d(\psi) \equiv \sup_{\Phi_f\in(\Phi^f_{--},\Phi^f_{++})} \left|\frac{\vartheta_1(\Phi^f)}{\vartheta_2(\Phi^f)} - \Phi^{d*}\right|. \tag{B8}$$

Then, by (B6a) and (B7), we can rewrite (B8) as:

$$d(\psi) = (1-\psi) \sup_{\Phi^f\in(\Phi^f_{--},\Phi^f_{++})} \vartheta(\Phi^f;\psi), \tag{B9}$$

where $\vartheta(\Phi^f;\psi)$ is some function in Φ^f and ψ.[34] Since we can show $\vartheta(\Phi^f;\psi)$ is bounded because $\Phi^f \in (\Phi^f_{--}, \Phi^f_{++})$, $\sup_{\Phi^f}\vartheta(\Phi^f;\psi)$ takes some finite value, say $\tilde{\vartheta}(\psi) < \infty$. Therefore,

[34]The formal definition is:

$$\vartheta(\Phi^f) \equiv \left|-\frac{\frac{1}{1-\psi+p_z\psi} + \frac{p_z}{\psi+p_z(1-\psi)}\left(1-\frac{1}{\tilde{\Psi}(\mu)}\left(1+\lambda^f\Phi^f\right)\left(\frac{1-\Phi^f}{\Phi^f}\right)^\Omega\right)}{1-\frac{1}{\tilde{\Psi}(\mu)}\frac{p_z(1-\psi)}{\psi+p_z(1-\psi)}\lambda^f\Phi^f\left(\frac{1-\Phi^f}{\Phi^f}\right)^\Omega}\right| \frac{\lambda^f\left(1-\Phi^f\right)^\Omega}{\tilde{\Psi}(\mu)\left(\Phi^f\right)^{\Omega-2}}.$$

by (B9) and the definition of ϑ, it is easy to show that $d(\psi) = (1 - \psi)\,\tilde{\vartheta}(\psi) \to 0$ as $\psi \to 1$. The proof of (B6b) follows in a similar way, paying attention to the assumption that $\lambda^d \to 0$ as $\psi \to 1$. ■

Given this lemma, there exists some sufficiently large ψ, say $\hat{\psi} < 1$, such that the results derived from (B6) are qualitatively equivalent to those from (A6) for $\psi \in [\hat{\psi}, 1]$.

Appendix C:

Table C1: Minimum wage on imported capital goods, capital, and capital-labor ratio

	(1) imp_value	(2) capital	(3) K/L
min_wage	0.199***	0.360***	0.377***
	(0.049)	(0.051)	(0.053)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	2,234,545	2,234,545	2,234,545
Adj R-Squared	0.714	0.861	0.716

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. The dependent variable in specification 1 is the (log) number of firms' importing capital goods (after adding 1); the dependent variable in specification 2 is the (log of) firms' capital; the dependent variable in specification 3 is the (log of) firms' capital-labor ratio. Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and year fixed effects in all specifications.

We match three set firm-level data by firms' name. Therefore, to improve matching efficiency, we first clean firms' names as follows: (1) delete spaces, punctuation marks, and other symbols; (2) standardize all letters in firm and applicant names in capital form in English style; (3) single out five high-frequency general terms by statistical analysis and drop them: "limited," "liability," "stock," "company," "factory;" (4) delete general terms for regions: "province," "autonomous region," "city," "district," "county." Then we match import data and patent data with ASIF data, year by year. The sample period is from 2001 to 2013, and we have 2,234,545 observations of 436,514 manufacturing firms after data cleaning.[35] The matching results are shown in Table C2.

Table C2: Matching results of import and patent data to ASIF data

Year	(1) ASIF firms	(2) Import	(3) All patents	(4) Invention
2001	81,834	9,800	15,660	2,288
2002	105,055	11,381	24,731	5,564
2003	116,247	12,918	30,862	8,884
2004	124,672	14,164	37,103	12,142
2005	195,292	20,450	55,448	18,481
2006	213,175	19,793	76,564	27,728
2007	239,351	21,442	96,944	35,781
2008	257,107	22,304	126,870	44,103
2009	256,554	20,647	167,300	53,745
2011	183,643	17,569	262,346	79,359
2012	238,228	22,472	417,047	125,031
2013	223,387	20,824	413,947	144,100

Notes: Specification 1 is the number of firms in our sample. Specification 2 is the number of firms which imported capital goods at $t-1$. Specification 3 is the number of all three types of patent applications at t. Specification 4 is the number of invention patent applications at t.

[35] ASIF data in 2010 include some misreported information, so we drop it.

Table C3: Summary statistics of key variables

Variables	(1) Observations	(2) Mean	(3) S.D.	(4) Min	(5) Max
Dependent Variables					
all patents	2,234,545	0.128	0.515	0	8.757
invention	2,234,545	0.050	0.290	0	8.668
utility	2,234,545	0.079	0.378	0	7.196
design	2,234,545	0.034	0.274	0	7.049
citations	2,234,545	0.065	0.400	0	10.574
products	2,234,545	1.862	6.687	0	764
TFP	1,820,071	2.608	1.030	-7.649	9.147
labor	2,234,545	5.038	1.081	0	12.145
imp_value	2,234,545	0.625	2.132	0	17.852
capital	2,234,545	8.890	1.684	0	19.011
K/L	2,234,545	3.852	1.374	-7.424	13.957
Independent Variables					
min_wage	2,234,545	6.430	0.418	5.075	7.313
import	2,234,545	0.096	0.294	0	1
*import*2	2,234,545	0.100	0.300	0	1
Control Variables					
firm size	2,234,545	10.089	1.436	0	20.160
age	2,234,545	2.044	0.771	0	4.159
GDP per capita	2,234,545	10.375	0.911	5.958	13.018
population	2,234,545	6.249	0.604	2.770	8.115

Notes: *All patents*, *invention*, *utility*, *design*, *citations*, and *imp_value* are logarithmic after adding 1. *Labor*, *capital*, and K/L are logarithmic. All independent variables and control variables are in year $t-1$.

Table C4: Data sources of key variables

Variables	(1) Definition	(2) Data source
all patents	Log of patent applications	CNIPA
invention	Log of invention patent applications	CNIPA
utility	Log of utility-model patent applications	CNIPA
design	Log of design patent applications	CNIPA
citations	Log of number of firms' patents cited	Google Patent
products	Number of products firms export	CGAC
TFP	Total factor productivity by Olley-Pakes method	ASIF
labor	Log of the number of labor	ASIF
imp_value	Log of total amount of imported capital goods	CGAC
capital	Log of capital	ASIF
K/L	Log of capital-labor ratio	ASIF
min_wage	Log of monthly minimum wage at city level	Local government websites
import	Dummy variable of import capital goods	CGAC
*import*2	Dummy variable of import capital goods (alternative definition)	CGAC
firm size	Log of total assets	ASIF
age	Log of firm age	ASIF
GDP per capita	Log of GDP per capita at city level	CCSY
population	Log of population at city level	CCSY

Table C5: Results by different categories of patent applications

	Utility models		Design	
	(1)	(2)	(3)	(4)
min_wage × *import*	0.200***	0.206***	0.022**	0.025**
	(0.015)	(0.014)	(0.010)	(0.010)
min_wage	-0.062***	-0.071***	-0.028***	-0.032***
	(0.013)	(0.012)	(0.010)	(0.009)
import	-1.240***	-1.283***	-0.121*	-0.146**
	(0.093)	(0.090)	(0.062)	(0.062)
Controls	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2,234,545	2,234,545	2,234,545	2,234,545
Adj R-Squared	0.409	0.412	0.329	0.329

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. The dependent variable in specifications 1 to 2 is the (log of) utility model applications (after adding 1); the dependent variable in specifications 3 to 4 is the (log of) design applications (after adding 1). Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and year fixed effects in all of the specifications.

Table C6: Results by different types of imported goods

	all patents				invention			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
min_wage	-0.085***	0.030	-0.031	-0.029	-0.031***	0.039	-0.003	0.016
	(0.016)	(0.047)	(0.045)	(0.045)	(0.008)	(0.025)	(0.024)	(0.025)
min_wage × *capital share*			0.266***				0.180***	
			(0.019)				(0.012)	
capital share			-1.723***				-1.160***	
			(0.117)				(0.079)	
min_wage × *differential*				0.091***				0.035***
				(0.016)				(0.009)
differential				-0.608***				-0.230***
				(0.101)				(0.061)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,818,515	387,221	387,221	387,221	1,818,515	387,221	387,221	387,221
Adj R-Squared	0.383	0.565	0.567	0.566	0.344	0.567	0.568	0.567

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. The sample in specifications 1 and 5 is of non-importing firms; the sample in specifications 2 to 4 and 6 to 8 is of importing firms. The dependent variable in specifications 1 to 4 is the (log) number of all of the patent applications (after adding 1); the dependent variable in specifications 5 to 8 is the (log) number of invention patent applications (after adding 1). *Capital share* is the share of imported capital goods of all of the imported goods; *differential* is the share of imported differentiated goods of all of the imported goods. Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and year fixed effects in all of the specifications.

Table C7: Results by alternative definition of import status

	all patents		invention	
	(1)	(2)	(3)	(4)
min_wage × *import2*	0.096***	0.122***	0.082***	0.094***
	(0.019)	(0.019)	(0.012)	(0.012)
min_wage	-0.084***	-0.101***	-0.030***	-0.041***
	(0.020)	(0.019)	(0.011)	(0.010)
Controls	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2,234,545	2,234,545	2,234,545	2,234,545
Adj R-Squared	0.443	0.447	0.425	0.429

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. The dependent variable in specifications 1 to 2 is the (log) number of all of the patent applications (after adding 1); the dependent variable in specifications 3 to 4 is the (log) number of invention patent applications (after adding 1). *Import2* is equal to 1 when firms import capital goods at the time they first appeared in the sample, and otherwise is equal to 0. Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and year fixed effects in all of the specifications.

Table C8: Results by controlling industry-year fixed effects

	all patents		invention	
	(1)	(2)	(3)	(4)
min_wage × *import*	0.157***	0.167***	0.119***	0.123***
	(0.020)	(0.019)	(0.012)	(0.011)
min_wage	-0.066***	-0.081***	-0.029***	-0.038***
	(0.016)	(0.016)	(0.009)	(0.009)
import	-0.947***	-1.020***	-0.733***	-0.763***
	(0.126)	(0.119)	(0.075)	(0.071)
Controls	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Industry-year FE	Yes	Yes	Yes	Yes
Observations	2,234,533	2,234,533	2,234,533	2,234,533
Adj R-Squared	0.456	0.459	0.439	0.442

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. The dependent variable in specifications 1 to 2 is the (log) number of all of the patent applications (after adding 1); the dependent variable in specifications 3 to 4 is the (log) number of invention patent applications (after adding 1). Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and the 4-digit CIC industry-year fixed effects in all of the specifications.

Table C9: Heterogeneous effects by firms' capital-labor ratio

	all patents		invention	
	(1)	(2)	(3)	(4)
$min\_wage \times import \times firm\,K/L$	-0.018**	-0.020***	-0.005	-0.008
	(0.008)	(0.007)	(0.005)	(0.005)
$min\_wage \times import$	0.300***	0.233***	0.170***	0.137***
	(0.045)	(0.039)	(0.025)	(0.024)
$min\_wage \times firm\,K/L$	0.027***	0.032***	0.022***	0.020***
	(0.003)	(0.003)	(0.002)	(0.002)
$import \times firm\,K/L$	0.108**	0.124***	0.034	0.052*
	(0.050)	(0.045)	(0.029)	(0.031)
min_wage	-0.203***		-0.122***	
	(0.020)		(0.013)	
$import$	-1.845***	-1.439***	-1.058***	-0.860***
	(0.283)	(0.243)	(0.155)	(0.149)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	-	Yes	-
Industry-year FE	No	Yes	No	Yes
City-year FE	No	Yes	No	Yes
Observations	2,234,545	2,234,533	2,234,545	2,234,533
Adj R-Squared	0.450	0.464	0.432	0.446

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. The dependent variable in specifications 1 to 2 is the (log) number of all of the patent applications (after adding 1); the dependent variable in specifications 3 to 4 is the (log) number of invention patent applications (after adding 1). $Firm\,K/L$ is the firms' capital-labor ratio at the time they first appeared in the sample. Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and year fixed effects in specifications 1 and 3, and the firm fixed effects, 4-digit CIC industry-year fixed effects, and city-year fixed effects in specifications 2 and 4.

Table C10: Heterogeneous effects by firms' average wage

	all patents		invention	
	(1)	(2)	(3)	(4)
$min\_wage \times import \times firm\,wage$	-0.042***	-0.054***	-0.009	-0.028**
	(0.015)	(0.014)	(0.011)	(0.011)
$min\_wage \times import$	0.340***	0.321***	0.172***	0.191***
	(0.044)	(0.039)	(0.030)	(0.030)
$min\_wage \times firm\,wage$	0.075***	0.037***	0.052***	0.032***
	(0.006)	(0.005)	(0.005)	(0.004)
$import \times firm\,wage$	0.230**	0.317***	0.042	0.171**
	(0.095)	(0.087)	(0.069)	(0.070)
min_wage	-0.250***		-0.143***	
	(0.026)		(0.015)	
$import$	-2.006***	-1.921***	-1.025***	-1.169***
	(0.274)	(0.240)	(0.185)	(0.182)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	-	Yes	-
Industry-year FE	No	Yes	No	Yes
City-year FE	No	Yes	No	Yes
Observations	2,094,117	2,094,105	2,094,117	2,094,105
Adj R-Squared	0.445	0.459	0.426	0.441

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. The dependent variable in specifications 1 to 2 is the (log) number of all of the patent applications (after adding 1); the dependent variable in specifications 3 to 4 is the (log) number of invention patent applications (after adding 1). $Firm\,wage$ is the firms' wage per worker at the time they first appeared in the sample. Controls include log firm size, log firm age, log per capita city GDP, and log city population. We control the firm fixed effects and year fixed effects in specifications 1 and 3, and the firm fixed effects, 4-digit CIC industry-year fixed effects, and city-year fixed effects in specifications 2 and 4.