Effects of Minimum Wage on Import and 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. Using firm-level data in China, we find that a higher minimum wage is associated with more innovation by importing firms but less innovation by non-importing firms. To interpret these empirical findings, we develop an open-economy R&D-based growth model and find that a higher 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 more inputs, which have technology spillovers and enhance their innovation.

JEL classification: E24, F43, O31
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1 Introduction

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 use firm-level data in China to document some empirical patterns. Then, we develop an open-economy R&D-based growth model in which some firms import inputs from abroad whereas other firms use domestic inputs. We apply this growth-theoretic framework to explore the different effects of minimum wage on the innovation of the two types of firms.

Within our growth-theoretic framework, a higher 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 in the literature,[1] 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.

As for the empirics, we consider firm-level data in China and obtain the following results. First, a higher minimum wage is associated with a larger amount of imported inputs. Furthermore, 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. All these empirical results are consistent with our theory.

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 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, Kou and Wang (2019) and Chu, Cozzi, Furukawa and Liao (2019). 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. Amiti and Konings (2007), Goldberg *et al.* (2010), Chen *et al.* (2017) and Mo *et al.* (2019) use firm-level data to show that imported inputs enhance innovation and productivity.[3] Mayneris *et al.* (2018) and Hau *et al.* (2019) use firm-level data in China to show that minimum wage improves the productivity of firms.[4] Our study complements these interesting studies by examining the effects of minimum wage on firm-level innovation and by showing that minimum wage affects non-importing firms and importing firms differently via imported inputs and their spillover effects on technologies.[5]

[1] See Amiti and Konings (2007), Goldberg *et al.* (2010), Chen *et al.* (2017) and Mo *et al.* (2019).

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

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

[4] Fan *et al.* (2018) use firm-level data in China to examine the effects of minimum wage on FDI.

[5] Liu *et al.* (2015) and Liu and Qiu (2016) find that trade liberalization and tariff reduction also have

The rest of this study is organized as follows. Section 2 documents empirical evidence. Section 3 describes the theoretical model. Section 4 presents our results. Section 5 concludes.

2 Evidence

In this section, we first specify our regressions and describe the data that we use. Then, we present some regression results.

2.1 Empirical specification

We explore the effects of minimum wage on firms' imported inputs and innovation using manufacturing firm-level data in China from 2001 to 2013. Specifically, we estimate the effects of minimum wage using the following two regression models.

Our first regression model is specified as

$$imp\_value_{it} = \beta_0 + \beta_1 min\_wage_{c,t-1} + \gamma_1 X_{i,t-1} + \gamma_2 Z_{c,t-1} + \varphi_i + \varphi_t + \epsilon_{it},$$

where imp_value_{it} is the log value of imported capital goods by firm i in year t.[6] $min\_wage_{c,t-1}$ is the log value of monthly minimum wage in city c in year $t-1$. $X_{i,t-1}$ is a vector of firm-level control variables, whereas $Z_{c,t-1}$ is a vector of city-level control variables. φ_i denotes firm fixed effects, whereas φ_t denotes year fixed effects. The standard errors ϵ_{it} are clustered at city level. β_1 captures the effects of minimum wage on firms' imported inputs.

Our second regression model is specified as

$$\begin{aligned} patent_{it} = \beta_0 + \beta_1 min\_wage_{c,t-1} + \beta_2 min\_wage_{c,t-1} \times import_{i,t-1} + \beta_3 import_{i,t-1} \\ + \gamma_1 X_{i,t-1} + \gamma_2 Z_{c,t-1} + \varphi_i + \varphi_t + \epsilon_{it}, \end{aligned}$$

where $patent_{it}$ is the log value of the number of patent applications by firm i in year t.[7] 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.[8] The interaction term $min\_wage_{c,t-1} \times import_{i,t-1}$ captures the additional effect of minimum wage on importing firms. Other variables are the same as before. Here β_1 captures the effects of minimum wage on non-importing firms' innovation. $\beta_1 + \beta_2$ captures the effects of minimum wage on importing firms' innovation.

Firm-level control variables $X_{i,t-1}$ include firm size measured by total assets, the capital-labor ratio, the proportion of the firm's exports in total sales, and firm age. City-level control variables $Z_{c,t-1}$ include GDP per capita and the population size. All variables are in log, except for the proportion of the firm's exports in total sales. Appendix A provides their summary statistics and data sources.

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multiple effects on innovation.

[6] Given that some firms do not import, we add one to the value of imported capital goods. Capital goods are those with BEC classification code of 41 and 521 provided by United Nations, see BEC classification in https://unstats.un.org/unsd/trade/classifications/correspondence-tables.asp.

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

[8] We will consider an alternative definition of importing firms in the robustness checks.

2.2 Regression results

This section reports regression results on the effects of minimum wage on firms' imported inputs and innovation. Table 1 presents the estimation results of the first regression, in which we consider imported capital goods.[9] As shown in Table 1, the coefficients of minimum wage are positive and significant at 1% significance level across all three columns. Therefore, a higher minimum wage is associated with a positive effect on imported capital goods.

Table 1: Minimum wage on imported inputs

	imported capital goods		
	(1)	(2)	(3)
min_wage	0.238***	0.199***	0.203***
	(0.054)	(0.048)	(0.050)
Firm-level controls	No	Yes	Yes
City-level controls	No	No	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	2236711	2236711	2236711
Adj R-Squared	0.713	0.714	0.714

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. All dependent variables are logarithmic after adding 1. Firm-level controls include log firm size, log capital-labor ratio, the proportion of firm exports in total sales and log firm age. City-level controls include log per capita city GDP and log city population.

Table 2 presents the estimation results of the second regression. Column (1), (3) and (5) show that minimum wage is negatively and significantly associated with patent applications. If we do not separate between importing firms and non-importing firms, we would conclude that raising the minimum wage negatively affects the innovation of all firms. However, in column (2), (4) and (6), we see that although minimum wage is negatively and significantly associated with non-importing firms' patent applications, it is positively and significantly associated with importing firms' patent applications; e.g., $\beta_1 + \beta_2 = 0.140$ in column (6). Therefore, raising the minimum wage has heterogeneous effects on the innovation of importing and non-importing firms.

Patents are classified into three categories: invention, utility model, and design. We now examine the separate effects of minimum wage on these three types of patent applications. Table 3 shows that minimum wage is negatively and significantly associated with all of non-importing firms' patent applications but positively and significantly associated with importing firms' applications for invention patents and utility patents, which capture innovation better than design patents.[10]

[9] Cavallo and Landry (2010) find that imported capital goods have a significant positive effect on economic growth in the US, whereas Mo *et al.* (2019) find that imported capital goods have a significant positive effect on Chinese firms' productivity and R&D investment.

[10] Liu *et al.* (2015) find that trade liberalization also has different effects on different types of patents.

Table 2: Minimum wage on patent applications

	all patents					
	(1)	(2)	(3)	(4)	(5)	(6)
min_wage	-0.087***	-0.084***	-0.101***	-0.098***	-0.103***	-0.100***
	(0.020)	(0.020)	(0.019)	(0.019)	(0.019)	(0.019)
min_wage × *import*		0.232***		0.241***		0.240***
		(0.021)		(0.020)		(0.020)
import		-1.418***		-1.490***		-1.486***
		(0.133)		(0.127)		(0.127)
Firm-level Controls	No	No	Yes	Yes	Yes	Yes
City-level Controls	No	No	No	No	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
F-test $\beta_1 + \beta_2 > 0$		34.750		33.989		32.917
Prob > F		0.000		0.000		0.000
Observations	2236711	2236711	2236711	2236711	2236711	2236711
Adj R-Squared	0.442	0.445	0.446	0.449	0.446	0.449

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. All dependent variables are logarithmic after adding 1. Firm-level controls include log firm size, log capital-labor ratio, the proportion of firm exports in total sales and log firm age. City-level controls include log per capita city GDP and log city population. The F-test of column (2), (4) and (6) test the sum of the estimated coefficients on *min_wage* and *min_wage* × *import*.

Table 3: Minimum wage on different categories of patent applications

	invention		utility		design	
	(1)	(2)	(3)	(4)	(5)	(6)
min_wage	-0.043***	-0.041***	-0.074***	-0.071***	-0.032***	-0.032***
	(0.011)	(0.010)	(0.012)	(0.012)	(0.009)	(0.009)
min_wage × *import*		0.162***		0.206***		0.025**
		(0.012)		(0.014)		(0.010)
import		-1.008***		-1.283***		-0.145**
		(0.073)		(0.089)		(0.062)
Firm-level controls	Yes	Yes	Yes	Yes	Yes	Yes
City-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
F-test $\beta_1 + \beta_2 > 0$		63.208		53.612		0.595
Prob > F		0.000		0.000		0.441
Observations	2236711	2236711	2236711	2236711	2236711	2236711
Adj R-Squared	0.427	0.431	0.408	0.411	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. All dependent variables are logarithmic after adding 1. Firm-level controls include log firm size, log capital-labor ratio, the proportion of firm exports in total sales and log firm age. City-level controls include log per capita city GDP and log city population. The F-test of column (2), (4) and (6) test the sum of the estimated coefficients on *min_wage* and *min_wage* × *import*.

In summary, we have identified the following patterns in the data. First, minimum wage is associated with a positive effect on imported capital goods. Second, minimum wage is associated with a negative effect on non-importing firms' innovation. Third, minimum wage is associated with a positive effect on importing firms' innovation. In Appendix B, we perform a number of robustness checks and find that these results are robust to a different measure of innovation, an alternative definition of importing firms and controlling industry-year fixed effects that capture time-varying industry characteristics. We also address endogeneity by using the approach developed by Dube *et al.* (2010) and adapted to China by Fan *et al.* (2018) to consider city pairs located near borders of different provinces in order to exploit policy discontinuities at provincial borders.

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

In this section, we develop an innovation-driven growth model to interpret the empirical patterns documented in the previous section. The open-economy R&D-based growth model is based on Grossman and Helpman (1991b). We follow Chu *et al.* (2018) to extend the Grossman-Helpman model into multiple sectors. Specifically, firms in one sector use domestic inputs for the production of differentiated products, whereas firms in the other sector use foreign inputs for the production of differentiated products. Furthermore, we generalize the model in Chu *et al.* (2018) by introducing minimum wage and allowing for a non-unitary elasticity of substitution between labor and imported inputs in production. For simplicity, we assume that the terms of trade is exogenous as in Grossman and Helpman (1991b).

3.1 Household

There is a representative household in the economy. The utility function of the household 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.[11] The parameter $\gamma \geq 0$ determines the importance of the consumption of a foreign final good $C_{z,t}$ imported from abroad.[12] 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:

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

a_t is the amount of assets, and r_t is the interest rate.[13] 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

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

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

[13] 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.

minimum wage. The household also supplies l units of low-skill production labor, among which $L_t^d + L_t^f$ units of low-skill labor 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:

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

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

3.2 Domestic final good

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

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

X_t^d denotes the intermediate good that uses domestic inputs, whereas X_t^f denotes 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

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

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

P_t^d denotes the price of X_t^d, whereas P_t^f denotes the price of X_t^f.

3.3 Intermediate goods

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

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

where L_t^d denotes domestic production labor and $x_t^d(\omega)$ denotes domestic capital goods $\omega \in [0, n_t^d]$ for the production of X_t^d. 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 $\omega \in [0, n_t^f]$.[14] This non-unitary elasticity of substitution

[14] 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.

between labor and imported capital goods will interact with the technology spillovers of imported capital goods to affect innovation.[15] From profit maximization, we derive the conditional demand functions for L_t^i and $x_t^i(\omega)$ as

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

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

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

where

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

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

3.4 Domestic capital goods

A monopolistic firm uses $x_t^d(\omega)$ units of domestic final good to produce $x_t^d(\omega)$ units of domestic capital good $\omega \in [0, n_t^d]$.[16] Therefore, the profit function for producing $x_t^d(\omega)$ units of domestic capital good ω is

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

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

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

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.[17] The steady-state value of an invention is

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

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

[15] Given the lack of evidence, we do not assume technology spillovers from domestic capital goods; therefore, we focus in the main text on a unitary elasticity of substitution between labor and domestic capital goods in the production of X_t^d for simplicity; see Appendix C for the case of a CES production function for X_t^d.

[16] A firm may own the patents for producing multiple varieties of domestic capital goods.

[17] See also Grossman and Lai (2004).

3.5 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 $\omega \in [0, n_t^f]$.[18] 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.

3.6 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.

3.7 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 invent 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

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

[18] An importing firm may own the patents for producing multiple varieties of foreign capital goods.

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,

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

is the value of imported inputs as a ratio of output. We adapt this specification from Grossman and Helpman (1991b), who also assume that knowledge spillovers arise from trade.[19] 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 re-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.

3.8 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 sector $i \in \{h, f\}$:

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

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

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

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

3.9 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 $\{p_z, r_t, w_t^h, \overline{w}_t^l, P_t^d, P_t^f, p_t^d(\omega), p_t^f(\omega), v_t^d, v_t^f\}_{t=0}^{\infty}$. Also, at each instance of time,

- the representative household chooses $\{C_{z,t}, C_{y,t}\}$ to maximize lifetime utility taking $\{p_z, r_t, w_t^h, \overline{w}_t^l\}$ as given;

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

- competitive firms produce Y_t to maximize profit taking $\{P_t^d, P_t^f\}$ as given;
- competitive firms produce X_t^d to maximize profit taking $\{\overline{w}_t^l, P_t^d, p_t^d(\omega)\}$ as given;
- competitive firms produce X_t^f to maximize profit taking $\{\overline{w}_t^l, P_t^f, p_t^f(\omega)\}$ as given;
- 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 taking p_z as given;
- R&D labor R_t^d performs innovation to maximize profit taking $\{w_t^h, v_t^d\}$ as given;
- R&D labor R_t^f performs innovation to maximize profit taking $\{w_t^h, v_t^f\}$ as given;
- 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 $Y_t - C_{y,t} - \int_0^{n_t^d} x_t^d(\omega) d\omega = p_z C_{z,t} + p_z \int_0^{n_t^f} x_t^f(\omega) d\omega$.

4 Effects of minimum wage on import and 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 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 given by

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

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

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

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 $n^d = R^d / \delta$ into (25) yields the relative level of R&D labor between the two sectors as[20]

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

[20] If we also assume a CES production function for X_t^d in (8a), then we have $R^f / R^d = \Phi^f / \Phi^d$, which is nonetheless increasing in μ if and only if $\lambda > 0$; see Appendix C for the derivations.

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. Therefore, 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, 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.

The above results can be summarized as follows. First, a higher minimum wage causes a positive effect on imported capital goods. Second, a higher minimum wage causes a negative effect on non-importing firms' innovation. Third, a higher minimum wage causes a positive effect on importing firms' innovation. Proposition 1 summarizes these results, which provide a theoretical interpretation on the empirical patterns documented in Section 2.

Proposition 1 *If the import-spillover parameter and the elasticity of substitution are not excessively large such that $\lambda < 1/\alpha$ and $\varepsilon < 1/(1-\alpha)$, then the economy features a unique steady-state equilibrium. In this case, a higher minimum wage causes the following effects: (1) an increase in the intensity of imported inputs; (2) a decrease in innovation of non-importing firms; and (3) an increase in innovation of importing firms.*

Proof. See Appendix C. ■

5 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 a higher 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 patterns that we have documented using firm-level data in China. Therefore, 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.

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Appendix A: Data

We use four databases in China: (1) firm-level financial statement data, (2) firm-product-level trade data, (3) firm-level patent application and citation data, and (4) city-level minimum wage and economic data. We merge first three set firm-level data by firms' name. The sample period is from 2001 to 2013, and we have 2236711 observations of 436751 manufacturing firms after data cleaning.

First, firm-level financial statement data come from the *Annual Survey of Industrial Firms* (ASIF) maintained by the *National Bureau of Statistics of China* (NBSC).[21] Second, firm-product-level trade data come from *China's General Administration of Customs* (CGAC). Third, firm-level patent application data come from *China National Intellectual Property Administration* (CNIPA), and patent citation data come from *Google Patent.* Finally, we collect city-level minimum wage from local government websites, and city-level economic data come from *China City Statistical Yearbook* (CCSY).

Table A1 and A2 provide the summary statistics and the data sources.

Table A1: Summary statistics of the key variables

Variables	(1) Observations	(2) Mean	(3) S.D.	(4) Min	(5) Max
Dependent Variables					
imp_value	2236711	0.624	2.131	0	17.852
all patents	2236711	0.128	0.515	0	8.757
invention	2236711	0.050	0.290	0	8.668
utility	2236711	0.079	0.378	0	7.196
design	2236711	0.034	0.274	0	7.049
citations	2236711	0.065	0.400	0	10.574
*citations*2	2236711	0.063	0.393	0	10.540
Independent Variables					
min_wage	2236711	6.431	0.418	5.075	7.313
import	2236711	0.096	0.294	0	1
*import*2	2236711	0.149	0.356	0	1
Control Variables					
firm size	2236711	10.089	1.435	3.296	19.295
K/L	2236711	3.846	1.361	-7.424	14.075
exp ratio	2236711	0.169	0.336	0	1
age	2236711	2.045	0.771	0	4.159
GDP per capita	2236711	10.376	0.911	5.958	13.018
population	2236711	6.249	0.603	2.770	8.115

Notes: All dependent variables are logarithmic after adding 1. All independent variables and control variables are in year $t-1$.

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

Table A2: Data sources of the key variables

Variables	(1) Definition	(2) Data source
imp_value	The log of total amount of imported capital goods	CGAC
all patents	The log of patent applications	CNIPA
invention	The log of invention patent applications	CNIPA
utility	The log of utility-model patent applications	CNIPA
design	The log of design patent applications	CNIPA
citations	The log of the number of firms' patents cited	Google Patent
*citations*2	The log of the number of firms' patents cited (exclude self cited)	Google Patent
min_wage	The log of monthly minimum wage at city level	Local government websites
import	A dummy variable of import capital goods	CGAC
*import*2	A dummy variable of import capital goods (alternative definition)	CGAC
firm size	The log of total asset	ASIF
K/L	The log of capital-labor ratio	ASIF
exp ratio	The proportion of firm exports in total sales	ASIF
age	The log of firm age	ASIF
GDP per capita	The log of GDP per capita at city level	CCSY
population	The log of population at city level	CCSY

Appendix B: Robustness checks

In this appendix, we perform a number of robustness checks. In Table B1, we consider patent citations as an alternative measure of innovation. In Table B2, we consider the following alternative definition of import status: we classify firms that have ever imported capital goods before time t as importing firms in time t. In Table B3, we add industry-year fixed effects to capture time-varying industry characteristics, such as industrial policies, that may influence firms' innovation activities. In Table B4, we use the approach in Dube *et al.* (2010) to address endogeneity by considering city pairs located near borders of different provinces in order to exploit policy discontinuities at provincial borders.[22]

Table B1: Minimum wage on patent citations

	citations		citations2	
	(1)	(2)	(3)	(4)
min_wage	-0.040***	-0.039***	-0.039***	-0.037***
	(0.010)	(0.010)	(0.010)	(0.009)
min_wage × *import*		0.145***		0.139***
		(0.013)		(0.013)
import		-0.893***		-0.856***
		(0.083)		(0.080)
Firm-level controls	Yes	Yes	Yes	Yes
City-level controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
F-test $\beta_1 + \beta_2 > 0$		39.820		39.179
Prob > F		0.000		0.000
Observations	2236711	2236711	2236711	2236711
Adj R-Squared	0.390	0.392	0.387	0.389

Notes: *** p < 0.01, ** p < 0.05, * p < 0.1. Robust standard errors clustered at the city level are reported in parentheses. All dependent variables are logarithmic after adding 1. Citations are the number of firms' patents cited, and citations2 are the number of firms' patents cited which exclude self cited. Firm-level controls include log firm size, log capital-labor ratio, the proportion of firm exports in total sales and log firm age. City-level controls include log per capita city GDP and log city population. The F-test of column (2) and (4) test the sum of the estimated coefficients on *min_wage* and *min_wage* × *import*.

[22] Finally, we get 2175642 observations from 201 city pairs and 171 unique cities among all 286 cities in our sample.

Table B2: Alternative definition of import status

	all patents	invention	utility	design	citations	citations2
	(1)	(2)	(3)	(4)	(5)	(6)
min_wage	-0.089***	-0.035***	-0.063***	-0.029***	-0.033***	-0.032***
	(0.019)	(0.010)	(0.012)	(0.009)	(0.009)	(0.009)
$min\_wage \times import2$	0.206***	0.137***	0.175***	0.023**	0.115***	0.109***
	(0.021)	(0.010)	(0.014)	(0.011)	(0.011)	(0.011)
import2	-1.170***	-0.802***	-1.019***	-0.110*	-0.652***	-0.620***
	(0.129)	(0.066)	(0.086)	(0.065)	(0.070)	(0.068)
Firm-level controls	Yes	Yes	Yes	Yes	Yes	Yes
City-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
F-test $\beta_1 + \beta_2 > 0$	27.128	58.824	44.243	0.619	33.480	32.460
Prob > F	0.000	0.000	0.000	0.432	0.000	0.000
Observations	2236711	2236711	2236711	2236711	2236711	2236711
Adj R-Squared	0.451	0.432	0.413	0.329	0.393	0.389

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. All dependent variables are logarithmic after adding 1. Citations are the number of firms' patents cited, and citations2 are the number of firms' patents cited which exclude self cited. Firm-level controls include log firm size, log capital-labor ratio, the proportion of firm exports in total sales and log firm age. City-level controls include log per capita city GDP and log city population. The F-test of each column tests the sum of the estimated coefficients on *min_wage* and $min\_wage \times import2$.

Table B3: Controlling industry-year fixed effects

	all patents	invention	utility	design	citations	citations2
	(1)	(2)	(3)	(4)	(5)	(6)
min_wage	-0.080***	-0.035***	-0.052***	-0.026***	-0.035***	-0.033***
	(0.018)	(0.009)	(0.011)	(0.008)	(0.009)	(0.009)
$min\_wage \times import$	0.175***	0.130***	0.147***	0.018**	0.118***	0.113***
	(0.020)	(0.012)	(0.014)	(0.008)	(0.014)	(0.013)
import	-1.073***	-0.804***	-0.910***	-0.101*	-0.726***	-0.693***
	(0.124)	(0.074)	(0.086)	(0.053)	(0.087)	(0.084)
Firm-level Controls	Yes	Yes	Yes	Yes	Yes	Yes
City-level Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry-year FE	Yes	Yes	Yes	Yes	Yes	Yes
F-test $\beta_1 + \beta_2 > 0$	16.366	37.696	30.821	1.006	24.427	23.935
Prob > F	0.000	0.000	0.000	0.317	0.000	0.000
Observations	2236711	2236711	2236711	2236711	2236711	2236711
Adj R-Squared	0.456	0.437	0.422	0.330	0.395	0.391

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors clustered at the city level are reported in parentheses. All dependent variables are logarithmic after adding 1. Citations are the number of firms' patents cited, and citations2 are the number of firms' patents cited which exclude self cited. Firm-level controls include log firm size, log capital-labor ratio, the proportion of firm exports in total sales and log firm age. City-level controls include log per capita city GDP and log city population. The F-test of each column tests the sum of the estimated coefficients on *min_wage* and $min\_wage \times import$.

Table B4: Considering city pairs located near boarders of different provinces

	all patents	invention	utility	design	citations	citations2
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Unweighted Regressions						
min_wage	-0.068***	-0.044***	-0.032***	-0.016***	-0.047***	-0.045***
	(0.013)	(0.008)	(0.009)	(0.006)	(0.008)	(0.008)
min_wage × *import*	0.206***	0.158***	0.175***	0.019	0.151***	0.144***
	(0.034)	(0.024)	(0.021)	(0.017)	(0.027)	(0.026)
import	-1.251***	-0.974***	-1.070***	-0.105	-0.925***	-0.881***
	(0.206)	(0.146)	(0.124)	(0.104)	(0.165)	(0.159)
F-test $\beta_1 + \beta_2 > 0$	13.963	20.415	37.357	0.030	13.797	13.363
Prob > F	0.000	0.000	0.000	0.863	0.000	0.000
Adj R-Squared	0.494	0.467	0.477	0.361	0.425	0.421
Panel B: Weighted Regressions						
min_wage	-0.070***	-0.044***	-0.037***	-0.018**	-0.047***	-0.045***
	(0.013)	(0.008)	(0.010)	(0.007)	(0.009)	(0.009)
min_wage × *import*	0.204***	0.156***	0.177***	0.012	0.148***	0.141***
	(0.031)	(0.022)	(0.020)	(0.014)	(0.024)	(0.023)
import	-1.243***	-0.967***	-1.089***	-0.063	-0.906***	-0.864***
	(0.187)	(0.131)	(0.118)	(0.089)	(0.148)	(0.142)
F-test $\beta_1 + \beta_2 > 0$	15.091	25.398	35.376	0.111	16.164	15.646
Prob > F	0.000	0.000	0.000	0.740	0.000	0.000
Adj R-Squared	0.492	0.463	0.475	0.363	0.424	0.420
Firm-level Controls	Yes	Yes	Yes	Yes	Yes	Yes
City-level Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry-year FE	Yes	Yes	Yes	Yes	Yes	Yes
City pair-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2175642	2175642	2175642	2175642	2175642	2175642

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. All dependent variables are logarithmic after adding 1. Citations are the number of firms' patents cited, and citations2 are the number of firms' patents cited which exclude self cited. Firm-level controls include log firm size, log capital-labor ratio, the proportion of firm exports in total sales and log firm age. City-level controls include log per capita city GDP and log city population. The F-test of each column tests the sum of the estimated coefficients on *min_wage* and *min_wage* × *import*. Regressions in Panel A are unweighted, and regressions in Panel B are weighted by the inverse of the number of duplicates in the city-pair firm-level sample.

Appendix C

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

$$(n_t^f)^{\frac{1}{\alpha}} x_t^f = \frac{\alpha \Phi_t^f}{2p_z} (n_t^f)^{\frac{1-\alpha}{\alpha}} Y_t. \tag{C1}$$

Substituting (C1) and (22b) into (24), we have

$$\Phi_t^f = \frac{\alpha \left[\alpha\mu\Phi_t^f (n_t^f)^{\frac{1-\alpha}{\alpha}}\right]^{(\varepsilon-1)/\varepsilon}}{(1-\alpha)\left[p_z(1-\Phi_t^f)\right]^{(\varepsilon-1)/\varepsilon} + \alpha\left[\alpha\mu\Phi_t^f (n_t^f)^{\frac{1-\alpha}{\alpha}}\right]^{(\varepsilon-1)/\varepsilon}}, \tag{C2}$$

which can be re-expressed as

$$\Phi_t^f = \frac{(n_t^f)^{\frac{(1-\alpha)(\varepsilon-1)}{\alpha}}}{(1-\alpha)^{\varepsilon}(p_z)^{\varepsilon-1}/(\alpha^{2\varepsilon-1}\mu^{\varepsilon-1}) + (n_t^f)^{\frac{(1-\alpha)(\varepsilon-1)}{\alpha}}} \equiv f(n_t^f) \in (0,1). \tag{C3}$$

It is useful to note that $f'(n_t^f) > 0$ and $f''(n_t^f) < 0$ due to $\varepsilon > 1$. From (26), there exist unique steady-state levels of R&D spending given by $R^d = \alpha/(\alpha + \Phi_t^f) \in (0,1)$ and $R^f = \Phi_t^f/(\alpha + \Phi_t^f) \in (0,1)$ where $\Phi_t^f \in (0,1)$ from (C3). Then, we combine $n^f = (1 + \lambda\Phi^f)R^f/\delta$ and $R^f = \Phi_t^f/(\alpha + \Phi_t^f)$ into the following expression:

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

which can be re-expressed as

$$n^f = \frac{1}{\delta}\frac{\Phi^f\left(1 + \lambda\Phi^f\right)}{\alpha + \Phi^f}. \tag{C4}$$

Finally, substituting (C3) into (C4) yields

$$\Psi(\mu)\frac{1}{\Phi^f}\left(\frac{\Phi^f}{1-\Phi^f}\right)^{\frac{\alpha}{(1-\alpha)(\varepsilon-1)}} = \frac{1 + \lambda\Phi^f}{\alpha + \Phi^f}, \tag{C5}$$

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. Note that the left-hand side of (C5) is monotonically increasing in Φ^f if $\alpha > (\varepsilon - 1)/\varepsilon$ and that the right-hand side is decreasing in Φ^f if $\alpha < 1/\lambda$. Therefore, if $\alpha \in ((\varepsilon - 1)/\varepsilon, 1/\lambda)$, then (C5) uniquely determines the steady-state value of Φ^f. Given that $\Psi(\mu)$ is decreasing in μ, an increase in μ leads to a decrease in the left-hand side of (C5), which in turn yields an increase in Φ^f. The increase in Φ^f increases the intensity of imported inputs, decreases non-importing firms' innovation and increases importing firms' innovation as shown in (25) and (26). ■

CES function in (8a): We now show that our results are robust to generalizing (8a) to the following CES production function for X_t^d:

$$X_t^d = \left\{ (1-\alpha)(L_t^d)^{\frac{\varepsilon-1}{\varepsilon}} + \alpha \left[\int_0^{n_t^d} [x_t^d(\omega)]^\alpha d\omega \right]^{\frac{\varepsilon-1}{\alpha\varepsilon}} \right\}^{\frac{\varepsilon}{\varepsilon-1}}. \tag{C6}$$

Following the same derivations as in the proof of Proposition 1, one can show that (C5) becomes the following system that determines Φ^d and Φ^f:

$$\Psi(\mu)\frac{1}{\Phi^f}\left(\frac{\Phi^f}{1-\Phi^f}\right)^{\frac{\alpha}{(1-\alpha)(\varepsilon-1)}} = \frac{1+\lambda\Phi^f}{\Phi^d+\Phi^f}, \tag{C7a}$$

$$\Gamma(\mu)\frac{1}{\Phi^d}\left(\frac{\Phi^d}{1-\Phi^d}\right)^{\frac{\alpha}{(1-\alpha)(\varepsilon-1)}} = \frac{1}{\Phi^d+\Phi^f}, \tag{C7b}$$

where we have defined the following composite parameters:

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

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

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

Proof. We re-express (C7) as

$$\Phi^d = \left[\zeta(\Phi^f)-1\right]\Phi^f, \tag{C8a}$$

$$\Phi^f = \left[\frac{1}{\Gamma(\mu)}\left(\frac{1-\Phi^d}{\Phi^d}\right)^\Omega - 1\right]\Phi^d, \tag{C8b}$$

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 (C8a) into (C8b) and rearranging some terms yield

$$\left[\Gamma(\mu)\frac{\zeta(\Phi^f)}{\zeta(\Phi^f)-1}\right]^{1/\Omega} = \frac{1}{[\zeta(\Phi^f)-1]\Phi^f} - 1. \tag{C9}$$

Multiplying both sides of (C9) by $[\zeta(\Phi^f)-1]/\zeta(\Phi^f)$, we obtain

$$\left[\frac{\zeta(\Phi^f)-1}{\zeta(\Phi^f)}\right]^{(\Omega-1)/\Omega} = \frac{1}{[\Gamma(\mu)]^{1/\Omega}}\left[\frac{1+\Phi^f}{\zeta(\Phi^f)\Phi^f} - 1\right]. \tag{C10}$$

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 $\zeta(\Phi^f)\Phi^f$ would decrease from infinity to 0.[23] 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 $\zeta(\Phi^f_+) < \zeta(\Phi^f_-) = 1 + 1/\Phi^f_-$.[24]

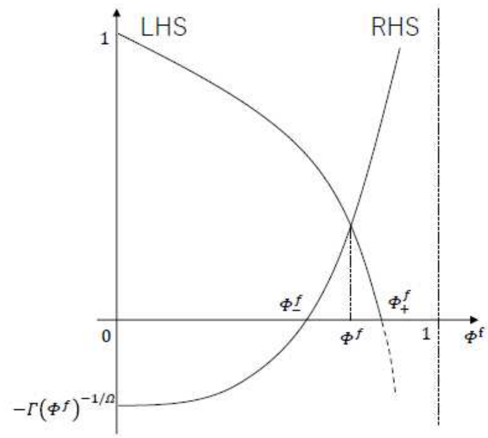

Figure 1: Equilibrium uniqueness

As shown in Figure 1, the left-hand side of (C10) decreases from 1 to 0 as Φ^f increases from 0 to Φ^f_+, whereas the right-hand side of (C10) increases from 0 to infinity as Φ^f increases from Φ^f_- to 1. Given $\Phi^f_- < \Phi^f_+$, (C10) uniquely determines the equilibrium value of $\Phi^f \in (0,1)$, which then determines the equilibrium value of $\Phi^d \in (0,1)$ in (C8a). ■

Lemma 2 Φ^f *is increasing in* μ.

Proof. Given that the left-hand side (LHS) of (C10) is increasing in $\zeta(\Phi^f)$ and that $\zeta(\Phi^f)$ is also increasing in μ,[25] an increase in μ shifts up the LHS to the right in Figure 1. Then, the right-hand side (RHS) of (C10) 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 1. Finally, both the shifts in the LHS and the RHS give rise to an increase in Φ^f. ■

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

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 (C7a) and (C7b) and then apply the approximation $\ln(1 + \Phi^i) \approx \Phi^i$ to derive

$$\Phi^f - \Phi^d = \frac{1}{2\Omega - 1}\left[-\frac{\alpha}{1-\alpha}\ln p_z + \lambda\Phi^f\underset{+}{(\mu)}\right], \tag{C11}$$

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

Given $\overline{\lambda}I = \lambda\Phi^f$ and $R^f/R^d = \Phi^f/\Phi^d$, Lemma 2 and 3 imply that all the results in Proposition 1 are robust to generalizing (8a) to the CES version in (C6).