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Abstract

We study the impact of international trade on a firm's technology choice in an infinite-horizon model. Banks engage in oligopolistic competition in providing capital for the manufacturing sector. Manufacturing firms also engage in oligopolistic competition and choose technologies with different levels of fixed and marginal costs. In the steady state, firms in a country with a larger market size or a more efficient financial sector choose more advanced technologies, and this country has a higher capital stock. The opening of international trade leads manufacturing firms to choose more advanced technologies and the steady-state capital stock increases.

Keywords: International trade, technology choice, financial development, infinite-horizon model, two-stage oligopoly

JEL Classification Numbers: F12, D43, O14

1. Introduction

A firm's technology choice could be affected by various factors, such as market size and financial development. How financial development affects a country's economic performance has been studied extensively in the literature (Feenstra, Li, and Yu, 2014; Egger and Keuschnigg, 2017; Fan et al., 2018; Choi, 2020). Banks can play an important role in a country's industrialization process, such as coordinating investment in German. For countries such as South Korea, it has been argued that cheaper sources of finance facilitated the adoption of more advanced technologies and led to the stronger export performance of the manufacturing sector (Kletzer and Bardhan, 1987). Technology choice is ubiquitous, and this type of choice is likely to be affected by aggregate capital stock. When firms choose technologies efficiently, capital stock in the next period could change and is thus endogenously determined. Interestingly, how financial development affects a country's comparative advantage through technology choice with endogenous capital stock has not been studied with the usage of formal models.

To fill this gap, in this paper we study how financial sector development affects technology choice and the pattern of international trade in an infinite-horizon model. In this model, capital and labor are the two factors of production. There are four sectors of production: agriculture, financial sector, manufacture, and investment good sector. First, the agricultural sector produces the agricultural good with labor only and firms in this sector engage in perfect competition. Second, the financial sector provides loans to the manufacturing sector to be used as fixed costs of production. Firms in the financial sector are called banks. The existence of increasing returns in the financial sector leads banks engaging in Cournot competition (Williamson, 1986; Jungblut, 2004).[1] Third, firms producing manufactured goods choose technologies to maximize profits. A more advanced technology uses more capital and less labor, leading to higher fixed costs and lower marginal cost of production. With the existence of fixed costs, there are also increasing returns in the manufacturing sector. Like banks, manufacturing firms engage in Cournot competition. Finally, manufactured goods can be used to produce the investment good, and firms producing the investment good engage in perfect competition.

Different from international trade models based on monopolistic competition, in this model manufacturing firms engage in oligopolistic (Cournot) competition. The motivation for this assumption is as follows. In a model with monopolistic competition such as Krugman (1980, equation (9), p. 952), a firm's equilibrium output depends only on fixed and marginal costs and a consumer's elasticity of demand. If this elasticity is assumed to be constant, then the opening of international trade does not change a firm's output.[2] With oligopoly, even with constant elasticity of demand, a firm's output is also affected by the number of firms producing the same product. Since the number of firms is affected by the opening of international trade, a firm's output changes correspondingly. Because we want to address a firm's technology choice which is affected by its output level, it is essential to capture how a firm's output changes with the opening of international trade. Thus, we choose oligopoly as the type of market structure in the manufacturing sector.[3]

This dynamic general-equilibrium model with two-stage oligopoly is surprisingly tractable. In a closed economy, we show that a country with a more efficient financial sector chooses more advanced technologies, has a higher equilibrium wage rate, and enjoys a comparative advantage in producing manufactured goods. With the amount of capital endogenously determined by saving

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[1] There might be no need for financial intermediation and a manufacturing firm might contact individuals directly for capital if there were no increasing returns in the intermediation of financial services. Increasing returns to scale in the financial sector exist for various reasons. First, banks rely extensively on computer systems with significant fixed costs. Second, there are increasing returns in advertising when banks advertise through medias such as radio and television. Third, banks engage in monitoring of firms and monitoring costs are fixed costs (Williamson, 1986), which leads to increasing returns in the financial sector. Consequently, the opening of international trade can increase market size and thus increases national welfare substantially.

[2] If this elasticity is not constant, then the opening of international trade can change a firm's output under monopolistic competition. However, this is not as tractable as the case with constant elasticity of demand.

[3] Oligopoly is an important type of market structure in reality. For example, in the United States, with increasing returns in production, management, and distribution since the Second Industrial Revolution, there were tendencies for industries to become monopolized. However, with antitrust laws preventing monopoly from happening, many industries are dominated by oligopolistic firms in the United States.

behavior of individuals, a country's steady-state capital stock increases with the level of efficiency in the financial sector.

With the opening of international trade, we show that manufacturing firms choose more advanced technologies and the equilibrium wage rate increases. The opening of international trade also leads to an increase in a country's steady-state capital stock. The opening of international trade is more beneficial to a country when a foreign country has a more efficient financial sector.

This paper is related to the literature on the impact of international trade on technology choice, as in the stimulating paper of Yeaple (2005). There are two significant differences between this paper and Yeaple. First, model specification is different. In his model, there are two technologies. In this model, there is a continuum of technologies. Second, the question addressed is different. Yeaple is mainly interested in demonstrating that technology choice can lead to firm heterogeneity. In this model, we do not address firm heterogeneity and instead focus on how the opening of trade induces firms to choose more advanced technologies. How financial development affects technology choice in an open economy is studied by Gong and Zhou (2014) in a general equilibrium model. One essential difference between that model and this one is that the amount of capital is exogenously given in that one-period model while it is endogenously determined in this infinite-horizon model. This endogeneity of capital allows us to address how the amount of capital changes with key parameters such as population size in a closed economy. Meanwhile, the endogeneity of capital allows an additional channel for the impact of the opening of international trade to affect a country's welfare. As a result, we show that the opening of international trade leads to a higher capital stock in the steady state.

This paper is also related to the literature on financial development. First, Saint-Paul (1992) studies how financial development affects economic development in a closed economy. Like this model, financial development affects technology choice in his model. One significant difference between his model and this one is that the two models differ in the specification of the financial sector. In his model, a more developed financial sector means a better possibility for the diversification of risk. In this model, a more developed financial sector means a smaller amount of resources used to provide the same level of financial service. With this difference in specification, the channels through which the financial sector influences the manufacturing sector are different between the two models. Second, for open economies, Kletzer and Bardhan (1987), Beck (2002), Matsuyama (2005), Ju and Wei (2011), and Egger and Keuschnigg (2017) have addressed how financial development affects a country's comparative advantage.[4] Third, Antras and Caballero (2009) and Wynne (2005) have studied the impact of financial efficiency in dynamic models of open economies. Wynne (2005) demonstrates that wealth distribution can affect the pattern of trade among countries. Antras and Caballero (2009) reveal that a country that is less constrained in external finance has a comparative advantage in the sector with a higher level of financial friction. There are two noteworthy differences between this paper and the above models. First, there is no financial friction in this model. Second, the above models do not focus on technology choices.

2. The home country in autarky

There are a home country and some foreign countries. In this section, we focus on the home country in autarky. Our model is in continuous time. Usually, superscript will be used to denote sectors of production and subscript will be used to denote time period. To avoid clutter, variables are frequently not indexed by time if there is no confusion from doing this.

There are two factors of production: capital and labor. While the initial aggregate capital stock is k_0, the total amount of capital available for the home country in period t is k_t. Capital is owned by individuals as assets. For simplicity, there is no depreciation of capital.

A consumer derives utility from two types of goods: an agricultural good and a continuum of manufactured goods. The agricultural good is used for consumption only, and it is produced under perfect competition. A manufactured good can be used either for consumption or investment. Manufactured goods are indexed by a number $\varpi \in [0,1]$ (He and Yu, 2015; Ji and Seater, 2020).[5] All manufactured goods are symmetric in the sense that they enter a consumer's utility in the same way, and they have the same production costs. To produce each manufactured good, banks provide capital to manufacturing firms and banks engage in Cournot competition. Firms producing the same manufactured good also engage in Cournot competition (Ishikawa, Sugita, and Zhao, 2009;

[4] In a stimulating paper, Kletzer and Bardhan (1987) demonstrate that a country with better enforcement of contracts or a smaller default risk has a comparative advantage in sectors requiring more credit. Beck (2002) captures financial friction with an iceberg type search cost. Matsuyama (2005) shows that a country with better corporate governance has comparative advantage in sectors relying more on external finance. Ju and Wei (2011) reveal that agency costs in the financial sector determines a country's comparative advantage if agency costs are sufficiently high. Egger and Keuschnigg (2017) establish that fundamental determinants of corporate finance affect a country's comparative advantage.

[5] Like Neary (2016), in a general equilibrium model with oligopoly, the motivation of specifying a continuum of manufactured goods rather than one manufactured good is to eliminate a bank's market power in the input market (attracting deposits) so that we can focus on a bank's market power in the output market (market for loans).

Zhou, 2018, 2021, 2022; Fujiwara and Kamei, 2018; Choi and Lim, 2019). There are two types of interest rates in this model: one is the interest rate banks pay to depositors and the other is the interest rate banks charge manufacturing firms. Since the latter is a markup over the former, the latter is higher than the former.

For the rest of this section, first, we study a consumer's utility maximization. Second, we derive a bank's optimal choice of output. Third, we address a manufacturing firm's profit maximization. Fourth, we examine the sector producing the investment good. Finally, we establish various market-clearing conditions, including markets for goods and factors of production.

2.1. Utility maximization

There are l individuals in the home country. Individuals live forever. In each period, an individual supplies one unit of labor inelastically at the wage rate w. An individual's discount rate is ρ. A consumer's consumption of the agricultural good in period t is c_t^a and her consumption of manufactured good ϖ in period t is $c_t(\varpi)$. For the constant $\alpha \in (0, 1)$, the utility function of a representative individual is

$$v_t = \alpha ln c_t^a + (1-\alpha)\int_0^1 ln c_t(\varpi) d\varpi, \tag{1}$$

$$u_t = \int_0^{\infty} e^{-\rho} \ v_t dt. \tag{2}$$

The price of the agricultural good is p_t^a and that of manufactured good ϖ is $p_t(\varpi)$. A consumer's expenditure in a period is $e_t \equiv p_t^a c_t^a + \int_0^1 p_t(\varpi) c_t(\varpi) d\varpi$. The interest rate a bank pays to a depositor is r_t. For an individual with assets a_t, the interest income in a period is $r_t a_t$ and the wage income is w_t, and her expenditure is e_t. Let a dot over a variable denote its time derivative. Thus, the evolution of assets for an individual is

$$\dot{a}_t = r_t a_t + w_t - e_t. \tag{3}$$

A consumer maximizes the utility function (2), subject to the constraint (3). A consumer's utility maximization can be handled in two stages. In the first stage, for a given level of expenditure e_t and prices of the agricultural good and manufactured goods, a consumer chooses c_t^a and $c_t(\varpi)$ to maximize her utility in period t. Utility maximization in the first stage yields

$$p_t^a c_t^a = \alpha e_t, \tag{4a}$$

$$\int_0^1 p_t(\varpi) c_t(\varpi) d\varpi = (1\text{-}\alpha) e_t, \tag{4b}$$

$$\frac{\partial c}{\partial p}\frac{p}{c} = -1. \tag{5}$$

From equations (4a) and (4b), a consumer's utility maximization leads to α percent of expenditure spent on the agricultural good and 1-α percent of expenditure spent on manufactured goods. From equation (5), the absolute value of a consumer's elasticity of demand for a manufactured good is one.

From (4a) and (4b), a consumer's utility in period t is

$$v_t = ln\left[\left(\frac{\alpha e_t}{p_t^a}\right)^{\alpha} \int_0^1 \left(\frac{(1-\alpha)e_t}{p_t(\varpi)}\right)^{1-\alpha} d\varpi\right]. \tag{6}$$

In the second stage, an individual chooses e_t to maximize (2), subject to constraint (3). With λ_t denoting the costate variable, the present value Hamiltonian is

$$e^{-\rho}\ ln\left[\left(\frac{\alpha e_t}{p_t^a}\right)^{\alpha} \int_0^1 \left(\frac{(1-\alpha)e_t}{p_t(\varpi)}\right)^{1-\alpha} d\varpi\right] + \lambda_t(r_t a_t + w_t - e_t).$$

An individual's optimal choice of expenditure e_t over time satisfies

$$\frac{\dot{e_t}}{e_t} = r_t - \rho. \tag{7}$$

The no-Ponzi-game condition is

$$\lim_{t\to\infty} a_t e^{-\int_0^t r_s ds} \geq 0.$$

2.2. The financial sector

Variables associated with the banking sector are usually identified with superscript b. A bank attracts deposits from individuals and provides loans to manufacturing firms. With increasing returns in both sectors, banks and manufacturing firms engage in Cournot competition. Like Salinger (1986), a bank does not think it can influence the price of a manufactured good, and a manufacturing firm does not think it can influence the interest rate charged by a bank. To capture increasing returns to scale in the financial sector, we assume that each bank needs a fixed cost of f^b units of labor to operate.[6] Since this fixed cost serves no other purpose, a higher fixed cost of operation indicates a less efficient financial sector.[7]

[6] One motivation for specifying labor as fixed costs in the financial sector is because employees in the financial sector have relatively stable long-term employment contracts (often with three to five year terms), and it takes time to recruit more employees.
[7] The fixed costs in the financial sector may be a result of governmental regulations and this type of regulations may not increase a bank's productivity. A higher level of fixed costs means a higher level of entry barrier into the financial sector.

For manufactured good ϖ, the number of identical banks providing financial services is $m^b(\varpi)$. The interest rate offered by a bank to depositors is r. The interest rate charged by a bank to a manufacturing firm for one unit of loan is z. For a bank attracting x^b units of deposits, this bank's revenue is zx^b. Since its fixed cost is $f^b w$ and its marginal cost is rx^b, its profit is $zx^b - f^b w - rx^b$. Since there is a continuum of manufactured goods and each manufactured good has serving banks, there is a continuum of banks in the home country. Thus, a bank does not have market power in the determination of interest rate paid to depositors and takes it as given.

In this model, a bank's lending rate depends neither on a borrowing firm's management nor on technology choice. This is different from the usual financial friction case. The reason for this difference is that there is no asymmetric information (arising from moral hazard or adverse selection) specified in this model. In a model with the existence of asymmetric information, a bank's optimal decision depends on the realization of output. Here, without asymmetric information, a bank just charges the same interest rate for any customer because there is no difference among customers.

Since banks serving the same manufactured good engage in Cournot competition, a bank chooses its quantity of deposits optimally to maximize its profit. The first order condition for a bank's optimal choice of quantity of deposits requires that $z + x^b \frac{\partial z}{\partial x^b} - r = 0$, or

$$z\left(1 + \frac{x^b}{z}\frac{\partial z}{\partial x^b}\right) - r = 0. \tag{8}$$

Equation (8) can be used to show strategic interaction among banks. Specifically, an increase in the output of a bank will lead to a decrease in output of other banks serving the same manufactured good.[8] This is a standard result in Cournot competition which shows that reaction functions of players are downward sloping.

For convenience, the number of banks serving a manufactured good is a real number rather than restricted to be an integer. This simplifies the presentation because the number of banks

[8] This result can be demonstrated clearly when there are only two banks. In this case, when a bank's output is x^b, suppose the other bank's output is x^{-b}. A bank's profit is $z(x^b, x^{-b})x^b - f^b w - rx^b$. Thus, the first order condition for a bank's optimal choice of output is $\Theta \equiv z(x^b, x^{-b}) + x^b \frac{\partial z(x^b, x^{-b})}{\partial x^b} - r = 0$. From the second order condition for a bank's optimal choice of output, we have $\frac{\partial \Theta}{\partial x^b} < 0$. Partially differentiating the first order condition, $\frac{\partial \Theta}{\partial x^{-b}} = \frac{\partial z(x^b, x^{-b})}{\partial x^b} + \frac{\partial^2 z(x^b, x^{-b})}{\partial x^b \partial x^{-b}}$, which is usually assumed to be negative in the industrial organization literature such as Zhou (2005). Thus, $\frac{\partial x^b}{\partial x^{-b}} = -\frac{\frac{\partial \Theta}{\partial x^{-b}}}{\frac{\partial \Theta}{\partial x^b}} < 0$. That is, a bank's reaction function is negatively sloped.

becomes a continuous rather than a discrete variable. With this specification, the number of banks serving a manufactured good is determined by the zero-profit condition:

$$zx^b - f^b w - rx^b = 0. \tag{9}$$

2.3. The manufacturing sector

For each manufactured good ϖ, there are $m(\varpi)$ identical firms producing it. To produce manufactured goods, since capital is frequently associated with machines and buildings, capital is specified as fixed costs of production. Labor is specified as the marginal cost of production in the manufacturing sector. This is because workers in the manufacturing sector often have short-term employment contracts, and this trend is accelerated by the increasing use of big data.[9]

To produce a manufactured good, there is a continuum of technologies indexed by a number $n \in R^1_+$ (Zhou, 2004, 2009; Ma, Wang, and Zeng, 2015). A higher value of n indicates a more advanced technology. For technology n, the fixed cost is $f(n)$ units of loan and the marginal cost is $\beta(n)$ units of labor. Both cost functions are assumed to be twice continuously differentiable in n. To capture the substitution between capital and labor in production, we assume that fixed costs increase with the level of technology while the marginal cost decreases with the level of technology. That is, $f'(n) > 0$ and $\beta'(n) < 0$.[10] More specifically, we specify the cost functions as follows:

$$f(n) = n^\theta, \tag{10a}$$

$$\beta(n) = n^{-h}, \tag{10b}$$

where θ and h denote positive constants.

The motivation of the specification in (10a) and (10b) is to ensure that a manufacturing firm's elasticity of demand for loan is constant. This specification plays a role like the specification of Cobb-Douglas utility function which ensures a consumer's constant elasticity of demand for goods.

[9] According to some recent surveys in China (Lu and Xiang 2022; Wang, Zhou, and Cui, 2020), blue collar workers, especially migrant workers, in the manufacturing sector mostly have flexible employment depending on the number of orders, which is highly seasonal. 91% of the workers mediated by a major blue collar job search platform are on their current jobs for less than 2 months, and 83.1% worked on their last jobs for less than 6 months.

[10] To make sure that a manufacturing firm's second order condition for technology choice is satisfied, we also assume that $f''(n) \geq 0$ and $\beta''(n) \geq 0$. That is, fixed costs increase with the level of technology at a nondecreasing rate and marginal cost decreases at a nonincreasing rate.

There are various examples that more advanced technologies are associated with higher fixed costs and lower marginal costs. First, compared with drilling and blasting in building tunnels, tunnel-boring machines have higher fixed costs of construction and transportation but lower marginal costs. The longer the tunnel (which maps into higher levels of output in the manufacturing sector in this model), the less the average cost using tunnel-boring machines compared with drilling and blasting methods. Second, before the adoption of containers, the loading and unloading of cargos were handled by longshoremen. Since specially designed cranes, containerships, and container ports had to be built to use containers, containerization means sharp rises in fixed costs. However, marginal costs of loading and unloading decrease sharply. Third, crude oil could be transported either by pipeline or by truck. While the fixed costs of building pipelines are larger than using trucks, marginal cost is lower. When high volume of oil needs to be transported, the larger fixed costs can be spread to a higher level of output and the average cost of using pipelines will be lower than that of using trucks.

For a manufacturing firm with output level $x(\varpi)$ charging price $p(\varpi)$, this firm's total revenue is $p(\varpi)x(\varpi)$ and its fixed cost is zf and marginal cost is $\beta x(\varpi)\, w(\varpi)$. Thus, its profit is $px - zf - \beta xw$. Since there is a continuum of manufacturing firms demanding labor in the home country, a manufacturing firm does not have market power in the determination of the wage rate and takes it as given. A manufacturing firm also takes the interest rate charged by a bank as given. A manufacturing firm chooses its level of output and its technology to maximize its profit. The first order condition for its optimal choice of output is

$$p + x\frac{\partial p}{\partial x} - \beta w = 0. \tag{11}$$

The first order condition for a manufacturing firm's optimal choice of technology is

$$f'z + \beta' xw = 0. \tag{12}$$

Like the number of banks, the number of manufacturing firms is determined by the zero-profit condition:[11]

$$px - fz - \beta xw = 0. \tag{13}$$

2.4. The investment good sector

[11] See Zhang (2007) for an example of models of Cournot competition with free entry.

The investment good sector is perfectly competitive. This sector combines manufactured goods to produce the investment good without incurring any additional cost. If the amount of manufactured good ϖ used for investment is $i_t(\varpi)$, the investment good is produced in the following way:

$$I_t = \int_0^1 ln i_t(\varpi) d\varpi. \tag{14}$$

A firm producing the investment good takes the prices of manufactured goods as given and chooses quantities of manufactured inputs to maximize profit. With the specification in (14), an investment firm's elasticity of demand for a manufactured good is

$$\frac{\partial i_t}{\partial p}\frac{p}{i_t} = -1. \tag{15}$$

2.5. Market-clearing conditions

For the market for loans for a manufactured good, each bank supplies x^b units of loan and the total amount of loan supplied by banks is $m^b x^b$. The total demand for loan equals total fixed costs mf. In equilibrium, for each manufactured good, the supply of loan should be equal to the demand for loan:

$$m^b x^b = mf. \tag{16}$$

For each manufactured good, the total amount of deposits is $m^b x^b$. Integrating over all manufactured goods, the total amount of deposits in the home country is $\int_0^1 m^b\, x^b d\varpi$. Since each of the l individuals has a units of assets, total assets are la. In equilibrium, the amount of deposits of banks $\int_0^1 m^b\, x^b d\varpi$ should be equal to total assets la of individuals:[12]

$$\int_0^1 m^b\, x^b d\varpi = la. \tag{17}$$

For the labor market, the total demand for labor is the sum of demand from the agricultural sector, the financial sector, and the manufacturing sector. The number of individuals employed in the agricultural sector is l^a, the demand for labor from the financial sector is $\int_0^1 m^b\, f^b d\varpi$, and the demand for labor from the manufacturing sector is $\int_0^1 m\, \beta x d\varpi$. Thus, total labor demand in a

[12] For each manufactured good, there are banks associated with it. The integration is over the range of manufactured goods. That is why the index is the same for manufactured goods and banks.

period is $l^a + \int_0^1 (m^b f^b + m\beta x)\, d\varpi$. Total supply of labor is l. Labor market clearance requires that quantity demanded equals quantity supplied:

$$l^a + \int_0^1 (m^b f^b + m\beta x)\, d\varpi = l. \tag{18}$$

Producing the agricultural good requires labor only. The agricultural sector has constant returns in production. Without further loss of generality, assume that each worker in the agricultural sector produces one unit of the agricultural good. Thus, for an individual employed in the agricultural sector, the return is p^a. For an individual employed in the manufacturing sector, the return is w. For an individual to be indifferent between working in the two sectors, the return in the two sectors should be equal:

$$p^a = w. \tag{19}$$

For the market for the agricultural good, each individual spends α percent of expenditure on the agricultural good and the total expenditure in a period is le. The total value of the supply of the agricultural good is $p^a l^a$. In a period, the clearance of the market for the agricultural good requires

$$p^a l^a = \alpha le. \tag{20}$$

For the market for manufactured goods, each individual spends $1-\alpha$ percent of expenditure on manufactured goods. The demand for manufactured goods is the sum of consumption demand $(1-\alpha)le$ and investment demand $P\dot{k}$. The total value of manufactured goods is $\int_0^1 mpx\, d\varpi$. In a period, the clearance of the market for manufactured goods requires

$$\int_0^1 mpx\, d\varpi = (1-\alpha)le + \dot{k}. \tag{21}$$

Manufactured goods can be used either for consumption or investment. The amount used for consumption is lc and the amount used for investment is i. Thus, the total demand for manufactured goods in a period is $lc + i$. Each of the m firms supplies x units of output, and the total supply of manufactured goods is mx. The clearance of the market for manufactured goods in a period requires

$$lc + i = mx. \tag{22}$$

Let x^j denote the level of output of a manufactured good producer j and x^{-j} denote the sum of other manufactured good producers' output. Then, $mx = x^j + x^{-j}$. In a Cournot-Nash equilibrium, when a manufacturing firm chooses its output x^j, it takes output of other manufacturing firms x^{-j} as given. With this in mind, partial differentiating equation (22) and combining the result with equations (5) and (15) yields

$$\frac{\partial x^j}{\partial p}\frac{p}{x^j} = \frac{\partial(x^j + x^{-j})}{\partial p}\frac{p}{x^j} = l\frac{\partial c_t}{\partial p}\frac{p}{x^j} + \frac{\partial i}{\partial p}\frac{p}{x^j}$$

$$= \frac{\partial c_t}{\partial p}\frac{p}{c}\frac{Lc}{x^j} + \frac{\partial i}{\partial p}\frac{p}{x^j} = -\frac{lc}{x^j} + \frac{\partial i}{\partial p}\frac{p}{x^j} = -\frac{1}{m}. \quad (23)$$

Plugging equation (23) into equation (11) yields the following relationship between a manufacturing firm's price and its marginal cost:

$$p\left(1 - \frac{1}{m}\right) = \beta w. \quad (24)$$

Plugging equations (10a) and (10b) into equation (12) yields $\frac{z}{f}\frac{\partial f}{\partial z} = -\frac{\theta}{\theta + h}$. That is, with the specification of cost functions in (10a) and (10b), a manufacturing firm's elasticity of demand for capital is constant. Let x^{-b} denote the sum of other banks' output. Like the derivation of equation (23), from equation (16), it can be shown that

$$\frac{\partial x^b}{\partial z}\frac{z}{x^b} = \frac{\partial(x^b + x^{-b})}{\partial z}\frac{z}{x^b} = \frac{\partial(mf)}{\partial z}\frac{z}{f}\frac{f}{x^b} = \frac{\partial(f)}{\partial z}\frac{z}{f}\frac{mf}{x^b} = -\frac{\theta m^b}{\theta + h}.$$

Combining this result with equation (8), the relationship between a bank's marginal cost and the price it charges is given by

$$z\left(1 - \frac{\theta + h}{\theta m^b}\right) = r. \quad (25)$$

In each period, total capital stock is equal to the total amount of assets owned by individuals: $k = la$. This equation will be used to eliminate the variable k in the steady state.

For the remaining of the paper, a manufactured good is used as the numeraire: $p \equiv 1$.

3. The steady state

In the steady state, variables do not change over time. Therefore, we drop the time subscript for variables in the steady state. We focus on a symmetric equilibrium in which the number of producers, the level of output, the price, the level of technology, and the level of consumption for all manufactured goods are the same.

3.1. Stability of the steady state

The interest rate paid to depositors can be expressed as $r = \frac{(1-\alpha)lc}{k^2} - \frac{1}{k^2}\sqrt{\frac{(1-\alpha)(\theta+h)f^b f(k-f)lc}{\theta\beta}}$.[13] Plugging this interest rate into equations (7), the evolution of the expenditure per capita is given by

$$\Psi_1 \equiv \dot{e} = e\left\{\frac{(1-\alpha)lef}{k^2} - \frac{1}{k^2}\sqrt{\frac{(1-\alpha)(\theta+h)f^b f(\sigma k-f)le}{\theta\beta}} - \rho\right\}. \tag{26a}$$

Plugging the interest rate paid to depositors and the value of w from equation (24) into equations (3), the evolution of aggregate capital stock is given by

$$\Psi_2 \equiv \dot{k} = \frac{(1-\alpha)lef}{k} - \frac{1}{k}\sqrt{\frac{(1-\alpha)(\theta+h)f^b f(k-f)le}{\theta\beta}} - \frac{L}{\beta}\left(1-\frac{f}{k}\right) - le. \tag{26b}$$

Equations (26a) and (26b) form a system of two equations defining the evolution of expenditure and aggregate capital stock around the steady state. Plugging the value of x from equation (13) and the value of w from equation (24) into equation (12), and using k/f to replace m, we get

$$f'\beta + \beta'(k-f) = 0. \tag{27}$$

Here $f(n)$ and $\beta(n)$ depend on k through equation (27). Let $\bar{e}$ and $\bar{k}$ denote the amount of per capita expenditure and aggregate capital stock in the steady state respectively. Linearizing equations (26a) and (26b) around the steady state yields

$$\begin{pmatrix}\dot{e}\\ \dot{k}\end{pmatrix} = \begin{pmatrix}\frac{\partial\Psi_1}{\partial e} & \frac{\partial\Psi_1}{\partial k}\\ \frac{\partial\Psi_2}{\partial e} & \frac{\partial\Psi_2}{\partial k}\end{pmatrix}\begin{pmatrix}e-\bar{e}\\ k-\bar{k}\end{pmatrix}. \tag{28}$$

We now study the stability of the steady state. From equation (26a), $\frac{\partial\Psi_1}{\partial e} = 0$. From equation (26b), $\frac{\partial\Psi_2}{\partial e} < 0$. First, suppose the level of technology is exogenously given (f and β do not depend on n). For the system of equations (26a) and (26b) with $\frac{\partial\Psi_1}{\partial k} < 0$, the determinant of

[13] The derivation of the interest rate paid to depositors is as follows. From equation (9), $x^b = \frac{f^b w}{z-r}$. Combining this result with equations (16) and (17) yields $m^b = \frac{K(z-r)}{f^b w}$. Plugging this value of m^b into equation (25) yields $r = z - \sqrt{\frac{(\theta+h)f^b wz}{\theta k}}$. From equation (21) in the steady state, $x = \frac{(1-\alpha)lef}{k}$. Plugging this result into equation (13) yields $z = \frac{(1-\alpha)lef}{k^2}$. From equation (24), $w = \frac{1}{\beta}\left(1-\frac{f}{k}\right)$. Plugging z and w into the expression of r yields $r = \frac{(1-\alpha)lc}{k^2} - \frac{1}{k^2}\sqrt{\frac{(1-\alpha)(\theta+h)f^b f(k-f)lc}{\theta\beta}}$.

(28) is negative. With $\frac{\partial \Psi_2}{\partial k} = 0$, there are a positive and a negative characteristic root. Thus, the steady state for the system of equations (26a) and (26b) is a saddle path. Second, when the level of technology is endogenously chosen, plugging marginal and fixed costs in (10a) and (10b) into equation (27) yields $n = \left(\frac{hk}{h+\theta}\right)^{\frac{1}{\theta}}$. Plugging this value of n into equations (26a) and (26b), the dynamics of the system is defined by

$$\Phi_1 \equiv \dot{e} = e\left\{\frac{(1-\alpha)hle}{(h+\theta)k} - \frac{1}{k}\sqrt{\frac{(1-\alpha)hf^b le}{\theta+h}\left(\frac{hk}{\theta+h}\right)^{\frac{h}{\theta}}} - \rho\right\}, \tag{29a}$$

$$\Phi_2 \equiv \dot{k} = \frac{(1-\alpha)hl}{\theta+h} - \sqrt{\frac{(1-\alpha)hf^b le}{\theta+h}\left(\frac{hk}{\theta+h}\right)^{\frac{h}{\theta}}} - \frac{\theta l}{\theta+h}\left(\frac{hk}{\theta+h}\right)^{\frac{h}{\theta}} - le. \tag{29b}$$

With $\frac{\partial \Phi_1}{\partial e} = 0$, $\frac{\partial \Phi_2}{\partial c} < 0$, and $\frac{\partial \Phi_1}{\partial k} < 0$, the determinant of the linearized system of (29a) and (29b) is negative. That is, when the level of technology is optimally chosen, the steady state described by equations (29a) and (29b) is also a saddle path.

3.2. Properties of the steady state

From equation (7), the interest rate paid to depositors equals the discount rate in the steady state:

$$r = \rho. \tag{30}$$

In the steady state, equations (9), (12)-(13) and (16)-(21), (24)-(25), and (30) form a system of twelve equations defining twelve variables e, l^a, k, w, r, m, m^b, p, n, z, x, and x^b as functions of exogenous parameters. An equilibrium in a closed economy is a tuple (e, l^a, k, w, r, m, m^b, p, n, z, x, x^b) satisfying equations (9), (12)-(13), (16)-(21), (24)-(25), and (30). Since the total measure of manufactured goods is one and all manufactured goods are symmetric, we drop the integration operator for the manufacturing sector.

To make the analysis manageable, we simplify the system of twelve equations defining the autarky equilibrium to the following system of three equations defining three variables n, w, and z as functions of exogenous parameters:[14]

[14] The derivation of (31a) - (31c) is as follows. First, plugging the value of x from equation (13) into equation (12) yields equation (31a). Second, equation (31b) comes from plugging the value of x^b from equation (9), the value of m from equation (24), the value of m^b from equation (25), and the value of r from equation (30) into equation (16).

$$\Gamma_1 \equiv -f'(1-\beta w) - \beta' f w = 0, \tag{31a}$$

$$\Gamma_2 \equiv \frac{f}{1-\beta w} - \frac{(\theta+h) z w f^b}{\theta (z-\rho)^2} = 0, \tag{31b}$$

$$\Gamma_3 \equiv (1-\alpha)[(1-\beta w)^2 w l - (1-\beta w)\rho f] - f z = 0. \tag{31c}$$

Partial differentiating equations (31a)-(31c) with respect to n, w, z, ρ, l, and f^b yields[15]

$$\begin{pmatrix} \frac{\partial \Gamma_1}{\partial n} & \frac{\partial \Gamma_1}{\partial w} & 0 \\ 0 & \frac{\partial \Gamma_2}{\partial w} & \frac{\partial \Gamma_2}{\partial z} \\ \frac{\partial \Gamma_3}{\partial n} & \frac{\partial \Gamma_3}{\partial w} & \frac{\partial \Gamma_3}{\partial z} \end{pmatrix} \begin{pmatrix} dn \\ dw \\ dz \end{pmatrix} = -\begin{pmatrix} 0 \\ \frac{\partial \Gamma_2}{\partial \rho} \\ 0 \end{pmatrix} d\rho - \begin{pmatrix} 0 \\ 0 \\ \frac{\partial \Gamma_3}{\partial l} \end{pmatrix} dl - \begin{pmatrix} 0 \\ \frac{\partial \Gamma_2}{\partial f^b} \\ 0 \end{pmatrix} df^b. \tag{32}$$

Let Δ denote the determinant of the coefficient matrix of endogenous variables of (32). According to the correspondence principle (Samuelson, 1983, chap. 9), stability requires that $\Delta < 0$.

A country has a comparative advantage in producing manufactured goods if its relative price of manufactured goods to that of the agricultural good is lower. Since the price of a manufactured good is equal to one and the price of the agricultural good is equal to the wage rate in this model, a country has a comparative advantage in producing manufactured goods if the wage rate is higher.

Empirical studies show that countries have highly different saving rates, which could be the result that individuals in different countries differ in their discount rates. The following proposition studies the impact of a change in the discount rate on the equilibrium level of technology and other variables.

Proposition 1: In the steady state, a country with a higher discount rate has a comparative disadvantage in producing manufactured goods, manufacturing firms choose less advanced technologies, and the amount of capital decreases with the discount rate.

Proof: Since $z > \rho$, partial differentiating equations (31b) and (31c) yields

$$\frac{\partial \Gamma_2}{\partial \rho}\frac{\partial \Gamma_3}{\partial z} - \frac{\partial \Gamma_2}{\partial z}\frac{\partial \Gamma_3}{\partial \rho} = \frac{(\theta+h) f w f^b}{\theta (z-\rho)^3}[2z - (1-\alpha)(1-\beta w)(\rho + z)] > 0.$$

Applying Cramer's rule on (32) yields

Third, equation (31c) comes from dividing equation (20) by equation (21) and plugging the value of x from equation (13), the value of l^a from equation (18), the value of p^a from equation (19), and the value of m from equation (24) into the resulting equation and combining with equation (31b).

[15] Equation (31a) is used to show $\frac{\partial \Gamma_2}{\partial n} = 0$.

$$\frac{dn}{d\rho} = \frac{\partial\Gamma_1}{\partial w}\left(\frac{\partial\Gamma_2}{\partial\rho}\frac{\partial\Gamma_3}{\partial z} - \frac{\partial\Gamma_2}{\partial z}\frac{\partial\Gamma_3}{\partial\rho}\right)/\Delta < 0,$$

$$\frac{dw}{d\rho} = \frac{\partial\Gamma_1}{\partial n}\left(\frac{\partial\Gamma_2}{\partial z}\frac{\partial\Gamma_3}{\partial\rho} - \frac{\partial\Gamma_2}{\partial\rho}\frac{\partial\Gamma_3}{\partial z}\right)/\Delta < 0.$$

With $k = mf = \frac{f}{1-\beta w}$, $\frac{dk}{d\rho} = \frac{dk}{dn}\frac{dn}{d\rho} + \frac{dk}{dw}\frac{dw}{d\rho} = \frac{dk}{dw}\frac{dw}{d\rho} < 0$ since $\frac{dk}{dn} = 0$ from equation (31a). ■

The intuition behind Proposition 1 is as follows. When the discount rate increases, since individuals are less concerned about their future, the steady-state capital stock decreases. With a smaller amount of capital, manufacturing firms choose less advanced technologies. A less advanced technology is associated with a higher average cost of production in the manufacturing sector and a comparative disadvantage in producing manufactured goods. A higher average cost means a lower productivity and thus a lower equilibrium wage rate.

When the discount rate increases, the impact on the interest rate charged by a bank for providing loans to manufacturing firms is ambiguous. The reasoning is as follows. With a higher discount rate, the steady-state capital is lower, and this tends to reduce the number of banks. However, with a lower wage rate, a bank's fixed costs decrease, and this tends to increase the number of banks. With the two effects working in opposite directions, it is not clear whether the equilibrium number of banks will increase. The number of banks is a measure of the degree of competition in the financial sector. Since we are not sure whether the degree of competition in the financial sector increases or not, the impact of a change in the discount rate on the interest rate charged by a bank for providing loans is ambiguous.

As illustrated in Adam Smith's pin factory, technology choice is likely to be affected by market size. Other things being equal, a higher population size means a higher market size. The following proposition addresses the impact of population size on technology choice.

Proposition 2: In the steady state, an increase in population size leads manufacturing firms to choose more advanced technologies. While the equilibrium wage rate and aggregate capital stock increase, the interest rate charged by a bank for providing loans decreases.

Proof: Applying Cramer's rule on (32) yields

$$\frac{dn}{dl} = -\frac{\partial\Gamma_1}{\partial w}\frac{\partial\Gamma_2}{\partial z}\frac{\partial\Gamma_3}{\partial l}/\Delta > 0,$$

$$\frac{dw}{dl} = \frac{\partial \Gamma_1}{\partial n}\frac{\partial \Gamma_2}{\partial z}\frac{\partial \Gamma_3}{\partial l}/\Delta > 0,$$

$$\frac{dz}{dl} = -\frac{\partial \Gamma_1}{\partial n}\frac{\partial \Gamma_2}{\partial w}\frac{\partial \Gamma_3}{\partial l}/\Delta < 0.$$

With $k = \frac{f}{1-\beta w}$, $\frac{dk}{dl} = \frac{dk}{dw}\frac{dw}{dl} > 0$. ■

The result here that the wage rate increases with population size reflects the assumption of increasing returns to scale in producing manufactured goods. The intuition behind Proposition 2 is as follows. Other things equal, an increase in market size increases the demand for each manufactured good. This makes the adoption of more advanced technologies more profitable because the higher fixed cost of a more advanced technology can be spread over a higher level of output. Thus, average cost of producing a manufactured good decreases. Since the price of a manufactured good is normalized to one, a lower average cost in producing manufactured goods shows up as a higher wage rate because the price is equal to average cost when firms earn zero-profits. To produce a higher total level of output, the number of manufacturing firms will not decrease. Since each manufacturing firm uses a higher amount of capital, the total amount of capital in the steady state increases. When the amount of capital increases, the number of banks will not decrease. A higher level of competition in the financial sector leads to a lower interest rate charged by banks.

The following proposition studies the impact of a change in financial efficiency on technology choice and the steady-state capital stock.

Proposition 3: In the steady state, manufacturing firms in a country with a more efficient financial sector choose more advanced technologies and this country has a comparative advantage in producing manufactured goods. Aggregate capital stock increases with the level of efficiency in the financial sector.

Proof: Applying Cramer's rule on (32) yields

$$\frac{dn}{df^b} = \frac{\partial \Gamma_1}{\partial w}\frac{\partial \Gamma_2}{\partial f^b}\frac{\partial \Gamma_3}{\partial z}/\Delta < 0,$$

$$\frac{dw}{df^b} = -\frac{\partial \Gamma_1}{\partial n}\frac{\partial \Gamma_2}{\partial f^b}\frac{\partial \Gamma_3}{\partial z}/\Delta < 0.$$

With $k = \frac{f}{1-\beta w}$, $\frac{dk}{df^b} = \frac{dK}{dw}\frac{dw}{df^b} < 0$. ■

The intuition behind Proposition 3 is as follows. A higher level of efficiency in the financial sector generates two effects. First, a more efficient financial sector leads to a lower interest rate charged by a bank for its loans, and a lower cost of getting loans from banks encourages a manufacturing firm to adopt a more advanced technology. Second, a more efficient financial sector releases resources for production from the financial sector into the manufacturing sector. More factors of production leads to a higher level of output in the manufacturing sector, which makes the adoption of more advanced technologies profitable. With a higher level of output, steady-state capital stock increases.

When the level of financial efficiency increases, the impact on the interest rate charged by a bank for providing loans is ambiguous. The reasoning is as follows. With $f^b w$ as a bank's fixed costs, when f^b decreases, fixed costs do not necessarily decrease because the wage rate w increases. Since the impact of an increase in the level of financial efficiency on the number of competing banks is ambiguous, the impact on the interest rate charged by a bank is ambiguous.

For empirical research, Chen, Poncet, and Xiong (2020) show that the development of city commercial banks in China helps domestic private firms in exporting. Their finding is consistent with Proposition 3 that an increase in the level of financial efficiency improves a country's comparative advantage in the manufacturing sector.

4. Equilibrium with international trade

In this section, we study the impact of international trade on a manufacturing firm's technology choice. We focus on the steady state. For τ denoting a nonnegative real number, the number of identical foreign countries is τ. We use capitalized letters to denote foreign variables. For example, the wage rate in a foreign country is W. A foreign country is identical to the home country except that the two countries may have different population sizes and different levels of efficiency in the financial sector. Without loss of generality, assume a foreign country is less efficient in the financial sector than the home country: $F^b > f^b$. There is no factor mobility between countries. Since we assume no capital mobility in this model, the clearance of the market for capital with international trade in each country is like that in the autarky case.

With the opening of international trade, from Proposition 3, the home country will export manufactured goods. In this model the trade pattern in which manufacturing firms engage in oligopolistic competition is different from that in a model in which manufacturing firms engage in monopolistic competition. If the type of market structure is monopolistic competition, with unlimited number of varieties, to avoid competition a manufacturing firm will always produce a variety different from others. Thus, a manufacturing firm in the country with a lower population can sell its product to the country with a higher population because it is the only firm in the world producing this manufactured good. That is, countries engage in intra-industry trade under monopolistic competition. In this model with oligopolistic competition, the number of varieties shown as the measure of manufactured goods is fixed. From Proposition 2, a manufacturing firm in the country with a higher population has a higher scale of production which leads to a lower average cost and a lower price. A manufacturing firm in the country with a lower population will not be able to sell its product to the country with a higher population. Countries thus engage in inter-industry trade: the country with a higher population exports manufactured goods to other countries in exchange for the agricultural good. As we are going to see in Proposition 5, this difference in the specification of market structure affects the impact of international trade on a manufacturing firm's technology choice.

There is no transportation cost among countries. With the opening of international trade, prices of the agricultural good and manufactured goods will be the same in all countries since markets are integrated.

Like equation (24), with international trade, a domestic manufacturing firm's optimal choice of output yields

$$p\left(1-\frac{x}{mx+\tau MX}\right)=\beta(n)w. \tag{33}$$

In equation (33), when the number of foreign countries τ equals zero, this equation degenerates to equation (24), the autarky case.

Like equation (33), a foreign manufacturing firm's optimal choice of output yields

$$p\left(1-\frac{X}{mx+\tau MX}\right)=\beta(N)W. \tag{33*}$$

For the market for the agricultural good, each individual spends α percent of expenditure on the agricultural good and the total world expenditure in a period is $(le+\tau LE)$. Thus, total world demand for the agricultural good is $\alpha(le+\tau LE)$. Total value of the world supply of the agricultural good is $p^a(l^a+\tau L^a)$. The clearance of the world market for the agricultural good requires

$$p^a(l_a+\tau L_a)=\alpha(le+\tau LE). \tag{34}$$

For the market for manufactured goods, each individual spends $1-\alpha$ percent of expenditure on manufactured goods. Thus, total demand for manufactured goods is $(1-\alpha)(le+\tau LE)$. In the steady state, the amount of investment is zero. Total value of the supply of manufactured goods is $\int_0^1 p(mx+\tau MX)d\varpi$. The clearance of the world market for manufactured goods requires

$$\int_0^1 p(mx+\tau MX)d\varpi = (1-\alpha)(le+\tau LE). \tag{35}$$

With the opening of international trade, equations (9), (12)-(13), (16)-(18), (21), (25), and (30) are still valid. A corresponding set of equations (9*), (12*)–(13*), (16*)-(18*), (21*), (25*), and (30*) is valid for a foreign country:

$$ZX^b - F^b W - RX^b = 0, \tag{9*}$$

$$f'(N)Z + \beta'(N)XW = 0, \tag{12*}$$

$$pX - f(N)Z - \beta(N)XW = 0, \tag{13*}$$

$$\int_0^1 M^b X^b d\varpi = \int_0^1 M f(N) d\varpi, \tag{16*}$$

$$\int_0^1 M^b X^b d\varpi = K, \tag{17*}$$

$$L^a + \int_0^1 (M^b F^b + M\beta(N)X)\, d\varpi = L, \tag{18*}$$

$$p^a = W, \tag{19*}$$

$$Z\left(1 - \frac{\theta+h}{\theta M^b}\right) = R, \tag{25*}$$

$$R = \rho. \tag{30*}$$

Equations (9), (12)-(13), (16)-(19), (25), (30), (9*), (12*)-(13*), (16*)-(19*), (25*), (30*), (33), (33*), (34), and (35) form a system of 23 equations defining a set of 23 variables e, E, l^a, L^a, k, K, w, W, r, R, m, M, m^b, M^b, p, p_t^a, n, z, Z, x, X, x^b, and X^b as functions of exogenous parameters for the equilibrium with international trade.

From equations (19) and (19*), since countries have the same technology in the agricultural sector, the wage rate will be equal in all countries, i.e., $w = W$. From equations (30) and (30*), the interest rate paid to depositors will be equal for countries: $r = R$. From equation (31a) and the corresponding equation for a foreign country, since technology choice depends on the wage rate only and countries have the same wage rate, manufacturing firms in different countries choose the same technology in equilibrium: $n = N$. From equations (33) and (33*), the level of output of a domestic manufacturing firm equals that of a foreign manufacturing firm: $x = X$. From equations

(13) and (13*), the interest rate charged by a bank for providing loans will be the same in all countries: $z = Z$.

From (9) and (9*), since a foreign country is less efficient in the financial sector than the home country, the level of output of a foreign bank will be higher than that of a domestic bank: $X^b > x^b$.[16] Compared with the home country, a foreign country has a lower number of workers employed in the agricultural sector.

The set of 23 equations defining the equilibrium with international trade can be reduced to the following set of three equations defining three variables n, w, and z as functions of exogenous parameters:[17]

$$\Lambda_1 \equiv -f'(1-\beta w) - \beta' f w = 0, \tag{36a}$$

$$\Lambda_2 \equiv \frac{f}{1-\beta w} - \frac{(\theta+h)zw(f^b+\tau F^b)}{\theta(z-\rho)^2} = 0, \tag{36b}$$

$$\Lambda_3 \equiv (1-\alpha)[w(1-\beta w)^2(l+\tau L) - (1-\beta w)\rho f] - fz = 0. \tag{36c}$$

Partial differentiating equations (36a) - (36c) with respect to n, w, z, L, and F^b yields

$$\begin{pmatrix} \frac{\partial \Lambda_1}{\partial n} & \frac{\partial \Lambda_1}{\partial w} & 0 \\ 0 & \frac{\partial \Lambda_2}{\partial w} & \frac{\partial \Lambda_2}{\partial z} \\ \frac{\partial \Lambda_3}{\partial n} & \frac{\partial \Lambda_3}{\partial w} & \frac{\partial \Lambda_3}{\partial z} \end{pmatrix} \begin{pmatrix} dn \\ dw \\ dz \end{pmatrix} = -\begin{pmatrix} 0 \\ 0 \\ \frac{\partial \Lambda_3}{\partial L} \end{pmatrix} dL - \begin{pmatrix} 0 \\ 0 \\ \frac{\partial \Lambda_3}{\partial F^b} \end{pmatrix} dF^b. \tag{37}$$

Let Δ_T denote the determinant of the coefficient matrix of endogenous variables of (37). Stability requires that $\Delta_T < 0$.

The following proposition studies the impact of a change in the level of efficiency in the financial sector of a foreign country.

Proposition 4: An increase in the level of financial efficiency in a foreign country leads domestic manufacturing firms to choose more advanced technologies and the equilibrium wage rate increases.

Proof: Applying Cramer's rule on (37) yields

[16] Since fixed costs of a bank are just operation costs and a higher level of output is needed to cover a higher level of fixed costs, a bank's output is inversely related to its efficiency.

[17] Equation (36b) is derived by using the value of $m + \tau M$ from equation (33). Dividing equation (34) by equation (35), plugging the value of x from equation (13), the value of X from equation (13*), the value of l^a from equation (18), the value of L^a from equation (18*), the value of p^a from equation (21), and the value of $m + \tau M$ from equation (33) into the resulting equation lead to equation (36c).

$$\frac{dn}{dF^b} = \frac{\partial \Lambda_1}{\partial w}\frac{\partial \Lambda_2}{\partial F^b}\frac{\partial \Lambda_3}{\partial z}/\Delta_T < 0,$$
$$\frac{dw}{dF^b} = -\frac{\partial \Lambda_1}{\partial n}\frac{\partial \Lambda_2}{\partial F^b}\frac{\partial \Lambda_3}{\partial z}/\Delta_T < 0. \blacksquare$$

Proposition 4 shows that an improvement in the level of financial efficiency in a foreign country will benefit the domestic country. When foreign financial efficiency increases, with resources released from the financial sector in a foreign country, output in the manufacturing sector increases. This leads to the adoption of more advanced technologies in the manufacturing sector.

When $\tau = 0$, there is no international trade and equations (36a) -(36c) degenerate to equations (31a) -(31c). When τ is positive, there is international trade. Thus, the impact of the opening of international trade can be captured by an increase in the value of τ. The following proposition studies the impact of the opening of international trade on endogenous variables such as the equilibrium level of technology.

Proposition 5: In the steady state, the opening of international trade among similar countries leads to the adoption of more advanced technologies. Aggregate capital stock and the wage rate increase. The impact of international trade on the interest rate charged by banks to manufacturing firms is ambiguous.[18]

Proof: Applying Cramer's rule on (37) yields

$$\frac{dn}{d\tau} = \frac{\partial \Lambda_1}{\partial w}\left(\frac{\partial \Lambda_2}{\partial \tau}\frac{\partial \Lambda_3}{\partial z} - \frac{\partial \Lambda_2}{\partial z}\frac{\partial \Lambda_3}{\partial \tau}\right)/\Delta_T,$$
$$\frac{dw}{d\tau} = \frac{\partial \Lambda_1}{\partial n}\left(\frac{\partial \Lambda_2}{\partial z}\frac{\partial \Lambda_3}{\partial \tau} - \frac{\partial \Lambda_2}{\partial \tau}\frac{\partial \Lambda_3}{\partial z}\right)/\Delta_T,$$
$$\frac{dz}{d\tau} = \left(\frac{\partial \Lambda_1}{\partial n}\frac{\partial \Lambda_2}{\partial \tau}\frac{\partial \Lambda_3}{\partial w} - \frac{\partial \Lambda_1}{\partial n}\frac{\partial \Lambda_2}{\partial w}\frac{\partial \Lambda_3}{\partial \tau} - \frac{\partial \Lambda_1}{\partial w}\frac{\partial \Lambda_2}{\partial \tau}\frac{\partial \Lambda_3}{\partial n}\right)/\Delta_T.$$

Partial differentiation of (36b) and (36c) yields

$$\frac{\partial \Lambda_2}{\partial \tau}\frac{\partial \Lambda_3}{\partial z} - \frac{\partial \Lambda_2}{\partial z}\frac{\partial \Lambda_3}{\partial \tau} = \frac{(\theta+h)w}{\theta(z-\rho)^2}\left(zfF^b - \frac{(1-\alpha)wL(f^b+\tau F^b)(z+\rho)(1-\beta w)^2}{z-\rho}\right)$$
$$= \frac{(\theta+h)(1-\alpha)(1-\beta w)w}{\theta(z-\rho)^2}\left[w(l+\tau L)(1-\beta w)F^b + \rho f F^b - wL(1-\beta w)(f^b+\tau F^b)\frac{z+\rho}{z-\rho}\right].$$

[18] The intuition behind this result is as follows. While a higher wage rate tends to cause the interest rate charged by a bank for providing loans to increase, a higher capital stock tends to cause the interest rate charged by a bank to decrease. Overall, the impact of the opening to international trade on the interest rate charged by a bank for providing loans is ambiguous.

In general, the sign of $\frac{\partial \Lambda_2}{\partial \tau}\frac{\partial \Lambda_3}{\partial z} - \frac{\partial \Lambda_2}{\partial z}\frac{\partial \Lambda_3}{\partial \tau}$ is ambiguous. However, for countries with the same level of financial efficiency and the same population size, $w(l+\tau L)(1-\beta w)F^b + \rho f F^b - wL(1-\beta w)(f^b+\tau F^b)\frac{z+\rho}{z-\rho} = \rho f^b(1-\beta w)\left[\frac{f}{1-\beta w} - \frac{2wl(1+\tau)}{z-\rho}\right] < 0$ because total payment to banks $\frac{zf}{1-\beta w}$ is smaller than the sum of labor income $2wl$ and capital income $\frac{\rho f}{1-\beta w}$: $\frac{zf}{1-\beta w} < \frac{\rho f}{1-\beta w} + 2wl$. In this case, $\frac{\partial \Lambda_2}{\partial \tau}\frac{\partial \Lambda_3}{\partial z} - \frac{\partial \Lambda_2}{\partial z}\frac{\partial \Lambda_3}{\partial \tau} < 0$, thus $\frac{dn}{d\tau} > 0$ and $\frac{dw}{d\tau} > 0$. With $\frac{dk}{d\tau} = \frac{dk}{dw}\frac{dw}{d\tau}$, $\frac{dk}{d\tau} > 0$ if $\frac{dw}{d\tau} > 0$.

Since the sign of $\frac{\partial \Lambda_1}{\partial n}\frac{\partial \Lambda_2}{\partial \tau}\frac{\partial \Lambda_3}{\partial w} - \frac{\partial \Lambda_1}{\partial n}\frac{\partial \Lambda_2}{\partial w}\frac{\partial \Lambda_3}{\partial \tau} - \frac{\partial \Lambda_1}{\partial w}\frac{\partial \Lambda_2}{\partial \tau}\frac{\partial \Lambda_3}{\partial n}$ is ambiguous, the sign of $\frac{dz}{d\tau}$ is ambiguous. ■

Proposition 5 is valid for countries with the same level of financial efficiency and the same population size. Because the wage rate and the level of technology are continuous functions of the parameters, for countries with close enough levels of efficiency in the financial sector and population sizes, Proposition 5 should also hold.

Proposition 5 shows that the result in Gong and Zhou (2014) that the opening of international trade induces firms to adopt more advanced technologies is robust to this alternative setup of endogenous capital. With the opening of international trade, a domestic manufacturing firm's technology choice is affected by two additional factors: the level of efficiency in a foreign country's financial sector and foreign population size. While an increase in the population size of a foreign country tends to induce a domestic manufacturing firm to choose a more advanced technology, a decrease in financial efficiency in a foreign country tends to lead a domestic manufacturing firm to choose a less advanced technology. When countries are the same in terms of population size and financial efficiency, the first effect still exists and the second one disappears, thus a domestic manufacturing firm chooses a more advanced technology with the opening of international trade.

How robust is this result that the opening of international trade leads to the adoption of more advanced technologies? Proposition 5 is based on the specification that manufacturing firms engage in oligopolistic competition. With oligopolistic competition, the opening of international trade leads to an increase in the output of a manufacturing firm and thus the choice of a more advanced technology. With monopolistic competition and constant elasticity of demand for a consumer, the opening of international trade leads to an increase in the number of manufacturing firms and the level of output of a manufacturing firm does not change (Krugman, 1980). That is, for international trade based on imperfect competition, if the type of market structure is monopolistic competition and a consumer's elasticity of demand is constant, the opening of international trade will not lead to the adoption of more advanced technologies because a manufacturing firm's output does not change with the opening of international trade. However, the constant elasticity assumption is adopted mainly for convenience. If this assumption is dropped, the opening of international trade under monopolistic competition will lead to increases in the number of varieties and output simultaneously, thus the opening of international trade will lead to the adoption of more advanced technologies!

Since the interest rate paid to depositors does not change and the capital stock increases, an individual's income from owning capital is higher with the opening of international trade among similar countries. Because the wage income is also higher, an individual's overall income is higher. Since the price of a manufactured good does not change and the price of the agricultural good increases at the same rate as the wage rate, an individual always benefits from the opening of international trade with similar countries.

5. Conclusion

In this paper, we have studied how a firm's technology choice is affected by international trade in a general equilibrium model in which banks and manufacturing firms engage in oligopolistic competition and the amount of capital stock is determined endogenously. Since technology advances are represented by higher capital stock solely, this paper differs from the trade and growth literature. Differing from the trade literature of imperfection competition based on monopolistic competition, this paper has inter-industry trade rather than intra-industry trade. Different from the literature on financial development and international trade usually examining the effects of financial frictions, this paper assumes banks engaging in oligopolistic competition without financial frictions.

The model is tractable, and we have established the following analytical results. In the steady state, a country with a higher population has a higher wage rate and manufacturing firms adopt more advanced technologies. A country with a more efficient financial sector has a higher steady-state capital stock and a comparative advantage in producing manufactured goods. With the opening of international trade among similar countries, a country's capital stock increases, manufacturing firms choose more advanced technologies, and the equilibrium wage rate increases.

The model has various specifications, such as technological advances imply more fixed capital inputs and financial development equals to less bank employments. Based on those assumptions we show that a financial development can bring out more capital accumulation, and hence leads to more advanced technologies. How robust is this main result? We believe that alternative specifications keeping the tradeoff between marginal and fixed costs and the existence of increasing returns will preserve our main result. The reasoning is as follows. If there is a tradeoff between fixed and marginal costs of production, a larger market size will help the adoption of more advanced technologies because the higher fixed costs could be spread to a higher level of output and thus average cost of production will be lower. That is, anything increasing the market size will lead to the adoption of more advanced technologies. Specifically, with international trade increasing the market size, manufacturing firms will adopt more advanced technologies.

References

Antras, Pol, Ricardo Caballero. 2009. Trade and capital flows: a financial frictions perspective. *Journal of Political Economy* 117, 701-744.

Beck, Thorsten. 2002. Financial development and international trade: is there a link? *Journal of International Economics* 57, 107-131.

Chen, Zhao, Sandra Poncet, and Ruixiang Xiong. 2020. Local financial development and constraints on domestic private-firm exports: evidence from city commercial banks in China. *Journal of Comparative Economics* 48, 56-75.

Choi, ByeongHwa. 2020. Financial development, endogenous dependence on external financing, and trade. *Economica* 87, 530-587.

Choi, Kangsik, and Seonyoung Lim. 2019. A reappraisal of strategic trade policies with the endogenous mode of competition under vertical structures. *Journal of International Trade and Economic Development* 28, 11-29.

Egger, Peter, and Christian Keuschnigg. 2017. Access to credit and comparative advantage. *Canadian Journal of Economics* 50, 481-505.

Fan, Jiao-Jiao, Ruzhi Xu, Chi Wei Su, and Qing-Hua Shi. 2018. Demand-following or supply-leading. *Journal of International Trade and Economic Development* 27, 314-332.

Feenstra, Robert, Zhiyuan Li, and Miaojie Yu. 2014. Export and credit constraints under incomplete information: theory and evidence from China. *Review of Economics and Statistics* 96, 729-744.

Fujiwara, Kenji, and Keita Kamei. 2018. Trade liberalization, division of labor and welfare under oligopoly. *Journal of International Trade and Economic Development* 27, 91-101.

Gong, Binglin, and Haiwen Zhou. 2014. Financial development, the choice of technology, and comparative advantage. *Journal of International Trade and Economic Development* 23, 1238-1261.

He, Huanlang, and Zhihao Yu. 2015. The evolving patterns of global production of multi-product firms. *Canadian Journal of Economics* 48: 1175-1194.

Ishikawa, Jota, Yoichi Sugita, and Laixun Zhao. 2009. Corporate control, foreign ownership regulations and technology transfer. *Economic Record* 85, 197-209.

Ji, Lei, and John Seater. 2020. The dance of the dynamics: the interplay of trade and growth. *Macroeconomic Dynamics* 24: 479-537.

Ju, Jiandong, and Shang-Jin Wei. 2011. When is quality of financial system a source of comparative advantage? *Journal of International Economics* 84, 178-187.

Jungblut, Stefan. 2004. Financial instability, oligopolistic banking, and monetary growth. *Oxford Economic Papers* 56, 513-538.

Kletzer, Kenneth, and Pranab Bardhan. 1987. Credit markets and patterns of international trade. *Journal of Development Economics* 27, 57-70.

Krugman, Paul. 1980. Scale economies, product differentiation, and the pattern of trade. *American Economic Review* 70, 950-959.

Lu, Ming, Kuan-Hu Xiang. 2022. Flexible employment based on big data and manufacturing labor market prosperity index. Working Paper, Shanghai Jiaotong University.

Ma, Hongkun, X. Henry Wang, and Chenhang Zeng. 2015. Cournot and Bertrand competition in a differentiated duopoly with endogenous technology adoption. *Annals of Economics and Finance* 16, 231-253.

Matsuyama, Kiminori. 2005. Credit market imperfections and patterns of international trade and capital flows. *Journal of the European Economic Association* 3, 714-723.

Neary, J. Peter. 2016. International trade in general oligopolistic equilibrium. *Review of International Economics* 24, 669-698.

Saint-Paul, Gilles. 1992. Technological choice, financial markets and economic development. *European Economic Review* 36, 763-781.

Salinger, Michael. 1988. Vertical mergers and market foreclosure. *Quarterly Journal of Economics* 103, 345-356.

Samuelson, Paul. 1983. *Foundations of Economic Analysis*. Enlarged edition, Cambridge, MA: Harvard University Press.

Wang, Junxiu, Yingnan Zhou, and Yuqing Cui. 2000. Mobile "new citizens": A survey of the life and mentality of the new generation of migrant workers. Working Paper, Chinese Academy of Social Sciences.

Wynne, Jose. 2005. Wealth as a determinant of comparative advantage. *American Economic Review* 95, 226-254.

Williamson, Stephen 1986. Increasing returns to scale in financial intermediation and the nonneutrality of government policy. *Review of Economic Studies* 53, 863-875.

Yeaple, Stephen. 2005. A simple model of firm heterogeneity, international trade, and wages. *Journal of International Economics* 65, 1-20.

Zhang, Junxi. 2007. Endogenous markups, intensity of competition, and persistence of business cycles. *Southern Economic Journal* 74, 546-565.

Zhou, Haiwen. 2004. The division of labor and the extent of the market. *Economic Theory* 24, 195-209.

Zhou, Haiwen. 2005. Market structure and organizational form. *Southern Economic Journal* 71, 705-719.

Zhou, Haiwen. 2009. Population growth and industrialization. *Economic Inquiry* 47, 249-265.

Zhou, Haiwen. 2018. Impact of international trade on unemployment under oligopoly. *Journal of International Trade and Economic Development* 27, 365-379.

Zhou, Haiwen. 2021. Fixed costs and the division of labor. *Annals of Economics and Finance* 22, 63-81.

Zhou, Haiwen. 2022. The choice of technology and economic geography. *International Economic Journal* 36, 1-18.