INDUSTRIALIZATION OF DEVELOPING ECONOMIES IN THE GLOBAL ECONOMY WITH AN INFECTIOUS DISEASE

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First version received October 2020; final version accepted March 2021

Manufacturing has long been the center of industrialization strategies for poor developing countries. This article first investigates the effects of labor supply constraints on industrialization, which may have been caused by the coronavirus disease 2019 (COVID-19). Then, it examines how manufacturing automation could affect industrialized developing economies based on the premise that manufacturers may accelerate production automation in response to the COVID-19 pandemic. The model predicts declines in developing economies’ manufacturing competitiveness and a heterogeneous pattern of recovery from the COVID-19 recession. In comparison, developing economies with large manufacturing bases would recover relatively quickly, whereas those with weaker manufacturing bases would suffer from a long-term decline and manufacturing contraction trends (undesirable deindustrialization). Manufacturing automation can enhance economic welfare, causing a contraction in the unproductive nontradable good (service) sector. However, with low labor mobility, the welfare effect is ambiguous, thereby widening the wage gap between skilled and unskilled labor.

Keywords: COVID-19; Industrialization; Automation; Financial globalization; Social mobility

JEL classification: F12, F16, O14

1. INTRODUCTION

The coronavirus disease 2019 (COVID-19) has forced drastic changes in our economic activities, causing serious health, economic, and social crises. Private firms reconsider how they could operate their business safely in the global economy, which is riskier than previously thought. Governments have struggled to balance controlling the spread of the COVID-19 while keeping...
their economies alive. As in many other difficult times, the highest costs fall on those least prepared to bear them, which is particularly true in developing economies. How would the COVID-19 pandemic affect the industrialization of developing economies? Manufacturing has long been the center of industrialization strategies for poor developing countries, but their performance seems to be dichotomous. That is, some countries (mainly in Asia) have successfully developed manufacturing sectors, whereas others have been sluggish and remained in nonindustrial states. The main goal of this article is to shed light on this industrialization heterogeneity and potential effects of the pandemic on industrialization.

To address this issue, this article proposes a small open economy model with multiple sectors, based on Rodríguez-Clare (1996). This article first considers conditions for industrialization of developing economies in an open economy setting. Then, we examine how the pandemic would affect the identified conditions while focusing on labor supply constraints, which is one of the most evident difficulties caused by the pandemic through social distancing.

The novelty of the model is twofold. First, a nontradable final good (service) sector is introduced. The majority of the workers in developing economies are informal employment, which is largely engaged in nontradable final goods and services. Hence, the introduction of the nontradable sector enables us to examine the potential effect of the pandemic on one of developing economies’ remarkable traits. Second, the supply of skilled labor is endogenous. Unskilled workers may become skilled by taking costly education (or vocational training), which is the model’s other fundamental ingredient: separating labor supply constraints into those over total labor supply and over skilled labor supply.

We model a small country with three final consumption sectors: two tradable sectors and one nontradable sector. The first tradable sector is unskilled labor intensive, referred to as the agricultural sector. The other tradable sector, which is referred to as the manufacturing sector, is characterized by productivity growth with increasing varieties of intermediate inputs. Such inputs are nontradable and skilled labor intensive. The nontradable consumption good sector is unskilled-labor intensive and its sole difference from the agricultural sector is that the product demand is constrained by the size of the home market.

In this framework, trade openness requires a minimum scale of the local intermediate good sector for industrialization (i.e., the threshold size of the manufacturing base). As the intermediate good sector exhibits increasing returns to scale, the threshold size of the manufacturing base leads to multiple equilibria; that is, an industrialization equilibrium and a nonindustrial equilibrium. Thus, the

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1 In 2016, informal employment excluding agriculture occupies approximately 60% of the total employment in developing economies, whereas approximately 18% in developed economies (ILO 2018).
model shows that developing economies may be trapped in a nonindustrial state even though they can potentially reach a Pareto-superior industrialized state, which is a common property in the big push literature exemplified by Murphy, Shleifer, and Vishny (1989).

Given the possibility of the “industrialization trap,” this article first investigates the effects of labor supply constraints on industrialization, which may have been caused by the COVID-19 pandemic. Then, the article examines how manufacturing automation could affect industrialized developing economies, based on the premise that manufacturers may accelerate production automation in response to the incremental labor supply constraints due to the COVID-19 pandemic. Automation is not exceptional in developing countries. Indeed, long before the pandemic, manufacturing automation had begun mainly in multinational plants even in poor developing economies (e.g., Seric and Winkler 2020). To investigate automation consequences, the model is extended to include international capital flows (i.e., machine imports), which allow manufactures to replace unskilled labor input with capital.

The main findings of this article are as follows. First, labor supply constraints may have a critical impact on industrialization, weakening the manufacturing competitiveness of developing economies in the world market. Nonindustrial developing economies face more restrictive industrialization conditions, and worse, industrialized developing economies may be back to the nonindustrial state if their manufacturing base drops below their industrialization thresholds. Thus, the model predicts that although developing economies with relatively large manufacturing bases may recover quickly from the current recession, those with weaker manufacturing bases will suffer from long-term decline and manufacturing contraction trends (undesirable deindustrialization).

Second, manufacturing automation will expand the intermediate good sector by increasing manufacturing productivity and cause a contraction of the unproductive nontradable final good (service) sector, resulting in a positive impact on aggregate productivity. Thus, manufacturing automation is expected to mitigate the negative economic effect of the pandemic. However, the ability of manufacturing automation to enhance economic welfare crucially depends on high labor liquidity, not only in inter-sectoral mobility (horizontal mobility) but also in skill upgrading (vertical mobility). With low labor liquidity, automating manufacturing production will expand the nontradable final sector and enlarge the wage gap between skilled and unskilled. Therefore, the direction of economic welfare change is ambiguous. Hence, policies for increasing labor mobility, including enhancing education systems, become more important under the COVID-19 crisis.

Although the economics literature on COVID-19-related issues has been rapidly expanding, to my best knowledge, apart from descriptive policy briefs such as Hartwich and Isaksson (2020), formal analyses on the effect on industrialization and economic development are still limited. Developing a simple model of a
small open economy with endogenous skill accumulation, this article provides a formal analysis on the potential effects of the COVID-19 pandemic on the industrialization of developing countries through the lens of constrained labor supply (skilled and unskilled) and manufacturing automation.

A large body of literature points out that whereas only a limited number of developing countries succeeded in catching up with developed economies through industrialization, many developing countries failed to do so and even experienced declines in their manufacturing goods. Rodrik (2016), referring to this phenomenon as “premature deindustrialization,” claims that terms-of-trade deterioration owing to the rapid growth of China and technological progress in the rest of the world have disturbed developing countries’ industrialization. Eichengreen, Park, and Shin (2014) empirically find that fast-growing middle-income countries tend to experience growth slowdowns, but those with relatively rich human capital accumulation or high-technology products tend to escape from growth slowdowns. This article’s predictions are consistent with their findings. However, contrary to Rodrik (2016), I stress the role of labor mobility including skill formation.

In the trade- and skill-formation literature, Atkin (2016) recently investigates Mexican data and finds that less-skilled manufacturing exports slow down the country’s skill accumulation. Using a panel of 102 countries and 45 years, Blanchard and Olney (2017) find the evidence that skill-intensive exports encourage educational attainment. This article, primarily theoretical, incorporates endogenous skill formation and argues that a country’s comparative advantage affects its skill accumulation. Furthermore, this article aims to examine the potential impact of the COVID-19 pandemic on industrialization and to derive related policy implications.

Rodríguez-Clare (1996) and Rodrik (1996) are the two closest to this article in the sense that both studies present coordination failure problems in comparative advantage formation. Rodríguez-Clare (1996) primarily focuses on multinationals’ creation of backward linkage in developing economies. Rodrik (1996) discusses policy measures, such as minimum wages to avoid the coordination failure problem. Both studies lack endogenous skill formation and nontradable sectors, which are highlighted in this article. Venables (2017) examines a dichotomous feature of developing countries’ industrialization by explicitly modeling a nontradable sector. However, although Venables (2017) stresses the role of urbanization as a prerequisite for industrialization, this article focuses on endogenous skill formation and the role of manufacturing automation.

The remaining part of this article is as follows. The next section introduces a simple open economy model with a nontradable sector and endogenous skill formation. Then, Section 3 discusses conditions for industrialization, and Section 4 considers the potential impacts of the COVID-19 pandemic on developing economies’ industrialization, focusing on labor supply constraints and manufacturing automation. Section 5 concludes.
2. A SIMPLE MODEL

2.1. Preferences and Demand

We consider a small open economy populated with \( L \) individuals, each of which inelastically supplies one unit of unskilled labor. A representative individual consumes a unit interval of sectors indexed by \( j \) with the following Cobb–Douglas utility function:

\[
\ln U = \int_0^1 \ln q_j dj,
\]

where \( q_j \) represents consumption of sector \( j \). Following Epifani and Gancia (2009), we assume that sectors are sorted into three categories: tradable manufacturing goods (\( M \)), nontradable goods (services) (\( N \)), and tradable agricultural goods (\( A \)). For analytical simplicity, subintervals for each category are exogenous, and we assign intervals \( \theta > 0 \) and \( \eta > 0 \) for the manufacturing and nontradable goods, respectively. Assuming that \( \theta + \eta < 1 \), the remaining interval is assigned to the agricultural goods. The embedded idea of the specification of the nontradable good (service) sector is that trade costs for interval \( \eta \) are prohibitively high. We view recent globalization as a decrease in \( \eta \); that is, as trade costs decline, goods and services that were nontradable become tradable (e.g., online consulting services).

By sectoral symmetry, the utility function can be rewritten as

\[
U = \zeta q^{\theta}_M q^{\eta}_N q^{1-\theta-\eta}_A, \quad \zeta > 0, \quad \theta > 0, \quad \eta > 0, \quad 0 < \theta + \eta < 1,
\]

where \( q_i \) stands for consumption of good \( i = \{M, N, A\} \) and \( \theta \) and \( \eta \) are distribution parameters that determine the importance of the three goods. The agricultural good is a numéraire in the model, and its price is normalized to unity. Utility maximization yields the following demand for each good:

\[
q_M = \frac{\theta E}{p_M}, \quad q_N = \frac{\eta E}{p_N}, \quad q_A = (1 - \theta - \eta)E,
\]

where \( p_M \) is the manufacturing price that is exogenously determined in the world market, \( p_N \) is the endogenous price of nontradable good, and \( E \) is the economy’s aggregate income.

By choosing \( \zeta \) appropriately, the indirect utility is given as

\[
V(E, p) = p_M^{-\theta} p_N^{-\eta} E. \tag{1}
\]
2.2. Production and Labor Demand

All the three final consumption goods are perfectly competitive and produced with constant returns to scale technologies. The production of the agricultural good requires only unskilled labor, and its labor productivity is normalized such that the unskilled wage $w$ is 1 as long as the agricultural good is produced. Denoting the output of the agricultural good by $y_A$, the unskilled labor demand from this sector is simply

$$L_A = y_A.$$  \hfill (2)

The nontradable good (service) also requires only unskilled labor. Denoting output by $y_N$, the production function is $y_N = \psi_N L_N$, where $\psi_N > 0$ stands for labor productivity and $L_N$ is unskilled labor input in the nontradable final sector. The price of nontradable good is $p_N = w/\psi_N$. Using market-clearing condition, $y_N = q_N$, the unskilled labor demand from this sector is

$$L_N = \frac{\eta E}{w}.$$  \hfill (3)

The manufacturing good employs the following Cobb–Douglas technology:

$$y_M = \left(\frac{X}{\beta}\right)^\beta \left(\frac{L_X}{1-\beta}\right)^{1-\beta}, \quad \beta \in (0,1),$$

where $L_X$ is the input of unskilled labor and $X$ is a composite of intermediate goods. The composite of intermediate goods is specified by the following CES function:

$$X = \left[\int_0^n x(i)^{(\sigma-1)/\sigma} \, di\right]^{\sigma/(\sigma-1)},$$  \hfill (4)

where $\sigma > 1$ is the elasticity of substitution between any two varieties of the intermediate goods and $n$ is the mass of varieties of the intermediate goods.

This specification of manufacturing production indicates that final manufacturing production is constant returns to scale while the production of the composite of intermediate goods exhibits increasing returns to scale.\footnote{To see this convexity and symmetry among $x(i)$ in equation (4), ensure that final firms use the same quantity of all available intermediate goods, thereby denoting this usage level by $\bar{x}$ for all $x(i)$, $X = n^{\sigma/(\sigma-1)}\bar{x} = n^{1/(\sigma-1)}(n\bar{x})$. Hence, as input $n\bar{x}$ increases, $X$ increases more than proportionally.} Hence the access to a
wider range of inputs enhances manufacturing productivity, which can be interpreted as the division of labor as a source of increased productivity (Ethier 1982). As \( \beta \) increases, the productivity-enhancing effect by the division of labor becomes more powerful.

Each intermediate variety is produced with skilled labor under increasing returns and monopolistic competition. The stock of skilled labor is endogenous. It is assumed that to acquire skills necessary for intermediate production, each household must incur an iceberg-type education (or job training) cost measured in units of unskilled labor. Specifically, each household can provide either one unit of unskilled labor or \( 1/t \) units of skilled labor, where \( t \) (>1) measures costly education. Given that the manufacturing sector is active in the economy, households must be indifferent between becoming skilled and remaining unskilled, which implies that the skilled wage, \( w_s \), just compensates the education cost:

\[
w_s = tw. \tag{5}
\]

The total amount of skilled labor required for quantity \( x(i) \) of intermediate good \( i \) is given by \( l_s(i) = \psi x(i) + f \), where \( \psi \) is the marginal requirement of skilled labor. Profit maximization leads to the standard markup pricing. Choosing the unit of skilled labor such as \( \psi = (\sigma - 1)/\sigma \), we have \( p(i) = w_s \) for all varieties.\(^3\) Using this result, the monopoly profits are expressed by \( \pi(i) = [p(i) - \psi w_s]x(i) - fw_s = [x(i)/\sigma - f]w_s \). Free entry drives the monopoly profits down to zero, which ensures that each intermediate firm produces a fixed amount of \( \bar{x} \equiv \sigma f \) in equilibrium. Hence, the firm-level skilled labor requirement is also fixed at

\[
\bar{l}_s \equiv \psi \bar{x} + f = \sigma f (= \bar{x}).
\]

To derive unskilled labor requirement from the direct input in manufacturing, final producers’ cost minimization yields

\[
L_X = \frac{1 - \beta}{\beta} \cdot \frac{P_X X}{w}, \tag{6}
\]

where \( P_X \) is the price index of a continuum of intermediate goods, which is expressed as

\(^3\) This unit normalization does not sacrifice generality in the CES functional form and is occasionally applied for notional simplicity. See, for example, Matsuyama (1995).
\[ P_X = \left[ \int_0^n p(i)^{(1-\sigma)} di \right]^{1/(1-\sigma)} = n^{1/(1-\sigma)} t w, \quad (7) \]

where equation (5) is used. As \( x(i) = \bar{x} \) for all \( i \), equations (4), (5), and (7) suggest that \( P_X X = n t w \bar{x} \). Substituting this into equation (6), we obtain unskilled-labor demand in the manufacturing sector as follows:

\[ L_X = \frac{(1-\beta) n t \bar{x}}{\beta}. \]

Considering that the total demand of skilled labor for intermediate production is \( n \bar{x} \), the aggregate labor demand in the manufacturing sector in units of unskilled labor is expressed as

\[ L_M \equiv L_X + n t \bar{x} = \frac{n t \bar{x}}{\beta}, \quad (8) \]

which is proportional to the mass of intermediate varieties, \( n \). Furthermore, else equal, \( L_M \) is increasing in the training cost \( t \), but decreasing in the intermediate intensity \( \beta \). The intuition is straightforward. As education for skill acquisition is more costly, unskilled labor demand increases for given \( n \). By contrast, an increase in the intensity of intermediate goods enhances productivity and saves labor input.

To close this section, labor productivity in manufacturing increases as more intermediate varieties become available to the final producers. Defining labor productivity by \( y_M / L_M \), we obtain

\[ \frac{y_M}{L_M} = \left[ \frac{n^{1/(\sigma-1)}}{t} \right]^{\beta}. \quad (9) \]

Hence, as the availability of intermediate varieties increases (\( n \uparrow \)), the manufacturing productivity improves, which can be interpreted as a well-developed manufacturing base increases manufacturing productivity, leading to enhanced manufacturing competitiveness in the world market. Education efficiency is also transmitted to manufacturing productivity because inefficient education (\( t \uparrow \)) requires more labor input to produce the same amount of output.
3. INDUSTRIALIZATION IN AN OPEN ECONOMY

3.1. Sector Specialization

The production possibilities frontier with respect to the two tradable goods is linear. Thus, the economy perfectly specializes in either one of the two tradable sectors, depending on the economy’s comparative advantage, which is determined by the ratio of unit costs of the manufacturing and agricultural goods, $c_M/c_A$, and the terms of trade. Letting $p_A$ denote the price of the agricultural good, if

$$\frac{p_M}{p_A} < \frac{c_M}{c_A}$$

holds, then complete specialization in the agricultural good occurs. Otherwise, the economy perfectly specializes in the manufacturing goods.

The unit production costs of the manufacturing and agricultural goods are given by $c_M = w^{1-\beta}P_X^\beta$ and $c_A = w$, respectively. Using equation (7), the relative production cost is

$$\frac{c_M}{c_A} = \left(\frac{P_X}{w}\right)^\beta = \left[\frac{t}{n^{1/(\sigma-1)}}\right]^\beta,$$

which is infinitely high when $n$ is very low and monotonically decreases as $n$ increases. Noting that $p_A = 1$, the threshold $\hat{n}$ at which the ratio of unit cost equals $p_M$ is expressed as

$$\hat{n} = \left[\frac{t}{P_M^{1/\beta}}\right]^{\sigma-1}. \quad (10)$$

If the mass of intermediate varieties that the economy can produce is greater than $\hat{n}$, then the economy can be industrialized. Otherwise, the economy can never be industrialized.

To understand this point from the view of the labor market, it is useful to consider the wage rate that firms in the manufacturing sector can offer (payable wages). If the manufacturing sector is active, then $p_M = c_M$ holds. Applying equation (7) to $c_M$, the payable unskilled wage is expressed by an increasing function of $n$:}

4 For a given $n$, the marginal rate of transformation between the two goods is constant. See equations (2) and (9).
\[ w(n) = p_M \left[ \frac{n^{1/(\sigma-1)}}{t} \right]^\beta. \]  

By definition, \( w(\hat{n}) = 1 \), which equals the unskilled wage that the agricultural and the nontradable final sectors offer. Thus, no manufacturing firms cannot attract workers unless more than \( \hat{n} \) varieties of intermediate goods are available.

### 3.2. Nonindustrial Equilibrium

We start with the case that the economy perfectly specializes in the agricultural and nontradable goods (nonindustrial equilibrium). The unskilled wage equals the agricultural price: \( w = 1 \). Given free labor mobility across the two sectors, the same wage prevails in the nontradable sector, which leads to \( p_N = 1/\psi_N \). At this price, the demand for the nontradable good is \( q_N = \psi_N \eta L \), which equals the output level. The sector’s unskilled labor requirement is \( \eta L \) and the remaining is allocated to the agricultural sector, which leads to \( L_A = y_A = (1 - \eta)L \).

As wages are the sole source of income, economic welfare (per capita) is

\[ V_u = p_M^{-\theta} \psi_N^\eta. \]  

The economy hosts only constant returns to scale sectors, and thus population size (\( L \)) does not affect welfare. Welfare increases due to either decreases in \( p_M \) (terms-of-trade gain) or increases in \( \psi_N \) (productivity growth in nontradable goods).

To complete the description of the nonindustrial equilibrium, the agricultural good is the economy’s export good. Domestic consumption of the agricultural good is \( q_A = (1 - \theta - \eta)L \). Hence, the export volume is given by \( EX_u = y_A - q_A = \theta L \). The balanced trade condition gives the volume of manufacturing imports, \( IM_u = \theta L/p_M \).

### 3.3. Industrialization Equilibrium

We now turn to an industrialization equilibrium, in which the economy has the manufacturing and nontradable final sectors. As the nonindustrial case, the economy’s aggregate income is still given by \( E = wL \) because the skill premium just compensates labor supply depreciation for education. The labor market clearing condition is \( L = L_M + L_N \). Substituting equations (3) and (8) into this condition, the mass of intermediate varieties in equilibrium is derived such that

\[ n^* = \frac{\beta(1 - \eta)L}{t\hat{x}}. \]
Comparative statics on $n^*$ is straightforward. The mass of equilibrium intermediate varieties, $n^*$, is proportional to the economy’s population size $L$. As the size of the nontradable sector, $\eta$, increases, $n^*$ declines. In addition, as education quality declines ($t^\uparrow$), $n^*$ also declines.

Applying equation (13) to equation (11), the equilibrium unskilled wage is expressed as

$$w^* = p_M \left[ \frac{\beta (1 - \eta)L}{t^\sigma x} \right]^ {\beta/(\sigma - 1)}.$$

Using this result, per capita welfare is expressed by

$$V_I = p_M^{-\theta} p_N^{-\eta} w = p_M^{-\theta} \psi_N^\eta (w^*)^{1-\eta}.$$  \hfill (14)

In equilibrium, $n^* > \hat{n}$. Given that $w(\hat{n}) = 1$ and $w$ is increasing in $n$, $w^*$ must be greater than 1. Thus, compared with $V_u$ in equation (12), industrialization unambiguously raises per capita economic welfare. These results are recorded in the following proposition.

**Proposition 1.** Industrialization raises per capita economic welfare by fostering the manufacturing sector that productivity grows with a range of specialized intermediate inputs. With a larger population and an efficient education for skill formation, the economy has a wider range of specialized inputs, resulting in a larger and more productive manufacturing sector.

Trade impediments may increase the range of nontradable consumption goods ($\eta^\uparrow$). Equation (13) suggests that the range of intermediate varieties decreases. Consequently, the manufacturing sector decreases in terms of output share and employment share (“deindustrialization”). The effect of deindustrialization on

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5 Parameter $\eta$ represents the size of the nontradable sector in terms of both employment and income shares. To see this, from equation (3), $L_N/L = \eta E/(wL) = \eta$ and $p_N y_N/(wL) = L_N/L$.

6 Note that the manufacturing price $p_M$ does not affect the size of the manufacturing base. This result is due to the specification of CES and homogenous intermediate firms. The manufacturing price $p_M$ is determined in the world market and represents the terms of trade. Relaxing either the CES or firm-homogeneity assumption leads to $n^*$ that depends on $p_M$. Although the model extension in this direction is an interesting exercise, I maintain the specification of CES and homogenous intermediate firms not only for the model’s tractability, but also for the fact that the current model can present the effect of terms-of-trade changes on industrialization by the threshold size of the manufacturing base $\hat{n}$.

7 Manufacturing output and employment shares are defined by $y_M/(y_M + y_N)$ and $L_M/L$, respectively.
economic welfare is somewhat complicated. Equation (14) suggests that as long
as \( \psi_N < w^* \), deindustrialization would unambiguously decrease economic welfare
through the following: (i) increasing the weight of low productive industries in
the economy (composition effect) and (ii) decreasing the wages with reducing
 gains from division of labor in the manufacturing (\( n^* \)). This “undesirable” dein-
 dustrialization is likely to occur in economies with relatively unproductive non-
 tradable sectors. This observation is consistent with Rodrik’s (2016) “premature
deindustrialization” of developing countries, which means that manufacturing
shares in output and employment decrease before reaching a sufficiently high
 income level.

3.4. Industrialization Conditions

Although nontradable consumption goods are always domestically produced,
the manufacturing good is not necessarily because the small economy faces the
infinite import supply at the world price \( p_M \). The necessary condition for
the economy to be industrialized is \( n^* \geq \hat{n} \). Using equations (10) and (13), this
condition is expressed as

\[
\frac{\beta (1 - \eta) L}{t^\sigma \bar{x}} p_M^{(\sigma - 1)/\beta} \geq 1.
\]

This inequality tends to be reversed when:
1. the economy size is small (\( L_\downarrow \)),
2. the education (training) cost for acquiring skills is high (\( t \uparrow \)),
3. the size of the nontradable sector is large (\( \eta_\uparrow \)), and
4. the terms of trade deteriorate (\( p_M_\downarrow \)).

All these results are intuitive. For industrialization, the economy must foster a
competitive manufacturing sector. Competitiveness critically depends on the
range of specialized intermediate inputs. The availability of labor resources for
intermediate production is crucial. The economy size, education efficiency, and
labor demand from the nontradable final sector affect labor available to interme-
diate production.

Figure 1 illustrates the industrialization condition in equation (15) with two
gross profit schedules in intermediate production (more precisely, they express
the gross return rates of skilled labor input. See Appendix A.1 for the derivation
of these schedules). A schedule labeled as \( \pi^g_H \) satisfies the industrialization condition.
As the number of intermediate varieties increases, \( \pi^g_H \) monotonically
decreases, and the intersection with a horizontal line of \( f \) gives the equilibrium
level of intermediate varieties, where \( n^*_H > \hat{n} \).

8 The presentation of the gross profits schedules in Figure 1 is indebted to Matsuyama (1995).
In any of the adverse shocks in $L$, $t$, and $\eta$, the gross profit schedule shifts leftward. The schedule labeled as $\pi^L_t$ is located far left relative to $\pi^H_t$, and the equilibrium mass of varieties $n^*_L$ does not satisfy the condition for industrialization. In such a case, the economy cannot be industrialized and must stay at the non-industrial stage.

**Proposition 2.** An economy with a larger population, an efficient education for skill formation, and a smaller nontradable final sector tends to have a comparative advantage in manufacturing and a larger possibility of industrialization.

The industrialization condition of equation (15) is a necessary condition because the model has two equilibria even if $n^* > \hat{n}$ is satisfied. Industrialization and nonindustrial equilibria are stable. To observe this, in the nonindustrial state ($n = 0$), the payable manufacturing wage is 0, and thus the sector cannot attract workers who obtain $w = 1$ in the other sectors. Hence, this nonindustrial equilibrium is stable. However, Figure 1 shows that once the economy somehow acquires $\hat{n}$ of intermediate varieties (and the economy has a sufficiently large production capacity), firm entry occurs, and the economy can reach $n^*_H$. Thus, the industrialization equilibrium is also stable. The economy has an “industrialization trap” stemming from a coordination failure problem in the manufacturing sector.

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Suppose that a relatively small private coordination, \( n_{\text{min}} < \hat{n} \), is feasible. Effective policy interventions aim to reduce the threshold varieties of intermediate inputs, \( \hat{n} \), and not to increase the equilibrium varieties, \( n^* \). Equation (10) indicates two potential measures. The first one is raising the domestic manufacturing price by import tariffs (or any nontariff measures to restrict imports). However, this intervention is problematic in terms of feasibility and efficiency. Trade agreements, such as the GATT/WTO, regulate the use of import restrictions. Furthermore, import restrictions yield economic distortions, thereby reducing economic welfare.9

The second possible measure is enhancing education efficiency. This measure also helps exploiting gains from division of labor by increasing \( n^* \) (although pushing up \( n^* \) itself is not sufficient for initiating the manufacturing sector). The model highlights the importance of education for acquiring appropriate skills for avoiding the industrialization problem.10

**Proposition 3.** Even if an economy has the potential of industrialization, the economy can still be trapped in a nonindustrial state in an open economy because of a coordination failure problem. Government interventions may help to foster a sufficiently large specialized intermediate good sector, with which the economy can escape from the nonindustrial trap. Among others, improving education (or vocational training) efficiency would be feasible and effective.

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9 A large body of literature discusses the pros and cons of import restrictions. Krueger (1984), a classical survey on trade policy in developing countries, comprehensively discusses the costs of trade protection. For a more recent survey on the effect of trade policy, see Goldberg and Pavcnik (2016).

10 Readers may point out that importing intermediate goods or hosting subsidiaries of multinational companies can solve the “industrialization trap” illustrated here. Hence, this article’s results depend on the assumption of nontradability of intermediate goods. For the possibility of imports of intermediate goods, intermediate inputs often include nontradable services, such as accounting, legal, and consulting services. Thus, the assumption of nontradable intermediate goods is not so unrealistic. Multinationals often bring supporting firms (their intermediate good suppliers) to host developing countries. In this sense, the host developing countries can be industrialized. However, the developing countries may still face another challenge: upgrading their role in the supply chains led by multinationals, including fostering local companies able to supply to multinationals. The current model can illustrate this problem by replacing the agricultural sector with another manufacturing sector with a lower intermediate intensity. The small economy now faces a problem that it may be trapped in the manufacturing sector with the lower intermediate intensity. Hence, this article’s major points are largely unchanged.

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4. COVID-19 CONSIDERATIONS

This section performs comparative statics with respect to the model’s parameters affected by COVID-19 shocks. The results of comparative statics exhibit how the economy would respond to such shocks after all adjustments have been worked out. The COVID-19 pandemic is temporary in the sense that it will end sometime (probably by the spread of immunization). Hence, one may expect that the economy will recover to the initial state once the pandemic ends. However, it does not necessarily hold due to the “industrialization trap” discussed in the previous section.

4.1. Erosion of Comparative Advantage

The COVID-19 pandemic is primarily a health crisis, forcing us to self-isolate (e.g., lockdowns, workplace closures, and stay at home). An immediate consequence is tougher labor supply constraints (Bonadio et al. 2020). Working from home (WFH) can mitigate the impact of labor supply constraints. However, not all jobs can be done from home, and especially, lower-income economies have lower shares of WFH available jobs compared with high-income countries (Dingel and Neiman 2020). Thus, one of the major impacts of the pandemic is perceived as a labor supply contraction; that is, a decrease in \( L \) in the present model.\(^{11}\)

Another great concern is a serious disruption of education systems (United Nations 2020). Social distancing causes a direct negative impact on education efficiency even though online classes can substitute in-person classes to a certain extent (which holds particularly true in higher education, such as colleges and universities). However, a lack of resources or enabling environment to access online learning is a serious issue particularly in developing economies. Education financing is another concern for households and governments because of the deep worldwide recession that we are facing. In our model, this type of shock can be dealt with as increases in the education cost \( t \) for acquiring skills for participating in the increasing-returns-to-scale sector.

Although world trade has sharply dropped since the outbreak of the pandemic because of the supply and demand shocks, the effect on the world prices of manufacturing goods is much less clear. This effect may vary across goods/sectors, which makes speculating the direction of changes in a country’s terms of trade (the ratio of export price to import price) less easy. Thus, this article will not discuss terms-of-trade changes because of the COVID-19 pandemic. In what

\(^{11}\) Each individual in the economy inelastically supplies one unit of unskilled labor services without the COVID-19 pandemic. Decreases in \( L \) imply productivity loss at the individual level due to, for example, staying at home without WFH.
follows, I will discuss the effects of the pandemic on industrialization from the perspectives of labor supply and education shocks.  

We infer that the COVID-19 crisis makes the small economy’s industrialization difficult by generating tougher labor supply constraints \(L\downarrow\) and more costly education \((t\uparrow)\). From equations (10) and (13), \(\frac{\partial \hat{n}}{\partial L} = 0\), \(\frac{\partial n^*}{\partial L} > 0\), \(\frac{\partial \hat{n}}{\partial t} > 0\), and \(\frac{\partial n^*}{\partial t} < 0\) are straightforward. Thus, labor constraints decrease the economy’s realizable size of intermediate good sector \(n^*\), while leaving the threshold size of the intermediate good sector \(\hat{n}\) intact. Costly education decreases \(n^*\) and increases \(\hat{n}\).

The model suggests that economies are unindustrialized due to either their too small intermediate good sector \((n^* < \hat{n})\) or coordination failures in the manufacturing sector (recall that \(n^* > \hat{n}\) is not sufficient for industrialization). Decreases in \(L\) or increases in \(t\) makes industrialization tougher for nonindustrial economies: decreasing \(n^*\) and/or increasing \(\hat{n}\) may enlarge the gap between \(n^*\) and \(\hat{n}\) for economies with \(n^* < \hat{n}\) or violate the necessary condition \(\hat{n} < n^*\).

Economies that have been successfully industrialized before the pandemic will be divided into two groups: those maintaining their prior comparative advantage, and those failing to do so. For all, \(\hat{n}\) shifts to the right (only for costly education) and \(n^*\) shifts to the left (for either labor supply constraints or costly education). If \(\hat{n}\) does not surpass \(n^*\), then the pandemic shock will not alter the economy’s comparative advantage. Although the manufacturing output and the skilled and unskilled wages decline during the COVID-19 shocks, the economy will recover as the COVID-19 pandemic ends (i.e., \(L\) or \(t\) returns to the initial value).  

However, if \(\hat{n}\) surpasses \(n^*\), then the economy becomes unstable because condition (15) is violated. One exit from the intermediate sector induces another exit, and this vicious cycle continues until the intermediate sector completely shuts down. The economy will be trapped in the nonindustrial state, losing its comparative advantage in manufacturing. Hence, even if the pandemic ends, the economy will not recover to the original state.

---

12 Baldwin and Freeman (2020) point out the effect of international supply-chain disruptions. Manufacturers relying on intermediate imports from economies seriously affected by the pandemic tend to experience more severe production disruptions. Although the current model does not have foreign intermediate goods as a manufacturing input, international supply-chain disruptions can be qualitatively analyzed as a negative productivity shock because we can interpret such disruptions as a decline in the available range of intermediate inputs. As a result, manufacturers’ unit cost \(c_M\) increases, and thus \(n^*\) shifts leftward and industrialization becomes more difficult.

13 Intuitively, since \(n^*\) decreases (for either \(L\downarrow\) or \(t\uparrow\)), the composite of intermediate goods \(X\) decreases, resulting in decreases in manufacturing productivity. The output of the nontradable good also declines when \(L\) decreases since \(L_N = \eta L\). However, costly education \((t\uparrow)\) does not affect the nontradable output. It decreases the manufacturing output only.
In sum, our model suggests that cross-country disparities in the degree of industrialization of developing economies in the post-COVID-19 era will be widened. Some already-industrialized countries will recover to the original state. Such countries feature a large working population, good education (job training) systems, and smaller shares of nontradable sectors (or informal sectors). By contrast, if these features are not satisfied, then even already-industrialized countries may experience erosion of the manufacturing base and a reversal of comparative advantage, leading to a nonindustrial state. The nonindustrial state is a stable equilibrium. Thus, once the economy falls into a nonindustrial state, the economy may stay in this state for long periods.

**Proposition 4.** Labor supply constraints and education disruptions due to the COVID-19 pandemic adversely affect the industrialization of developing economies. For nonindustrial countries, industrialization will be more difficult. Already-industrialized countries can be separated into two groups: those with a large working population, good education (job training) systems, and smaller shares of nontradable sectors will recover to the original state in the post-pandemic; however, those without such features would experience a reversal of comparative advantage and deindustrialization, which may last for long periods.

The COVID-19 pandemic is likely to affect the nontradable good (service) sector more severely because their provision tends to be associated with face-to-face communication (e.g., food services). In particular, remote work is far less available in developing economies. In the model, these negative shocks on the nontradable good (service) sector can be represented by negative productivity shocks \( \psi \). As observed in indirect utilities in equations (12) and (14), negative shocks on \( \psi_N \) decreases welfare, and the effect is severer when the sector share \( \eta \) is high.\(^{14}\)

4.2. Automation

The view that the COVID-19 pandemic will accelerate recent trends of automation appears to be a consensus among academia and policy and business circles (Seric and Winkler 2020). Several reasons for the pandemic are proposed to promote automation (Bloom and Prettner 2020). One clear explanation for automation spurring is that machines are not susceptible to pathogens unlike humans.

\(^{14}\) Productivity shocks on the nontradable sector do not influence the manufacturing sector, which can be seen unaltered \( n^e \) in equation (13). In addition, the minimum intermediate varieties for industrialization \( \bar{n} \) is intact (see equation 10), which implies that industrialization difficulty does not change, either. This separability is due to the unit elasticity demand for nontradable goods. If we generalize this demand specification, the separability will disappear.

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In economic terms, the COVID-19 pandemic and assured occurrence of future pandemics not only lower the expected labor productivity but also increase labor adjustment costs, making machine (capital) usage advantageous. Indeed, long before the COVID-19 pandemic, trends of automation were observed in manufacturing even in developing countries because of machine progress and wage increases.\(^\text{15}\) Thus, the current pandemic strengthens the trend of automation even in developing countries.

We attempt to derive the consequences of automation in our small open economy by slightly modifying the model. Assuming that machines (capital) are perfect substitutes of unskilled labor in the manufacturing sector, we model the process of automation by replacing unskilled labor input \((L_X)\) with capital input \((K)\).\(^\text{16}\) We provide a special assumption about capital endowment: The small economy has no capital stock but can rent capital as much as it wants from the world capital market at a given rental rate \(r^*\). Although no domestic capital endowment is extreme, this assumption helps to highlight the impact of financial globalization on savings-constrained developing countries.

If \(r^*\) is lower than unskilled wages, then manufacturers replace unskilled labor with capital, and we assume that it is the case. Hence, the labor market-clearing condition is now

\[
L = nt\bar{x} + L_N, \quad (16)
\]

which implies that unskilled workers who are used to be hired in the manufacturing sector are reallocated to either the intermediate good sector after taking job training (incurring \(t\)) or the nontradable good sector.

We also need to modify the aggregate income because the economy must pay capital cost \(r^*K\) to the world financial market. Gross national income remains intact as \(wL\). Thus, aggregate income that individuals can spend on consumption is expressed as

\[
E = wL - r^*K, \quad (17)
\]

which is equivalent to balanced trade.

Labor demand from the nontradable sector is still given by equation (3). Substituting equation (17) to equation (3), we obtain

\(^{15}\) For example, a newspaper article vividly describes that factory automation has begun to replace manual workers in the apparel industry in Bangladesh, one of the largest exporters of textile and clothing. See Emont (2018).

\(^{16}\) Thus, the production function in manufacturing is modified as \(y_M = \left(\frac{\alpha}{\beta}\right)^\beta \left(\frac{L_X + K}{\lambda + \beta}\right)^{1-\beta}\).
Thus, when the small economy borrows foreign capital and uses it for the manufacturing sector, the labor-intensive nontraded sector declines, which is consistent with the Rybczynski effect.

The capital input in the manufacturing sector is analogous to $L_X$. equation (6) holds with replacing $L_X$ and $w$ with $K$ and $r^*$, respectively:

$$K = \frac{1 - \beta}{\beta} \cdot \frac{P_{X,X}}{r^*}.$$  \hfill (19)

To avoid explanatory redundancy, I relegate the detailed derivation process to the Appendix and state results with minimum algebra. Using equations (16), (18), and (19) along with the zero-profit condition $p_M = r^{*1-\beta}P_{X,X}$, the equilibrium number of intermediate goods is

$$n^*_k = \frac{\beta(1 - \eta)L}{\beta - (1 - \beta)\eta L \bar{x}},$$

in which we add a parameter restriction $\beta > 0.5$ to warrant the model’s solution.\(^{17}\)

As expected, the equilibrium number of varieties increases relative to the one without the labor replacement with capital (see equation 13). The small economy can exploit more gains from the division of labor, and economic welfare increases. The results of capital introduction are summarized in the following proposition.

**Proposition 5.** In the small economy, manufacturing automation that replaces unskilled labor with capital borrowed from the international market leads to a contraction of the nontraded good sector and an expansion of the manufacturing sector with increased skill-intensive intermediate good varieties. Thus, economic welfare increases.

\(^{17}\) Thus, the manufacturing sector must be intermediate goods intensive to a certain degree when the economy borrows all the necessary capital from the world market. This restriction can be relaxed either by assuming a positive home capital endowment or allowing to run a current account deficit. Thus, the condition $\beta > 0.5$ is not so restrictive as appeared.
The model highlights that introducing machines (capital use in the model) to the manufacturing sector in replacement of unskilled labor yields various benefits to the economy: human capital accumulation, a richer industry base (a wider range of intermediate varieties and advanced division of labor), contraction of the relatively unproductive nontradable sector, and wage increases.

It is well known that workers in the informal sector are more likely to be exposed to the infection risk of COVID-19 because the provision of their services tends to require face-to-face interactions. Many anecdotes and reports illustrate that COVID-19 has reduced informal employment and income more severely than the formal counterparts (e.g., World Bank 2020). In the model, it is reasonable to assume that workers in the nontradable good (service) sector are more susceptible to the disease, and labor supply constraints are more severe than those in the manufacturing sector. When the economy uses imported capital, the employment share in the nontradable good (service) sector is expressed as

\[
\frac{L_N}{L} = \eta \left[ \frac{2\beta - 1}{\beta - (1 - \beta)\eta} \right].
\]

Since the counterpart employment share in case of no capital use is \(\eta\), the employment share in the nontradable good (service) sector unambiguously declines by using capital (see the Appendix A.3 for derivation). Hence, machine introduction contributes to making the economy not only more productive (i.e., \(n^* < n_k^*\)) but also less vulnerable to the COVID-19 pandemic, reducing employment more susceptible to the disease and relaxing labor supply constraints due to the pandemic.

In developing countries, nontradable sectors largely coincide with informal sectors. Thus, the contraction of the nontradable sector presented here may be good news for policymakers in such countries. However, notably, the predictions illustrated here depend on the flexibility of labor mobility in terms of skills and sectors. In the real world of developing countries (and to a lesser extent in developed countries), this may be one of the most difficult problems to be resolved. What if manufacturing automation occurs with slow labor adjustments? I illustrate this issue in the following section.

4.3. Stagnant Social Mobility

To make the problem of slow labor adjustments crystal clear, I consider it an extreme case: The supply of skilled labor is perfectly inelastic. Suppose that the small open economy with the manufacturing sector cannot increase the number of skilled workers from the initial level. Then, the international capital market
becomes available, and the manufacturing firms start to use capital instead of unskilled labor as before.

Two points are immediate. First, the wage equation (5) is not applicable because no labor upgrading from unskilled to skilled occurs. As a result, the wage gap increases (more than just compensating the training cost). Second, all unskilled workers who were formerly employed in manufacturing move to the nontradable good sector. Thus, the nontradable good sector expands, and the unskilled wage declines.

As the model is easy to solve, I summarize the equilibrium with stagnant labor mobility. The labor market–clearing condition of equation (16) is still applicable by just applying \( n^* \) in equation (13). Substituting equation (13) to equation (16) leads to the equilibrium labor allocation to the nontradable sector:

\[
L_N = \frac{1}{\beta} \left( \frac{1 - \eta}{1 - \beta(1 - \eta)} \right) L,
\]

which is greater than the size without capital inflows \( L_N = \eta L \).

As shown in the Appendix A.4, the ratio of the skilled wage to unskilled wage is expressed as

\[
\frac{w_s}{w} = \frac{1 - \beta + \eta}{\beta \eta} t.
\]

Recall that the wage gap before the capital introduction is \( w_s/w = t \). Hence, the wage gap unambiguously increases. Intuitively, although the skilled wage increases because of the unskilled labor replacement, the unskilled wage must decrease because the unskilled workers released from the manufacturing sector enter the nontradable final good sector.

Skilled workers are better off because \( p_N \) falls. Unskilled workers are worse off because their wage \( w \) decreases. Thus, on average, real income per capita may fall, depending on the share of unskilled workers.\(^{18}\) If the economy has a relatively small manufacturing base (a low number of specialized inputs), the economy is likely to suffer from a real income decrease.

**Proposition 6.** If the cost for skill accumulation is prohibitively high, then manufacturing automation expands the nontradable good (service) sector. Consequently, the wage gap between skilled and unskilled labor grows. Gains from automation are ambiguous.

\(^{18}\) The payment of the rental cost of capital \( r^*K \) must be incurred across the economy’s population. For simplicity, I assume that a negligible mass of the population incurs the rental cost.
The proposition emphasizes that skill accumulation is crucial to obtain gains from automation. Given that the COVID-19 pandemic is likely to cause education disruption, our results stress that improving education systems (particularly for supplying workers contributing manufacturing bases) is more important.

In addition, financial globalization does not always generate good economic performances, such as high economic growth. Some expositions have been proposed (Rodrik and Subramanian 2009). However, nonbeneficial financial globalization is still an open question (Kose et al. 2010). Highlighting the role of flexible social mobility, in particular workers’ skill-upgrading, our model provides an account on why financial globalization is not always promising for economic development: high cost for skill acquisition and low social mobility in developing economies.

5. CONCLUDING REMARKS

The COVID-19 pandemic has not only generated the deepest world recession in our living memory but also convinced us about future pandemic’s recurring, which almost assures long-lasting effects on economies. Long before the pandemic, automation and digital technologies and trade and production networks have evolved hand in hand, forming two dominant world trends. The COVID-19 pandemic seems to strengthen these trends with some alternations from health and risk concerns. I have argued in this paper that these trends are important from the point of view of the industrialization of developing economies, proposing a simple open economy model with the development trap.

The following findings are emphasized. First, the pandemic may cause the reversal of comparative advantage by imposing labor supply constraints through curtailing worker mobility (social distancing) and degrading education systems. In particular, education systems can be easily damaged for several reasons, including school closures, poor access environments for remote learning, public financial shortages, and household income falls by the recession. If a reversal of comparative advantage does not occur, then a developing economy will recover to the original state. However, if the reversal of comparative advantage is the case, then the original state turns to be an unstable equilibrium and the economy will be trapped in a nonindustrial equilibrium. Hence, the negative impact will be long-term.

Second, manufacturing automation supported by international capital inflows improved the economy’s welfare by enhancing the manufacturing base and making the (relatively) unproductive nontradable sector smaller. Human capital accumulation (increases in skilled labor) will increase. However, exploiting the benefits of automation, labor mobility, and specifically smooth acquisition of skills is critical. Otherwise, as the model suggests, manufacturing automation may lead to an expansion of the nontradable sector, and thus, the wage gap between skilled and unskilled labor
will grow, thereby lowering economic welfare. Thus, this paper emphasizes that enhancing social mobility (i.e., labor mobility across sectors and skill acquisition) becomes more important in the era of global pandemic risks.

The model’s predictions are intuitive, and their logic is clear. However, empirical validation is desirable to make them more useful for policy practitioners. In addition, although this paper’s model is deliberately kept simple to highlight the major logic, some extensions, including endogenous sector size and more general preferences, are also desirable to make the model a base for empirical studies. These agendas are left for future work.

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APPENDIX

A.1. Derivation of the Gross Profits of Intermediate Firms

Labor constraints in an industrialized economy are expressed as

\[ L_X + nt(yx+f) + L_N = L, \]

(1.1)

where \( L_N \) is the labor demand from the nontradable sector. For labor requirements from intermediate good production, \( t \) is multiplied to convert units from skilled to unskilled. Applying \( L_X = (1 - \beta)nt/\beta \) to equation (1.1) and factoring with respect to \( x \),

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\[ x = \frac{\beta}{1 - \beta + \beta \psi} \left( \frac{L - L_N}{nt} - f \right). \]  

(1.2)

Using equation (1.2), the gross profits \( \pi^g = w_x / \sigma \) can be expressed by

\[ \pi^g(n) = \frac{\beta w_s}{\sigma - \beta} \left( \frac{L - L_N}{nt} - f \right). \]

Equivalently, in the return rate of skilled labor,

\[ \frac{\pi^g(n)}{w_s} = \frac{\beta}{\sigma - \beta} \left( \frac{L - L_N}{nt} - f \right), \]

(1.3)

which is decreasing in \( n \). New firm entry continues until the return rate decreases until \( f \). It is immediate that \( \pi^g/w_s \) schedule shifts leftward by a higher training cost (\( \beta \uparrow \) ) or a larger nontradable sector (\( L_N \uparrow \)).

### A.2. Capital Introduction

The labor market clearing is now given by equation (16). Solving it with respect to \( n \),

\[ n_k = \frac{L - L_N}{t \bar{x}}. \]  

(2.1)

Substituting \( L_N \) in equation (18) into equation (2.1),

\[ n_k = \frac{(1 - \eta)L + (r^*/w)\eta K}{t \bar{x}}. \]

(2.2)

\( K \) is given by equation (19).

\[ K = \frac{1 - \beta}{\beta} \cdot \frac{P_X X}{r^*} = \frac{1 - \beta}{\beta} \cdot \frac{n_k tw \bar{x}}{r^*}. \]

(2.3)

Substituting equation (2.3) into equation (2.2), we have

\[ n_k t \bar{x} = (1 - \eta)L + \frac{r^*}{w} \times \frac{1 - \beta}{\beta} \cdot \frac{n_k tw \bar{x}}{r^*}. \]
\[ n_k = \frac{\beta(1 - \eta)L}{[\beta - (1 - \beta)\eta]t}\bar{x}. \]  

(2.4)

Since \( p_M = (r^*)^{1 - \beta}P_X^\beta = (r^*)^{1 - \beta}[n^{1/(1 - \sigma)}t\bar{w}]^\beta \), the equilibrium unskilled wage is

\[ w = \frac{1}{t} \left[ \frac{p_M}{(r^*)^{1 - \beta}} \right]^{1/\beta} n_k^{1/(\sigma - 1)}, \]

(2.5)

where \( n_k \) is given by equation (2.4).

Capital input is

\[
K = \frac{1 - \beta}{\beta} \cdot \frac{n_k t\bar{w}\bar{x}}{r^*} = \frac{1 - \beta}{\beta} \cdot \frac{n_k}{r^*} \times \left[ \frac{p_M}{(r^*)^{1 - \beta}} \right]^{1/\beta} n_k^{1/(\sigma - 1)}
\]

\[= \frac{1 - \beta}{\beta} \left( \frac{p_M}{r^*} \right)^{1/\beta} n_k^{\sigma/(\sigma - 1)}. \]

(2.6)

Aggregate income is expressed as

\[ E = \frac{L}{t} \left[ \frac{2\beta - 1}{\beta - (1 - \beta)\eta} \right] \left[ \frac{p_M}{(r^*)^{1 - \beta}} \right]^{1/\beta} n_k^{1/(\sigma - 1)}. \]

A.3. Manufacturing and Nontradable Outputs and Employment

Without borrowing capital from the international capital market, manufacturing output is expressed as

\[ y_M = \left( \frac{X}{\beta} \right)^\beta \left( \frac{L_X}{1 - \beta} \right)^{1 - \beta} = \left[ \frac{n^{\sigma/(\sigma - 1)}\bar{x}}{\beta} \right] \left[ \frac{(1 - \beta)nt\bar{x}}{\beta(1 - \beta)} \right]^{1 - \beta}
\]

\[= \frac{\bar{x}}{\beta} t^{1 - \beta} n^{1 + \beta/(\sigma - 1)}. \]

When capital (machines) is introduced, manufacturing output is
\[
Y_{Mk} = \left( \frac{X}{\bar{\beta}} \right)^{1-\beta} \left( \frac{K}{1-\bar{\beta}} \right)^{1-\beta} = \left[ \frac{n^{\sigma/(\sigma-1)} x}{\bar{\beta}} \right]^{\bar{\beta} \left( \frac{(1-\beta)ntw}{r^*\beta(1-\beta)} \right)}^{1-\beta}
\]

where equation (2.6) is used.

Without imported capital, the output of nontradable good is simply expressed as

\[
y_N = \psi_N L_N = \psi_N \eta L.
\]

Since the employment in the N sector is \( \eta L \), the employment share is simply \( L_N/L = \eta \).

When the economy uses imported capital in the manufacturing sector,

\[
y_N = \psi_N L_N = \psi_N \eta \left[ L - \frac{r^*}{w} K \right] = \psi_N \eta L \left[ \frac{2\beta - 1}{\beta - (1-\beta)\eta} \right].
\]

The corresponding employment is

\[
L_N = \eta L \left[ \frac{2\beta - 1}{\beta - (1-\beta)\eta} \right].
\]

Since \( 2\beta - 1 < \beta - (1-\beta)\eta \leftrightarrow \eta < 1 \), \( L_N \) declines when the economy uses capital in the manufacturing sector.

A.4. Stagnant Labor Mobility

\[
L_N = [1 - \beta(1-\eta)]L, \quad (4.1)
\]

\[
K = \frac{1-\beta}{\bar{\beta}} \cdot \frac{P_X X}{r^*} = \frac{1-\beta}{\bar{\beta}} \cdot \frac{n^* tw\bar{x}}{r^*}.
\]

Since \( n^* = \beta(1-\eta)L/(t\bar{x}) \),

\[
K = \frac{1-\beta}{\bar{\beta}} \cdot \frac{tw\bar{x}}{r^*} \cdot \frac{\beta(1-\eta)L}{t\bar{x}} = (1-\beta)(1-\eta)w \frac{L}{r^*}. \quad (4.2)
\]

Total expenditure is
Market clearing of the nontradable good (service) sector is

\[ \eta E = wL_N. \tag{4.4} \]

Perfect competition implies that

\[ p_M = r^{*1-\beta} p^\beta X = r^{*1-\beta} \left( (n^*)^{1/(1-\sigma)} w_s \right)^\beta. \tag{4.5} \]

Equation (4.5) determines \( w_s \):

\[ w_s = \left[ \frac{p_M}{r^{*1-\beta}} (n^*)^{-1/(1-\sigma)} \right]^{1/\beta}. \tag{4.6} \]

Comparing to the skilled wage before capital introduction, \( w_s \) in equation (4.6) increases because \( r^* < w \) by assumption.

Using equations (4.3) and (4.4) and eliminating \( E \), we obtain

\[ \eta [w_s n^* x - r^* K] = (1 - \eta) w L_N. \tag{4.7} \]

Further substituting equations (4.1), (4.2), and \( n^* \) in equation (13) into equation (4.7), we obtain the ratio of skilled to unskilled wages (i.e., skill premium) such that

\[ \frac{w_s}{w} = \frac{1 - \beta + \eta}{\beta \eta} t. \]

Since \( 1 - \beta + \eta > \beta \eta \) is immediate, the wage gap increases compared to the one before capital introduction.

With \( w \) and \( L_N \), equation (4.4) gives \( E \). Then, equation (4.3) gives \( K \). Thus, the model is solved.