Trade, Structural Transformation, and Growth*

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Abstract

This paper analyzes a simple model of a small economy with agricultural and non-agricultural sectors to study how opening to international trade affects structural transformation and output growth. Key features of the model are endogenous growth and an explicit trade sector. The model connects trade, output growth, and structural transformation to generate "growth miracles". The effects from accelerated structural transformation are quintessential in accounting for the explosive growth patterns observed in newly industrialized economies. Trade policies, relative productivity between agriculture and non-agriculture, and the persistence of structural transformation process jointly affect the growth dynamics after opening.

Keywords: Growth, Structural transformation, Learning by Doing, International Trade

JEL Classifications: O11, O24, O40

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1. Introduction

Newly industrialized economies, such as Korea, Singapore and Taiwan, experienced "growth miracles." For these economies, export-oriented structural transformation from agricultural to non-agricultural production and high output growth coexisted, which is a distinctive feature, not shared by numerous other economies. While there have been several attempts to study the "growth miracles," most of the theoretical models remain unquantified. Other models which have been calibrated often use exogenous productivity growth, providing only a limited insight to understand the engine of growth, or do not introduce an explicit trade sector which is essential to explain the patterns of explosive economic growths in newly industrialized economies. Furthermore, as Lucas (2009) reviews, available estimates of the gains from trade remain counterfactually small. These observations imply a need for a better quantifiable model of trade, structural transformation, and growth.

This paper analyzes a simple model of a small economy with agricultural and non-agricultural sectors to study how opening affects structural transformation and output growth.[1] As we review below, we are one of the first authors to connect all three of trade, structural transformation and output growth in order to generate "growth miracles," with endogenous growth and an explicit role for international trade. Hence, this paper can be viewed as providing a theoretical framework to the empirical results reported by McMillan and Rodrik (2011). While our endogenous model can generate large gains from trade (depending on the country's initial conditions regarding relative productivity between agricultural and non-agricultural sectors and trade policy), we also offer a version which attaches other sources of growth such as international knowledge transfer, as modelled in Lucas (2009).[2]

[1] Papageorgiou and Spatafora (2012) also emphasize a broad connection among trade, structural transformation, and growth.

[2] Of course, opening to international trade may work to the other direction to slow down the structural transformation and to discourage output growth, depending on initial conditions. For instance, in one of

Our contribution is on quantitative side: Our model is parsimonious and highly quantifiable. That is, it is possible to obtain closed-form solutions for many variables, which facilitates the understanding of the main mechanism. Hence, the growth accounting can easily separate the contribution of labor composition effect (i.e., moving from the less productive agricultural sector to the more productive non-agricultural sector) from the contribution of learning by doing (which is assumed as a main endogenous source of productivity growth) and others, if any, such as international knowledge transfer.

The model is based on Matsuyama's (1992) model of international trade. An economy features two goods: the agricultural good, produced with labor and a fixed input, and the non-agricultural good, produced with labor only. In the non-agricultural sector, there is learning by doing such that the economy-wide productivity growth is proportional to employment share in that sector. In addition, there is knowledge transfer from the non-agricultural to the agricultural sector, implying that agricultural productivity growth is proportional to non-agricultural productivity growth. In an extension, we also introduce international knowledge inflow.

Even when closed, the economy experiences structural transformation from agriculture to non-agriculture, converging to the steady state of agricultural share. However, by opening to international trade, an economy exports either non-agricultural or agricultural good, depending on (i) the productivity in non-agriculture relative to agriculture, (ii) the international price of non-agricultural good relative to agricultural good, and (iii) trade policy (tariffs). If the economy exports non-agricultural goods, trade can accelerate the structural transformation from agriculture to non-agriculture. If the non-agricultural sector provides a higher value of marginal product of labor due to frictions, the accelerated structural transformation also expedites output growth. Additionally, since learning by doing arises from non-agricultural sector, a specialization in non-agriculture will intensify the learning-by-doing effect, thereby increase productivity faster.

our simulation examples with a strong protection in agricultural sector, opening can decrease the welfare level as well as the real GDP, compared to an autarky.

We calibrate the rest of the world to an aggregate economy of high-income OECD countries, referred to as the "North". We then consider a small open economy that begins trading with the "North." We find that the model can generate a relatively fast structural transformation and relatively high output growth, comparable to the growth miracles experienced by newly industrialized economies.

The implications of our model fit the following international evidence as well. Figure 1 plots the relationship between non-agricultural exports, as logarithm of share of GDP, and real per-capita GDP growth for 128 economies in the period of 1975-2000.[3] The correlation coefficient between these two variables is 0.41, while the hypothesis of no correlation against the alternative that there is a non-zero correlation is rejected at 1% level.[4] Figure 2 compares the real GDP growths in 1975-2000 of two groups of economies. Each group consists of 64, with the higher and lower shares of non-agricultural exports out of GDPs, respectively. The figure shows that the economies with higher shares of non-agricultural exports tend to grow faster, controlling for initial per-capita GDPs.[5] In Figure 3, the cross-country data of 86 economies in year 2001, as well as the time-series data of four selected economies, report a negative association between real per-capita GDP and agricultural employment share.[6] Indeed, we generate these associations with the calibrated model. Therefore, our quantitative model can explain the cross-sectional variations of economic growth without challenging key stylized facts on international trade and structural transformation.

[3] The data for real GDP and population are from the World Development Indicators (WDI) published by the World Bank. The data for manufacturing exports are from the United Nations (UN) Commodity Trade Statistics Database ("Comtrade"). They are obtained by aggregating Standard International Trade Classification (SITC) Revision 2 codes starting from 5 to 8, and a half of the one starting from 9.

[4] In Figure 1, Equatorial Guinea appears as an outlier. The discovery of petroleum reserves contributed to the growth of this economy.

[5] While Figures 1 and 2 illustrate the correlation only, the causality is further supported by cross-country instrument-variable (IV) regressions provided in Appendix III.

[6] The data for GDP per capita are from Angus Maddison's website. The cross-country data for agricultural employment in Part (A) are obtained from World Development Indicators published by the World Bank. The time-series data for agricultural employment in Part (B) are from Kuznets (1971) and World Development Indicators. See, also, McMillan and Rodrik (2011), for empirical discussions on structural transformation.

We do not claim that our model is the only possible way to explain the growth miracles. While the components of our model, such as learning by doing and cross-sector knowledge transfer, provide a convenient and simple way to endogenously connect trade, structural transformation and growth, there can be other economic forces which can be complementary to our arguments. For example, the incentive to innovate tends to increase with trade openness, as reviewed by Melitz and Trefler (2012).[7]

This remainder of the paper is organized as follows. The rest of this section discusses the related literature. Section 2 provides a theoretical model. Section 3 studies a quantification of the model. Section 4 connects the quantification of the model to data. Section 5 concludes.

1.1. Related Literature

A positive empirical relationship between international trade and real GDP growth is documented by Sachs and Warner (1995), Frankel and Romer (1999), Alcalá and Ciccone (2004), and Felbermayr and Gröschl (2012).[8] Several theoretical models were proposed to understand how trade affects real GDP growth. However, the literature lacks *endogenous* growth models which can *quantitatively* connect trade and real GDP growth. Further, there are few endogenous models, if any, which connects them further to structural transformation and generates the "growth miracles."

[7] Appendix IV discusses other possible theories.

[8] Keller (2004, p.767) provides further backgrounds on the causality from trade to growth.

Figure 1. Non-agricultural exports, as a share of GDP, and per-capita GDP growth, 1975-2000 (128 economies)

Correlation between two variables is 0.41. The trend line is based on the OLS regression.

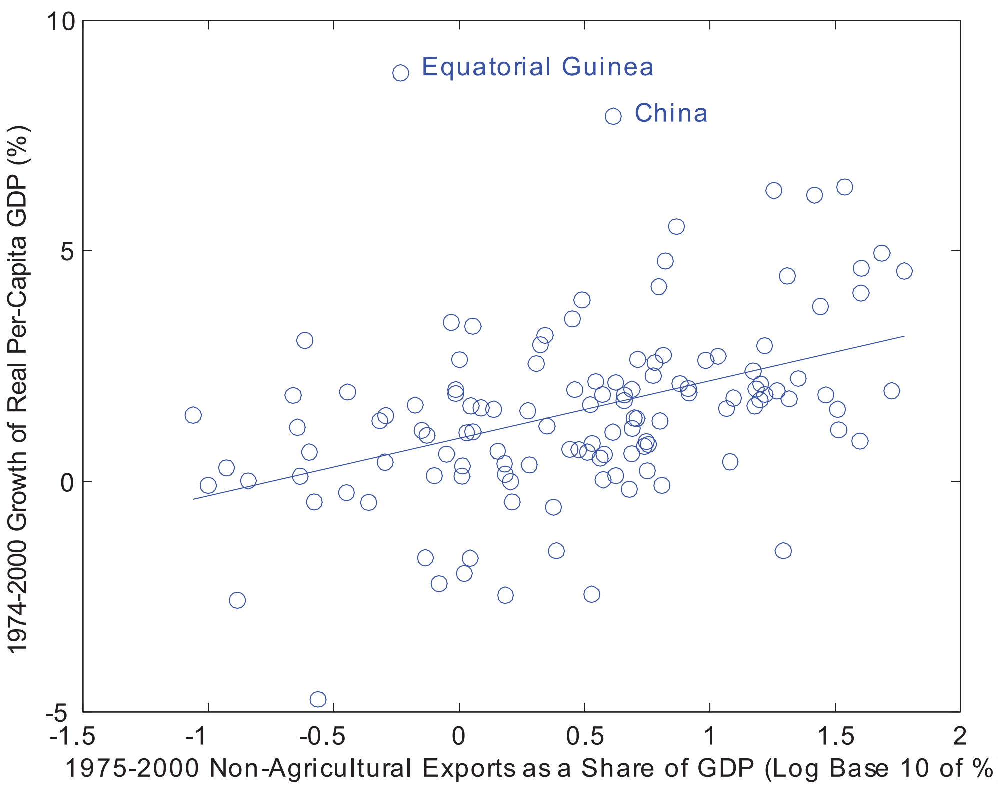


Figure 2. Initial per-capita GDP and per-capita GDP growth, for top and bottom halves in non-agricultural exports as a share of GDP, 1975-2000 (128 economies)

Five (outlier) economies in “Top Half,” Zambia, Central Africa, Niger, Gambia, and Congo Rep., are excluded in the figure. To define “non-agriculture”, “agriculture” is first defined as all products in industry codes 1 through 4 and one half in industry code 9 in SITC revision 2. The main exports of those five economies include copper, diamonds, and coal, some of which are included in code 5.

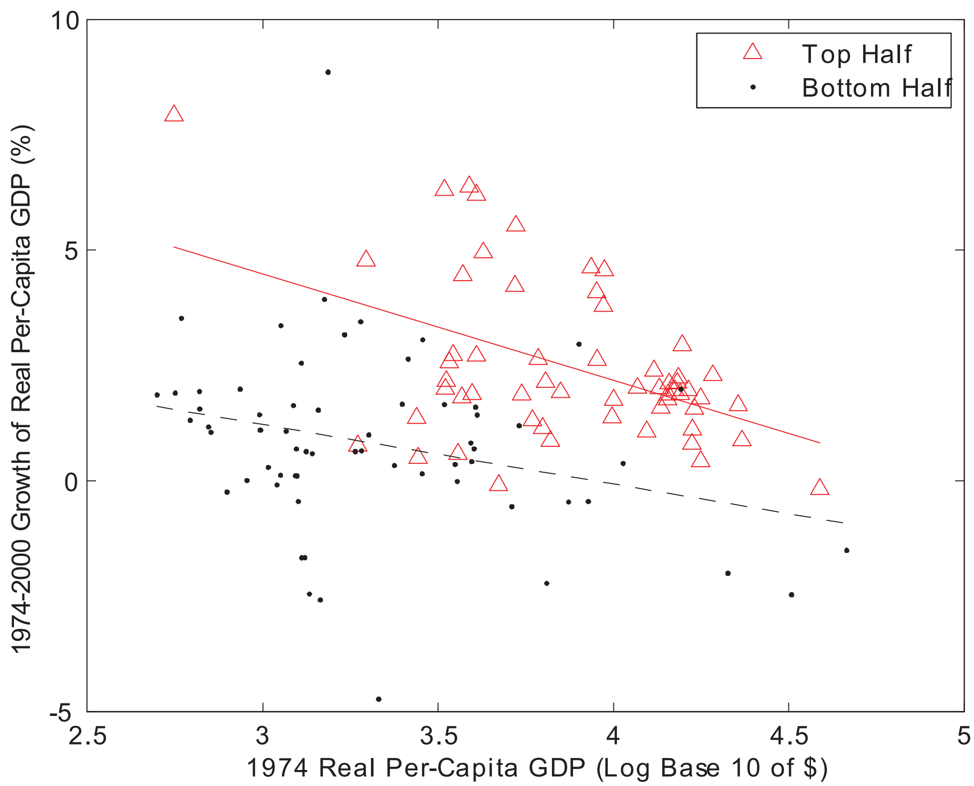
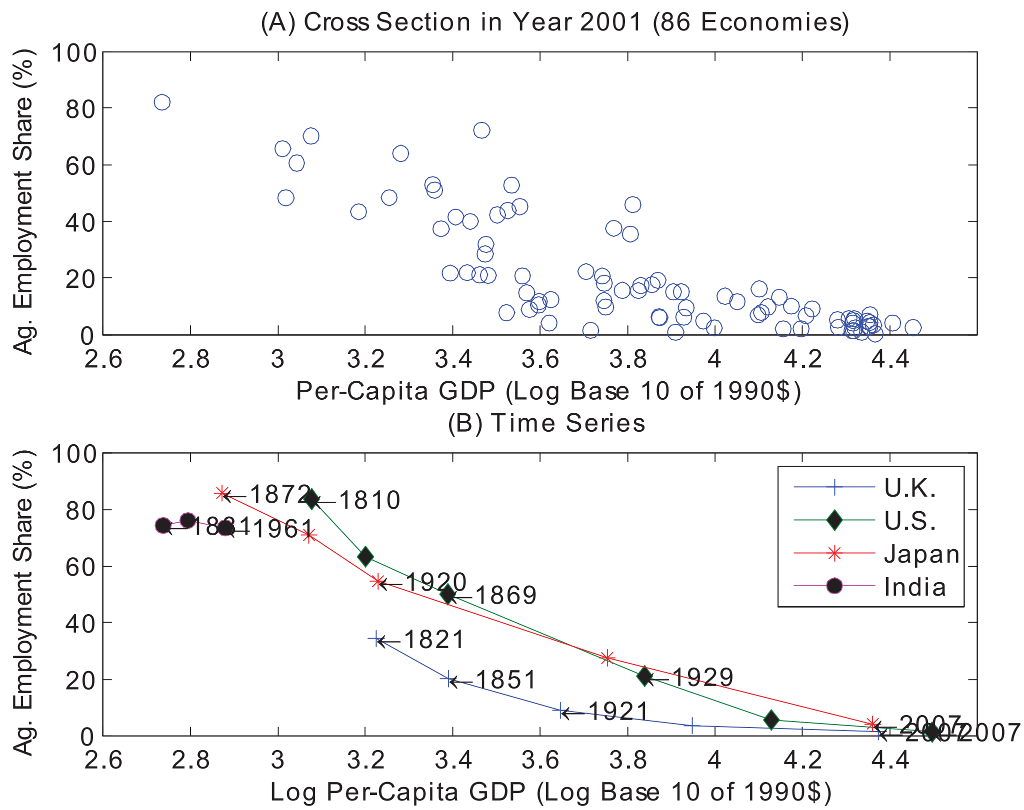


Figure 3. Per-capita GDP and employment share in agriculture

These figures illustrate an association between real per-capita GDP and agricultural employment share. Part (A) is the cross-country data of 86 economies in year 2001. Part (B) is the time-series data of four selected economies.



Lucas (2009) provides a simple model in which productivity growth explicitly depends on the share of non-agricultural employment and the output gap against a "leader" economy, in order to connect trade, structural transformation, and growth. In Lucas (2009), the exchange of useful ideas occurs more actively in the urban area, and hence, the open economies with an initially lower share of agricultural employment, such as Korea and Singapore, have advantages to benefit more from international knowledge inflow. However, international knowledge inflow occurs exogenously, and hence, which specific components of trade contribute fundamentally to structural transformation and growth is not clearly answered. In addition, the economy is either completely closed or completely open. Hence, a more sophisticated model with an explicit trade sector would help to answer, for example, under what conditions opening to international trade is beneficial.

While this paper has its motivation from Lucas (2009), the theoretical model that it employs is based on Matsuyama (1992) and Lewis (1954). Matsuyama's (1992) model can be understood as an extension of Lewis (1954) by introducing international trade. While Lewis (1954) describes how structural transformation occurs on micro level, Matsuyama (1992) focuses more on the evolution of quantifiable macro variables such as output and employment. However, Matsuyama's (1992) discussion is limited to theory. This paper can be viewed as a quantitative extension with modifications.[9]

Ventura (1997) also provides a model of international trade to explain how "miracle" economies were able to grow faster than others. Hence, this paper could alternatively adopt Ventura (1997) as a theoretical framework. Ventura (1997) assumes constant productivity, explaining output growth mainly with physical capital accumulation. On the other hand, Matsuyama's (1992) model does not have physical capital, and hence, productivity growth solely explains output growth. While Matsuyama (1992) and Ventura (1997) are complementary, this paper's calibration chooses Matsuyama (1992) because it

[9]It is useful to note that in Lewis (1954), incomplete rural-urban migration with higher urban wages results from the uncertainty of finding a high-paying urban job. For simplicity, this role is captured by a parameter λ in this paper's model, while Matsuyama (1992) does not have an incomplete migration.

is simpler. Related, Prescott (1998) documents that an accumulation of measured inputs does not seem to solely explain the real GDP growth.

Song, Storesletten and Zilibotti (2011) study how financial imperfections in emerging economies can be linked to growth, structural transformation and trade surplus. The main difference from this paper is that their model does not explicitly model the trade sector, and hence, the impact of opening is solely attributed to the financial sector. Stokey (2001) suggests that food imports made structural transformation possible in the British Industrial Revolution, which is also consistent with this paper's model. However, this paper focuses on the role of non-agricultural exports which ultimately make food imports possible. In addition, this paper focuses more on how the newly industrialized economies were able to accelerate their own Industrial Revolutions. Teignier (2013) focuses on the relationship between opening and structural transformation while output growth is exogenously given.[10] This paper's focus extends to output growth.[11]

Duarte and Restuccia (2010) investigate the role of sectoral labor productivity to explain structural transformation. Restuccia, Yang and Zhu (2008) study the relationships among sectoral productivity differences, labor market frictions, and the sectoral shares of employment. Also, Dolores Guilló, Papageorgiou and Pérez-Sebastián (2011) also provide a model of structural transformation. All of them share some features with this paper, such as structural transformation and labor market frictions. However, they do not explicitly focus on the role of international trade on structural transformation and eventually on output growth.

[10] Teignier (2013) argues that Korea's gain in structural transformation and real GDP growth arising from opening could have been larger with less protections.

[11] There are other works that attempt to examine the roles of trade in a neoclasssical growth framework, such as Bajona and Kehoe (2010) and Uy, Yi and Zhang (2013).

2. The Model

We spell out our model in this section. There is a mass one of identical workers. Two goods, $\mathcal{N}$ (non-agriculture) and $\mathcal{A}$ (agriculture), exist. There are no storage technologies.

2.1. Environment

Production: Each worker owns one non-agricultural firm producing good $\mathcal{N}$, and one farm producing good $\mathcal{A}$. At each period t, the worker allocates a fraction $0 \leq l_t \leq 1$ of his time into non-agricultural firm and $1 - l_t$ into farm. Each non-agricultural firm's production function is

$$Y_t^N = N_t l_t, \tag{1}$$

where Y_t^N is the output in units of good $\mathcal{N}$, and N_t is the economy-wide productivity in $\mathcal{N}$ sector.[12] The productivity, N_t, features learning by doing.[13] To be specific, N_t evolves externally according to the economy-wide production, following

$$N_{t+1} - N_t = \mu N_t \bar{l}_t, \tag{2}$$

for $\mu > 0$, where $\bar{l}_t$ is an economy-wide level of l_t (so in equilibrium, $\bar{l}_t = l_t$). Since an individual firm is small, its production decision does not affect the evolution of economy-wide productivity.[14] In Section 4, we study an extension of (2) to consider international productivity catch-up, as $N_{t+1} - N_t = \mu \left(N_t\right)^{1-\delta} \left(N_t^*\right)^{\delta} \bar{l}_t$ for $0 < \delta < 1$, where N_t^* is non-agricultural productivity of the "leader" economy.

Each farm's production function is

$$Y_t^A = A N_t^{\theta} \left(1 - l_t\right)^{\phi}, \tag{3}$$

[12] We abstract from physical capital in this model, mainly for tractability. Trade in capital input may increase technology and spur growth, which is an interesting extension.

[13] See Thompson (2010) for empirical survey on learning by doing.

[14] Matsuyama (1992) and Lucas (2009) also assume external learning-by-doing effects. An alternative set-up, to internalize the learning by doing, complicates the analysis without notable gains.

where Y_t^A is the output in units of good $\mathcal{A}$. Here, A is a constant which captures cross-country differences in fertilities, etc. Also, N_t^θ reflects the knowledge transfer from $\mathcal{N}$ sector to $\mathcal{A}$ sector, where $\theta \geq 0$ is a parameter of the size of such transfer.[15] A parameter ϕ determines the curvature of $\mathcal{A}$ production, where a condition $0 < \phi < 1$ is imposed to reflect decreasing marginal products due to fixed amount of lands, etc.

The learning-by-doing effect is in $\mathcal{N}$ sector only. This is to consider the fact that the growth of per-capita GDP had been slower until the Industrial Revolution and the well-known effect of technological advances toward agricultural sector.[16]

Labor Decision under Frictions: Provided that each worker maximizes the aggregate revenue from $\mathcal{N}$ Sector and $\mathcal{A}$ sector, the worker's problem is specified as follows: Given N_t and the unit prices of good $\mathcal{N}$ and good $\mathcal{A}$, p_t^N and p_t^A, he solves

$$\max_{\{l_t\}} \sum_{t=0}^{\infty} e^{-rt} \left[p_t^N N_t l_t + \lambda p_t^A A N_t^\theta (1 - l_t)^\phi \right], \tag{4}$$

$s.t.$

$$l_t \leq (1 + \alpha) l_{t-1}, \tag{5}$$

where $r > 0$ is a constant, $\lambda > 0$ and $\alpha > 0$ represent two distortions associated with structural transformation. Without these frictions, the solution to this problem provides an equality between the values of marginal products in two sectors, and under some conditions, the structural transformation can be completed instantly. However, these predictions are inconsistent with data, and the introduction of the distortions help to match the model with data.[17]

[15] Lucas (2009) and Dolores Guilló, Papageorgiou and Pérez-Sebastián (2011) adopt similar approaches. See, for example, Johnson and Evenson (1999) for empirical discussions on the knowledge transfer to agricultural sector.

[16] See, for example, Lucas (2009).

[17] Intuitively, these distortions can represent the costs in living in urban areas (including higher urban housing prices), institutional sectoral distortions (as in, for example, Hayashi and Prescott (2008)), or labor market distortions (as in Restuccia, Yang and Zhu (2008)).

Regarding λ, empirical evidence states that the urban per-capita GDP is higher than the rural per-capita GDP (e.g., Clark (1951), Kuznets (1955), and Yang (1999)).[18] The data used in the calibration of Section 3 also imply that the agricultural share of employment is 5.0% in high-income OECD economies, on average of years 1992 and 2006. However, the agricultural share of value added is only 2.0% out of the GDP. These imply that the agricultural labor productivity – or value added per employee – is only 40% of the non-agricultural counterpart. This observation supports $\lambda > 1$. That is, in the model, if $\lambda > 1$, then in worker's optimal decision, $\mathcal{N}$ sector provides a higher value of marginal product. Indeed, it turns out that the calibration of Section 3 provides $\lambda > 1$. The observation that agricultural value-added share is higher than agricultural employment share also holds in developing economies. In year 1999 (in the middle of 1992 and 2006 that we consider in calibration), the agricultural employment was 24.0% while the agricultural value added was only 12.0% of GDP, for 39 economies (providing data observations) that are not high-income OECD economies in World Development Indicators. After the model is calibrated, we further discuss the model's implications on the relative labor productivity in Subsection 3.2.

Regarding α, it is well known that the structural transformation takes several decades, as in Part (B) of Figure 3. The purpose of (5) is to prevent a situation in which structural transformation is immediately completed after an economy opens with a specialization in $\mathcal{N}$ sector. As Kuznets (1971) points out, at the early stage of development, an economy concentrates on agriculture and there are few urban areas with industry or service sectors. Hence, reallocating labor from the agriculture to the non-agricultural sector is limited by the extent of urbanization and various factors that facilitate the transitions in labor market. The constraint (5) on l_t is designed to capture these frictions in shifting from $\mathcal{A}$ sector to $\mathcal{N}$ sector. An alternative, perhaps more elegant, way to produce the delayed transition process is to explicitly introduce a transition cost between $\mathcal{A}$ sector

[18] In Lewis (1954), incompleteness of rural-urban migration while urban wages are higher results from the uncertainty of finding a high-paying urban job. The parameter λ can be also motivated in that way.

and $\mathcal{N}$ sector. For example, problem (4) can be replaced by an unconstrained problem maximizing the discounted sum of $p_t^N N_t l_t + \lambda p_t^A A N_t^\theta (1-l_t)^\phi - \psi(l_t - l_{t-1})^2$ for all t, where $\psi > 0$ reflects the size of transition cost. However, this provides additional terms in the first-order conditions, which complicates theoretical and empirical analyses of the model without adding much new insight. Furthermore, our goal is not to theoretically explain the sources of structural transformation, but to discuss how the structural transformation is affected by opening.[19]

How does an introduction of λ and α change the implications of the model? For λ, as we discuss later, the level of l_t, as well as the relative price between $\mathcal{N}$ good and $\mathcal{A}$ good, is determined in an equilibrium of a closed economy. As λ increases (for example, from one to 2.5), the level of l_t will decrease (since λ increases $1-l_t$) and the price of $\mathcal{N}$ good will be higher (since less units of good $\mathcal{N}$ are produced). In a small open economy, the prices are exogenously given, but the level of l_t is still affected by λ. However, it turns out that there can be a range of the values of λ that provide $l_t = 1$ (a full specialization in $\mathcal{N}$ sector) as a corner solution. Notice that if $\lambda > 1$, the structural transformation becomes a process of moving workers from lower-productivity sector ($\mathcal{A}$ sector) to higher-productivity sector ($\mathcal{N}$ sector) even in a closed economy. Hence, λ represents the labor composition effect which becomes a contributor to the real GDP growth. However, it is uncertain whether this is a quantitatively important factor in a small open economy, because the prices are internationally determined, which reduces the role of λ. We investigate this issue in the next section.

Regarding α, as discussed above, it is mainly toward accounting for the persistence in the process of structural transformation. Thus, for the remaining of this section, we assume that constraint (5) does not bind in order to facilitate theoretical discussions. This does not affect the main theoretical implications of the model (e.g., whether opening facilitates the structural transformation and accelerate the GDP growth). Constraint (5)

[19] See, also, Caselli and Coleman (2001).

is re-introduced in the quantitative analysis of Section 3.[20]

Hence, the first-order condition of (4) becomes

$$p_t^N N_t = \lambda \phi p_t^A A N_t^{\theta} (1 - l_t)^{\phi - 1}. \tag{6}$$

This is because the decision on l_t at period t does not affect the future periods. That is, in (2), the evolution of $\{N_t\}$ is affected by $\bar{l}_t$, not by l_t.

Preferences: The representative consumer at period t solves

$$\max_{\{C_t^N, C_t^A\}} \sum_{\tau=0}^{\infty} e^{-\rho(t+\tau)} \left[\log(C_{t+\tau}^N) + \beta \log(C_{t+\tau}^A - \gamma) \right], \tag{7}$$

for $\rho > 0$, $\beta > 0$ and $\gamma > 0$, where C_t^N is the consumption of good $\mathcal{N}$, C_t^A is the consumption of good $\mathcal{A}$, and γ is the subsistence level, subject to

$$p_{t+\tau}^N C_{t+\tau}^N + p_{t+\tau}^A C_{t+\tau}^A \leq p_{t+\tau}^N Y_{t+\tau}^N + p_{t+\tau}^A Y_{t+\tau}^A, \tag{8}$$

for all $\tau = 0, 1, ...$ Assume $C_t^A > \gamma$ for all t. These preferences imply that at each period t, (i) the consumer first purchases γ units of good $\mathcal{A}$, and (ii) spends a fraction $\frac{1}{1+\beta}$ of the remaining budget to purchase C_t^N units of good $\mathcal{N}$ and the fraction $\frac{\beta}{1+\beta}$ to purchase $C_t^A - \gamma$ units of good $\mathcal{A}$. Hence,

$$\beta p_t^N C_t^N = p_t^A \left(C_t^A - \gamma \right). \tag{9}$$

If $\gamma > 0$, then the consumption share of good $\mathcal{A}$ decreases as the consumer's income increases.[21]

Real GDP Growth: We obtain the real GDP growth using the prices of the previous year. That is, the real GDP growth is

$$\frac{p_t^N Y_{t+1}^N + p_t^A Y_{t+1}^A}{p_t^N Y_t^N + p_t^A Y_t^A} - 1. \tag{10}$$

[20] Roles of (5) are further discussed in Appendix 2.

[21] Since the consumer purchases γ units of good $\mathcal{A}$ before she proportionally assigns the remaining budget, learning by doing (and thus income growth) will increase the proportion of spending on good $\mathcal{N}$, deriving structural transformation in production. Since good $\mathcal{N}$ has higher marginal productivity, the structural transformation also increases the real GDP. Hence, the levels of β and γ affects the features of structural transformation and real GDP growth.

2.2. Small Open Economy

We consider the solution of the model for a small open economy. Comparing this solution to the one for a closed economy, we discuss the impacts of opening for a small economy.

Comparative Advantage and Structural transformation: A unique currency is used in all economies. For a small open economy, the international prices, p_t^{A*} and p_t^{N*}, for good $\mathcal{A}$ and good $\mathcal{N}$, are exogenously given. Throughout this paper, a superscript "$*$" implies the world. The government can intervene in international trade, through tariffs, subsidies, quotas, etc. Such policies are summarized as effective tariff rates, denoted by τ_A and τ_N, which satisfy

$$p_t^A = (1+\tau_A)p_t^{A*}, \tag{11}$$

$$p_t^N = (1+\tau_N)p_t^{N*}. \tag{12}$$

We disregard the government surpluses or deficits caused by such policy.

Definition 1: *The solution in a small open economy is a set of* $\{l_t, N_t, Y_t^N, Y_t^A, C_t^N, C_t^A\}$ *such that (i) each worker solves problem (4), taking* N_t *(from (2)),* p_t^N *and* p_t^A *as given, (ii) the representative consumer solves problem (7), taking* p_t^N, p_t^A, Y_t^N *and* Y_t^A *as given.*

Since the economy takes the international prices as given, there is no market-clearing condition. Since p_t^N, p_t^A and N_t are given, (6) determines l_t as

$$l_t = 1 - \left(\frac{1}{\phi\lambda}\frac{p_t^N}{p_t^A}\frac{N_t^{1-\theta}}{A}\right)^{\frac{1}{\phi-1}}. \tag{13}$$

This implies that l_t is determined by the following:

(i) Relative price, $\frac{p_t^N}{p_t^A}$: Since $0<\phi<1$, a higher level of $\frac{p_t^N}{p_t^A}$ increases l_t. Since $\frac{p_t^N}{p_t^A} = \frac{1+\tau_N}{1+\tau_A}\frac{p_t^{N*}}{p_t^{A*}}$, a heavier protection in $\mathcal{N}$ sector, relative to $\mathcal{A}$ sector, tends to accelerate the structural transformation, given p_t^{N*} and p_t^{A*}.

(ii) $\frac{N_t^{1-\theta}}{A}$: A higher level of $\frac{N_t^{1-\theta}}{A}$ increases l_t. Notice that $\frac{N_t^{1-\theta}}{A} = \frac{N_t}{AN_t^{\theta}}$ is the ratio of the productivity of $\mathcal{N}$ sector (N_t) relative to "the productivity of $\mathcal{A}$ sector reflecting the knowledge transfer from $\mathcal{N}$ sector" (AN_t^{θ}). Hence, if $\mathcal{N}$'s productivity (N_t) is higher relative to $\mathcal{A}$'s (AN_t^{θ}), then the economy tends to specialize in $\mathcal{N}$ sector more intensively after opening, which accelerates the structural transformation. Only relative productivity, not absolute productivities, matters in structural transformation.

In order to derive the net export in each sector, compute Y_t^N and Y_t^A from (1) and (3) as follows:

$$Y_t^N = N_t \left[1 - \left(\frac{1}{\phi\lambda A} \frac{p_t^N}{p_t^A} N_t^{1-\theta} \right)^{\frac{1}{\phi-1}} \right], \tag{14}$$

$$Y_t^A = AN_t^{\theta} \left(\frac{1}{\phi\lambda A} \frac{p_t^N}{p_t^A} N_t^{1-\theta} \right)^{\frac{\phi}{\phi-1}}. \tag{15}$$

Then, (8) (with equality) and (9) determine C_t^N and C_t^A. Then, net export in $\mathcal{N}$ sector, $X_t^N \equiv Y_t^N - C_t^N$, is given by

$$\begin{aligned} X_t^N &= \frac{\beta}{1+\beta} N_t \left[1 - \left(\frac{1}{\phi\lambda A} \frac{p_t^N}{p_t^A} N_t^{1-\theta} \right)^{\frac{1}{\phi-1}} \right] + \frac{1}{1+\beta} \frac{p_t^A}{p_t^N} \left[\gamma - AN_t^{\theta} \left(\frac{1}{\phi\lambda A} \frac{p_t^N}{p_t^A} N_t^{1-\theta} \right)^{\frac{\phi}{\phi-1}} \right] \\ &= \frac{1}{1+\beta} [\frac{\gamma}{\phi\lambda A} \frac{1}{Q_t} + \beta N_t - (A+\beta) Q_t^{\frac{1}{\phi-1}} N_t^{\frac{\theta-\phi}{1-\phi}}] \end{aligned} \tag{16}$$

where $Q_t \equiv \frac{1}{\phi\lambda A} \frac{p_t^N}{p_t^A}$. The net export in $\mathcal{A}$ sector, $X_t^A \equiv Y_t^A - C_t^A$, can be computed in a similar way. Note that since consumer's problem (7) faces the budget constraint, the trade is always balanced as $p_t^N X_t^N + p_t^A X_t^A = 0$ for all t.

Equation (16) implies that the comparative advantage depends on N_t and $\frac{p_t^N}{p_t^A}$. First, regarding N_t, $\frac{\partial X_t^N}{\partial N_t}$ is computed as

$$\frac{\partial X_t^N}{\partial N_t} = \frac{1}{1+\beta} \left[\beta - \left(\frac{\theta-\phi}{1-\phi} \right) (A+\beta) Q_t^{\frac{1}{\phi-1}} N_t^{\frac{\theta-1}{1-\phi}} \right].$$

To evaluate the effect of N_t on X_t^N, let us assume that $\theta > 1$.[22] Then, the sign of $\frac{\partial X_t^N}{\partial N_t}$ is not clear. If N_t is small, then $N_t^{\frac{\theta-1}{1-\phi}}$ also tends to be small, implying that $\frac{\partial X_t^N}{\partial N_t}$ is likely to

[22] We provide more details on the calibration result in Subsection 3.1.

be positive, provided that $Q_t^{\frac{1}{\phi-1}}$ is not too big. Thus, as N_t increases over time in the early stage of growth resulting from its strategic complementarity (learning by manufacturing), the transfer benefit to $\mathcal{A}$ sector surpasses the productivity growth of $\mathcal{N}$ sector, and hence, the export in $\mathcal{N}$ sector may start decreasing.

Second, for the relative price ratio between two sectors,

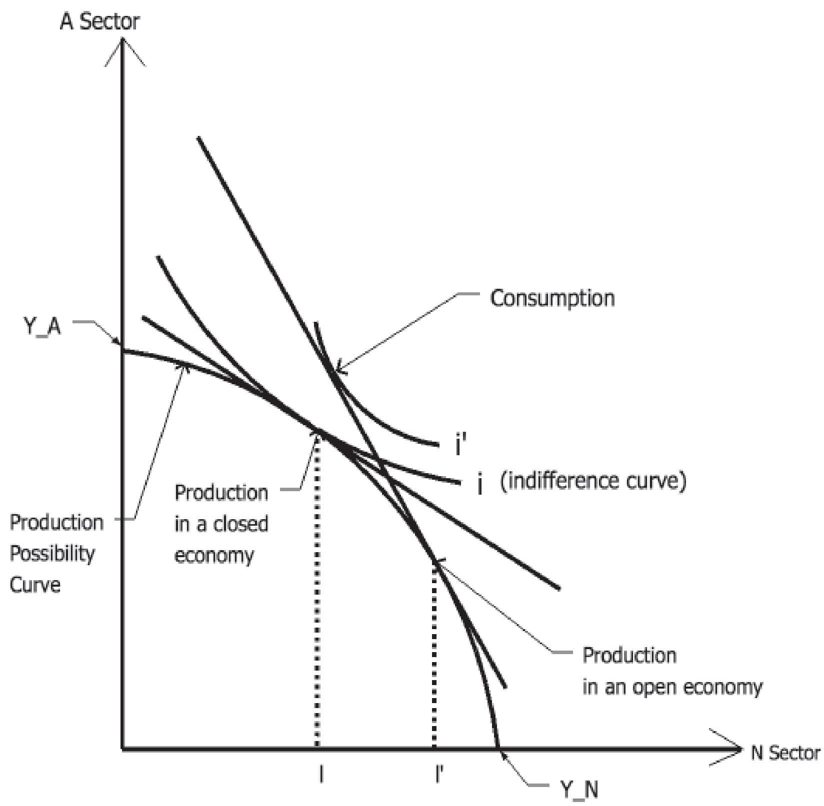
$$\frac{\partial X_t^N}{\partial Q_t} = \frac{Q_t^{-2}}{1+\beta}\left[\left(\frac{A+\beta}{1-\phi}\right) Q_t^{\frac{-\phi}{1-\phi}} N_t^{\frac{\theta-\phi}{1-\phi}} - \frac{\gamma}{\phi\lambda A}\right]$$

holds. Again, it is not obvious how an increase in $\frac{p_t^N}{p_t^A}$ (or Q_t) affects net exports. However, similar to the case of N_t, if Q_t is small, it is more likely that this partial derivative is positive. Provided that Q_t increases over time (as in the example of Subsection 3.2), this effect erodes, making $\frac{\partial X_t^N}{\partial Q_t}$ more likely to be negative. However, N_t also grows due to the learning by doing effect, and hence, if $\theta > 1$, then $\frac{\partial X_t^N}{\partial Q_t}$ can remain positive at least for a while. Quantitative analyses in Subsections 3.1 and 3.2 confirm this explanation with some empirical support.

Figure 4 illustrates the production possibility curve of an economy which was originally closed but has opened to international trade. The economy is assumed to specialize in $\mathcal{N}$ sector, while $\lambda = 1$ is assumed and the constraint about α, (5), is disregarded, both for simplicity. The production possibility curve is concave due to the diminishing returns to labor in $\mathcal{A}$ sector. The figure illustrates a static gain of international trade. That is, by opening, the level of utility increases from the level implied by indifference curve i to i'. However, another gain is dynamic, which occurs due to an increase in $\mathcal{N}$ sector employment from l to l', which enhances the learning-by-doing effect. We discuss this dynamic gain in detail in the next subsection.

Figure 4. Production possibility curve

This figure illustrates the production possibility curve of an economy which was originally closed but has opened to international trade. The economy is assumed to specialize in N sector, while $\lambda = 1$ is assumed and the constraint about α, (5), is disregarded, both for simplicity.



C. Gains (or Losses) from Opening

We now analyze the short-run and long-run impacts of opening. The opening takes place at period 0 for a small economy. For comparison, a closed counterpart of this economy is derived below.

Closed Economy: A closed economy requires $C_t^N = Y_t^N$ and $C_t^A = Y_t^A$. We define an equilibrium of a closed economy as follows.

Definition 2: *An equilibrium of a closed economy is a set of* $\{l_t, N_t, Y_t^N, Y_t^A, C_t^N, C_t^A\}$ *and a set of* $\{p_t^N / p_t^A\}$ *such that (i) each worker solves problem (4), taking* N_t *(from (2)),* p_t^N *and* p_t^A *as given, (ii) the representative consumer solves problem (7), taking* p_t^N*,* p_t^A*,* Y_t^N *and* Y_t^A *as given, and (iii) the market clears, i.e.,* $C_t^N = Y_t^N$ *and* $C_t^A = Y_t^A$*, for all* t*.*

Using (1) and (3), along with $C_t^N = Y_t^N$ and $C_t^A = Y_t^A$, we write (9) as

$$\frac{p_t^N}{p_t^A} = \frac{1}{\beta} \frac{AN_t^{\theta} (1 - l_t)^{\phi} - \gamma}{N_t l_t}. \tag{17}$$

Then, two equations, (6) and (17), determine l_t and p_t^N / p_t^A in an equilibrium. Combining the two equations, l_t is determined in

$$\frac{\phi \lambda A N_t^{\theta} (1 - l_t)^{\phi - 1}}{N_t} = \frac{1}{\beta} \frac{AN_t^{\theta} (1 - l_t)^{\phi} - \gamma}{N_t l_t}.$$

Here, the left-hand side is the relative price implied by the marginal rate of substitution in production, while the right-hand side is the relative price determined by the consumer's preferences. Hence,

$$\phi \lambda A N_t^{\theta} (1 - l_t)^{\phi - 1} = \frac{1}{\beta} \frac{AN_t^{\theta} (1 - l_t)^{\phi} - \gamma}{l_t}. \tag{18}$$

The solution $0 < l_t < 1$ uniquely exists.[23]

[23] The left-hand side is a strictly increasing function of l_t, while the right-hand side is a strictly decreasing

Short-Run Impact (Before the Steady State is Reached): Continue to assume (5) is not binding. At period 0 (when the economy opens), l_0 is determined by (13) with $t = 0$. If the economy continues to be closed at period 0, then l_0 would be alternatively determined by (18). The left-hand side of (18) is an increasing function of l_t, while the right-hand side is a decreasing function of l_t. This easily proves the following result.

Result 1: *The opening accelerates the structural transformation from $\mathcal{A}$ sector to $\mathcal{N}$ sector of a small economy if and only if*

$$\phi\lambda AN_0^{\theta}(1-l_0)^{\phi-1} > \frac{1}{\beta}\frac{AN_0^{\theta}(1-l_0)^{\phi}-\gamma}{l_0}, \tag{19}$$

where l_0 is the solution to l_t in (13).

The opening can accelerate or decelerate the structural transformation from $\mathcal{A}$ sector to $\mathcal{N}$ sector, depending on parameter values (such as A and N_0) and after-tariff relative price, $\frac{p_0^N}{p_0^A}$. For example, in (13), a higher level of $\frac{p_0^N}{p_0^A}$ or a higher level of $\frac{N_0^{1-\theta}}{A}$ ($\mathcal{N}$'s productivity relative to $\mathcal{A}$) increases l_0. If l_0 increases, then the left-hand side of (19) increases while the right-hand side decreases. Hence, the inequality in (19) is more likely to hold. This implies that since $\frac{p_t^N}{p_t^A} = \frac{1+\tau_N}{1+\tau_A}\frac{p_t^{N*}}{p_t^{A*}}$, a higher level of $\frac{1+\tau_N}{1+\tau_A}$ is more likely to accelerate the structural transformation. In addition, a higher $\mathcal{N}$-sector relative productivity, $\frac{N_0^{1-\theta}}{A}$, is also more likely to accelerate the structural transformation.

If the structural transformation is accelerated, then the real GDP growth is also accelerated since (i) more labor is employed in $\mathcal{N}$ sector which provides a higher value of marginal product and (ii) the growth of productivity (N_t) is solely contributed by the production in $\mathcal{N}$ sector.

Result 2: *If (19) holds, then the real GDP growth is also accelerated.*

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function of l_t. Since both sides are continuous in l_t, the solution $0 < l_t < 1$ exists if $\phi\lambda AN_t^{\theta}(1-l_t)^{\phi-1} < \frac{1}{\beta}\frac{AN_t^{\theta}(1-l_t)^{\phi}-\gamma}{l_t}$ when $l_t = 0$ and $\phi\lambda AN_t^{\theta}(1-l_t)^{\phi-1} > \frac{1}{\beta}\frac{AN_t^{\theta}(1-l_t)^{\phi}-\gamma}{l_t}$ when $l_t = 1$. The first condition holds if and only if $AN_t^{\theta}(1-l_t)^{\phi}-\gamma > 0$. But this implies that the production of A goods is higher than the subsistence level, which is already assumed in (7) for a closed economy. The second condition holds if and only if $-\gamma/\beta < 0$, which already holds.

Long-Run Impact: We now study whether the opening affects a steady-state level of l_t. We compare the convergence of $\{l_t\}$ in a closed economy and in a small open economy.

First, consider a closed economy. Taking derivatives with respect to t in $AN_t^{\theta}(1-l_t)^{\phi} - \gamma - \phi\lambda\beta AN_t^{\theta}(1-l_t)^{\phi-1}l_t = 0$ (which is equivalent to (18)), we use (2) to have

$$\frac{dl_t}{dt} = \frac{\theta A\mu l_t(1-l_t)(1-l_t-\phi\lambda\beta l_t)}{\phi(1+\lambda\beta-l_t-\phi\lambda\beta l_t)}.$$

Hence, the sign of $\frac{dl_t}{dt}$ depends on the sign of $\frac{1-l_t-\phi\lambda\beta l_t}{1+\lambda\beta-l_t-\phi\lambda\beta l_t}$. It is easy to see that if $l_t < \frac{1}{1+\phi\lambda\beta}$, then $\frac{dl_t}{dt} > 0$, and vice versa. Hence, the steady-state value of l_t is $l_{SS} = \frac{1}{1+\phi\lambda\beta}$.

It is useful to study the convergence of $\{p_t^N/p_t^A\}$. By plugging $l_{SS} = \frac{1}{1+\phi\lambda\beta}$ into (17), it is easy to see that If $\theta > 1$, then p_t^N/p_t^A goes to infinity since N_t goes to infinity in (2). If $\theta = 1$, then p_t^N/p_t^A converges to $\frac{1}{\beta}\frac{A\left(\frac{\phi\lambda\beta}{1+\phi\lambda\beta}\right)^{\phi}-\gamma}{\frac{1}{1+\phi\lambda\beta}}$. If $0 < \theta < 1$, then p_t^N/p_t^A converges to zero.

Second, consider a small open economy. Taking derivative with respect to t in (13) with $p_t \equiv \frac{(1+\tau_N)p_t^{N*}}{(1+\tau_A)p_t^{A*}}$,

$$\frac{dl_t}{dt} = -\frac{1}{\phi-1}\left(\frac{1}{\phi\lambda A}p_t N_t^{1-\theta}\right)^{\frac{1}{\phi-1}}\left(\frac{dp_t/dt}{p_t} + (1-\theta)\frac{dN_t/dt}{N_t}\right).$$

Since

$$p_t = \frac{1}{\beta}\frac{(1+\tau_N)}{(1+\tau_A)}\frac{A(N_t^*)^{\theta}\left(\frac{\phi\lambda\beta}{1+\phi\lambda\beta}\right)^{\phi} - \gamma}{N_t^*\frac{1}{1+\phi\lambda\beta}},$$

we have

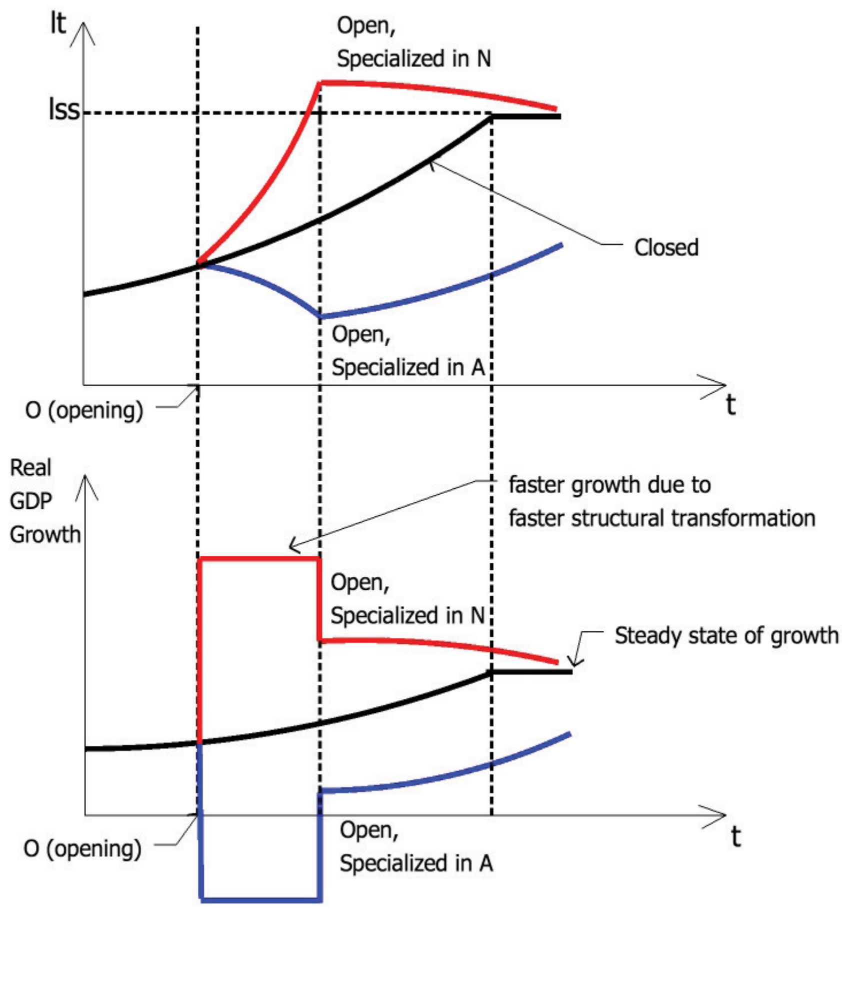
$$\frac{dl_t}{dt} \approx -\frac{1}{\phi-1}\left(\frac{1}{\phi\lambda A}p_t N_t^{1-\theta}\right)^{\frac{1}{\phi-1}}(\theta-1)\mu\left(l_t^* - l_t\right).$$

from (2). Since $0 < \phi < 1$, we have $\frac{dl_t}{dt} > 0$ if $l_t < l_t^*$ (where l_t^* is the world fraction of $\mathcal{N}$-sector employment), and $\frac{dl_t}{dt} < 0$ if $l_t > l_t^*$. This implies that l_t converges to l_t^*. Taking the closed economy considered above as the world, we have $l_{SS}^* \equiv \frac{1}{1+\phi\lambda\beta}$. Hence, the small open economy also has $l_{SS} \equiv \frac{1}{1+\phi\lambda\beta}$.

Result 3: *All economies, whether closed or small-open, regardless of the comparative advantage, have the same steady-state value of* $l_{SS} \equiv \frac{1}{1+\phi\lambda\beta}$.

Figure 5. Theoretical impacts of opening

This figure illustrates the impacts of the opening on a small open economy. If the economy specializes in $\mathcal{N}$ sector after opening, l_t grows faster, possibly reaching a maximum level of $l_t = 1$ depending on the intensity of comparative advantage, before it eventually converges to l_{SS} when the steady-state is reached (not shown) as described in Result 3. The GDP growth becomes accordingly higher. The opposite impact exists for the economy specialized in $\mathcal{A}$ sector.



This result implies that all economies converge to the same value of l_{SS}, regardless of the current values of N_t. However, the opening to international trade can affect the speed of convergence, depending on after-tariff world relative price and domestic relative productivity.

Figure 5 conceptually illustrates possible impacts of opening on a hypothetical small open economy. If the economy specializes in $\mathcal{N}$ sector after opening, l_t grows faster, possibly reaching a maximum level of $l_t = 1$ depending on the intensity of comparative advantage, before it eventually converges to l_{SS} when the steady-state is reached (not shown) as described in Result 3. The GDP growth becomes accordingly higher, since learning by doing becomes more intense while structural transformation is also faster. The opposite impact exists for the economy specialized in $\mathcal{A}$ sector. That is, l_t may decline depending on the intensity of comparative advantage. After a point in which (5) is no longer binding, the level of l_t will eventually converge to l_{SS}. The GDP growth becomes accordingly lower.

3. Numerical Analysis

Subsection 3.1 calibrates the model of a closed economy with an aggregated economy of high-income OECD countries. We call this aggregate "North." On average of 1992-2007, the "North" GDP was 78% of the world's GDP, according to World Development Indicators. During the same period, the "North" trade volume was 70% of the world's trade volume.[24] In Subsection 3.2, we then consider an opening of a hypothetical small economy to trade with "North". Subsection 3.2 generates and analyzes a "growth miracle" in our model.

[24] An alternative way for the calibration is to use the world, as a whole, instead of the high-income OECD economies, for the calibration of the closed economy. However, the World Development Indicators do not provide observations on the employment share for the world, which we need for the calibration.

3.1. Calibration of "North"

We normalize (i) the units of good $\mathcal{N}$ as $N_0 = 1$, (ii) the units of good $\mathcal{A}$ as $A = 1$, and (iii) the price level as $p_t^A = 1$ for all t. Following Caselli and Coleman (2001), we assume $\phi = 0.81$, implying that 19% of $\mathcal{A}$ production belongs to the owners of fixed inputs (such as lands).

We use the following data observations for "North" from World Development Indicators. The years are 1992-2006, where 1992 (period 0) and 2006 (period T) are the first and last years in which all variables are observed. First, the fraction of non-agricultural value added out of GDP was 0.975 in 1992 and 0.986 in 2006. We match these with $\frac{p_0^N Y_0^N}{p_0^A Y_0^A + p_0^N Y_0^N}$ and $\frac{p_T^N Y_T^N}{p_T^A Y_T^A + p_T^N Y_T^N}$, respectively. Second, the fraction of non-agricultural employment was 0.937 in 1992 and 0.964 in 2006. We match these with l_0 and l_T, respectively. Third, the growth of real per-capita GDP was 1.9% per year in 1992-2006. Fourth, the growth of agricultural production ("crop production index") was 0.4% per year during the same period. We match this with $\log(Y_T^A/Y_0^A)/T$.

Appendix A discusses the calibration of λ, μ and θ in detail from these matches. To summarize, the calibration of λ uses the data on the fractions of non-agricultural value added and of non-agricultural employment, with (1), (3) and (6). Based on the calibrated value of λ, the calibration of μ and θ further uses the growth of real per-capita GDP and the growth of agricultural production, with (2). The results are $\lambda = 3.237$, $\mu = 0.021$ and $\theta = 1.863$, providing $N_T = 1.318$, $Y_0^N = 0.937$, $Y_T^N = 1.271$, $Y_0^A = 0.107$, $Y_T^A = 0.113$, $p_0^N = 1.370$, and $p_T^N = 6.269$. Notice that $\theta > 1$. This calibration result is in accordance with the fact that scientific and technological advances significantly affect agriculture. One might argue that $\theta \leq 1$ looks more reasonable because θ captures the knowledge transfer from non-agriculture to agriculture. However, since the production functions in these two sectors, (1) and (3), are not identical, the productivities are not directly comparable, either. In Appendix B, we discuss how the assumption $\theta \leq 1$ can affect the model's implications.

Table 1. Calibration results

(A) Calibrated outside the model

Parameter/Variable	Description	Value
N_0	$\mathcal{N}$-Sector Productivity at Period 0	1 (normalized)
A	Parameter determining $\mathcal{A}$-Sector Productivity	1 (normalized)
p_t^A	Unit Price of $\mathcal{A}$ Good at Each Period	1 (normalized)
ϕ	Parameter determining $\mathcal{A}$-Sector Returns to Scale	0.81
$\frac{p_0^N Y_0^N}{p_0^A Y_0^A + p_0^N Y_0^N}$	$\mathcal{N}$-Sector Value Added out of GDP in 1992	0.975
$\frac{p_T^N Y_T^N}{p_T^A Y_T^A + p_T^N Y_T^N}$	$\mathcal{N}$-Sector Value Added out of GDP in 2006	0.986
l_0	Fraction of $\mathcal{N}$-Sector Employment in 1992	0.937
l_T	Fraction of $\mathcal{N}$-Sector Employment in 2006	0.964
	Annual Growth of Real Per-Capita GDP	1.9%
$\log(Y_T^A/Y_0^A)/T$	Annual Growth of $\mathcal{A}$-Sector Output	0.4%

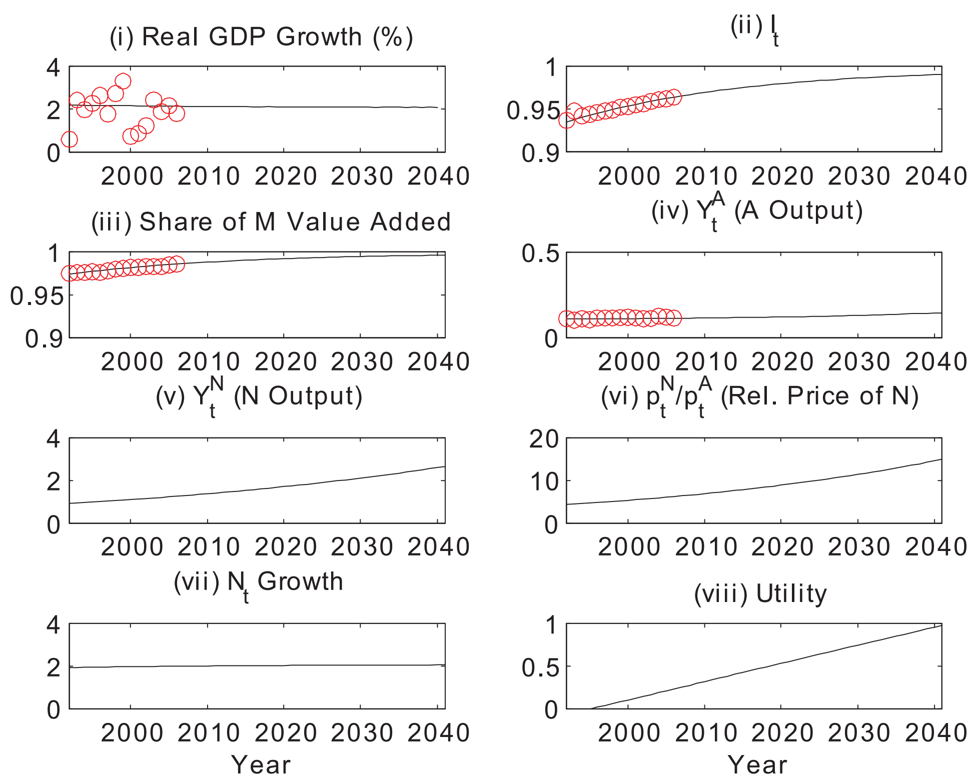
(B) Calibrated inside the model

Parameter/Variable	Description	Value
λ	Parameter determining the Friction between Two Sectors	3.242
μ	Learning-by-Doing Productivity	0.021
θ	Knowledge Transfer from $\mathcal{N}$ Sector to $\mathcal{A}$ sector	1.863
β	Weight of A-Good Consumption in Preferences	0.001
γ	Subsistence Level	0.105

Note.—This table displays the calibration results based on the model of a closed economy described in Section 2.2, with the data from high-income OECD countries.

Figure 6. Calibration of the "North" as a closed economy

Solid lines are projections. In Parts (i), (ii), (iii) and (iv), circles indicate the data.



Regarding β and γ, from (9), we have $\beta p_0^N Y_0^N = Y_0^A - \gamma$ and $\beta p_T^N Y_T^N = Y_T^A - \gamma$ since $p_t^A = 1$ for all t. These two equations provide $\beta = 0.001$ and $\gamma = 0.105$. This completes the model calibration. Given the parameter values, our discussions in Subsection 2.3 provide the steady-state value of $\{l_t\}$ equal to 0.997. In addition, the steady-state annual growth of $\{N_t\}$ becomes 2.1%. Table 1 summarizes the calibration results.

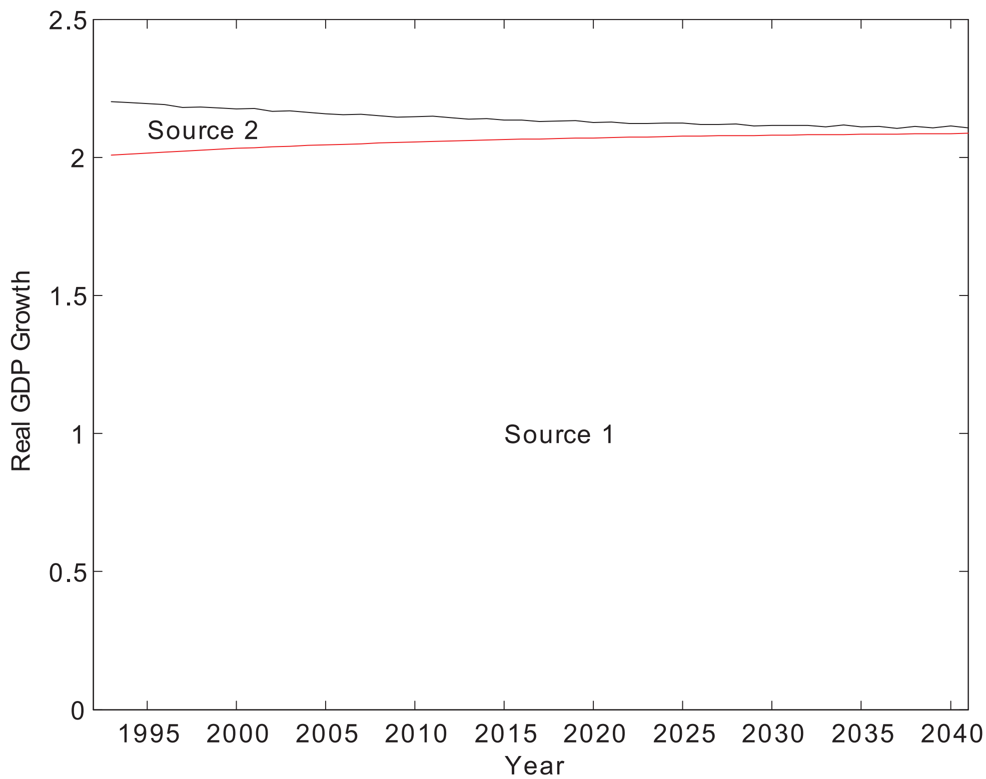
Figure 6 compares the model's projections on real GDP growth, l_t, the share of $\mathcal{N}$ value added out of GDP, and Y_t^A, to the data. It also shows the projections on Y_t^N, the relative price of good $\mathcal{N}$, productivity growth, and utility. These projections are constructed as follows. Consider period 0 (year 1992) with $N_0 = 1$. From (18), we obtain l_0. We obtain p_0^N from (17), as well as Y_0^A and Y_0^N from (1) and (3). Then, (2) provides N_1. We repeat this procedure to solve for all remaining periods.

In Figure 6, solid lines are projections. In Parts (i), (ii), (iii) and (iv), the circles indicate the data. The results imply that the real GDP growth is relatively stable over time (Part (i) of Figure 6). The productivity growth is also relatively stable (Part (vii)). Both Y_t^N and Y_t^A grow over time (Parts (iv) and (v)), which increases the utility (Part (viii)). At the same time, structural transformation occurs, increasing both l_t (Part (ii)) and the share of $\mathcal{N}$ Sector's value added out of GDP (Part (iii)).

The model also implies that the price of good $\mathcal{N}$ relative to good $\mathcal{A}$, p_t^N/p_t^A, increases over time due to the knowledge transfer from $\mathcal{N}$ sector to $\mathcal{A}$ sector (Part (vi)). It turns out that this implication is, indeed, consistent with data. For the U.S. economy, Alvarez-Cuadrado and Poschke (2011) show that the relative price ratio of manufacturers to agricultural goods increased between 1950 and 2000 and that all of the "North" and other small open countries experienced the same pattern (Figures 2 and 4 of Alvarez-Cuadrado et al. (2011)).

Figure 7. Decomposition of real GDP growth in "North" (%)

This figure is also based on the model's prediction on "North" as in Figure 6. The real GDP growth is decomposed into two sources. Source 1 is the productivity growth due to learning by doing. Source 2 is the structural transformation.



Growth Decomposition: What drives the economic growth of "North"? Using (1) and (3), one can write the real GDP growth, (10), as a function of N_{t+1} and l_{t+1}, given N_t, l_t, p_t^N and p_t^A, as

$$\Gamma(N_{t+1}, l_{t+1}; N_t, l_t, p_t^N, p_t^A) = \frac{p_t^N N_{t+1} l_{t+1} + p_t^A A N_{t+1}^{\theta} (1 - l_{t+1})^{\phi}}{p_t^N N_t l_t + p_t^A A N_t^{\theta} (1 - l_t)^{\phi}} - 1. \tag{20}$$

For brevity, we write this as $\Gamma(N_{t+1}, l_{t+1})$. We decompose the real GDP growth into contributions from the following two sources:

(i) Source 1 (Contribution from an increase in N_t): Productivity growth due to learning by doing. Measured by $\Gamma(N_{t+1}, l_t)$.

(ii) Source 2 (Contribution from an increase in l_t): Structural transformation, which increases the real GDP due to higher marginal product of labor in $\mathcal{N}$ sector. Measured by $\Gamma(N_t, l_{t+1})$.

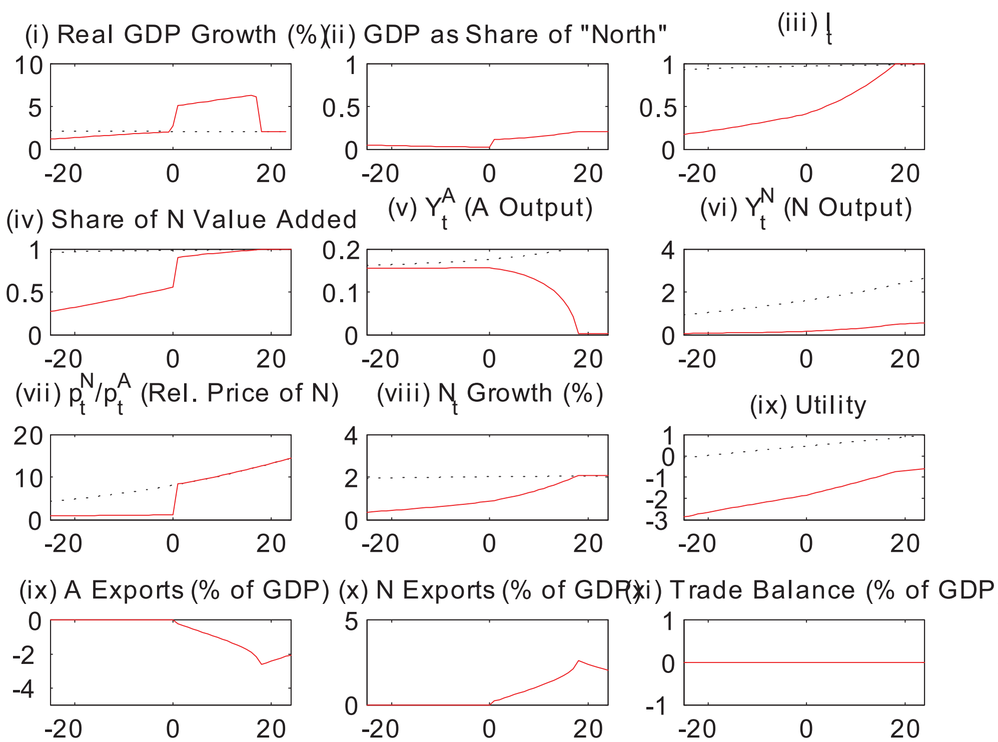
Figure 7 provides the decomposition of the real GDP growth for "North." Most of the real GDP growth is due to productivity growth (Source 1). The contribution of structural transformation (Source 2) is small. This is because l_t in "North," is already high and close to the steady-state level, l_{SS} so that the role of structural transformation becomes small.

3.2. A Hypothetical Small Open Economy

By opening, a small open economy may (net-)export either good $\mathcal{N}$ or good $\mathcal{A}$, and we consider a small open economy which exports good $\mathcal{N}$. We use the parameter values calibrated in Subsection 3.1, and the small economy has $\mathcal{N}$-sector productivity equal to one third of the $\mathcal{N}$-sector productivity of "North". That is, $N_0 = (1/3)N_0^*$, at the time of opening (period 0), where the asterisk ($*$) implies the "North". Assume $A = A^*$. To focus on the impact of opening to international trade, we assume that effective tariff rates do not distort the world relative price. That is, we assume $\frac{1+\tau_N}{1+\tau_A} = 1$. We now use $\alpha = 0.05$, implying that the maximum growth rate of $\{l_t\}$ is 5%. This number is based on our examination on the data, and Appendix B provides the results with alternative parameter assumptions for α, θ, and λ for robustness checks.[25]

Figure 8. Effects of opening at period 0

Solid lines indicate the small economy. Dotted lines indicate "North". The small economy satisfies $N_0 = (1/3)N_0^*$, $A = A^*$, $\tau_N = 0$ and $\tau_A = 0$. The parameter values follow the calibration in Subsection 3.1 for "North." Assume $\alpha = 0.05$.



[25]World Development Indicators provide observations for l_t (non-agricultural employment share) for Korea from 1980. In early 1980s, l_t grew at 3% or 4% annually, and l_t increased from 65% to 75%. The growth rate may have been higher during 1970s in which Korea's real GDP growth was faster. In case of China, during the period of 1980-1985, it shows growths in l_t with an average of 3.8%, and l_t grew from 31% to 40%. World Development Indicators do not provide observations for Taiwan. They provide observations for Hong Kong and Singapore from 1980, but l_t already reached 0.99 in 1980. Based on the data, we find that $\alpha = 0.05$ is a reasonable bound.

Under these assumptions, i.e., $N_0 = (1/3)N_0^*$, $A = A^*$, and $\frac{1+\tau_N}{1+\tau_A} = 1$, the small open economy specializes in good $\mathcal{N}$ even though its $\mathcal{N}$-sector productivity, N_0, is lower than that of "North", N_0^*. This is because the small open economy's $\mathcal{N}$-sector productivity *relative to A-sector productivity*, $\frac{N_0^{1-\theta}}{A}$, is higher than that of "North", $\frac{(N_0^*)^{1-\theta}}{A^*}$, when $\theta > 1$. This is consistent with the Ricardian theory of comparative advantage. One can easily set up an alternative example in which A is sufficiently higher than A^* so that the small open economy specializes in $\mathcal{A}$ sector.

In Figure 8, solid lines indicate the small economy, while dotted lines indicate "North". The small economy specializes in $\mathcal{N}$ sector, exporting good $\mathcal{N}$ and importing good $\mathcal{A}$. In Part (i), the growth rate of real GDP remains higher than 5% per period (year) for almost 20 periods. In Part (ii), the (per-capita) GDP of the small economy was only 3% of the GDP of "North," which becomes 21% after 25 years from the opening. For almost 20 years, the structural transformation occurs rapidly, reaching the level of l_t close to 1, as can be seen in Part (iii) of Figure 8. In addition, after almost 20 years, the real GDP growth drops to about 2% per period since the learning by doing effect becomes the only source of economic growth.

In Part (vii), the relative price ratio p_t^N/p_t^A is low before opening but quickly jumps to the path of "North" after opening. This is because the small economy takes international prices as exogenously given after opening. A higher international price of good $\mathcal{N}$ relative to good $\mathcal{A}$ encourages this economy to specialize in $\mathcal{N}$ sector, contributing to the accelerated process of structural transformation. As mentioned earlier, this is highly comparable to the empirical finding of Alvarez-Cuadrado and Poschke (2011), stating that the post-1960 era is represented by the rapid increases in the relative price ratio (p_t^N/p_t^A).

At first glance, our model's implication that a "miracle" economy has a low level of p_t^N/p_t^A before opening, compared to p_t^{N*}/p_t^{A*}, appears to be at odds with the common perception that the relative price of manufacturing goods is higher in less developed economies than the established economies. However, as implied by the time-series evidence, developed countries which have successfully transformed their industry structure are likely to have a high level of the relative price ratio, compared to the developing countries with an early stage of structural transformation. In addition, as discussed and reported by Duarte and Restusccia (2010), the relative price ratio is often lower for developing countries, and the conventional notion is associated with expenditure prices rather than producer prices, while our model provides implications for producer prices. Restusccia, Yang, and Zhu (2008) show that for producer prices, the non-agricultural goods prices relative to those of agricultural goods are often much higher in developed economies than developing economies. If p_t^N/p_t^A is higher than internationally given at the time of opening, the economy will specialize in good $\mathcal{A}$. This contradicts the fact that "miracle" economies tend to specialize in good $\mathcal{N}$ as we discussed in the beginning. In fact, the empirical observation that the relative price of manufacturing goods may be higher in less developed economies may imply an existence of market distortions resulting from opening. For example, τ_N may be higher in less developed economies, which makes domestic non-agricultural prices higher.

Growth Decomposition: What makes high real GDP growth observed as in Part (i) of Figure 8 possible? Figure 9 provides the growth decomposition according to (20). We identify the stages of growth as follows.

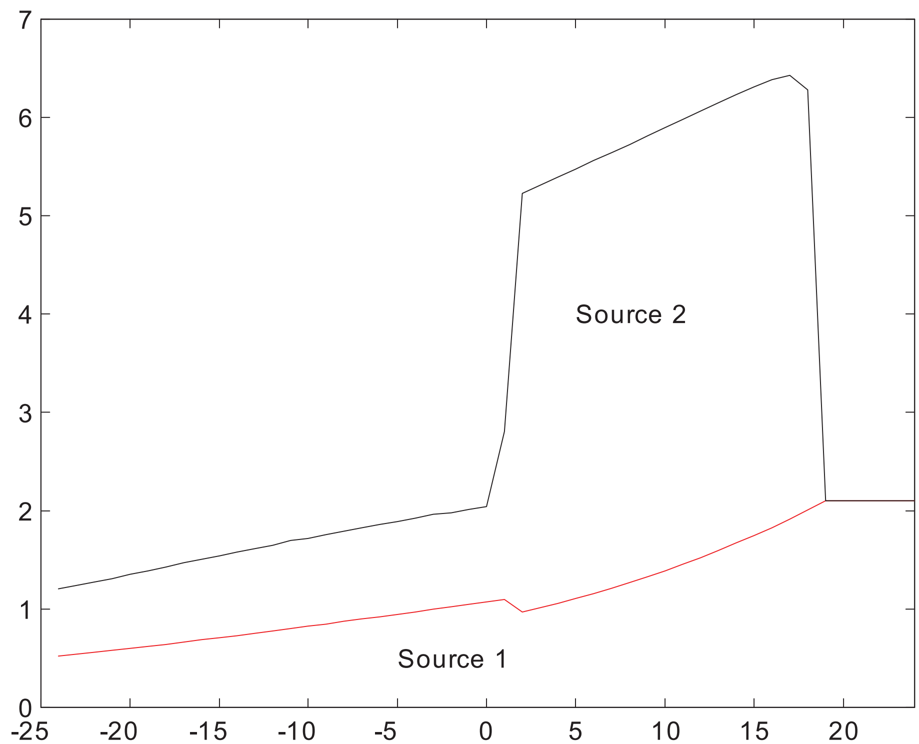
(i) *Before the opening*: The small economy's real GDP growth is lower than 2% per period. Both Source 1 and Source 2 contribute. The real GDP growth increases over time since the contribution from Source 1 increases over time. That is, as structural transformation occurs, the learning by doing becomes more intense.

(ii) *From the opening to a completion of structural transformation*: The real GDP growth remains higher than usual. This is because the structural transformation is accelerated due to the specialization in $\mathcal{N}$ sector, reinforcing Source 2.

(iii) *After the structural transformation is completed*: Learning by doing (Source 1) becomes the only source of growth.

Figure 9. Decomposition of real GDP growth in "small economy" (%)

This figure is also based on the model's prediction on "small economy" as in Figure 7. See Figure 7 for the definitions of Source 1 and Source 2.



Policy Implications: We previously studied the small economy satisfying $N_0 = (1/3)N_0^*$, $A = A^*$ and $\frac{1+\tau_N}{1+\tau_A} = 1$. To understand how trade policies affect the economy (i.e., the decision of opening, as well as the decision on the levels of τ_N and τ_A), we consider the following three scenarios in which trade policy varies for the small economy. In the first scenario, the economy is closed forever. In the second scenario, the economy is open, with $\tau_N = 0$ and $\tau_A = 0$, implying $\frac{1+\tau_N}{1+\tau_A} = 1$, which is the same before. In the third scenario, $\mathcal{A}$ sector is very strongly protected, satisfying $\tau_N = 0$ and $\tau_A = 6$ $\left(i.e., \frac{1+\tau_N}{1+\tau_A} = \frac{1}{7}\right)$.[26]

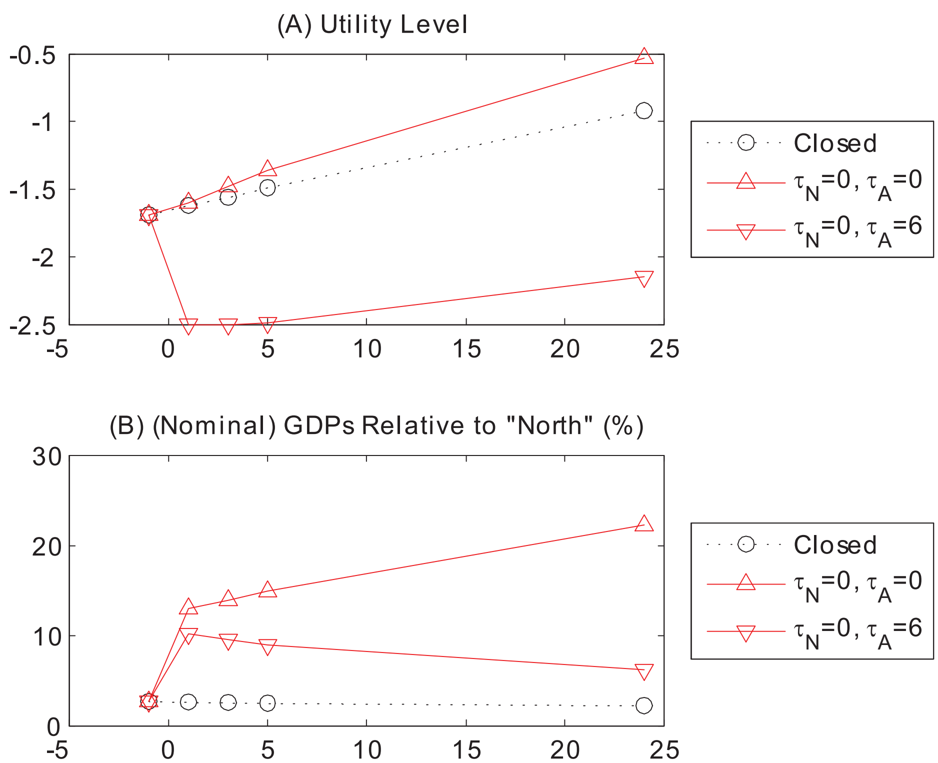
Part (A) of Figure 10 illustrates the evolution of the utility level for each scenario. In this figure, the decision to open substantially affects the utility level in the long run, comparing the first and second scenarios. In the third scenario, the protection for $\mathcal{A}$ sector is so strong that there exists a "loss" from opening. Therefore, not only the decision to open but also the decision on the effective tariff/subsidy rates can substantially affect the welfare. That is, the effective tariff rates can affect the comparative advantage, the speed of structural transformation, and hence productivity growth.

Part (B) of Figure 10 illustrates the nominal GDP relative to "North." Since nominal GDPs are measured in domestic prices, a high value of τ_A may increase the GDPs. This is the third scenario which provides the GDPs higher than the ones in the first scenario. This result also suggests that comparing the welfare levels of the economies using nominal GDPs may be problematic especially when trade policies are evaluated.

[26] The assumption of $\tau_A = 6$ is not necessarily extreme. For example, an economy may impose a strong production measure on $\mathcal{A}$ sector so that imports of $\mathcal{A}$ goods are not allowed. This can be interpreted as a very high value for τ_A in our model. In addition, notice that only the ratio of tariffs matter. It is possible to have the ratio of 1/7 by having $\tau_N = -0.5$ and $\tau_A = 2.5$. This implies a subsidy on $\mathcal{N}$ sector and a tariff on $\mathcal{A}$ sector. Indeed, many newly industrialized countries used both subsidy and tariff at their early stage of economic growth in an attempt to bolster industrial sectors.

Figure 10. Utility level and (nominal) GDPs relative to "North," according to trade policy

This figure reports the evolutions of the utility level and the nominal GDP relative to "North" in the small economy considered in Subsection 3.2, according to alternative trade policies. The economy opens at period 0.



4. Quantitative Evaluation

4.1. Relative Labor Productivity

The $\mathcal{N}$-sector labor productivity relative to $\mathcal{A}$ sector, obtained from the value of marginal product of labor in each sector in our model, is $\frac{p_t^N N_t}{\phi p_t^A A N_t^{\theta}(1-l_t)^{\phi-1}}$. Whether an economy is closed or open, (6) indicates that this relative labor productivity is constant at λ, as long as (5) is not binding, across the periods (for a given economy) or across the economies (when, of course, λ is the same across them). However, it can be higher for fast growing economies for which the constraint (5) is binding.

We discuss whether the data on relative labor productivity are consistent with this prediction. From the observations on $\mathcal{N}$-sector value added out of GDP and fraction of $\mathcal{N}$-sector employment, one can obtain the relative labor productivity with

$$\frac{(\mathcal{N}\text{-sector output}) \ / \ (\mathcal{N}\text{-sector employment})}{(\mathcal{A}\text{-sector output}) \ / \ (\mathcal{A}\text{-sector employment})}$$
$$= \left[\frac{(\mathcal{N}\text{-sector value added out of GDP})}{1-(\mathcal{N}\text{-sector value added out of GDP})}\right] \ / \ \left[\frac{(\text{Fraction of } \mathcal{N}\text{-sector employment})}{1-(\text{Fraction of } \mathcal{N}\text{-sector employment})}\right].$$

Recall that Part (A) of Table 1 reports the observations in 1992 and 2006. Figure 11 illustrates the evolution of the relative labor productivity between 1992 and 2006 for high-income OECD economies. The relative labor productivity did not change substantially over periods, which is consistent with the model's prediction. On the other hand, the economies other than high-income OECD economies ("other economies") have fewer observations. Since not all those economies provide the data for all periods, we illustrate the median out of country-level observations in each year. While the relative labor productivity in "other economies" fluctuates, the level appears to be stable. In addition, it is relatively close to the relative productivity of high-income OECD economies. The figure also illustrates the relative productivity of China which is one of fast growing economies. It is higher than other economies, and appears to have increased for several years since 1995.

The literature also finds that the relative labor productivity of developing economies is stable over time. However, the level of relative labor productivity, especially for "other economies," seem to be different across the sources. Gollin, Lagakos and Waugh (2013) document that "for developing countries, value added per worker is on average four times higher in the non-agriculture sector than in agriculture." This level of relative productivity is higher than illustrated by Figure 11. This may be because Figure 11 is based on the World Development Indicators while Gollin, Lagakos and Waugh (2013) use a more comprehensive set of national accounts data.

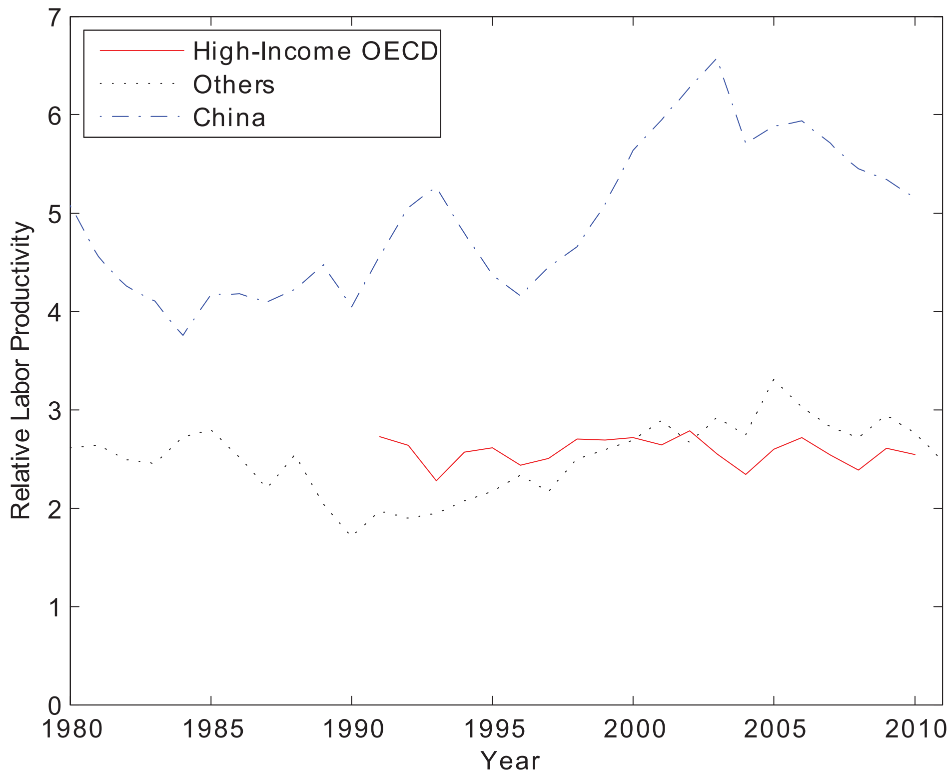
A possibility is that as discussed in Herrendorf and Schoellman (2013), the value added may be mis-measured in agriculture in many developing economies, which makes the relative labor productivity different depending on the sources. It is also possible that certain structural differences between developed and developing economies make the relative labor productivities different across them. For example, λ or ϕ can be different according to the income level.

For our perspective, if λ in developing economies is higher than developed economies, one may impose $\lambda_{\text{developing}} = \beta\lambda$ in our model. Here, λ is the parameter calibrated by high-income OECD economies (as reported in table 1). Also, β is a constant higher than one if developing economies have a level of relative labor productivity as in Gollin, Lagakos and Waugh (2013). However, this specification does not substantially affect the main result for a small open (developing) economy in our analysis. This is because the result is mainly driven by the difference between domestic and international relative prices. That is, even with $\lambda_{\text{developing}} = \beta\lambda$ where $\beta > 1$, a large productivity difference (for example, $N_0 = (1/3)N_0^*$ as assumed in the example) provides a similar prediction on output growth and structural transformation. Appendix B provides more detailed discussions.

Figure 11. Relative labor productivity

(Model's prediction: $\lambda = 3.242$.)

This figure illustrates the evolutions of the relative labor productivities for high-income OECD economies, "other economies," and China. The observations on "other economies" are a median out of country-level observations in each year. The model's prediction on the relative labor productivity is $\lambda = 3.242$.



4.2. Reproducing Figures 1, 2 and 3

We now discuss the quantitative implications of the model on Figure 1 (non-agricultural export as share of GDP versus per-capita GDP growth), Figure 2 (initial per-capita GDP versus per-capita GDP growth), and Figure 3 (per-capita GDP versus agricultural employment share). The goal is to study whether the trends generated by the model are consistent with the ones illustrated in Figures 1, 2 and 3.

As in the last subsection, we continue to assume $\frac{1+\tau_N}{1+\tau_A} = 1$ and use the parameters from Table 1. We consider three values of initial $\mathcal{N}$-sector productivity, $N_0 = 1/3$, $1/2$, and $2/3$ (while $A = 1$ as in Table 1). Then, we study the implications of the model for 25 periods after opening. In Figure 12, we provide the model's predictions on Figures 1, 2 and 3.

The three plots in Figure 12 have the same trends as in Figures 1, 2 and 3. This implies that the model successfully generates the important trends in growth observed in data. In Part (A), the non-agricultural export as share of GDP is positively related with per-capita GDP growth. An issue is that the predicted export shares are small around 1%. This is because in data, there exists intra-industry trade while our model does not allow it. In Part (B), initial per-capita GDP is negatively related with per-capita GDP growth. In particular, Part (B) considers two economies, with $A = 1$ and $A = 10$, respectively. The economy with $A = 1$ has a stronger comparative advantage in $\mathcal{N}$ sector than the one with $A = 10$. Hence, the former focuses more on $\mathcal{N}$ exports, featuring higher economic growth given the initial per-capita GDP. In Part (C), as per-capita GDP grows, agricultural employment share decreases for 25 periods.

Figure 12. Model's predictions on figures 1-3

These figures are the model's predictions on Figures 1-3. See the text for detail.

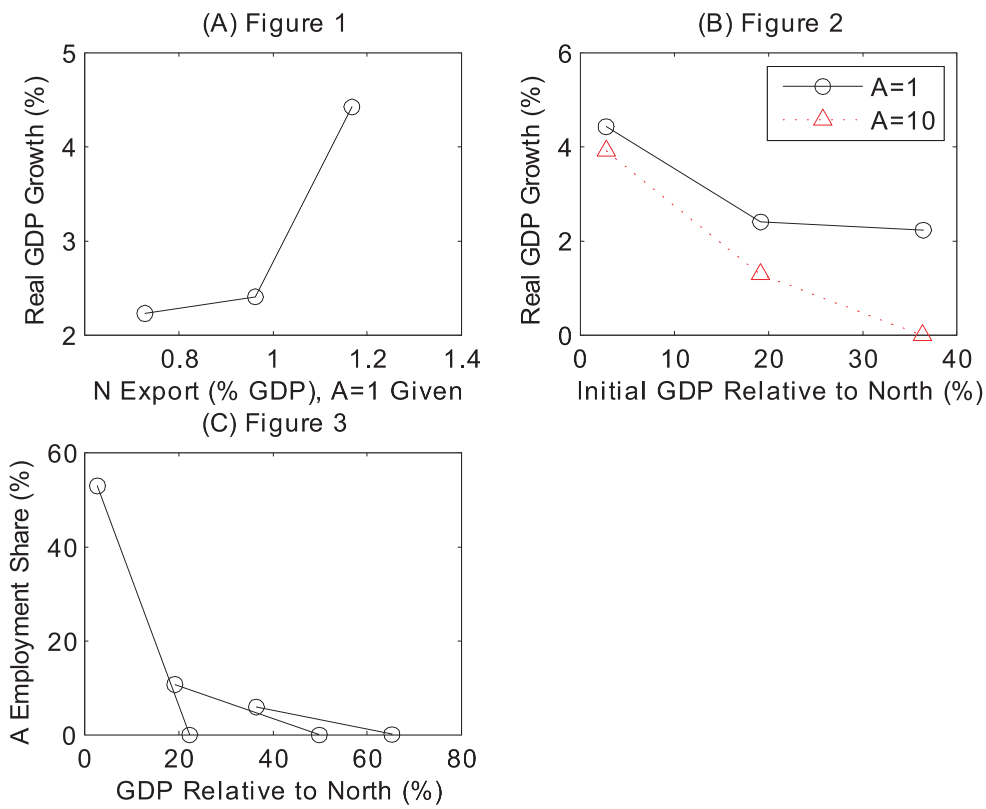
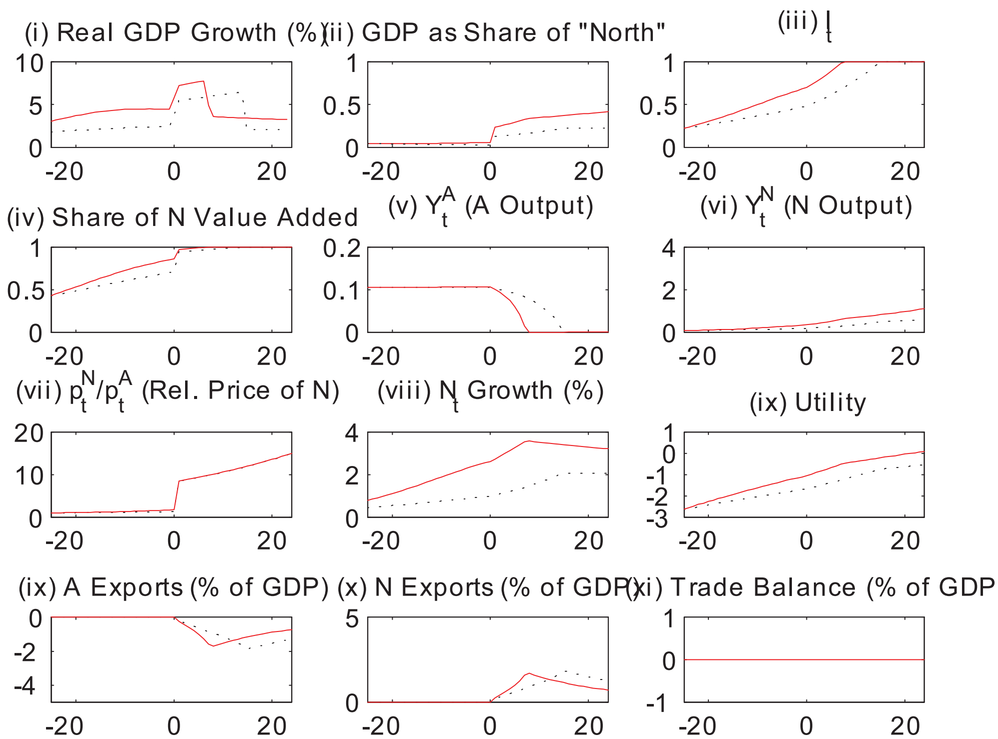


Figure 13. Introduction of productivity catch-up

This figure is an update to Figure 8, in which (2) is now replaced by $N_{t+1} - N_t = \mu (N_t)^{1-\delta} (N_t^*)^{\delta} \bar{l}_t$ where $\delta = 1/2$. Dotted lines are the original results with $\delta = 0$.



4.3. International Productivity Catch-Up

By construction, Part (viii) of Figure 8 shows that the small open economy does not catch up with "North" in productivity. However, productivity catch-up does occur for certain economies. To provide a transparent link between trade and growth by focusing on a fully endogenous model, we have not incorporated international knowledge spillovers so far. That is, while the calibration of Section 3 provides growth miracles, the non-agricultural productivity, N_t, does not catch up with the productivity of "North", N_t^*.

To allow international productivity catch-up, we now replace (2) by

$$N_{t+1} - N_t = \mu \left(N_t\right)^{1-\delta} \left(N_t^*\right)^{\delta} \bar{l}_t,$$

for $0 < \delta < 1$. The results for $\delta = 1/2$ are illustrated in Figure 13 as solid lines. For comparison, the results for $\delta = 0$ are also drawn as dotted lines. In Part (i), the real GDP growth for $\delta = 1/2$ is higher before the opening and while structural transformation actively occurs. Productivity catch-up also allows the economy to increase its GDP relative to "North" more rapidly in Part (ii), to urbanize more rapidly in Part (iii), and to increase the growth rate of N_t more rapidly in Part (viii).

4.4. Comparing the Result with "Miracle" Economies

To analyze the model performance with δ in matching the data from "miracle" economies, we take as given the opening years provided by Sachs and Warner (1995). Taiwan, Singapore and South Korea opened to trade in 1963, 1965 and 1968, respectively. Hong Kong has been always open in Sachs and Warner (1995), while we assume an opening year of 1950. On average, the per-capita GDP of these four economies was 27% of the average of high-income OECD economies (which joined before 1975) in the year of opening. After 10 years, it reached 39%. After 25 years, 66%.

Now we run the following thought experiment. Assume $\frac{1+\tau_N}{1+\tau_A} = 1$.[27] Table 2 considers different values of δ, which are 0, 1/3 and 1/2, to compare the model's predictions and the data. To do this, in the year of opening, we find the value of $\mathcal{N}$'s productivity relative to $\mathcal{A}$, $\frac{N_0^{1-\theta}}{A}$, that matches with the per-capita GDP as high as 27% of the "North." According to Table II, if $\delta = 0$, then the model predicts that in 25 years after opening, the small economy's per-capita GDP (which used to be 27% relative to "North" before opening) becomes 57% relative to "North." While this already accounts for a substantial portion of the convergence in per-capita GDPs, increasing δ further improves the prediction. For example, by assuming $\delta = 1/2$, the small economy's per-capita GDP becomes 66% relative to "North", as observed in data.

Table 2. Application of the model to East Asia

	$\frac{GDP_{-1}}{GDP^*_{-1}}$	$\frac{GDP_{25}}{GDP^*_{25}}$	$\frac{GDP_{25}}{GDP^*_{25}}$ if never opened
Data*	27%	66%	
Model w/ $\delta = 0$	27%	57%	27%
Model w/ $\delta = 1/3$	27%	63%	34%
Model w/ $\delta = 1/2$	27%	66%	38%

Note.—This table compares the model's predictions on the small open economy's catch-up to "North" to the data for Hong Kong, Taiwan, Singapore, and South Korea, according to different assumed values for δ. Period 0 is the year of opening. $\frac{GDP_{-1}}{GDP^*_{-1}}$ is the small open economy's per-capita GDP relative to "North" right before opening. $\frac{GDP_{25}}{GDP^*_{25}}$ is the one 25 years after opening. See the text for detail. "Data" are the average of four economies, Hong Kong, Taiwan, Singapore, and South Korea. The "relative per-capita GDP" is relative to the high-income OECD economies which joined the OECD before 1975.

Table 2 also provides the model implications for an alternative scenario in which the economy has never opened, reported in the fourth column. The difference between the

[27] Changing the value of $\frac{1+\tau_N}{1+\tau_A}$ does not affect the result. This is because the value of $\frac{N_0^{1-\theta}}{A}$ will be accordingly adjusted.

third column (factual GDP relative to “North”) and the fourth column (counterfactual GDP relative to “North”) can be understood as “gain from opening” in light of economic growth. The result shows that the gain from opening is large for “miracle” economies.

5. Concluding Remarks

We studied a quantifiable two-sector growth model, featuring learning by doing in non-agricultural production. The model is consistent with observed patterns in non-agricultural exports, structural transformation, and GDP growth. Opening up an economy and the persistence of transformation in industry structure play important roles in generating explosive and sustained growths of resource-poor economies. Related, an economy’s gain or loss from opening depends on relative productivity and trade policies. In particular, the model implies that non-agricultural exports are positively related to real GDP growth. Appendix C provides cross-country regression results that support this prediction.

Our model disregards intra-industry trade. An extension of this paper may consider intra-industry trade to provide more realistic quantitative links between trade and growth. Further, we matched the non-agricultural with all industries except agriculture. An alternative way is to introduce untradable service sector. Eaton, Kortum and Kramarz (2011) can be a quantitatively implementable framework. Finally, we assumed that trade is always balanced. One may also study how the results are affected when this assumption is released. To this direction, one may be able to study the effect of undervalued currency on structural transformation and growth.

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Appendix A: Calibration Strategy

We calibrate λ, μ and θ as follows.

- *Step 1: Obtaining* λ. Consider period 0. Using (1) and (3), we write (6) as

$$(1 - l_0)p_0^N Y_0^N = l_0 \phi \lambda p_0^A Y_0^A,$$

or equivalently,

$$\lambda = \frac{1 - l_0}{l_0} \frac{p_0^N Y_0^N}{\phi p_0^A Y_0^A} = 3.237$$

since $\frac{p_0^N Y_0^N}{p_0^A Y_0^A + p_0^N Y_0^N} = 0.975$, $l_0 = 0.937$ and $\phi = 0.81$. Repeat the same procedure for period T. Then, we have $\lambda = 3.247$ since $\frac{p_T^N Y_T^N}{p_T^A Y_T^A + p_T^N Y_T^N} = 0.986$ and $l_T = 0.964$. Notice that both values are highly close to each other. We simply take an average of these two values of λ and use for λ in the rest of the calibration. That is, $\lambda = 3.242$.

- *Step 2.* Given $\lambda = 3.242$, $\phi = 0.81$, $N_0 = 1$ (as normalized in the text), $l_0 = 0.937$, and $l_T = 0.964$, we have from (1), (3) and (6):

$$\begin{aligned}
Y_0^N &= l_0 N_0 = 0.937, \\
Y_0^A &= (1 - l_0)^\phi N_0^\theta = 0.107, \\
Y_T^N &= l_T N_T = 0.964 N_T, \\
Y_T^A &= (1 - l_T)^\phi N_T^\theta = 0.0677 N_T^\theta, \\
p_0^N &= \phi \lambda N_0^{\theta - 1} (1 - l_0)^{\phi - 1} = 1.370, \\
p_T^N &= \phi \lambda N_T^{\theta - 1} (1 - l_T)^{\phi - 1} = 4.939 N_T^{\theta - 1}.
\end{aligned}$$

- *Step 3: Obtaining* θ *and* μ. From (2),

$$N_T = \prod_{t=0}^{T-1} (1 + \mu l_t)$$

since $N_0 = 1$. Since we have $l_0 = 0.937$ and $l_T = 0.964$, we approximate $l_t = l_0 + \frac{l_T - l_0}{T} t$ for all $t = 1, ..., T-1$. Plugging l_t's into the above, we can write N_T as a function of μ.

(i) Following (10), the annual real GDP growth, between 0 and T, is written as

$$\left(\frac{p_0^N Y_T^N + p_0^A Y_T^A}{p_0^N Y_0^N + p_0^A Y_0^A} \right)^{1/T} - 1.$$

This is matched with the observed annual rate of 1.9%. With the equations obtained in Step 2, as well as the function of μ that we obtained for N_t, this provides an equation with μ and θ.

(ii) The annual growth rate of $\mathcal{A}$ production between periods 0 and T is $(Y_T^A / Y_0^A)^{1/T} - 1$. This is matched with the annual growth of $\mathcal{A}$ production, 0.4%. With the equations obtained in Step 2, as well as the function of μ that we obtained for N_t, this provides another equation with μ and θ.

The solutions are $\mu = 0.021$ and $\theta = 1.863$. Then, the equations in Step 2 provide $N_T = 1.318$, $Y_T^N = 1.271$, $Y_T^A = 0.113$, and $p_T^N = 6.269$.

Appendix B: Roles of α, θ, and λ

We consider the small open economy illustrated in Figure 8. To understand how parameters affect the projections, we check with alternative parameter values for α, θ, and λ. Recall that the calibrated values used for original projections were $\alpha = 0.05$, $\theta = 1.863$, and $\lambda = 3.242$. We continue to assume these parameter values for "North" to focus on the effects of alternative values on the small open economy.

First, Figure 14 compares the new projections without constraint (5) (in solid line) to the benchmark projections with $\alpha = 0.05$ of Figure 8 (in dotted line). As discussed in the text, the role of α is to decelerate the structural transformation to make projections more realistic. To be specific, in Part (iii), l_t jumps up from a level lower than 0.5 to a level close to one as soon as the economy opens to trade. However, it does not affect the long-run impacts of opening. That is, in Part (iii), the levels of l_t without constraint and with constraint become the same after about 20 years. This is true for all other variables in Figure 14. To conclude, releasing the original assumption of $\alpha = 0.05$ still provides a growth miracle, but it happens in an accordingly short period.

Second, Figure 15 compares the new projections with $\theta = 1$ (in solid line) to the benchmark projections with $\theta = 1.863$ (in dotted line). In Part (i), this new, lower level of θ still provides growth miracles. The lower level of θ makes it less profitable to engage in $\mathcal{A}$ sector, and hence, the level of l_t is higher when $\theta = 1$ than when $\theta = 1.863$, even before the opening. However, the main mechanism of our model still remains to generate growth miracles (except that the miracle is accomplished in a shorter period). This is true even when $0 < \theta < 1$ (not reported). To sum, the level of θ matters to connect the level of per-capita GDP to l_t in a closed economy, but it does not directly affect the mechanism of growth miracles in our model.

Third, Figure 16 compares the new projections with $\lambda = 5$ (in solid line) to the benchmark projections with $\lambda = 3.242$ (in dotted line). This is motivated by the fact that the income difference between the two sectors appears to be higher in developing economies, as discussed in text. The new level of λ indeed affects the projections before the opening ($t = 0$). For example, the price of $\mathcal{N}$ good relative to $\mathcal{A}$ good in Part (vii) decreased since a decrease in λ encourages $\mathcal{N}$-good productions. However, all projections remain the same after the opening. This is because problem (4) provides a corner solution, $l_t = 1$, for both $\lambda = 3.242$ and $\lambda = 5$ in the current example. That is, the solution implies a full structural transformation which is reached with a maximum speed (α). In short, the change in λ from 3.242 to 5 affects the closed economy, but not the main association between opening and growth miracles.

Figure 14. Alternative assumption for α

This figure reproduces Figure 8 with the restriction (5) now being eliminated. The new results are shown as solid lines. Dotted lines are the benchmark results with the original assumption of $\alpha = 0.05$ for (5).

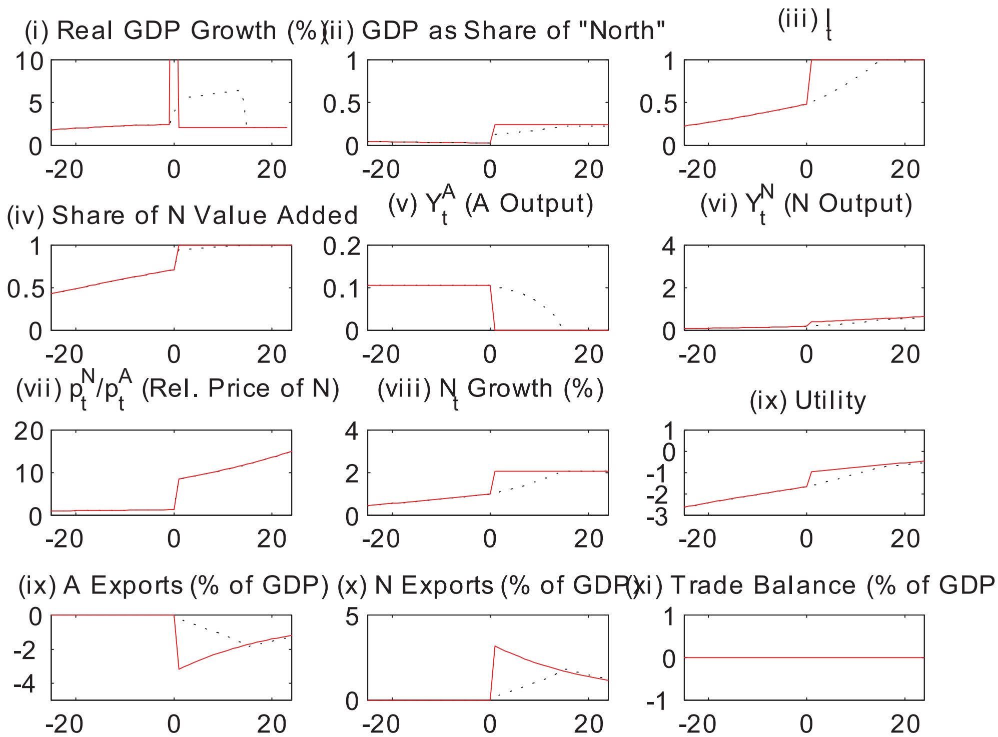


Figure 15. Alternative assumption for θ

This figure reproduces Figure 8 with $\theta = 1$ assumed. The new results are shown as solid lines. Dotted lines are the benchmark results with the original assumption of $\theta = 1.863$.

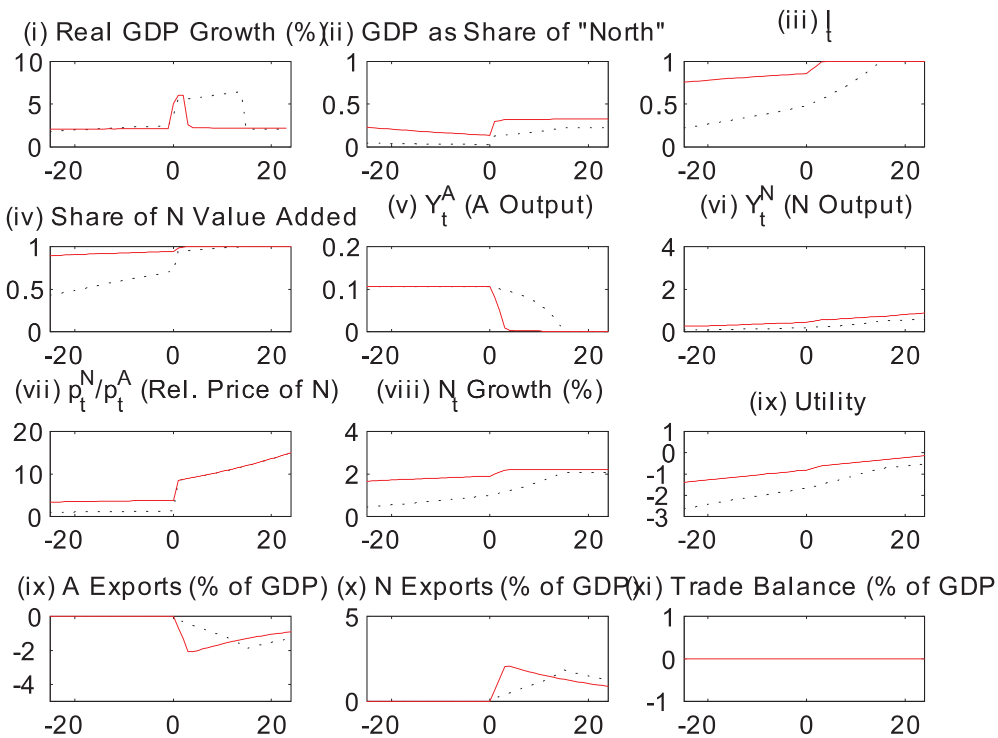
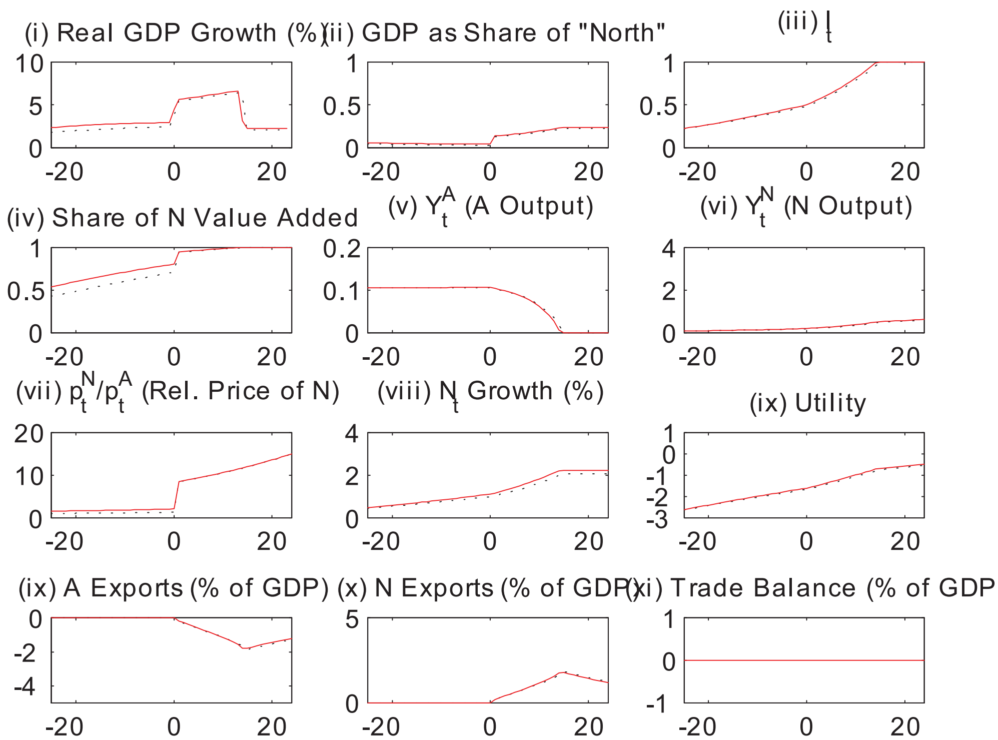


Figure 16. Alternative assumption for λ

This figure reproduces Figure 8 with $\lambda = 5$ instead. The new results are shown as solid lines. Dotted lines are the benchmark results with the original assumption of $\lambda = 3.242$.



Appendix C: Econometric Tests

According to our model and quantitative results, the shares of (i) total trade, (ii) non-agricultural exports, (iii) non-agricultural imports, (iv) agricultural exports, and (v) agricultural imports, out of GDP, cause GDP growth. In this appendix, we test whether our claims are consistent with data. In Appendix D, we provide a broader discussion of how opening can affect GDP growth.

We consider the following regression equation:

$$(ygrow)_i = \alpha + (trade)_i\beta_1 + (iqual)_i\beta_2 + (yini)_i\beta_3 + L_i\beta_4 + \varepsilon_i$$

for all economy i, where $(ygrow)_i$ is the annual growth (%) of per-capita real GDP over 1975-2000, $(trade)_i$ is the logarithm of one of the five trade shares over 1975-2000, $(iqual)_i$ is a proxy of institutional quality, which is constructed from the International Country Risk Guide (ICRG) data, following the method proposed by Alfaro, Kalemli-Ozcan and Volosovych (2005), $(yini)_i$ is the logarithm of year 1974 level of per-capita real GDP, and L_i is the logarithm of population on average in 1975-2000. Assume ε_i is i.i.d. with $N(0, \sigma^2)$.

A method of ordinary least squares (OLS) may not correctly capture the causality since growth may reversely affect trade or institutional quality. Hence, we use a method of instrumental variables (IVs). To control for the endogeneity regarding trade, we use the logarithm of trade share out of GDP predicted by the gravity equation suggested by Frankel and Romer (1996).[28] This IV is correlated with all five trade shares. To control for the endogeneity regarding institutional quality, we use the distance from equator as an absolute value of the latitude, as in Hall and Jones (1999). Historically, this variable

[28] The dependent variable is the logarithm of bilateral trade between economies. Explanatory variables are geographic or population related, including logarithm of distance, logarithm of population, dummy variable indicating whether two economies use a common language, dummy variable indicating whether two economies share the border, logarithm of the sum of populations, and a dummy variable indicating the number of economies landlocked. Predicted trade volume is obtained by summing up. The data in 1985 and 1993 are used for estimation.

is correlated with institutional quality. It is less likely to be directly related to the growth rate. See Rodríguez and Rodrik (2001) and Felbermayr and Gröschl (2012) for further discussions on this type of a regression.

The data for GDP, population, and the share of total trade out of GDP are obtained from the World Development Indicators (WDI) published by the World Bank. As for Figure 1 and Figure 2, the data for non-agricultural exports and imports are obtained from the United Nations (UN) Commodity Trade Statistics Database ("Comtrade"). They are obtained by aggregating Standard International Trade Classification (SITC) Revision 2 codes starting from 5 to 8, and a half of the one starting from 9. Agricultural exports and imports are obtained using the non-agricultural exports and imports and total trade. Data do not include Russia and Germany due to historical reasons. The data for institutional quality is constructed using the dataset provided by the International Country Risk Guide (ICRG). They are the sums of the following indices: government stability, internal conflict, external conflict, no-corruption, non-militarized politics, protection from religious tensions, law and order, protection from ethnic tensions, democratic accountability, and bureaucratic quality. This proxy takes values from 0 to 76 for each country, where a higher score means lower risk. The predicted level of trade can be found in Frankel and Romer (1996). The data on distance from equator are obtained from Robert Hall's website.

Table 3 summarizes estimation results for OLS and IV methods. The slope for total trade is significant at 5% level for OLS method but not for IV method. non-agricultural exports are significant at 5% level for both methods. This implies that as the share of non-agricultural exports increases by 20% (e.g, from 5% of GDP to 6%), annual GDP growth is raised by about 0.15% points (e.g, from 2.0% to 2.15%). non-agricultural imports are significant at 5% level for OLS method, but not for IV method. The slopes for agricultural exports and imports are negative or insignificant. The result also finds a convergence of GDP across economies. Institutional quality and population size are also often significant at 5% level.

Table 3. Factors affecting economic growth: regression results

	OLS	IV	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Total	1.12**	0.33								
Trade	(0.24)	(0.37)								
Non-Agriculture			0.81**	0.63**						
Exports			(0.12)	(0.15)						
Non-Agriculture					1.15**	0.45				
Imports					(0.23)	(0.31)				
Agricultural							-0.08	-0.85**		
Exports							(0.20)	(0.22)		
Agricultural									0.93**	0.42
Imports									(0.20)	(0.24)
Institutional	3.59**	3.88**	1.87*	2.24**	3.10**	3.62**	3.96**	2.88**	2.82**	3.44**
Quality	(1.04)	(1.44)	(1.01)	(1.12)	(1.03)	(1.16)	(1.17)	(1.10)	(1.06)	(1.17)
Initial Real	-0.78**	-0.35**	-0.78**	-0.44**	-0.69**	-0.31	-0.32	-0.33	-0.51**	-0.26
Per-Capita GDP	(0.19)	(0.19)	(0.16)	(0.17)	(0.17)	(0.18)	(0.20)	(0.17)	(0.17)	(0.19)
Population	0.35**	0.27	0.19**	0.30**	0.38**	0.32**	0.12	-0.23	0.36**	0.32**
	(0.11)	(0.17)	(0.09)	(0.10)	(0.11)	(0.16)	(0.12)	(0.14)	(0.10)	(0.14)
R^2	0.28	0.15	0.39	0.27	0.30	0.16	0.15	0.24	0.27	0.17
Number of Countries	118	118	118	118	118	118	118	118	118	118

Note.—This table displays cross-country regression results using ordinary least squares (OLS) and instrumental variables (IV) methods. Dependent variable is annual per-capital real GDP growth and the variables in the first column represent explanatory variables.

Appendix D: Opening to Trade and GDP Growth

This appendix discusses how opening to trade can affect GDP growth. First, trade affects an economy's learning-by-doing effect. Young (1991) predicts that low-income economies continue to specialize in low-quality products which have a less scope of learning by doing. Hence, those economies are likely to lose from trade. Using a multi-economy model extended from Young (1991), Nakajima (2003) suggests that middle-income economies can benefit from trade. Unlike Young (1991), Matsuyama (1992) predicts that relative productivity between non-agriculture and agriculture is important to determine the gain from opening. Matsuyama (1992) shows theoretically that low-income economies with scarce endowments may gain from opening. This paper is close to Matsuyama (1992) in this regard. However, this paper emphasizes the role of structural transformation together with international trade in explaining the relationships between trade and growth. As briefly discussed above, this model introduces a friction between the two sectors and knowledge transfer from non-agriculture to agriculture to describe the labor migration to cities. Indeed, our quantitative results show that this type of persistent structural transformation helps to quantitatively explain the major stylized facts of economic growth dynamics.

Second, trade encourages international knowledge spillover. Eaton and Kortum (1996) and Chuang (1998) provide a model of international knowledge spillovers enhanced by trade. Hausmann, Hwang and Rodrik (2007) extends a model of international knowledge spillovers to document that an economy with high-income export partners experiences faster productivity growth. They emphasize the composition of exports as we do. A major difference is that they provide a statistical test on a reduced-form model while we provide a full quantification of a fully structural model. In addition, we introduce the international productivity catch-up in an extended version of the model in Section 4 to further analyze the effect of international knowledge spillovers.

Third, trade allows the imports of cost-effective intermediate products and capital equipment. This theory is supported by an empirical study of Coe, Helpman and Hoffmaister (1997). Eaton and Kortum (2001) further develop a theoretical model in which low-income economies benefit from the technological advances of high-income economies. While our model does not introduce intermediate products and capital equipment, such an impact of openness can be analyzed by connecting the process of productivity catch-up to trade in intermediate products and capital equipment.

Fourth, trade affects physical capital accumulation. In Alvarez and Lucas (2007), trade enables a faster accumulation of physical capital accumulation. Teignier (2013) develops a two-sector model to study how trade affects structural transformation. While physical capital can be incorporated into the model to improve the fit, we do not pursue this approach in this paper to focus on the growth implications of openness to trade.