The Role of Trade in Structural Transformation*

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Abstract

The goal of this paper is to examine the effects of international trade on structural transformation and economic growth of poor countries. To do so, I introduce international trade into a two-sector neoclassical growth model. In the model, as countries get richer they experience a sectoral reallocation process from the agricultural sector to the rest of the economy due to the fact the agricultural good has a low income elasticity; international trade can accelerate this process for countries with low agricultural productivity. Then, I calibrate the model to match the structural transformation process of the United States, the United Kingdom and South Korea, and quantify the role played by trade in the United Kingdom during the 19th century, and in South Korea during the last 50 years. The results show that international trade had a significant effect on the structural transformation process of the United Kingdom, but a much smaller effect in the structural transformation process of South Korea. However, if South Korea had not introduced agricultural production subsidies and agricultural import tariffs, trade would have played a much bigger role, and the country would have experienced both a faster structural transformation process and higher welfare.

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1 Introduction

It is a well-known fact that that poor countries have a much larger agricultural sector than rich ones, and that the size of the agricultural sector of a country tends to decrease as the country's income increases[1]. This shows that the sectoral reallocation process away from the agriculture is a very important aspect of the economic development process.

Under autarky, a necessary condition for the structural transformation process to take place is high agricultural productivity, because of the need to produce enough food for the entire population. As a result, countries with low agricultural productivity are likely to allocate larger shares of their productive resources in the agricultural sector, and, as a consequence, are also likely to have low aggregate productivity. Under international trade, however, countries do not have to produce the agricultural goods they consume, but have the possibility of importing them from abroad instead. Countries open to international trade, thus, are likely to experience faster structural transformation if their agricultural productivity is low.

The view that low agricultural producivity leads to large agricultural sector and low aggregate income is consistent with Sachs (2001), who argues that economies in tropical zones are, in general, poorer than economies in temperate zones, and have lower agricultural productivity due to climate-related factors like the fragility of the soils, the high prevalence of crop pests and parasites, the higher rates of plant respiration, and the scarcity of water. Given all this, some authors[2] have stressed the importance of improving agricultural productivity for economic development.

On the other hand, other authors have argued that this relation is not necessarily true for open economies. As Matsuyama (1992) points out, the idea that high agricultural productivity is a necessary condition for economy development is based on the assumption that economies are closed sytems, but if an economy is open to foreign trade, low productivity in the agricultural sector or lack of arable land is likely to foster its industrialization process. Similarly, Mundlak (2000) argues that agricultural products are in general tradable, so that if trade restrictions are not too high, there is no need for countries to produce the agricultural products they consume.

The main goal of this paper is to examine the effects of intersectoral international trade on the structural transformation process, during which countries reallocate production factors from the agricultural to the nonagricultural sector, and the economic growth of poor countries. To do so, I start by presenting a general equilibrium, two-sector neoclassical growth model, which can be used to study the effects of the different elements playing a role in the process, like agricultural and nonagricultural productivity growth, and international trade. In the model, there are two goods, the agricultural and the nonagricultural

[1] See, for example, Caselli (2005), or Gollin, Parente and Rogerson (2004) for cross-country evidence, and Lucas (2007) for both cross-country as well as over time within countries evidence.

[2] See, for example, Johnston and Mellor (1961), Nurske (1953), Rostow (1960) Timmer (1988), or Todaro (1989).

good, and consumers decide how much to consume of each good, and how much capital to accumulate. Their preferences are such that they only derive utility from the agricultural good consumption until the subsistence level is reached, and after that point they start deriving utility from the nonagricultural good consumption as well. Under autarky, when the agricultural productivity is low, economies allocate large fractions of their productive resources to agriculture, and as exogenous technological change occurs, economies start reallocating labor and capital from the agricultural sector to the nonagricultural one. If they are open to international trade, economies no longer have to produce the amount of food they consume. Thus, if a country's autarky relative agricultural price is larger than the world agricultural price, the country can improve its welfare by importing agricultural good, and exporting the other good, decreasing its agricultural sector size and increasing its income. On the other hand, if a country's autarky relative agricultural price is lower than the world agricultural price, the economy will increase its agricultural employment share, with total specialization in the agricultural good being a possible outcome.

First, I calibrate the closed economy version of the model to match the structural transformation process in the United States during the period 1890-2007. The exercise shows the importance of productivity growth, both in the nonagricultural and, especially, in the agricultural sector. Next, I calibrate the open economy version of the model to match the structural transformation of the United Kindom during the period 1801-1901, and of South Korea during the period 1963-2007. In both cases, the countries imported agricultural goods during the period in which they are studied, which suggests that trade may have played some positive role in their transformation processes, on top of the factors in place for closed economies like the United States. To quantify the importance of international trade, their growth experiences are compared to the ones predicted by the autarky counterfactual simulations.

As Stokey (2001) shows, the importance of trade in the strucutural transformation process of the United Kingdom is very significant, which makes it a very interesting country to consider as a benchmark. South Korea also looks like a very interesting case to study, given that in the last 50 years it has experienced very fast economic growth, with its income per capita relative to the United States being about 10% in 1950 and more than 50% in 2005. Moreover, it has also experienced very fast structural transformation, with its agricultural employment share going from about 80% around 1950 to less than 10% in 2005, a decrease that took the United States more than 100 years. At the same time, South Korea has been very open to international trade, with the sum of total imports plus total exports over GDP going from 10% in 1955 to more than 80% in 2005, and has also been a net food importer during the entire sample period.

In spite of the views expressed by some that agricultural products are tradable and that countries with low agricultural productivity can benefit from food imports, there has been very little research studying the role of trade openess in structural change and income growth. On the theoretical side, one exception is precisely Matsuyama (1992), which studies the role of agricultural productivity in economic develpment using a two-sector growth model with learning by doing in the manufacturing sector and nonhomothetic preferences in the agricultural sector. The model predicts the relationship between agricultural productivity and growth to be positive for closed economies and negative for open economies. Another theoretical example is Echevarria (2008), which also presents a two-sector growth model, with non-homothetic preferences in the primaries sector and TFP growth only in the non-primaries sector and economies open to international trade. Her analysis concludes that in the long run countries specialize in one sector or the other depending on the TFP differentials, and that as the global economy develops, fewer and fewer countries export primary goods. Finally, Shin (1990) studies the relationship between structural change and economic development, focusing on the cases of South Korea and the United States, and argues that including trade to his two-sector growth model might be very useful to explain some characteristics of the South Korean experience, like the rapid decrease in the sectoral share of agriculture.

There is even less research aimed at quantifying.the effects of trade on structural transformation, with the very important exception of Stokey (2001), as mentioned above. As the author explains, the United Kingdom imported food and raw materials from 1780 to 1855, and the volume of trade grew significantly over the period, with the fraction of imported agricultural goods over the total being 13% in 1780 and 28% in 1850. Her conclusion is that foreign trade played an important role, and, according to the counterfactual exercises performed, the growth in food imports accounts for 100% of the decline in agricultural production, 25% of the increase in manufactures production, 20% of the increase in energy production, and 50% of the increase in real wage, and the relative price of agricultural goods would have increased by 43% instead of the 22% observed. Hayashi and Prescott (2008) also consider the possibility of food being a tradeable good in their study of the effects of Japan's prewar agricultural institutions on its structural transformation from 1885 to 1934, but the main focus of paper, as well as the main quantitative conclusions, assume that food was nontraded.

My paper clearly also builds on the vast literature that links agriculture and development, and examines the forces behind the process of structural change. Caselli and Coleman (2001), Echevarria (1997, 2007), Gollin, Parente and Rogerson (2002, 2004, 2007), Hansen and Prescott (2002), Hayashi and Prescott (2008), Kongsamut, Rebelo and Xie (2001), Laitner (2000), Lucas (2004, 2007), Matsuyama (1992), Restuccia, Yang and Zhu (2008), or Stokey (2001) are some recent examples[3], although most of them do the analysis in a context of a closed economy. In particular, this paper relates mostly to those studies that focus on the low income elasticity of food consumption as a key element behind the relationship between structural transformation and growth. One important example of this latter literature is Gollin, Parente and Rogerson (2007), which considers the effects of differences in initial agricultural productivity on the evolution of international incomes.

[3]Some of the classics are Fisher (1945), Clark (1940), Rostow (1960), Nurske (1953), Lewis (1954), Kuznets (1966), and Jorgenson (1961).

Their counterfactual exercise establishes that a country with an initial agricultural efficiency equal to 20% of the leader's one, for example, will experience a delay of its takeoff into modern growth of almost 250 years, at which point its per capita income level is only 5% of the leader.

Another important influence to this paper comes from the recent development accounting literature on international incomes, like Caselli (2005), Cordoba and Ripoll (2004), or Vollrath (2008), which take into account the sectoral composition of GDP, instead of assuming that total output is produced by a unique aggregate production function, as previous development accounting exercises did, like Hall and Jones (1999).

Finally, this paper is also related to a more recent literature that studies structural change but in contexts different than countries' transition out of the agricultural sector, like Acemoglu and Guerrieri (2008), Buera and Kaboski (2008), Ngain and Pissarides (2008), or Rogerson (2007).

The paper is organized as follows. Section 2 presents some data on the structural transformation process of different countries. Section 3 presents the two-sector growth model, and shows the main forces behind the structural transformation process of both a closed and an open economy. Section 4 calibrates the model to replicate the United States data of the last 120 years. Section 5 calibrates the model to replicate the United Kingdom data during the 19th century and quantifies the role played by the different factors in its development and structural change. Section 6 repeats the exercise for South Korea during the last 50 years. Section 6 concludes.

2 Empirical Motivation

[to be added]

3 Theoretical Model

3.1 Model Setup

In this section, I present the model, which is a two-sector neo-classical growth model. This model is similar to the one in Hayashi and Prescott (2008), and it is also related to other two-sector growth models in the literature like Echevarria (1997, 2007), Gollin, Parente, Rogerson (2007), or Matsuyama (1992). One of the sectors in the model is agriculture, which produces a good that is only used for consumption purposes, and the other sector is the rest of the economy, which produces a good that is used for both consumption and investment purposes.

In the model, there is a representative household with $N(t)$ infinitely-lived members, who derive utility from consuming the agricultural good and from consuming the nonagricultural good. $c_a(t)$ and $c_n(t)$ denote the amount of agricultural and nonagricultural good consumed by each member of the household. The instantaneous utility function is logarithmic, with μ_a being the relative weight on the agricultural consumption, $\underline{c_a}$ the minumum consumption level for the agricultural good, which can be interpreted as the subsistence level, and c_a^* the agricultural consumption level at which the agricultural good marginal utility changes [4]. A more detailed discussion about these preferences is provided in Appendix A. Finally, ρ denotes the intertemporal discount rate.

$$U(t) = \int_t^{\infty} e^{-\rho s} N(s)\, u(c_a(s), c_n(s))\, ds \tag{1}$$

where

$$u(c_a(s), c_n(s)) = u_a(c_a(s)) + u_n(c_n(s))$$

and

$$\begin{aligned} u_a(c_a(s)) &= \begin{cases} \mu_a^0 \log\left(c_a(s) - \underline{c_a}\right) & \text{if } c_a(s) \leq c_a^* \\ \mu_a^0 \log\left(c_a^* - \underline{c_a}\right) + \mu_a^1 \log\left(c_a(s) - c_a^*\right) & \text{if } c_a(s) > c_a^* \end{cases} \\ u_n(c_n(s)) &= \log(c_n(s)) \end{aligned} \tag{2}$$

The household decides the amount each member consumes of agricultural good and nonagricultural good at each point in time, as well as the fraction of its employed members that works in the agricultural sector, denoted by $s_e(t)$, and the fraction that works in the nonagricultural sector, denoted by $1 - s_e(t)$.

Household members own the capital stock of the economy in equal shares, and at each period they decide which fraction they rent to the agricultural sector firms, denoted by $s_k(t)$, and which fraction they rent to the nonagricultural sector firms, denoted by $1 - s_k(t)$.

Since both labor and capital are perfectly mobile across sectors, there is a unique wage rate $w(t)$ and a unique capital rental rate $r(t)$. The last element in the household's total income are the rents obtained from the land the household owns, which are denoted by $p_l(t) L$, with $p_l(t)$ denoting the price per unit of land and L denoting the total land available in the country.

The savings of the household, which are used to increase the capital stock household members own, are determined by the difference between the total income minus the consumption expenditures. Equation (3) shows the per capita budget constraint, with the price of the nonagricultural good normalized to 1, $k(t)$ denoting the per-capita capital

[4] These preferences exhibit decreasing agricultural good consumption share, a fact known as Engel's Law. The reason to choose them instead of more standard ones is to be able to fit the model to the data used in sections 3 and 4.

stock at time t, δ the capital depreciation rate, n the population growht rate, and $q(t)$ the relative price of the agricultural good at time t:

$$\dot{k(t)} = w(t) + (r(t) - \delta - n) k(t) + p_l(t) \frac{L}{N(t)} - q(t) c_a(t) - c_n(t) \quad (3)$$

The optimization problem of the househould consists of choosing the time functions $[c_a(t), c_n(t), s_e(t), s_k(t), \dot{K(t)}]_{t \geq 0}$ to maximize equation (1) subject to the budget constraint in equation (3), and taking the initial capital stock K_0 as given.

The relation between optimal agricultural consumption and optimal nonagricultural consumption at each point in time is given by equation (4), the optimal evolution of nonagricultural consumption is given by equation (5) and the optimal evolution of the capital stock is given by equation (3), together with the boundary conditions $k(0) = k_0$ and the transversality condition in equation (6).

$$c_a(t) = \begin{cases} \underline{c_a} + \mu_a^0 \frac{c_n(t)}{q(t)} \text{ if } c_a(t) \leq c_a^* \\ c_a^* + \mu_a^1 \frac{c_n(t)}{q(t)} \; c_a(t) > c_a^* \end{cases} \quad (4)$$

$$\frac{\dot{c_n(t)}}{c_n(t)} = r(t) - \delta - \rho \quad (5)$$

$$\lim_{t \to \infty} \left\{ e^{-\int_0^t (r(s) - n - \delta) ds} \frac{k(t)}{c_n(t)} \right\} = 0 \quad (6)$$

There are also a large number of identical and competitive firms in the economy, both in the agricultural and in the nonagricultural sector that rent labor and capital to maximize profits.

The production function for the agricultural good is given by equation (7), where A_a denotes the total factor productivity, K_a denotes the capital stock used in the production of the agricultural good, N_a the total labor input demanded in that sector, and L_a the total land employed in that sector.

$$Y_a(t) = A_a(t) (K_a(t))^{\alpha_a} (N_a(t))^{\beta_a} (L_a(t))^{1 - \alpha_a - \beta_a} \quad (7)$$

Equation (8) shows the production for the rest of the economy, with A_n denoting the total factor productivity outside the agricultural sector, K_n denoting the total capital stock used in that sector, and N_n the total labor input[5].

$$Y_n(t) = A_n(t) (K_n(t))^{\alpha_n} (N_n(t))^{1 - \alpha_n} \quad (8)$$

[5] Since firms exhibit constant returns to scale, the total number of firms is irrellevant for the equilibrium. Therefore, we can solve the equilibrium as if there was a representative firm in each sector.

Productivity grows exogenously in both sectors:

$$\frac{\dot{A_a}(t)}{A_a(t)} \equiv \gamma_a > 0$$
$$\frac{\dot{A_n}(t)}{A_n(t)} \equiv \gamma_n > 0$$

Firms' optimization makes them choose the level of inputs such that the value of their marginal productivity is equal to the price of the input, as equations (9) - (13) show.

$$r(t) = q(t)\alpha_a A_a(t)(K_a(t))^{\alpha_a-1}(N_a(t))^{\beta_a}(L_a(t))^{1-\alpha_a-\beta_a} \tag{9}$$
$$w(t) = q(t)\beta_a A_a(t)(K_a(t))^{\alpha_a}(N_a(t))^{\beta_a-1}(L_a(t))^{1-\alpha_a-\beta_a} \tag{10}$$
$$p_l(t) = q(t)(1-\alpha_a-\beta_a)A_a(t)(K_a(t))^{\alpha_a}(N_a(t))^{\beta_a}(L_a(t))^{-\alpha_a-\beta_a} \tag{11}$$

$$r(t) = \alpha_n A_n(t)(K_n(t))^{\alpha_n-1}(N_n(t))^{1-\alpha_n} \tag{12}$$
$$w(t) = (1-\alpha_n)A_n(t)(K_n(t))^{\alpha_n}(N_n(t))^{-\alpha_n} \tag{13}$$

3.2 Closed Economy Equilibrium

Under autarky, the total production of agricultural good has to be equal to the total consumption of that good, as shown in equation (14), and the total production of nonagricultural good has to be equal to the total consumption of that good plus total investment, as equation (15)[6] shows.

$$A_a(t)(K_a(t))^{\alpha_a}(N_a(t))^{\beta_a}(L_a(t))^{1-\alpha_a-\beta_a} = N(t)c_a(t) \tag{14}$$

$$A_n(t)(K_n(t))^{\alpha_n}(N_n(t))^{1-\alpha_n} = N(t)\left(c_n(t) + \dot{k}(t) + n(t)k(t) + \delta(t)k(t)\right) \tag{15}$$

Also, the total supply of each production input has to be equal to the total supply in each sector as we can see in equations (16) - (20).

$$s_e(t)N(t) = N_a(t) \tag{16}$$
$$(1-s_e(t))N(t) = N_n(t) \tag{17}$$

$$s_k(t)K(t) = K_a(t) \tag{18}$$
$$(1-s_k(t))N(t) = K_n(t) \tag{19}$$

$$L_a(t) = L \tag{20}$$

[6] The market clearing condition in equation (15) is actually redundant, since it can be obtained from the budget constraint in equation (3), using the fact that $wN + rK = qY_a + Y_n$, and the fact that $Y_a = Nc_a$.

Definition 1. *A competitve equilibrium for this closed economy, given the initial per-capita capital stock* k_0 *and the exogenous variables is a vector of time functions for prices and quantities* $[q(t), w(t), r(t), p_l(t), Y_a(t), Y_n(t), c_a(t), c_n(t), s_e(t), N_a(t), N_n(t), s_k(t), K_a(t), K_n(t), \dot{k(t)}]_{t\geq 0}$*, satisfying the consumers' optimization conditions (4) - (6), the firms' optimization conditions (9) -(13), and the market equilibrium conditions (41) -(20).*

The equilibrium conditions can be simplified to the two dynamic equations (21) and (22) below, with nonagricultural good consumption c_n as the control variable and per capita capital stock k as the state variable. These two dynamic equations also depend on the endogenous variables $s_e(t)$, and $s_k(t)$, which are defined, together with $q(t)$, in equations (25) - (25).

$$\frac{\dot{c_n(t)}}{c_n(t)} = \alpha_n A_n(t)\left((1-s_k(t))\,k(t)\right)^{\alpha_n - 1}\left((1-s_e(t))\right)^{1-\alpha_n} - \delta - \rho \tag{21}$$

$$\dot{k(t)} = A_n(t)\left((1-s_k(t))\,k(t)\right)^{\alpha_n}(1-s_e(t))^{1-\alpha_n} - (\delta+n)\,k(t) - c_n(t) \tag{22}$$

$$q(t)\,\alpha_a \frac{A_a(t)\,(s_e)^{\beta_a}\left(\frac{L}{N(t)}\right)^{1-\alpha_a-\beta_a}}{(s_k(t)\,k(t))^{1-\alpha_a}} = \alpha_n \frac{A_n(t)\,(1-s_e(t))^{1-\alpha_n}}{((1-s_k(t))\,k(t))^{1-\alpha_n}} \tag{23}$$

$$q(t)\,\beta_a \frac{A_a(t)\,(s_k(t)\,k(t))^{\alpha_a}\left(\frac{L}{N(t)}\right)^{1-\alpha_a-\beta_a}}{(s_e(t))^{1-\beta_a}} = (1-\alpha_n)\,\frac{A_n(t)\left((1-s_k(t))\,k(t)\right)^{\alpha_n}}{(1-s_e(t))^{\alpha_n}} \tag{24}$$

$$A_a(t)\,(s_k(t)\,k(t))^{\alpha_a}(s_e(t))^{\beta_a}\left(\frac{L}{N(t)}\right)^{1-\alpha_a-\beta_a} = \begin{cases} \underline{c_a} + \mu_a^0 \frac{c_n(t)}{q(t)} \text{ if } c_a(t) \leq c_a^* \\ c_a^* + \mu_a^1 \frac{c_n(t)}{q(t)} \;\; c_a(t) > c_a^* \end{cases} \tag{25}$$

One can derive these reduced equilibrium system using the equilibrium conditions defined above in equations (4) - (20). In particular, equation (21) can be obtained using equation from the Euler Equation (5) and equation (12) together with the inputs' market clearing equations (17) and (19). Equation (22), on the other hand, comes from the nonagricultural good market clearing condition in equation (15) together with the inputs' market clearing conditions (17) and (19). Equations (23) and24 result from (9) plus (12) and (10) plus (13) respectively, together with the inputs' market clearing conditions in equations (16) - (19). Finally, equation (25) is obtained from the consumers' intratemporal optimization condition in equation (4) and the agricultural good market clearing condition in equation (14), together with the inputs' market clearing conditions in equations (16) and (18).

Equations (21) - (25), together with the boundary conditions $k(0) = k_0$ and the transversality condition in equation (6), are the ones used to find the solution of the model.

If consumers get richer, their consumption of both goods increase and, in the limit, they behave as if their preferences were

$$u\left(c_a, c_n\right) = \mu_a^1 \log\left(c_a\right) + \log\left(c_n\right) \tag{26}$$

In the long run, as a result, the economy behaves as if preferences were homothetic (like the ones in equation (26)), and the agricultural good expenditure share converges to $\frac{\mu_a^1}{1+\mu_a^1}$. It is possible to prove that when the preferences are the ones showed in equation (26), the solution path is the one that leads the economy to the Balanced Growth Path, where all the variables grow at constant rate. Theorems 2 - 5 below state this more precisely. The first one is about the existence of a balanced growth path when the preferencesare homothetic.

Theorem 2. *If the preferences are the ones in equation (26) then there exists a Balanced Growth Path*[7] *where all the variables grow at constant rates, shown in equations (27) - (30):*

$$\frac{\dot{s_e}(t)}{s_e\left(t\right)} = \frac{\dot{s_k}(t)}{s_k\left(t\right)} = 0 \tag{27}$$

$$\frac{\dot{k}(t)}{k\left(t\right)} = \frac{\dot{c_n}(t)}{c_n\left(t\right)} = \frac{1}{1-\alpha_n}\gamma_n \tag{28}$$

$$\frac{\dot{c_a}(t)}{c_a\left(t\right)} = \gamma_a + \frac{\alpha_a}{1-\alpha_n}\gamma_n - \left(1-\alpha_a-\beta\right)n \tag{29}$$

$$\frac{\dot{q}(t)}{q\left(t\right)} = \left(1-\alpha_a-\beta\right)n + \frac{1-\alpha_a}{1-\alpha_n}\gamma_n - \gamma_a \tag{30}$$

As a result, we can rewrite the equilibrium system in equations (21) -(24) in terms of a new set of normalized or detrended endogenous variables. This is what the next theorem explains.

Theorem 3. *Let* $\left\{\widehat{k}\left(t\right), \widehat{c_n}\left(t\right), \widehat{q}\left(t\right)\right\}$ *be defined as follows:*

$$\begin{aligned}
\widehat{k}\left(t\right) &\equiv \frac{k\left(t\right)}{A_n\left(t\right)^{\frac{1}{1-\alpha_n}}} \\
\widehat{c_n}\left(t\right) &\equiv \frac{c_n\left(t\right)}{A_n\left(t\right)^{\frac{1}{1-\alpha_n}}} \\
\widehat{q}\left(t\right) &\equiv \frac{q\left(t\right)}{\frac{A_n(t)^{\frac{1-\alpha_a}{1-\alpha_n}}}{A_a(t)L^{1-\alpha_a-\beta_a}}\left(N\left(t\right)\right)^{1-\alpha_a-\beta_a}}
\end{aligned}$$

[7] Note that other authors do not define a situation like this as a Balanced Growth Path because the growth rates are not the same for all variables.

The equilibrium system defined above in equations (21) -(24), together with the initial condition for k_0 and the transversality condition in equation (6), can be rewritten in terms of the new set of normalized or detrended variables.

The next two theorems show that this detrended equilibrium system will have a steady state, both when the preferences are homothetic and when the preferences are nonhomothetic. The next theorem proves it for the homothetic preferences case.

Theorem 4. *If the preferences are the ones in equation (26), then the equilibrium system defined in equations (58) - (62) has a Steady State, where all the variables are constant. Moreover, the solution to this system of equations consists of the path that converges to this Steady State. Equations (31)- (35) define this Steady State.*

$$\alpha_n\left(\left(1-s_k^{ss}\right)\widehat{k}^{ss}\right)^{\alpha_n-1}\left(\left(1-s_e^{ss}\right)\right)^{1-\alpha_n}=\delta+\rho+\frac{1}{1-\alpha_n}\gamma_n \tag{31}$$

$$\widehat{c_n}^{ss}=\left(\left(1-ss_k^{ss}\right)\widehat{k}^{ss}\right)^{\alpha_n}\left(\left(1-s_e^{ss}\right)\right)^{1-\alpha_n}-\left(\delta+n+\frac{1}{1-\alpha_n}\gamma_n\right)\widehat{k}^{ss} \tag{32}$$

$$\widehat{q}^{ss}\alpha_a\frac{\left(s_e^{ss}\right)^{\beta_a}}{\left(s_k^{ss}\widehat{k}^{ss}\right)^{1-\alpha_a}}=\alpha_n\frac{\left(1-s_e^{ss}\right)^{1-\alpha_n}}{\left(\left(1-s_k^{ss}\right)\widehat{k}^{ss}\right)^{1-\alpha_n}} \tag{33}$$

$$\widehat{q}^{ss}\beta_a\frac{\left(s_k^{ss}\widehat{k}^{ss}\right)^{\alpha_a}}{\left(s_e^{ss}\right)^{1-\beta_a}}=\left(1-\alpha_n\right)\frac{\left(\left(1-s_k^{ss}\right)\widehat{k}^{ss}\right)^{\alpha_n}}{\left(\left(1-s_e^{ss}\right)\right)^{\alpha_n}} \tag{34}$$

$$\left(s_k^{ss}\widehat{k}^{ss}\right)^{\alpha_a}\left(s_e^{ss}\right)^{\beta_a}=\frac{\mu_a}{\mu_n}\frac{\widehat{c_n}^{ss}}{\widehat{q}^{ss}} \tag{35}$$

When the preferences are nonhomothetic, then we need an extra condition to make sure that the solution to the detrended equilibrium system is the steady state defined above. The condition is that the growth of agricultural production is large enough to compensate for the population growth, so that the nonhomothetic component of the preferences becomes less and less important over time.

Theorem 5. *With the preferences defined in equaiton (2), if $\left(1-\alpha_a-\beta_a\right)n<\gamma_a+\frac{\alpha_a}{1-\alpha_n}\gamma_n$, then the detrended equilibrium system defined in (58) - (62) converges to same equilibrium as the homothetic preferences case. Hence, the equilibrium solution is also the unique path that converges to the steady state defined in equations (31) - (35).*

3.3 Open Economy Equilibrium

Under international trade, countries no longer have to produce the amounts they consume since they have the possibility of exporting one of the goods in exchange for the other one, potentially even specializing. As a result, the conditions that characterize the open economy equilibrium are different than the ones charectarizing the closed economy equilibrium.

The consumers' optimiztion conditions, presetended above in equations (4) - (6) above for a closed economy are the same than under free trade. The optimization conditions of the firm are the same if the equilibrium is such that both goods are produced. If the country specialized in the production of one of the goods, then the conditions are obviously different because the factors' value of the marginal product does not have to be equalized across sectors any longer. Specialization in the production of the agricultural good is a possible outcome, but specialization in the production of the nonagricultural good is not, since the input land is only produced in the agricultural sector.

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Theorem 6. *Under international trade, the small open economy may specialize in the production of the agricultural good, with no production of nonagricultural good. This occurs if the condition below in equation (36) is violated. The small open economy, however, will not specialize in the production of the nonagricultural good, since the condition for this to be the case, shown in equation (37), will always be satisfied. If the conditions specified in equations (36) and (37) below are both satsfied, then the economy does not specialize and it produces both goods.*

$$q(t)\,\alpha_a A_a(t)\,(k(t))^{\alpha_a-1}\left(\frac{L}{N(t)}\right)^{1-\alpha_a-\beta_a} < \alpha_n A_n(t)\,(k(t))^{\alpha_n-1}\left(\frac{\frac{1-\alpha_n}{\alpha_n}}{\frac{\beta}{\alpha_a}}\right)^{1-\alpha_n} \tag{36}$$

$$q(t)\,\alpha_a A_a(t)\,(k(t))^{\alpha_a-1}\left(\frac{\frac{1-\alpha_n}{\alpha_n}}{\frac{\beta}{\alpha_a}}\right)^{\alpha_a}\left[\lim_{s_e(t)\to 0}\left\{s_e(t)^{\alpha_a+\beta_a-1}\right\}\right] > \alpha_n A_n(t)\,(k(t))^{\alpha_n-1} \tag{37}$$

The value of the capital rental rate, the wage rate, and the land rental price, thus, depend on whether the economy produces both goods ($0 < s_e(t) < 1$) or produces only the agricultural good ($s_e(t) = 1$). These new conditions from the firms optimization are presented in equations (38) - (40):

$$r(t) = \begin{cases} q(t)\,\alpha_a A_a(t)\,(K_a(t))^{\alpha_a-1}\,(N_a(t))^{\beta_a}\,(L_a(t))^{1-\alpha_a-\beta_a} & \text{if } s_e(t) > 0 \\ \alpha_n A_n(t)\,(K_n(t))^{\alpha_n-1}\,(N_n(t))^{1-\alpha_n} & \text{if } s_e(t) < 1 \end{cases} \tag{38}$$

$$w(t) = \begin{cases} q(t)\,\beta_a A_a(t)\,(K_a(t))^{\alpha_a}\,(N_a(t))^{\beta_a - 1}\,(L_a(t))^{1-\alpha_a-\beta_a} & \text{if } s_e(t) > 0 \\ (1-\alpha_n)\,A_n(t)\,(K_n(t))^{\alpha_n}\,(N_n(t))^{-\alpha_n} & \text{if } s_e(t) < 1 \end{cases} \tag{39}$$

$$p_l(t) = \begin{cases} q(t)\,(1-\alpha_a-\beta_a)\,A_a(t)\,(K_a(t))^{\alpha_a}\,(N_a(t))^{\beta_a}\,(L_a(t))^{-\alpha_a-\beta_a} & \text{if } s_e(t) > 0 \\ 0 \text{ if } s_e(t) = 0 \end{cases} \tag{40}$$

The goods' markets clearing conditions are also different under international trade, since now the total production of agricultural good has to be equal to the total consumption of that good plus net agricultural exports, as shown in equation (41), and the total production of nonagricultural good has to be equal to total consumption of that good plus net exports of that good, plus total investment, as equation (42)[8] shows.

$$A_a(t)\,(K_a(t))^{\alpha_a}\,(N_a(t))^{\beta_a}\,(L_a(t))^{1-\alpha_a-\beta_a} = N(t)\,c_a(t) + N(t)\,x_a(t) \tag{41}$$

$$A_n(t)\,(K_n(t))^{\alpha_n}\,(N_n(t))^{1-\alpha_n} = N(t)\left(c_n(t) + x_n(t) + \dot{k}(t) + nk(t) + \delta k(t)\right) \tag{42}$$

The model assumes that there is balanced trade every period, so that the value of net agricultural exports, denoted by $x_a(t)$, has to be equal to the value of net nonagricultural exports, denoted by $x_n(t)$, as illustrated in equation (43):

$$q(t)\,x_a(t) + x_n(t) = 0 \tag{43}$$

The model also assumes that the country is small relative to the rest of the word, which means that the country takes the international relative price $q^*(t)$ as given. The relative price consumers face inside the country, denoted by $q(t)$, is also determined by potential trade costs - transport costs, or tariffs -, which will be denoted t_a if the imported good is the agricultural one and t_n if it is the nonagricultural. These trade costs are assumed to be of the iceberg type, which means that a fraction of the goods shipped simply vanishes during transportation. Equation (44) shows the relation between $q^*(t)$ and $q(t)$:

$$q(t) = \begin{cases} \frac{1}{1+\tau_n(t)} q^*(t) & \text{if } x_a(t) < 0,\ x_n(t) > 0 \\ (1+\tau_a(t))\,q^*(t) & \text{if } x_a(t) > 0,\ x_n(t) < 0 \end{cases} \tag{44}$$

Note that now, compared to the closed economy case, the relative price $q(t)$ is not an endogenous variable since it is determined externally, but the net of exports of agricultural and nonagricultural goods are endogenous variable to be determined.

Finally, as it was the case under autarky, for the input markets to be in equilibrium, the total supply of each production input has to be equal to the total input demand in each sector, which was showed in equations (16) - (20).

[8] The market clearing condition in equation (15) is actually redundant, since it can be obtained from the budget constraint in equation (3), using the fact that $wN + rK = qY_a + Y_n$, and the fact that $Y_a = Nc_a + Nx_a$.

Definition 7. *A competitve equilibrium for a small open economy, given the per-capita initial capital stock* k_0 *and the exogenous variables is a vector of time functions for prices and quantities* $[w(t), r(t), Y_a(t), Y_n(t), c_a(t), c_n(t), x_a(t), x_n(t), s_e(t), N_a(t), N_n(t), s_k(t), K_a(t), K_n(t), \dot{k(t)}]_{t\geq 0}$*, satisfying the consumers' optimization conditions (4) - (6), the firms' optimization conditions (38) - (39), the goods' market equilibrium conditions (48) and (42), the factors' market equilibrium conditions (16) - (20), together with equations (43) and (44).*

Following a similar procedure than the one in the closed economy, the equilibrium conditions can be simplified to two dynamic equations - equations (45) and (46) below - and four static equations, also presented below. The two dynamic equations determine the change in the state variable $k(t)$ and in the control variable $c_n(t)$, as a function of some other endogenous variable. To solve for these other endogenous variables, we need the other equations defined below, which vary depending on the country's specialization pattern.

$$\frac{\dot{c_n(t)}}{c_n(t)} = r(t) - \delta - \rho \tag{45}$$

$$\dot{k(t)} = A_n(t)\left((1 - s_k(t))\,k(t)\right)^{\alpha_n}(1 - s_e(t))^{1-\alpha_n} - (\delta + n)\,k(t) - c_n(t) - x_n(t) \tag{46}$$

If the exogenous relative price $q(t)$ is such that the country produces both goods, then the static equations describing the equilibrium are equation (47) below - which defines the interest rate $r(t)$ -, together with equations (23) and (24) above - which state that the value of the marginal product of both factors has to be equal across sectors-, and equation (41) below - which is the agricultural good market clearing condition written in terms of nonagricultural consumption and nonagricultural exports-.

$$r(t) = \alpha_n \frac{A_n(t)(1 - s_e(t))^{1-\alpha_n}}{\left((1 - s_k(t))\,k(t)\right)^{1-\alpha_n}} \tag{47}$$

$$A_a(t)\left(s_k(t)\,k(t)\right)^{\alpha_a}(s_e(t))^{\beta_a}\left(\frac{L}{N(t)}\right)^{1-\alpha_a-\beta_a} = \frac{\mu_a}{\mu_n}\frac{c_n(t)}{q(t)} + \underline{c_a} - \frac{x_n(t)}{q(t)} \tag{48}$$

If the exogenous relative price $q(t)$ is such that only the agricultural good is produced, then the interest rate is defined by equation (49), the agricultural good market clearing condition in equation (48) does not change, and the two other equations defining the equilibrium are (50) and (51) below.

$$r(t) = q(t)\,\alpha_a \frac{A_a(t)(s_e)^{\beta_a}\left(\frac{L}{N(t)}\right)^{1-\alpha_a-\beta_a}}{\left(s_k(t)\,k(t)\right)^{1-\alpha_a}} \tag{49}$$

$$s_e(t) = 1 \tag{50}$$
$$s_k(t) = 1 \tag{51}$$

These equations, together with the boundary conditions $k(0) = k_0$ and the transversality condition in equation (6), are the ones used to find the solution of the model.

As it was the case in the closed economy, it is possible to show that when preferences are homothetic like in equation (26), then the economy has a Balanced Growth Path, and the solution to the system consists of the unique path that leads to it. When the preferences are nonhomothetic like in equaiton (2), one can prove that the solution is also the path that leads to the Balanced Growth Path of the homothetic preferences case.

The next theorem shows how the specialization pattern of the small open economy in the Balanced Growth Path depends on the growth rate of the exogenous relative price q, and the following one shows the growth rates in the Balanced Growth Path.

Theorem 8. *If the preferences are the ones defined in equation (26), then the open economy equilibrium is consistent with a Balanced Growth Path, in which all the variables grow at a constant rate. If the growth rate of the exogenous relative price q, denoted by γ_q, is equal to $(1-\alpha_a-\beta_a)n + \frac{1-\alpha_a}{1-\alpha_n}\gamma_n - \gamma_a$, then the Balanced Growth Path has positive production of both goods ($0 < s_e^{ss} < 1$, $0 < s_k^{ss} < 1$); if $\gamma_q > (1-\alpha_a-\beta_a)n + \frac{1-\alpha_a}{1-\alpha_n}\gamma_n - \gamma_a$, then only the agricultural good is produced in the Balanced Growth Path ($s_e^{ss} = 1$, $s_k^{ss} = 1$); finally, if $\gamma_q < (1-\alpha_a-\beta_a)n + \frac{1-\alpha_a}{1-\alpha_n}\gamma_n - \gamma_a$, then only the nonagricultural good is produced in the Balanced Growth Path ($s_e^{ss} = 0$, $s_k^{ss} = 0$).*

Theorem 9. *The growth rates of the endogenous variables in the BGP are the ones showed in equations (52) -(54):*

$$\frac{\dot{s_e}(t)}{s_e(t)} = \frac{\dot{s_k}(t)}{s_k(t)} = 0 \tag{52}$$

$$\frac{\dot{k}(t)}{k(t)} = \frac{\dot{c_n}(t)}{c_n(t)} = \frac{\dot{x_n}(t)}{x_n(t)} = \begin{cases} \frac{1}{1-\alpha_n}\gamma_n \text{ if } s_e^{ss} < 1 \\ \frac{1}{1-\alpha_a}\gamma_a + \frac{1}{1-\alpha_a}\gamma_q - \frac{1-\alpha_a-\beta_a}{1-\alpha_a}n \text{ if } s_e^{ss} = 1 \end{cases} \tag{53}$$

$$\frac{\dot{c_a}(t)}{c_a(t)} = \begin{cases} \frac{1}{1-\alpha_n}\gamma_n - \gamma_q \text{ if } s_e^{ss} < 1 \\ \frac{1}{1-\alpha_a}\gamma_a + \frac{\alpha_a}{1-\alpha_a}\gamma_q - \frac{1-\alpha_a-\beta_a}{1-\alpha_a}n \text{ if } s_e^{ss} = 1 \end{cases} \tag{54}$$

Corollary 10. *Let* $\widehat{k}(t)$*,* $\widehat{c_n}(t)$*, and* $\widehat{x_n}(t)$ *be defined as in equations (55) - (57). Hence,* $\widehat{k}(t)$*,* $\widehat{c_n}(t)$*, and* $\widehat{x_n}(t)$*, as well as* $s_e(t)$ *and* $s_k(t)$ *are constant in the BGP.*

$$\widehat{k}(t) \equiv \begin{cases} \frac{k(t)}{A_n(t)^{1/(1-\alpha_n)}} & \text{if } s_e^{ss} < 1 \\ \frac{k(t)}{\left(A_a(t)q(t)N(t)^{(1-\alpha_a-\beta_a)}\right)^{1/(1-\alpha_a)}} & \text{if } s_e^{ss} = 1 \end{cases} \tag{55}$$

$$\widehat{c_n}(t) \equiv \begin{cases} \frac{c_n(t)}{A_n(t)^{1/(1-\alpha_n)}} & \text{if } s_e^{ss} < 1 \\ \frac{c_n(t)}{\left(A_a(t)q(t)N(t)^{(1-\alpha_a-\beta_a)}\right)^{1/(1-\alpha_a)}} & \text{if } s_e^{ss} = 1 \end{cases} \tag{56}$$

$$\widehat{x_n}(t) \equiv \begin{cases} \frac{x_n(t)}{A_n(t)^{1/(1-\alpha_n)}} & \text{if } s_e^{ss} < 1 \\ \frac{x_n(t)}{\left(A_a(t)q(t)N(t)^{(1-\alpha_a-\beta_a)}\right)^{1/(1-\alpha_a)}} & \text{if } s_e^{ss} = 1 \end{cases} \tag{57}$$

Theorem 11. *The equilibrium system defined above in equations (45) -(48) can be rewritten in terms of the detrended variables* $\widehat{k}(t)$*,* $\widehat{c_n}(t)$*, and* $\widehat{x_n}(t)$

This detrended equilibrium system defined has a steady state, when the preferences are the homothetic preferences defined in equation (26) and also when they are the non-homothetic preferences defined in equation (2). The next theorem proves it for the first case.

Theorem 12. *If the preferences are the ones defined in equation (26), then the detrended equilibrium system defined in equations (65) - (70)*[9] *has a Steady State, where all the variables are constant. The solution to this detrended equilibrium system consists of the path that leads to this Steady State.*

As it was the case for a closed economy, when the preferences are the nonhomothetic ones, then we need an extra condition to make sure that the solution of the detrended equilibrium system is the steady state defined above, which is that the agricultural production growth rate is high enough to compensate for the population growth.

Theorem 13. *If the preferences are the ones defined in equation (13) and* $(1-\alpha_a-\beta_a)\, n < \gamma_a + \frac{\alpha_a}{1-\alpha_n}\gamma_n$*, then the detrended equilibrium system defined in (65) - (70)*[10] *converges to same equilibrium as the homothetic preferences case. Hence, the equilibrium solution is also the unique path that converges to the steady state defined above.*

[9] See Appendix C.
[10] See Appendix C.

3.4 Structural Transformation in a Closed and an Open Economy

Theorem 14. *In a closed economy, as the households get richer the fraction of consumption expenditures allocated to the agricultural good decreases due to the preferences used. As a result, unless the savings rate increases by enough, technology growth reduces the fraction of labor and capital employed in the agricultural sector.*

Theorem 15. *In a Closed Economy, the agricultural relative price can be written as*

$$q(t) = \frac{A_n(t)}{A_a(t)} \left(\frac{L}{N}\right)^{\alpha_a+\beta_a-1} k(t)^{\alpha_n-\alpha_a} \frac{s_e(t)^{1-\alpha_a-\beta_a}}{\left(\frac{\beta_a}{\alpha_a} - s_e(t)\left(\frac{\beta_a}{\alpha_a} - \frac{1-\alpha_n}{\alpha_n}\right)\right)^{\alpha_n-\alpha_a}}$$

Hence, other things equal, the lower the agricultural employment share $s_e(t)$, the lower the agricultural relative price $q(t)$.

Theorem 16. *Assume that, before internaitonal trade starts, the home country has a larger agricultural price relative to the rest of the world. In this case, the agricultural price of the home country decreases when international trade starts, leading to an increase in agricultural constumption relative to the nonagricultural consumption, and to reduction of agricultural production and agricultural employment share.*

4 Structural Transformation in the United States

In this section I simulate the closed economy version of the model to match the United States data during the period 1890-2007[11]. The goal is first to analyze the main factors behind the structural transformation process experienced by the United States during this period, as well as show that the model and the parametrization used are not only able to replicate the South Korea data but also the US data. The United States had already started its transition process at 1890, but the agricultural employment was still was above 40% of the total employment, much higher than the current value, which is approximately 1%.

[11] Although the United States is not a closed economy, its net agricultural exports are low in relation to its production. Only during the period 1975-1995 the net agricultural exports are more than 5% of the total output, and during this period they never reach 20%.

4.1 Parameter Values and Exogenous Variables Specification

To simulate the model, it is necessary to provide values for the parameters, specify the exogenous variables path (both for the sample period and for future periods), and give the initial condition for the capital stock. Appendix D contains a detailed explanation of all the time series used.

The agricultural sector is defined as the farm sector.

The initial value for capital is the actual value of nonresdential capital stock in the data for the year 1890.

The model parameters that must be calibrated are the production functions parameters (α_a, β_a, α_n), the depreciation rate δ, and the preferences parameters (ρ, μ_a^0, μ_a^1, $\underline{c_a}$, c_a^*). Table 1 contains a summary of all the parameters and the values used in the US simulations.

Table 1: Parameter Values United States Simulation

	Description	Value
$\boldsymbol{\alpha}_n$	Capital share nonagr sector	1/3
$\boldsymbol{\alpha}_a$	Capital share agr sector	0.21
β_a	Labor share agr sector	0.5
$\boldsymbol{\delta}$	Capital depreciation rate	0.10
$\boldsymbol{\rho}$	Intertemporal discount	0.06
$\boldsymbol{\mu}_a^0$	Agr good cons initial weight	0.5
$\boldsymbol{\mu}_a^1$	Agr good cons weight	0.01
$\underline{c_a}$	Agr subsistence level cons	60% c_a in 1890
c_a^*	Agr threshold level cons	95% c_a in 1890

The value used for the capital exponent in the nonagricultural production function, α_n, is 1/3. This is both the standard value used in the literature, and the value used in Caselli and Coleman (2001).

The value used for the capital and the labor exponents in the agricultural production function, α_a and β_a, are 0.21 and 0.6 respectively. These are the values used in Caselli and Coleman, and are also similar to the values used in other studies.

The value used for the depreciation rate parameter, δ, is 0.1. This is value corresponds to the depreciation rate when only using nonresidential structures and producer durables in the United States, according to Caselli and Coleman (2001) who cite Christensen and Jorgenson (1995).

The value used for the intertemporal discount factor ρ is 0.06, which is the value that makes the capital accumulation in the model match the one in the data.This value is also similar to the one used in the literature, like Caselli and Coleman (2001),who use 0.95 as the intertemporal discount factor of their discrete time model, and Hayashi and Prescott (2008), who use 0.96.

The preferences' parameters μ_a^1 and c_a^* are chosen to make the model simulations fit the agricultural consumption data well. μ_a^1 is equal to 0.01, and c_a^* is 95% of the agricultural good consumption in 1890. The parameters μ_a^0 and $\underline{c_a}$ do not affect the model simulation, since agricultural consumption in 1890 was already above c_a^*; μ_a^0 is given a value of 0.5, and $\underline{c_a}$ a value of

64% the value of c_a^*, which are the values used in the South Korea simulation, as explained in the next subsection.

To simulate the model, the values for some time series has to be given exogenously, since they are not determined in the model. The variables to be exogenously specified in the closed economy model are total population, total employment[12], agricultural TFP, nonagricultural TFP. Table 2 below briefly describes these variables, and figure 7 in Appendix D shows the time series used in the simulations and the measured data.

Total population N is obtained directly from the data, but eliminating the high-frequency fluctuations, with the inital value normalized to one and the out-of-sample growh rate assumed to be 1%, which is approximately the average population growth in the last 10 years. The employment-to-population ratio is approximated using a linear trend, assuming an out-of sample value of 45% which is approximately the value in recent data.

Agricultural and nonagricultural Total Factor Productivity are the smooth series of the measured data. They are measured in the data using the Cobb-Douglas production functions from equations (7) and (8), as well as data on value added and employment by sector. Agricultural and nonagricultural capital stocks are inferred from data on aggregate capital and assuming that both labor and capital are efficiently allocated across sectors, since the data on sectoral capital stocks is not complete and the different data sources do not seem to be compatible. The intial value of both is normalized to 100, and the future growth rate is taken from the average of the last 10 years, which is 6% for the agricultural TFP growth rate and 1.5% for the nonagricultural TFP growth rate.

Table 2: Exogenous Variables United States Simulation

	Description	**Initial Value**	**Sample period growth**	**Future growth**
$\mathbf{N}$	Population	1	Approx to actual data	0.01
$\mathbf{E}$	Employment	Data	Approx to actual data	0.01
$\mathbf{A}_a$	Agricultural TFP	100	Approx to actual data	0.06
$\mathbf{A}_n$	Nonagricultural TFP	100	Approx to actual data	0.015

[12] When simulating the model to match the data, employment is allowed to be different than total population, and the ratio of both variables is taken from the data.

4.2 United States Simulation

In this section the results of the closed economy model simulations are shown and compared to the US actual data. In figure 1 we can see these comparison for the fraction of employment in the agricultural sector, the fraction of capital in the agricultural sector, agricultural production per capita, nonagricultural production per capita, aggregate capital stock, and agricultural relative.price.

The model is able to replicate quite succesfully the agricultural employment share data, altough it seems to slightly underpredict it in the initial years. Although it still captures the main trend, the model does not match the data on the fraction of capital employed in the agricultural sector so well, since it overpredicts it for the initial years and underpredicts it for the final years. However, it matches pretty closely both the agricultural and the nonagricultural production data. Finally, the fit of the model is also quite good in terms of the aggregate capital stock, and the match with the agricultural price data of the last 60 years is not bad either. Before that, the data is very volatile and it is difficult to evaluate the performance of the model.

5 Structural Transformation in the United Kingdom

[to be added]

6 Structural Transformation in South Korea

In this section, I simulate the open economy model to match the South Korea data during the period 1963-2007, with the final goal of quantifying the role played by the different elements. First, the model is calibrated to match the data, and then it is simulated under alternative situations.

Table 3 presents some general data for South Korea, to motivate the study of this particular country. During the last 45 years South Korea has experienced a substantial decrease in the fraction of its labor force employed in the agricultural sector, as we can see in column 1. At the same time, its per capita GDP growth rate has been very high, which has allowed the country the catch up significantly with respect the United States. Finally, it has also been quite open to international trade, and has bee a net agricultural importer during the entire sample period.

6.1 Parameter Values and Exogenous Variables Specification

As before, to simulate the model, it is necessary to provide values for the parameters, specify the exogenous variables path (both for the sample period and for future periods),

Figure 1: Model Simulation vs United States Data

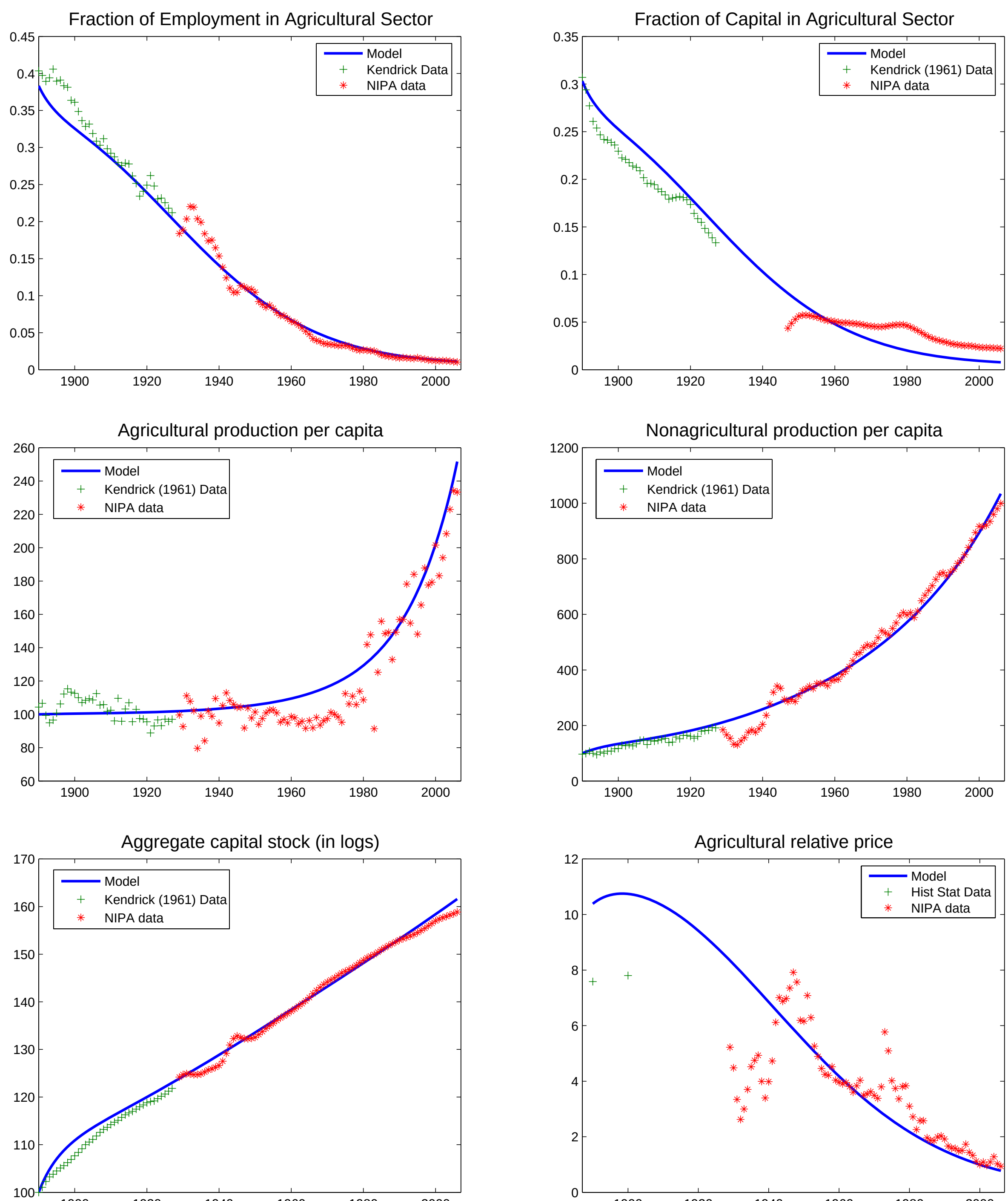


Table 3: South Korea Data Summary

	Agr employment %	GDP per capita (Korea / US) %	Openess (X+M)/GDP) %	Agr imports (over Agr GDP) %
1955	80 (approx)	11.3	11.6	
1965	58.5	11.1	24.22	7.8
1975	45.7	17.9	62	19.6
1985	24.9	25.2	64.4	17.2
1995	11.8	45.4	58.7	18.5
2004	8.1	51	84	24.1

and give the initial condition for the capital stock. A detailed explanation of the time series used can be found in Appendix E.

The initial capital stock is its actual value in the data for the year 1963[13]. The model parameters that must be calibrated are the production functions parameters (α_a, β_a, α_n), the depreciation rate δ, and the preferences parameters (ρ, μ_a^0, μ_a^1, $\underline{c_a}$, c_a^*).

The agricultural sector is defined as Agriculture, Forestry and Fishing, since for most data used this is the most disaggregated sector available. The nonagricultural sector is the rest of the economy.

Table 4 shows the value chosen for the different parameters of the model.

Table 4: Parameter Values South Korea simulation

	Description	**Value**
$\boldsymbol{\alpha}_n$	Capital share nonagr sector	1/3
$\boldsymbol{\alpha}_a$	Capital share agr sector	0.1
β_a	Labor share agr sector	0.5
$\boldsymbol{\delta}$	Capital depreciation rate	0.10
$\boldsymbol{\rho}$	Intertemporal discount	0.06
$\boldsymbol{\mu}_a^0$	Agr good initial weight	0.5
$\boldsymbol{\mu}_a^1$	Agr good weight in the LR	0.1
$\underline{c_a}$	Agr subsistence level cons	90% c_a in 1963
c_a^*	Agr threshold level cons	140% c_a in 1963

The value chosen for the labor exponent in the nonagricultural good production function, $1 - \alpha_n$, is 2/3, which is exactly equal to the average labor income share on total

[13]Capital stock data is available for the period 1962-1995 from the Korea Development Institute, as described in appendix E.

nonagricultural income in the data for the period 1963-1995[14]. This is also the customary value used in the literature[15].

The value chosen for the labor exponent in the agricultural good production function, β_a, is 0.5. This is almost the same as the average labor income share on total agricultural income in the data for the period 1963-1995, which is 0.46, but it is lower than the value for other studies in the literature[16]. The agricultural capital exponent in the agricultural production function, α_a is 0.1, which is the average income share in the agricultural sector for Structures and Equipment plus Inventories in the data for the period 1963-1995. This implies an exponent for land in the agricultural production function equal to 0.4.

The value used for the depreciation rate parameter δ is 0.1, and the value used for the intertemporal discount factor ρ is 0.06. These are the values used in the US parametrization, as explained in the previous subsection, and they seem to do also a good job in fitting the South Korea capital data.

The parameters of the instantaneous utility function (μ_a^0, μ_a^1, $\underline{c_a}$, c_a^*) are chosen to get a good fit in the agricultural consumption of the model compared to the data, and the value for μ_a^1 is also the one used in the US simulation. The subsistence level $\underline{c_a}$ is approximately 90% of the agricultural consumption in 1963, and the agricultural consumption threshold level c_a^* is approximately 140% of the agricultural consumption in 1963. The fact that μ_a^0 is much larger than μ_a^1 implies that the marginal utility of agricultural consumption above c_a^* is much lower than below c_a^*. If μ_a^1 was equal to zero, then c_a^* would effectively be a satiation level above which consumers do not get more utility from increase their agricultural consumption. The data, however, especially in the United States, show that agents do increase their agricultural consumption above c_a^*.

The exogenous variables that need to be specified are total population, total employment[17], agricultural TFP, nonagricultural TFP, and the agricultural relative price, as well government agricultural policy variables. Table 5 summarizes each of the exogenous variables, and Appendix E offers a detailed description of the time series used to compute them.

Total population, N, is taken directly from the data, although the high frequency fluctutions are elimianted using the Hodrick-Prescott filter. The initial value is normalized to one, and the population growth after 2007 is assumed to be constant and equal to 5%, which is approximately the average population growth of the last 10 years. Figure 8 in

[14] The income shares series are taken from Kwang Suk Kim and Sung Duk Hong (1997), published by the Korea Development Institute. See page 79 for the nonagricultural income shares, and page 67 for the agricultural income shares.

[15] See, for instance, Hayashi and Prescott (2008).

[16] Hayashi and Prescott (2008), for instance, use 0.545 for Japan, and Caselli and Coleman (2001) use 0.6 for the United States.

[17] When simulating the model to match the data, employment is allowed to be different than total population, and the ratio of both variables is taken from the data.

Table 5: Exogenous Variables South Korea simulation

	Description	Initial Value	Sample period growth	Future growth
$\mathbf{N}$	Population	1	Approx to actual data	0.005
$\mathbf{E}$	Employment	Data	Approx to actual data	0.005
$\mathbf{A}_a$	Agricultural TFP	100	0.0315	0.0315
$\mathbf{A}_n$	Nonagricultural TFP	100	0.0215	0.0215
$\mathbf{q}$	Relative agricultural price	4.35	Approx to $\frac{P_aY_a/Y_a}{P_nY_n/Y_n}$	-0.0156

Appendix E shows both the actual population time series and the data approximation used in the simulations.

Total employment, E, is approximated by estimating the employment-to-population ratio with a linear trend, and then multiplying this ratio by the variable N. Figure 8 in Appendix E shows the employment ratio in the data, and the linear approximation to it used in the simulations.

Agricultural and nonagricultural TFPs are assumed to have constant growth, since the data does not show any important trend. The growth rates chosen for both are the ones that make the simulated production variables fit the actual production variables, but as we can see in figure 8 in Appendix E , these growth rates are a very close approximation to the ones of the measured TFPs. Agricultural and nonagricultural TFP are measured in the data using the Cobb-Douglas production functions from equations (7) and (8), as well as data on value added and employment by sector. Agricultural and nonagricultural capital stocks are inferred from data on aggregate capital and assuming that both labor and capital are efficiently allocated across sectors, since the data on sectoral capital stocks does not seem very reliable.

Finally, the relative agricultural price is taken from the measured data, again eliminating the high frequency fluctuations using the Hodrick-Prescott filter. Since there is no data on the relative agricultural price directly available, the procedure used to measure it is divide the agricultural GDP deflator by the nonagricultural GDP deflator. In other words, the nominal agricultural GDP is divided by the real agricultural GDP to estimate the agricultural price, the nominal nonagricultural GDP is divided by the real nonagricultural GDP to estimate the nonagricultural price, and the agricultural relative price is the ratio of the two. Figure 8 in Appendix E shows the both the measured time series and the approximation to it used in the model simulation. With respect to the policy variables (t_a, t_n, σ_a, σ_n), there is a large literature documenting the efforts by the Korean government to protect their agricultural sector and increase the income of the agricultural producers. The two main policy tools have been the agricultural production subsidies, which according to the OECD[18] were 56% in 1980 and 65% in 2000, and the agricultural import tariffs, which

[18] See the OECD report "Agricultural Policies at a glance", 2008.

according to the United States Department of Agriculture[19] were 64% in 1975 and 104% in 1990. For the agricultural import tariffs t_a, I assume they do not generate any revenue or that it is not rebated to the households, since rebating the revenues to the consumers does not improve the fit of the model simulation. As a result, since I am already using data on the relative agricultural price in the domestic market, I do not have to worry about the value of the agricultural import tariff at this point. For the production subsidy, I use $\sigma_a = 0$ until 1972 because no subsidies seem to be used prior to that date, and $\sigma_a = 0.13$ from 1973 on since using a higher value increases agricultural production and agricultural employment unrealistically. I also assume that the government budget constraint is balanced every period using a lump-sum tax on households for the exact same value as the amount spent on production subsidies.

6.2 South Korea Simulation

In this section the outcome of the simulated model is compared with the actual data. Figure 2 shows this comparison for six different variables: fraction of employment in the agricultural sector, agricultural production per capita, agricultural consumption per capita, agricultural net imports, nonagricultural production per capita, and aggregate capital stock. Note that all the simulated variables are plotted starting at 100, to facilitate the reading of the figures.

In the first two subplots, one can easily see the effects of the agricultural production subsidy in 1972: both the agricultural employment share and the agricultural production per capita jump up. Obviously, the subsidy also affects the net agricultural imports, since the sudden increase in agricultural production also leads to a sudden decrease in net agricultural imports. The introduction of the subsidy is important to fit well the data, especially in the case of the agricultural production.

In the agricultural consumption subplot, one can see the consquences of the preferences used: around 1980 agricultural consumption per capita reaches the level c_a^*, and it grows more slowly after that date.

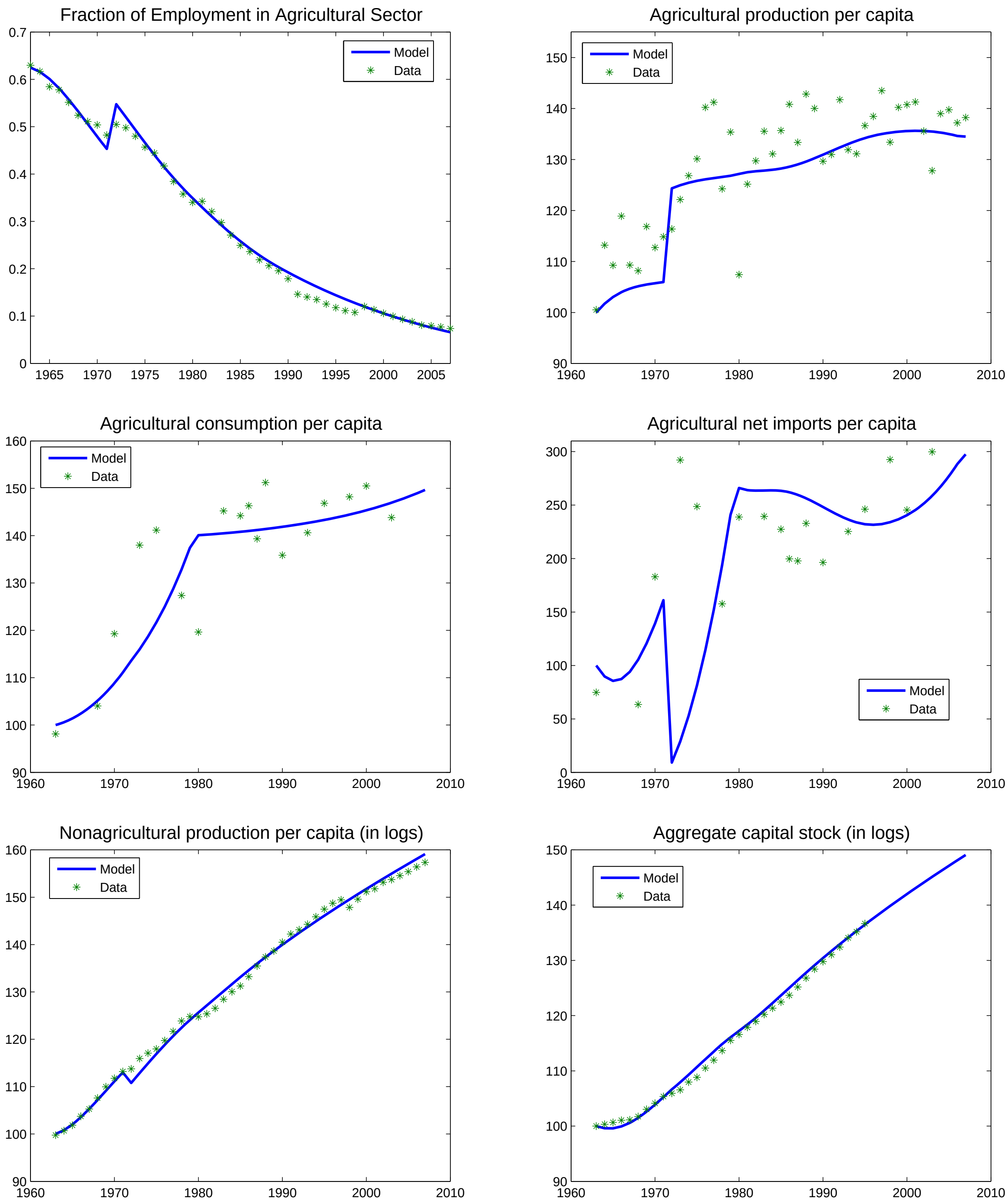
In general, the model with the parameter values described above seems to be able to capture the main aspects of the structural transformation process of South Korea during the period 1963 - 2007.

6.3 Counterfactual Exercises

To evaluate the importance of international trade, which offers South Korea the possibility of importing part of the agricultural good consumed, for its structural transformation

[19] See the USDA Agricultural Economic Report number 809 "Structural Change and Agricultural Protection: Costs of Korean Agricultural Policy, 1975 and 1990", 2002.

Figure 2: Model Simulation vs South Korea Data



process, I perform two counterfactual exercises. The first one consists of comparing the actual development process of South Korea with a situation where South Korea is not open to international trade and has to produce itself all the agricultural good consumed. The second one consists of comparing the actual development process of South Korea with a situation where no agricultural policies are implemented to protect the agricultural sector and reduce its dependency from foreign agricultural imports.

The autarky counterfactual exercise is performed by simulating the closed economy model, in which domestic demand is equal to domestic supply for both goods, and the agricultural relative price is endogenously determined to ensure market clearing. It is important to note that when simulating the closed economy model all the parameters and endogenous variables are kept identical, so that population, employment or productivity growth are not affected by openess to trade. Also, the agricultural production subsidy is not included.

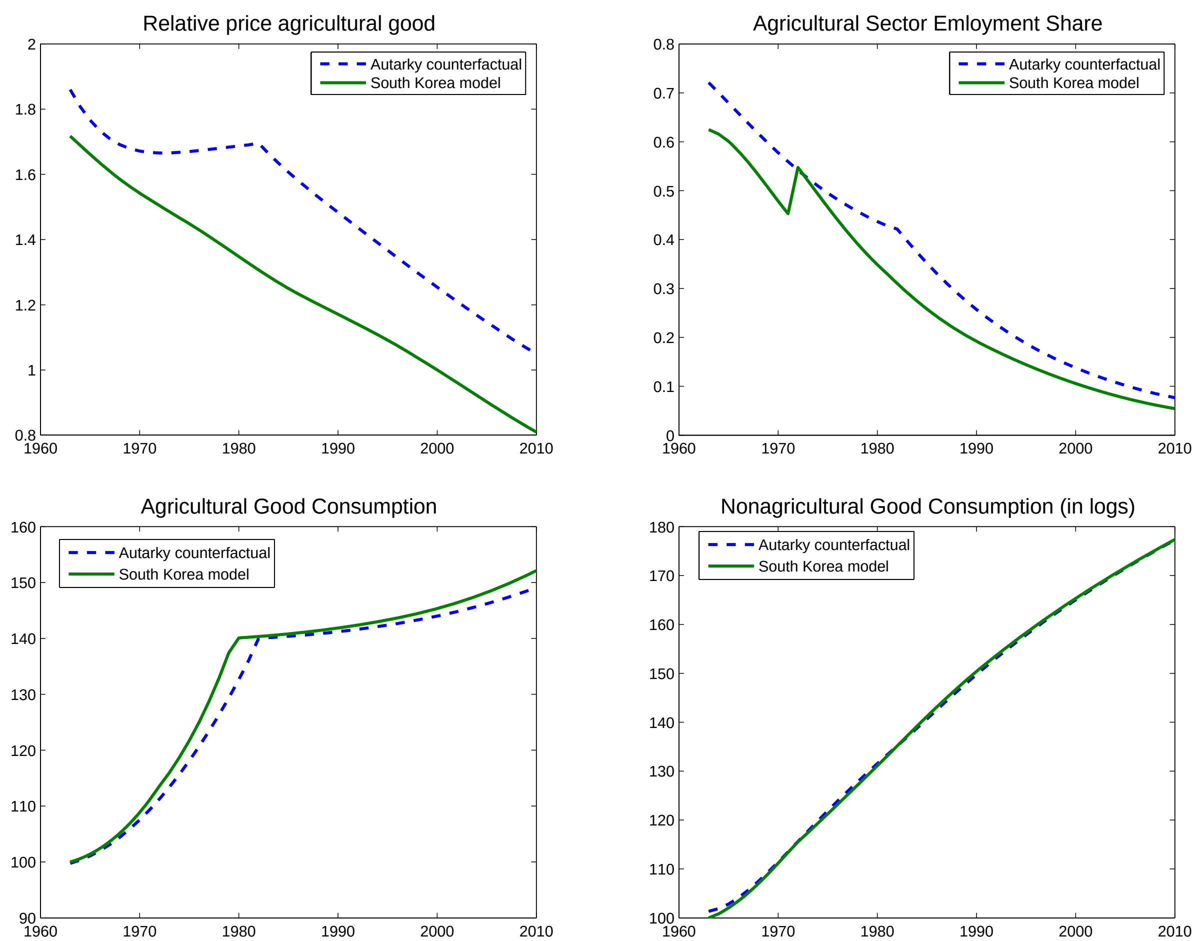
Figure 3 shows how the autarky model simulation compares with the South Korea simulation. It shows that the agricultural relative price would have been significantly larger, the agricultural employment share would have been somewhat larger, the agricultural consumption would have been slightly lower, and the nonagricultural consumption would have been basically the same.

A summary of these results is presented below in table 6. As we can see in the third row, according to this counterfactual exercise, if South Korea had remained under autarky, the agricultural relative price q would have been about 20% larger on average during the sample period 1963-2007 than it actually was, the agricultural employment share s_e would have been 25% on average, the nonagricultural consumption would have been almost the same, and the agricultural consumption would have benn 1.5% lower. In the first column it also shows that the GDP growth would actually have been about 3% larger, probably because of the fact that productivity growth was larger in the agricultural than in the nonagricultural sector, and the agricultural sector would have remained larger under autarky.

Table 7 shows that the gained in intertemporal welfare that South Korea experienced because it was open to international trade is equivalent to a 0.46% increase in the consumption expenditures every year.

The second counterfactual exercise, which I label as Free Trade, aims at predicting what would have been the South Korea development process if there had not been an active agricultural policy trying to protects its agricultural sector by introducing the agricultural production subsidy and the agricultural import tarifss. As explained above, the subsidy used in the South Korea simulation was equal to 0 until 1972, and 13% from 1973 onwards. The agricultural import tariffs were not specified in the South Korea simulation since I was already using data on domestic prices, and I assumed it did not generate any income for the country. What I do here is to choose the average growth in the United States

Figure 3: South Korea Simulation vs Autarky Counterfactual



data rate for the relative agricultural price during the period 1963–2007 -which is equal to -3.7%- with the underlying assumption that the price in the US is the same as in the world markets; then, I choose the level to match the USDA estimate of the implicit tariff rate for 1990, which is equal to 110%. Figure 4 compares the agricultural relative price used in this counterfactual simulation with the one observed in the data, and it shows it has both a lower level and a faster decrease.

Figure 4: Agricultural Relative Price with and without Agricultural Import Tariffs

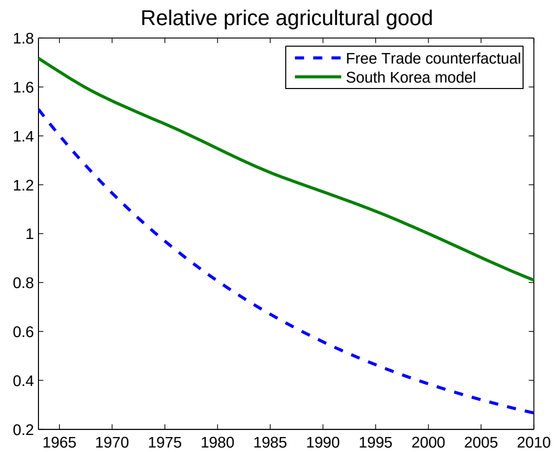
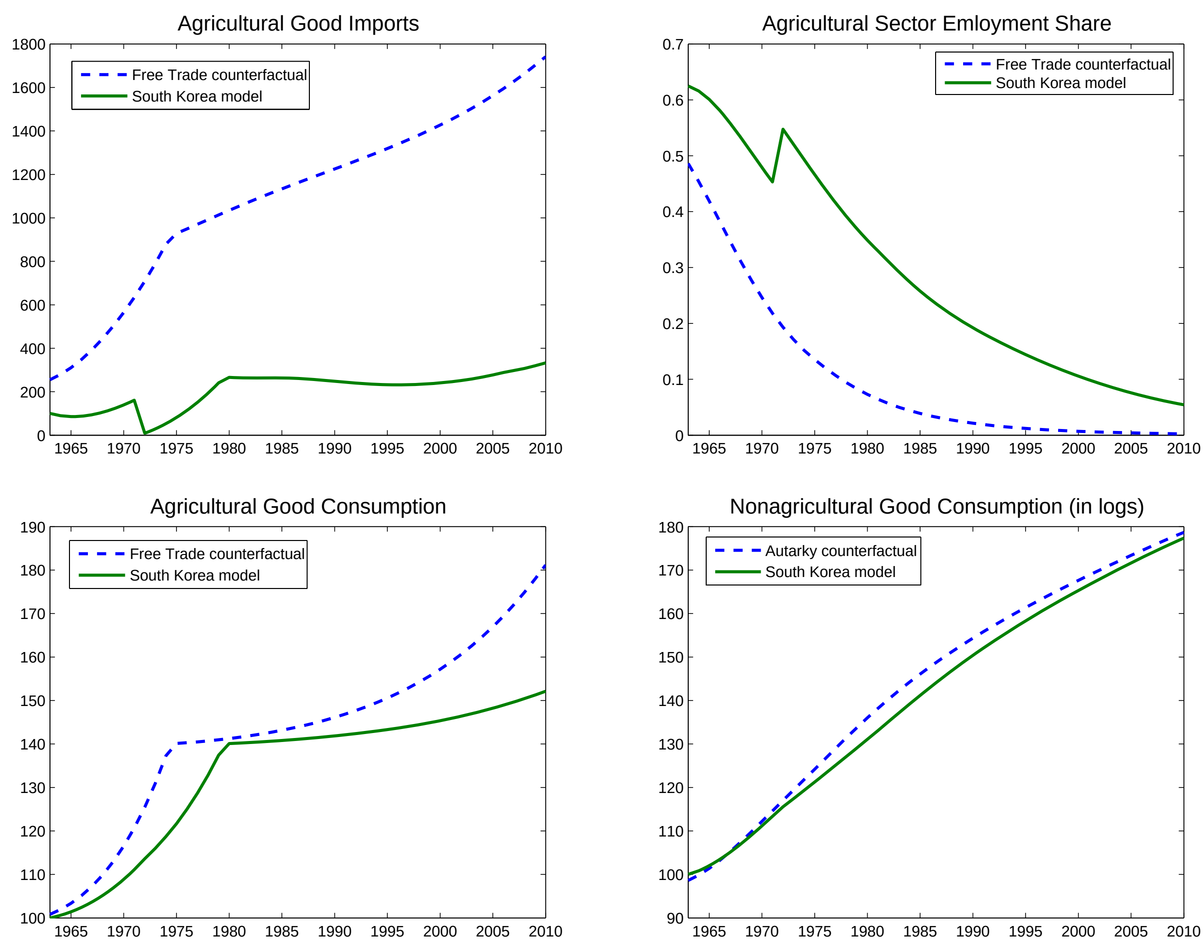


Figure 5 shows the comparison of this counterfactual with respect to the South Korea simulation. The first plot compares the agricultural net imports, second plot compares the agricultural sector employment share, the third plot compares the agricultural consumption per capita, and the fourth one the nonagricultural consumption per capita. They show that South Korea would have had a much higher level of net agricultural imports, a much lower agricultural employment share, a singnificanlty higher agricultural consumption, and a somewhat higher nonagricultural consumption if it had no production subsidies and no import tariffs.

These results are also summarized in table 6.The fourth row shows that if South Korea had not introduced the agricultural production subsidy but had kept the same import tariffs, its agricultural employment share would have been about 20% lower on average during the sample period 1963-2007, the nonagricultural consumption per capita would have been almost the same, and the agricultural consumption per capita would have been 1% larger on average. It also shows that the GDP growth rate would have been quite similar. The fifth row shows that if South Korea had no agricultural production subsidy

Figure 5: South Korea Simulation vs Free Trade Counterfactual



and no agricultural import tariffs, during the sample period 1963-2007,its agricultural relative price would have been 75% lower, its agricultural employment share 76% lower, its nonagricultural consumption 6% higher, and its agricultural consumption 12% larger.

Table 7 shows that if there had been no agricultural production subsidy, the intertemporal welfare gain of the representative consumer with respect to autarky would have been the equivalent of a 0.56% annual increase in the consumption expenditures. If there had been no agricultural production subsidy and no agricultural import tariffs the gain in intertemporal welfare with respect to autarky would have been equivalent to a 6.3% increase in the annual consumption expenditures.

Table 6: Sample Period Results Comparison

	GDP growth (avg)	**q gap (avg)**	**s_e gap (avg)**	**c_n gap (avg)**	**c_a gap (avg)**
Data	5.7%				
SK model	5.8%	0	0	0	0
Autarky	6.1%	21%	25%	0.1%	-1.5%
No subsidy	5.9%	0	-21%	0.1%	1%
No subsidy No import tariff	5.6%	-75%	-76%	6%	12%

Table 7: Intertemporal Welfare Gain with respect to Autarky

Autarky	**Korea model**	**No subsidy**	**Free trade**
0	0.46%	0.56%	6.3%

7 Conclusions

To evaluate the importance of international trade in the structural transformation process of countries, the closed and open economy versions of a neoclassical two-sector growth model are analyzed. In the autarky version of the model, as countries get richer they experience a sectoral reallocation of the production factors from the agricultural sector to the rest of the economy due to the fact the agricultural good has a low income elasticity. International trade may accelerate or slow down this transition process, depending on the relation between the international and the domestic prices.

First, the closed economy version of the model is calibrated to match the structural transformation process in the United States during the period 1890-2007. The exercise shows the importance of productivity growth, both in the nonagricultural and, especially, in the agricultural sector.

Then, the open economy version of the model is calibrated to match the structural transformation of the United Kindom during the period 1801-1901, and of South Korea during the period 1963-2007. In both cases, since the relative price of the agricultural good in the international market was lower than the one they would have faced under autarky, the countries imported agricultural goods during the entire sample period in which they are studied, which suggests that trade may have played some positive role in their transformation processes. The model is then simulated under the assumption that countries were under autarky, to compare the simulation outcomes and quantify the importance of trade in both countries.

In the case of the United Kingdom during the 19th century, the results show that international trade played a very significant role in its industrialization process, as Stokey (2001) showed. In particular, according to the results, if the country had been under autarky, the relative price of the agricultural good would have been between 40 and 60% larger during the sample period, the share of employment in the agricultural sector would have been between 120 and 180% larger, the nonagricultural good consumption would have been 17% lower on average, and the agricultural good consumption would have been 6% lower. The intertemporal welfare gain the United Kingdom experienced from the intersectoral trade with the rest of the world is equivalent to a 6.5% increase in the yearly consumption expenditures.

In the case of South Korea during the last 45 years, the results show that international trade had a negative effect on the agricultural relative price and on the agricultural employment share: the relative price of the agricultural good would have been between 10 and 30% larger if South Korea had been under autarky, and the share of employment in the agricultural sector would have been between 10 and 35 %. Agricultural and nonagricultural consumption, however, would not have been much different during the sample period, and the intertemporal welfare gain South Korea experienced because of international trade is equivalent to less than a 0.5% increase in the yearly consumption expenditures. The conclusion, therefore, is the role actually played by international trade is quite small compared to other factors like total factor productivity in the agricultural and nonagricultural sector,and capital accumulation. Actually, it is interesting to note that the growth rate of the nonagricultural TFP growth rate is only 50% higher than in the United States, and the agricultural TFP growth rate is actually lower. However, the per capita income growth rates South Korea experienced were much higher, probably due to the fact that their starting point was much lower.

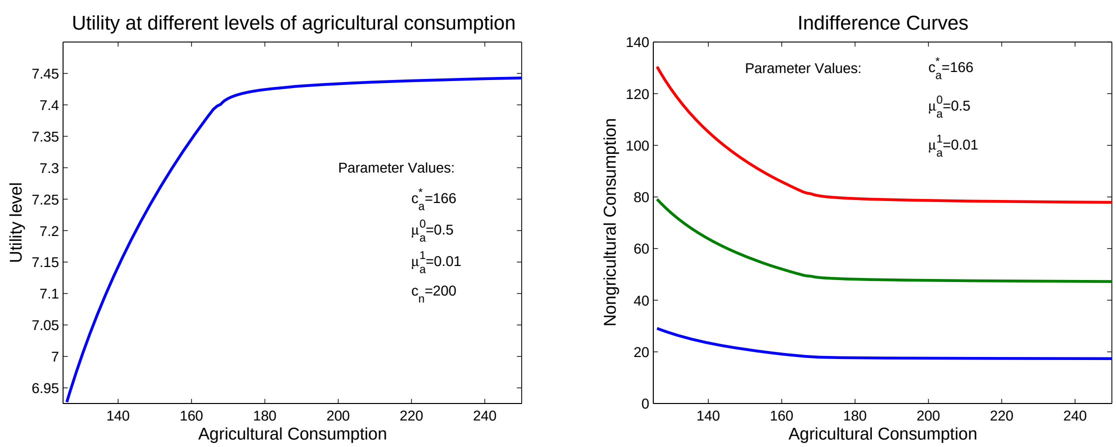
However, it is important to note that South Korea had a very active role in trying to protect its agricultural sector and reduce its dependency from foreign agricultural imports. With that goal, South Korea introduced an agricultural production subsidy in the early 70s, and applied tariffs to the agricultural imports, which actually raised over time. When the model is simulated without the agricultural production subsidy and without the agricultural import tariffs, it shows that international trade could have played a much larger role and the country could have experienced a much faster structural transformation process. In this counterfactual scenario, the gain in intertemporal welfare compared to autarky is equivalent to an increase of 6.3% in the annual consumption expenditures.

Appendices

A Preferences Description

[to be completed]

Figure 6: Graphical Description of Preferences



B Closed Economy Analysis

[to be completed]

Proof Theorem 2. [to be completed]

- when $\underline{c_a} = 0$, imposing that all variables grow at constant rate gives solution shown above.

□

Proof Theorem 4. [to be completed]

- steady state of detrended equilibrium system exists as long as solution to the system of equations (31) - (35) exists.
- show that system exhibits saddle path stability (only one path converges to the steady state), computing eigenvalues and showing one positive and one negative...
- argue that all paths in the phase diagram violate the transversality condition.

□

Proof Theorem 5. [to be completed] The equilibrium system defined in equations (21) - (24), together with the initial condition for k_0 and the transversality condition in equation (6), can be rewritten as shown in equations (58) - (62), together with the initial condition $\widehat{k}_0$ given and equation (63).

$$\dot{\widehat{c_n}}(t) = \widehat{c_n}(t)\left[\alpha_n\left((1-s_k(t))\,\widehat{k}(t)\right)^{\alpha_n-1}(1-s_e(t))^{1-\alpha_n} - \delta - \rho - \frac{1}{1-\alpha_n}\gamma_n\right] \tag{58}$$

$$\dot{\widehat{k}}(t) = \left((1-s_k(t))\,\widehat{k}(t)\right)^{\alpha_n}((1-s_e(t)))^{1-\alpha_n} - \left(\delta + n + \frac{1}{1-\alpha_n}\gamma_n\right)\widehat{k}(t) - \widehat{c_n}(t) \tag{59}$$

$$\widehat{q}(t)\,\alpha_a \frac{(s_e(t))^{\beta_a}}{\left(s_k(t)\,\widehat{k}(t)\right)^{1-\alpha_a}} = \alpha_n \frac{((1-s_e(t)))^{1-\alpha_n}}{\left((1-s_k(t))\,\widehat{k}(t)\right)^{1-\alpha_n}} \tag{60}$$

$$\widehat{q}(t)\,\beta_a \frac{\left(s_k(t)\,\widehat{k}(t)\right)^{\alpha_a}}{(s_e(t))^{1-\beta_a}} = (1-\alpha_n)\frac{\left((1-s_k(t))\,\widehat{k}(t)\right)^{\alpha_n}}{(1-s_e(t))^{\alpha_n}} \tag{61}$$

$$\left(s_k(t)\,\widehat{k}(t)\right)^{\alpha_a}(s_e(t))^{\beta_a} = \begin{cases} z(t)\,\underline{c_a} + \mu_a^0 \frac{\widehat{c_n}(t)}{\widehat{q}(t)} \text{ if } c_a(t) \leq c_a^* \\ z(t)\,c_a^* + \mu_a^1 \frac{\widehat{c_n}(t)}{\widehat{q}(t)}\ c_a(t) > c_a^* \end{cases} \tag{62}$$

$$\text{where } z(t) \equiv \frac{N(t)^{1-\alpha_a-\beta_a}}{A_a(t)\,L^{1-\alpha_a-\beta_a}A_n(t)^{\frac{\alpha_a}{1-\alpha_n}}}$$

$$\lim_{t\to\infty}\left\{e^{-\int_0^t(r(s)-\delta-n)ds}\frac{\widehat{k}(t)}{\widehat{c_n}(t)}\right\} = 0 \tag{63}$$

- if $(1-\alpha_a-\beta_a)\,n < \gamma_a + \frac{\alpha_a}{1-\alpha_n}\gamma_n$, then

$$\lim_{t\to\infty}\left\{\frac{\dot{z}(t)}{z(t)}\right\} = \lim_{t\to\infty}\left\{(1-\alpha_a-\beta_a)\,n < \gamma_a + \frac{\alpha_a}{1-\alpha_n}\gamma_n\right\} = 0$$

  As a result,

$$\lim_{t\to\infty}\left\{z(t)\,\underline{c_a}\right\} = 0$$

  which implies that same asymptotic equilibrium system when $\underline{c_a} > 0$ and when $\underline{c_a} = 0$.

- detrended equilibrium system with $\underline{c_a} > 0$ also exhibits saddle path stability; therefore, only one path converges to the SS.

- any other path different than the one convergins to ss violates transversality condition; therefore, convergent path is the only solution to the detrended equilibrium system.

□

C Open Economy Analysis

Proof Theorem 6. [to be completed]

- From equations (38) and (39), if both goods are produced, then

$$s_k(t) = \frac{\frac{1-\alpha_n}{\alpha_n} s_e(t)}{\frac{\beta}{\alpha_a} + s_e(t)\left(\frac{1-\alpha_n}{\alpha_n} - \frac{\beta}{\alpha_a}\right)} \tag{64}$$

- Also, agents have incentives to allocate production factor in nonagricultural good production if marginal productivity nonagricultural sector larger than marginal productivity agricultural sector when entirely allocated in agricultural production:

$$\lim_{s_e \to 1} \left\{ q(t)\, \alpha_a A_a(t) (K_a(t))^{\alpha_a - 1} (N_a(t))^{\beta_a} (L_a(t))^{1-\alpha_a-\beta_a} \right\} < \lim_{s_e \to 1} \left\{ \alpha_n A_n(t) (K_n(t))^{\alpha_n - 1} (N_n(t))^{1-\alpha_n} \right\}$$

  which is equivalent to equation (36), using equation (64).

- Finally, agents have incentives to allocate production factor in nonagricultural good production if marginal productivity agricultural sector larger than marginal productivity nonagricultural sector when entirely allocated in nonagricultural production:

$$\lim_{s_e \to 0} \left\{ q(t)\, \alpha_a A_a(t) (K_a(t))^{\alpha_a - 1} (N_a(t))^{\beta_a} (L_a(t))^{1-\alpha_a-\beta_a} \right\} > \lim_{s_e \to 0} \left\{ \alpha_n A_n(t) (K_n(t))^{\alpha_n - 1} (N_n(t))^{1-\alpha_n} \right\}$$

  which is equivalent to equation (37) using equation (64).

□

Proof Theorem 8. [to be completed]

- prove that:
  - when $\gamma_q > \frac{1-\alpha_a}{1-\alpha_n}\gamma_n + (1-\alpha_a-\beta_a)\, n - \gamma_a$, it must be that $s_e^{ss} = 1$: contradiction with $0 < s_e^{ss} < 1$, contradiction with $s_e^{ss} = 0$.
    * $\gamma_q > \frac{1-\alpha_a}{1-\alpha_n}\gamma_n + (1-\alpha_a-\beta_a)\, n - \gamma_a$ implies that $\frac{q(t)}{\frac{A_n(t)^{(1-\alpha_a)/(1-\alpha_n)}}{A_a(t)\left(\frac{L}{N(t)}\right)^{1-\alpha_a-\beta_a}}}$ growing over time.

* as a result, there is no constant s_e^{ss} satisfying

$$\frac{q(t)}{\frac{A_n(t)^{(1-\alpha_a)/(1-\alpha_n)}}{A_a(t)\left(\frac{L}{N(t)}\right)^{1-\alpha_a-\beta_a}}}\alpha_a\frac{(s_e^{ss})^{\beta_a}L^{1-\alpha_a-\beta_a}}{\left(s_k^{ss}\widehat{k}^{ss}\right)^{1-\alpha_a}}=\alpha_n\frac{(1-s_e^{ss})^{1-\alpha_n}}{\left(\left(1-s_k^{ss}\right)\widehat{k}^{ss}\right)^{1-\alpha_n}}$$

which implies that either $s_e^{ss}=0$ or $s_e^{ss}=1$.

* also,

$$\frac{q(t)}{\frac{A_n(t)^{(1-\alpha_a)/(1-\alpha_n)}}{A_a(t)\left(\frac{L}{N(t)}\right)^{1-\alpha_a-\beta_a}}}\alpha_a\left(\widehat{k}^{ss}\right)^{\alpha_a-1}\left[\lim_{s_e\to 0}\left\{{s_e}^{\alpha_a+\beta_a-1}\right\}\right]>\alpha_n\left(\frac{\frac{1-\alpha_n}{\alpha_n}}{\frac{\beta}{\alpha_a}}\right)^{-\alpha_a}\left(\widehat{k}^{ss}\right)^{\alpha_n-1}$$

which implies that $s_e^{ss}>0$.

* Hence, $s_e^{ss}=1$.

– when $\gamma_q<\frac{1-\alpha_a}{1-\alpha_n}\gamma_n+(1-\alpha_a-\beta_a)\,n-\gamma_a$, it must be that $s_e^{ss}=1$: contradiction with $0<s_e^{ss}<1$, contradiction with $s_e^{ss}=0$.

* $\gamma_q<\frac{1-\alpha_a}{1-\alpha_n}\gamma_n+(1-\alpha_a-\beta_a)\,n-\gamma_a$ implies that $\frac{q(t)}{\frac{A_n(t)^{(1-\alpha_a)/(1-\alpha_n)}}{A_a(t)\left(\frac{1}{N(t)}\right)^{1-\alpha_a-\beta_a}}}$ decreasing over time.

* as a result, there is no constant s_e^{ss} satisfying

$$\frac{q(t)}{\frac{A_n(t)^{(1-\alpha_a)/(1-\alpha_n)}}{A_a(t)\left(\frac{L}{N(t)}\right)^{1-\alpha_a-\beta_a}}}\alpha_a\frac{(s_e^{ss})^{\beta_a}L^{1-\alpha_a-\beta_a}}{\left(s_k^{ss}\widehat{k}^{ss}\right)^{1-\alpha_a}}=\alpha_n\frac{(1-s_e^{ss})^{1-\alpha_n}}{\left(\left(1-s_k^{ss}\right)\widehat{k}^{ss}\right)^{1-\alpha_n}}$$

which implies that either $s_e^{ss}=0$ or $s_e^{ss}=1$.

* also,

$$\frac{q(t)}{\frac{A_n(t)^{(1-\alpha_a)/(1-\alpha_n)}}{A_a(t)\left(\frac{L}{N(t)}\right)^{1-\alpha_a-\beta_a}}}\alpha_a\left(\widehat{k}^{ss}\right)^{\alpha_a-1}<\alpha_n\left(\widehat{k}^{ss}\right)^{\alpha_n-1}\left(\frac{\frac{1-\alpha_n}{\alpha_n}}{\frac{\beta}{\alpha_a}}\right)^{1-\alpha_n}$$

which implies that $s_e^{ss}<1$.

* Hence, $s_e^{ss}=0$.

□

Proof Theorem 9. [to be completed]

- prove that when $\underline{c_a} = 0$, imposing that all variables grow at constant rate in the system of equations (45) - (48) gives solution shown above: (see page 6f hand-written notes)
  - from equation (**??**), in BGP, $\frac{\dot{c_n(t)}}{c_n(t)} = \frac{\dot{k(t)}}{k(t)}$ and $\frac{\dot{x_n(t)}}{x_n(t)} = \frac{\dot{k(t)}}{k(t)}$; also, if $s_e^{ss} < 1$, $\frac{\dot{k(t)}}{k(t)} = \frac{1}{1-\alpha_n}\gamma_n$.
  - from equation (25), if $s_e^{ss} > 0$, $\gamma_q + \gamma_a + (\alpha_a - 1)\frac{\dot{k(t)}}{k(t)} - (1-\alpha_a-\beta_a)\,n = 0$, which implies that $\frac{\dot{k(t)}}{k(t)} = \frac{1}{1-\alpha_a}\left(\gamma_q + \gamma_a - (1-\alpha_a-\beta_a)\,n\right)$
  - hence, in order for $0 < s_e^{ss} < 1$, it must be that $\gamma_q = \frac{1-\alpha_a}{1-\alpha_n}\gamma_n + (1-\alpha_a-\beta_a)\,n - \gamma_a$.

□

Proof Theorem 11. [to be completed] The equilibrium system defined in equations (45) - (48) can be rewritten in terms of the detrended variables $\widehat{k}(t)$, $\widehat{c_n}(t)$, and $\widehat{x_n}(t)$, as shown in the equations below. If the country is not specialized and both goods are produced, then the detrended equilibrium system consists of equations (65) - (69). If only the agricultural good is produced, the detrended equilibrium system consists of equations (65), (66), and (70) together with equations $s_e(t) = s_k(t) = 1$.

$$\dot{\widehat{c_n}}(t) = \begin{cases} \widehat{c_n}(t)\left[\alpha_n\left((1-s_k(t))\,\widehat{k}(t)\right)^{\alpha_n-1}(1-s_e(t))^{1-\alpha_n} - \delta - \rho - \frac{1}{1-\alpha_n}\gamma_n\right] & \text{if } s_e^{ss} < 1 \\ \widehat{c_n}(t)\left[\begin{array}{c} \alpha_a\left(s_k(t)\,\widehat{k}(t)\right)^{\alpha_a-1} s_e(t)^{\beta_a}\left(\frac{L}{N(t)}\right)^{1-\alpha_a-\beta_a} - \delta - \rho \\ -\frac{1}{1-\alpha_a}\gamma_a - \frac{1}{1-\alpha_a}\gamma_q - \frac{1-\alpha_a-\beta_a}{1-\alpha_a}n \end{array}\right] & \text{if } s_e^{ss} = 1 \end{cases} \tag{65}$$

$$\dot{\widehat{k}}(t) = \begin{cases} \left((1-s_k(t))\,\widehat{k}(t)\right)^{\alpha_n}(1-s_e(t))^{1-\alpha_n} - \widehat{c_n}(t) - \widehat{x_n}(t) - \left(\delta + n + \frac{1}{1-\alpha_n}\gamma_n\right)\widehat{k}(t) & \text{if } s_e^{ss} < 1 \\ \left[\begin{array}{c} \left((1-s_k(t))\,\widehat{k}(t)\right)^{\alpha_n}(1-s_e(t))^{1-\alpha_n} - \widehat{c_n}(t) - \widehat{x_n}(t) \\ -\left(\delta + n + \frac{1}{1-\alpha_a}\gamma_a + \frac{1}{1-\alpha_a}\gamma_q + \frac{1-\alpha_a-\beta_a}{1-\alpha_a}n\right)\widehat{k}(t) - \widehat{c_n}(t) - \widehat{x_n}(t) \end{array}\right] & \text{if } s_e^{ss} = 1 \end{cases} \tag{66}$$

$$\left(s_k(t)\widehat{k}(t)\right)^{\alpha_a}(s_e(t))^{\beta_a} = \begin{cases} \left[\begin{array}{c} \left(\mu_a^0\widehat{c_n}(t) - \widehat{x_n}(t)\right)\left(\dfrac{q(t)}{\frac{A_n(t)^{(1-\alpha_a)/(1-\alpha_n)}}{A_a(t)\left(\frac{1}{N(t)}\right)^{1-\alpha_a-\beta_a}}}\right)^{-1} \\ + \underbrace{\left(\dfrac{(N(t))^{1-\alpha_a-\beta_a}}{A_a(t)(A_n(t))^{\frac{\alpha_a}{1-\alpha_n}}}\right)}_{\equiv z^1(t)}\underline{c_a} \end{array}\right] & \text{if } c_a(t) \leq c_a^* \\ \left(\mu_a^1\widehat{c_n}(t) - \widehat{x_n}(t)\right)\left(\dfrac{q(t)}{\frac{A_n(t)^{(1-\alpha_a)/(1-\alpha_n)}}{A_a(t)\left(\frac{1}{N(t)}\right)^{1-\alpha_a-\beta_a}}}\right)^{-1} + \underbrace{\left(\dfrac{(N(t))^{1-\alpha_a-\beta_a}}{A_a(t)(A_n(t))^{\frac{\alpha_a}{1-\alpha_n}}}\right)}_{\equiv z^1(t)}c_a^* & \text{else} \end{cases} \tag{67}$$

$$\frac{q(t)}{\frac{A_n(t)^{(1-\alpha_a)/(1-\alpha_n)}}{A_a(t)\left(\frac{1}{N(t)}\right)^{1-\alpha_a-\beta_a}}}\alpha_a\frac{(s_e(t))^{\beta_a}L^{1-\alpha_a-\beta_a}}{\left(s_k(t)\widehat{k}(t)\right)^{1-\alpha_a}} = \alpha_n\frac{((1-s_e(t)))^{1-\alpha_n}}{\left((1-s_k(t))\widehat{k}(t)\right)^{1-\alpha_n}} \tag{68}$$

$$\frac{q(t)}{\frac{A_n(t)^{(1-\alpha_a)/(1-\alpha_n)}}{A_a(t)\left(\frac{1}{N(t)}\right)^{1-\alpha_a-\beta_a}}}\beta_a\frac{\left(s_k(t)\widehat{k}(t)\right)^{\alpha_a}L^{1-\alpha_a-\beta_a}}{(s_e(t))^{1-\beta_a}} = (1-\alpha_n)\frac{\left((1-s_k(t))\widehat{k}(t)\right)^{\alpha_n}}{(1-s_e(t))^{\alpha_n}} \tag{69}$$

$$\left(s_k(t)\widehat{k}(t)\right)^{\alpha_a}(s_e(t))^{\beta_a} = \begin{cases} \left(\mu_a^0\widehat{c_n}(t) - \widehat{x_n}(t)\right) + \underbrace{\left(\dfrac{(N(t))^{1-\alpha_a-\beta_a}}{(q(t))^{\alpha_a}(A_a(t))}\right)^{\frac{1}{1-\alpha_a}}}_{\equiv z^2(t)}\underline{c_a} & \text{if } c_a(t) \leq c_a^* \\ \left(\mu_a^1\widehat{c_n}(t) - \widehat{x_n}(t)\right) + \underbrace{\left(\dfrac{(N(t))^{1-\alpha_a-\beta_a}}{(q(t))^{\alpha_a}(A_a(t))}\right)^{\frac{1}{1-\alpha_a}}}_{\equiv z^2(t)}c_a^* & \text{if } c_a(t) > c_a^* \end{cases} \tag{70}$$

□

Proof Theorem 12. [to be completed]

- steady state of detrended equilibrium system exists as long as there exists solution to the system of equations defining steady state.
- show that system exhibits saddle path stability (only one path converges to the steady state), computing eigenvalues and showing one positive and one negative...

- argue that all paths in the phase diagram violate the transversality condition.

□

Proof Theorem 13. [to be completed]

- if $0 < s_e(t) < 1$
  - $(1-\alpha_a-\beta_a)\, n < \gamma_a + \frac{\alpha_a}{1-\alpha_n}\gamma_n$ implies
  $$\lim_{t\to\infty}\left\{\frac{\dot{z}^1(t)}{z^1(t)}\right\} = \lim_{t\to\infty}\left\{(1-\alpha_a-\beta_a)\, n < \gamma_a + \frac{\alpha_a}{1-\alpha_n}\gamma_n\right\} = 0$$
  As a result,
  $$\lim_{t\to\infty}\left\{z^1(t)\,\underline{c_a}\right\} = 0$$
  which implies that same asymptotic equilibrium system when $\underline{c_a} > 0$ and when $\underline{c_a} = 0$.
  - detrended equilibrium system with $\underline{c_a} > 0$ also exhibits saddle path stability; therefore, only one path converges to the SS.
  - any other path different than the one converging to SS violates transversality condition; therefore, convergent path is the only solution to the detrended equilibrium system.
- if $s_e(t) = 1$,
  - $(1-\alpha_a-\beta_a)\, n < \gamma_a+\frac{\alpha_a}{1-\alpha_n}\gamma_n$ together with $\gamma_q < \frac{1-\alpha_a}{1-\alpha_n}\gamma_n+(1-\alpha_a-\beta_a)\, n-\gamma_a$ implies that $\alpha_a\gamma_q+\gamma_a > (1-\alpha_a-\beta_a)\, n$; as a result
  $$\lim_{t\to\infty}\left\{z^2(t)\,\underline{c_a}\right\} = 0$$
  which implies that same asymptotic equilibrium system when $\underline{c_a} > 0$ and when $\underline{c_a} = 0$.
- If $s_e(t) = 0$,
  - $(1-\alpha_a-\beta_a)\, n < \gamma_a+\frac{\alpha_a}{1-\alpha_n}\gamma_n$ together with $\gamma_q > \frac{1-\alpha_a}{1-\alpha_n}\gamma_n+(1-\alpha_a-\beta_a)\, n-\gamma_a$ implies that $\gamma_q < \frac{1}{1-\alpha_n}n$; as a result
  $$\lim_{t\to\infty}\left\{z^3(t)\,\underline{c_a}\right\} = 0$$
  which implies that same asymptotic equilibrium system when $\underline{c_a} > 0$ and when $\underline{c_a} = 0$.

□

D United States Exogenous Variables and Data Sources

This appendix describes the construction and data sources of the exogenous variables used in the United States simulations. The exogenous variables used in the simulations are total population, total employment, agricultural TFP and nonagricultural TFP. The data sources for other time series used to evaluate the fit of the model with the actual data are also explained. The information is summarized in table 8.

Table 8: Sources United States Data

Variable	**Description**	**Period**	**Source**
N	Total Population	1890-2007	Maddison (2005)
E	Total Employment	1890-1928 1929 - 2007	J.W. Kendrick (1961) National Income and Product Accounts
Y, Y_a	Real GDP by Sector	1890-1928 1929 - 2007	J.W. Kendrick (1961) National Income and Product Accounts
PY	Nominal GDP	1890-1928 1929 - 2007	J.W. Kendrick (1961) National Income and Product Accounts
P_aY_a	Agriculture Nominal GDP	1890:10:1900 1929 - 2007	Historical Statistics of the United States National Income and Product Accounts
N_a, N_n	Employment by Sector	1890 - 1928 1929 - 2007	J.W. Kendrick (1961) National Income and Product Accounts
K, K_a	Real Net Capital Stock by Sector	1890 - 1928 1929 - 2007	J.W. Kendrick (1961) National Income and Product Accounts

Data on total population for the entire sample period 1890-2007 is available in Maddison (2005). Data on total employment is available in Kendrick (1961) for the subperiod 1890-1928, and in the National Income and Product Accounts[20] for the subperiod 1929-2007.

Measures for agricultural and nonagricultural Total Factor Productivity are obtained using the production functions defined in equations (7) and (8),together with data on sectoral real GDP, sectoral employment and sectoral real capital.

Data on real GDP by sector also comes from these two different sources: for the period 1890-1928 data on constant dollars gross value added is available in Kendrick (1961) for both the farm sector and the aggregate economy, and for the period 1929-2007 data on chained dollars gross value added is also available for both the farm sector and the aggregate economy in the National Income and Product Accounts.

Data on gross value added in current prices is available in Kendrick (1961) for the subperiod 1890-1928, and in the National Income and Product Accounts for the subperiod 1929-2007. Data on farm sector gross value added in current prices is available in the

[20] http://www.bea.gov.

Historical Statistics of the United States[21] for the years 1890 and 1900, and in the National Income and Product Accounts for the subperiod 1929-2007.

Data on total employment and farm sector employment is available in Kendrick (1961) for the subperiod 1890-1928, and in the National Income and Product Accounts for the subperiod 1929-2007.

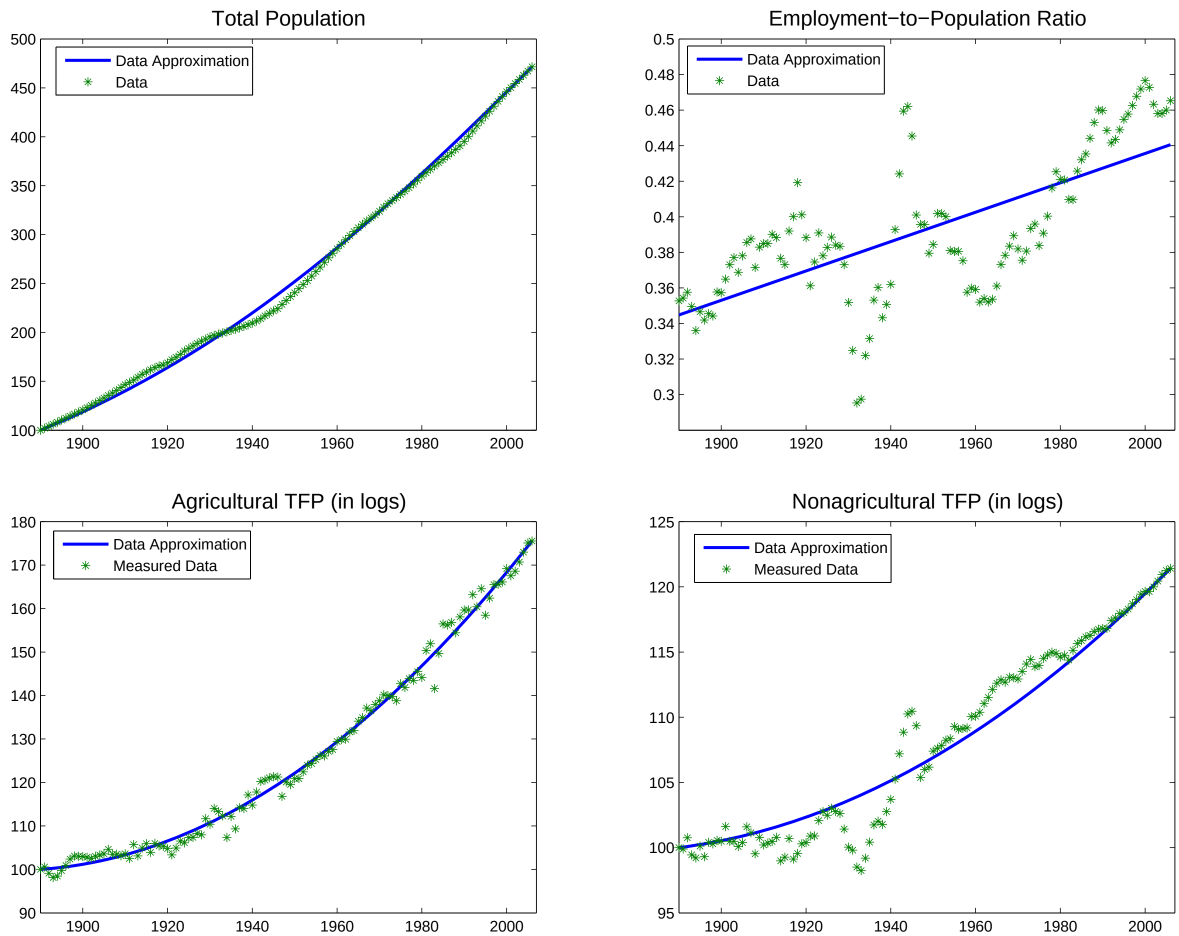
Finally, the data used for the aggregate capital stock for the period 1890-1928 is the Real Capital Stock Domestic Economy series minus Farm, Forest and Park Land series, minus Monetary Gold and Silver, and minus Residential Capital Stock in Kendrick (1961). This corresponds to the sum of Structures, Equipment, and Inventories. The data used for aggregate capital stock for the period 1929-2007 is the Chain-Type Quantity Indexes for Net Stock of total fixed series assets minus the Chain-Type Quantity Indexes for Net Stock of private residential assets series, minus the Chain-Type Quantity Indexes for Net Stock of government residential assets in the National Income and Product Accountes. The data used for the agricultural sector capital stock for the period 1890-1928 is the Real Capital Stock Farm Economy series minus Farm Land[22] from Kendrick (1961), and for the period 1929-2007 is the series Chain-Type Quantity Indexes for Net Stock of Private Farms Fixed Assets from the National Income and Product Accounts[23].

[21] Historical Statistics of the United States, Millennial Edition Online.

[22] Farm land data is not available for all the years of the 1890-1928 period in Kendrick (1961), but it is estimated to be 92% of Farm, Forest and Park land data series.

[23] Note that the data capital stock data from Kendrick (1961) includes inventories, while the data from the National Income and Product Accounts only includes fixed assets. This is probably not a big problem for the aggregate capital stock, but it may make a significant differnce in the agricultural capital stock. As a result, the capital stock data by sector may not be completely compatible, which is one of the reasons why it is not used to measure sectoral TFP.

Figure 7: Exogenous Variables United Sates Data



E South Korea Exogenous Variables and Data Sources

This appendix describes the construction and data sources of the exogenous variables used in the open economy model simulations. The exogenous variables used in the simulations are total population, total employment, agricultural relative price, agricultural TFP and nonagricultural TFP. The data sources for other time series used to compare the fit of the model with the actual data are also explained. The information is summarized in table 9.

Table 9: Sources South Korea Data

Variable	Variable description	Period	Source
N	Total Population	1950 - 1970 1960 - 2007	Statistical Yearbooks Bank of Korea
E	Total Employment	1957 - 1970 1963 - 2007	Statistical Yearbooks Korea Statistical Information
P_aY_a, P_nY_n	Nominal GDP by industry	1953 - 2007	Bank of Korea
Y_a, Y_n	Real GDP by industry	1953 - 2007	Bank of Korea
N_a, N_n	Employment by industry	1963 - 2007	Korea Statistical Information Service
P_ax_a	Agricultural net exports	1960 - 2003 (various years)	Statistical Yearbooks Bank of Korea
K	Real net capital stock	1963 - 1995	Korea Development Institute

Data on total population is available from 1960 onwards from the Korean Statistical Information Service[24], and it is available from 1944 to 1966 in the Economic Statistics Yearbook 1970 (Bank of Korea).

Data on total employment is available from 1963 onwards from the Korean Statistical Information Service, and it is available from 1957 in the Statistical Yearbook of the Republic of Korea, year 1960.

Data on the relative price of the agricultural good is not directly available. The way I construct it is by dividing the agricultural sector GDP deflator by the GDP deflator of the rest of the economy, where the sectoral GDP deflator is obtained by dividing nominal GDP data by real GDP data for each sector. Data on current and constant pricesl GDP by industry is available from the Economic Statistics System of the Bank of Korea[25] starting at 1953. Agricultural sector sector production is Agriculture, Forestry and Fishing GDP, and nonagricultural sector production is total GDP minus the agricultural sector GDP.

Data on agricultural and nonagricultural Total Factor Productivity is obviously not directly available either. Using the production functions defined in equations (7) and (8), one can infer the sectoral TFPs with data on sectoral real GDP, sectoral employment and

[24] http://www.kosis.kr/eng/index.htm
[25] http://ecos.bok.or.kr/EIndex_en.jsp

sectoral real capital[26]:

$$A_a = \frac{Y_a}{(K_a)^{a_a} (N_a)^{\beta_a}}$$

$$A_n = \frac{Y_n}{(K_n)^{\alpha_n} (N_n)^{1-\alpha_n}}$$

Real GDP data for each sector is available from the Economic Statistics System of the Bank of Korea from 1953 onwards, as just explained.

Data on total employment and employment in Agricultura, Forestry and Fishing is available from the Korean Statistical Information Service from 1963 onwards. For the period 1957-1960 employment data is available in the Statistical Yearbook of the Republic of Korea, year 1961. Data for aggregate physical capital is obtained from Kim and Hong (1997, Korea Development Institute) for the period 1962-1995.

The capital time series used is the sum of the Net Fixed Capital Stock of Nonresidential Business at 1990 constant prices plus Total Inventories for Nonresidential Business at 1990 Constant Prices[27]. Capital stocks for the agricultural and the nonagricultural sector are also available from the same publication, but instead of using them I created alternative series assuming that both employment and capital are efficiently allocated across sectors.

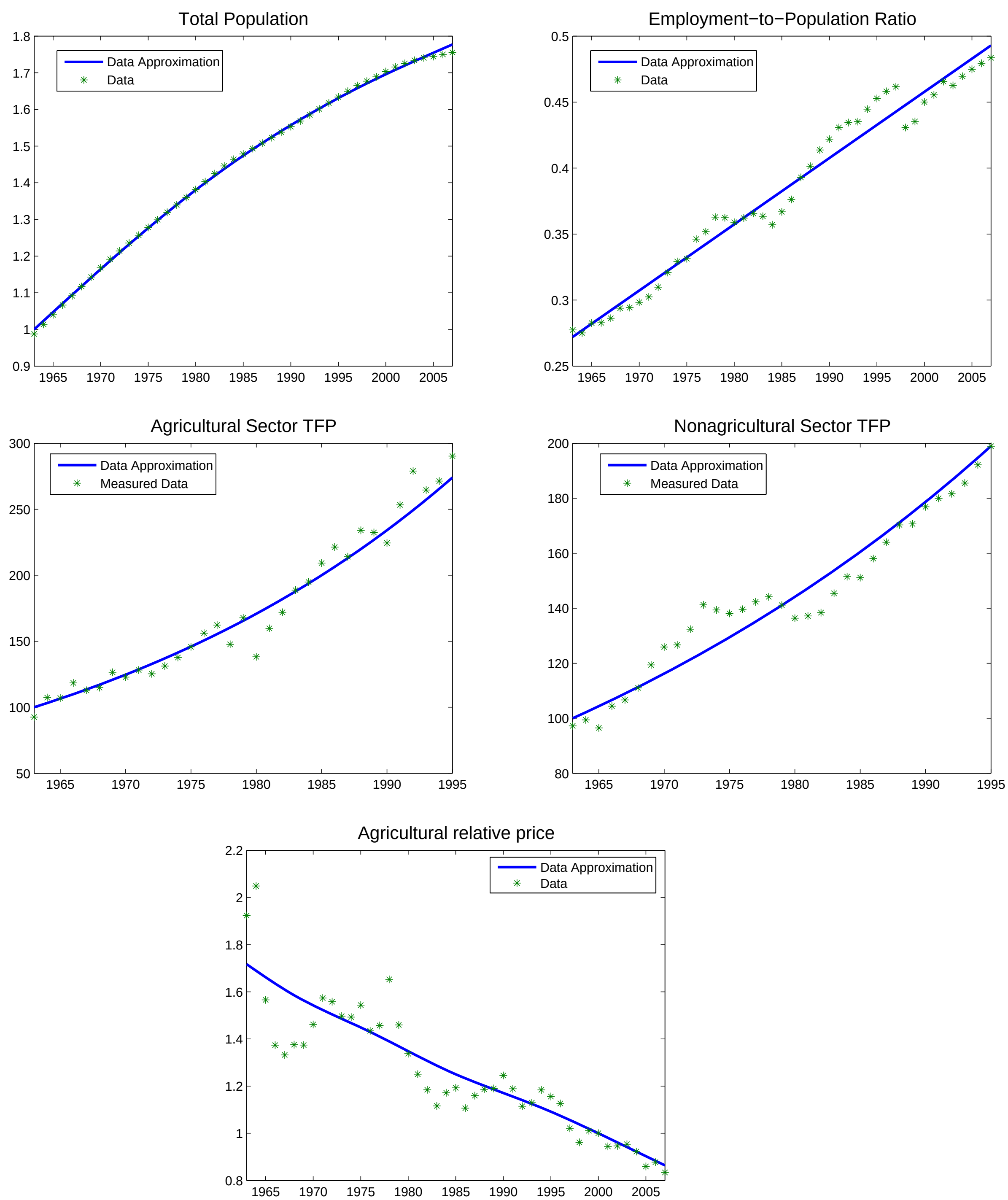
As explained above, however, the simulations do not use the sectoral TFPs measured this way, but an alternative ones with constant growth in both sectors (0.0315 in the agricultural sector, and 0.0215 in the nonagricultural sector). As figures **??** and **??** show, the measured TFPs growth are quite similar to the ones used in the simulations.

Finally, data on net agricultural exports is needed to compute agricultural consumption (which is defined as the sum of the domestic production plus the net agricultural exports). Data on net agricultural exports is obtained from the Input-Output tables published in the Economic Statistics System of the Bank of Korea for many years between 1970 and 2003. Data for the years 1960, 1963 and 1968 is form the Input-Output tables published in the Economic Statistics Yearbook of the Bank of Korea (years 1965, 1966, 1970). Agricultural net exports are defined here as the net exports of crops, livestock breeding, forestry products, and fishery products.

[26]Note that the the measured agricultural TFP in this case corresponds the agricultural TFP defined in equation (7) times total land to the power of $(1 - \alpha_a - \beta_a)$, but this is not a problem because total land is assumed to be constant.

[27]See pages 166 and 168 of the Korea Development Institute (1997) publication.

Figure 8: Exogenous Variables South Korea Data



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