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The Role of Agricultural Productivity on Structural Change

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Abstract

Many authors have estimated and found that the productivity growth in agriculture is higher than that in non-agriculture in today's richest countries. Several papers suggested that growth in agricultural productivity was essential for today's richest countries to take off early. However, few articles noticed that growth in agricultural productivity is critical in driving structural change in today's richest countries. This paper studies a two-sector neoclassical growth model with subsistence agricultural consumption and shows that growth in agricultural productivity plays a more important role than growth in non-agricultural productivity in governing massive structural change in today's richest countries.

1. Introduction

Since the onset of the industrial revolution, the world's richest countries have experienced tremendous structural change with income per capita roughly 35 times greater than the world's poorest countries. Recent work argued that the proximate cause of this disparity is that today's richest countries took off early (Lucas, 2000). After take-off, these richest countries underwent a process of structural change by which labor was gradually reallocated from agriculture to non-agriculture with agriculture eventually accounting for a negligible share.[1] Variations in productivity performance between sectors are contended to be important for structural change.[2]

Many authors have estimated the total factor productivity (TFP) growth and found that the productivity growth in agriculture was higher than that in non-agriculture in today's richest countries.[3] Moreover, several papers showed that growth in agricultural productivity was essential for today's richest countries to take off early (Timmer, 1988; Gollin et al., 2002, 2007).[4] However, few noticed that growth in agricultural productivity is critical in governing structural change in today's richest countries. This paper shows that growth in agricultural productivity is more important than growth in non-agricultural productivity in driving structural change.

Our viewpoint is shown in an otherwise standard two-sector neoclassical growth model extended to include subsistence agricultural consumption. The benchmark model comprises non-agricultural and agricultural sectors, and capital and labor are used in both sectors. Non-agricultural output is used for consumption and investment, and agricultural output is used for consumption. There is subsistence agricultural consumption, so the consumption path is tilted towards non-agriculture as the economy grows. With a more capital-intensive non-agricultural sector, in order to sustain this

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shift in the consumption pattern it is necessary to allocate more capital and hence more labor to the non-agricultural sector, owing to the complementarity between capital and labor. We investigate the effects of sectoral productivity growth on such factor reallocation across sectors.

Our main findings are as follows. First, in the long run, productivity growth in agriculture and non-agriculture both increase non-agricultural capital and employment and decrease agricultural employment. Growth in agricultural productivity decreases agricultural capital, but growth in non-agricultural productivity may increase or decrease agricultural capital. As growth in agricultural productivity decreases agricultural capital, through the complementarity between capital and labor, it eventually causes a negligible agricultural share of employment as experienced by today's richest countries. However, because growth in non-agricultural productivity may increase agricultural capital, it cannot lead to a negligible agricultural share of employment.

Next, we explore the effects of growth in sectoral productivity progress on structural change. We use a quantitative method and choose the USA to represent today's richest countries. We envisage which sectoral technological progress can generate structural change that matches with the actual change observed in the USA over the period 1820–2011. Our estimates indicate that the average rate of the TFP growth in the agricultural sector is slightly higher than that in the non-agricultural sector over this period, which is consistent with the estimates calculated by Jorgenson and Gollop (1992) over the period 1947–1985. By applying the data of sectoral technological progress, if the model has no capital or the agricultural sector does not use capital, we find that neither growth in agricultural productivity nor growth in non-agricultural productivity can generate structural change that fits the long-term data in the USA. If both sectors use capital, then growth in agricultural productivity can generate structural change that matches reasonably well with the data, but growth in non-agricultural productivity generates structural change that deviates far from the data. Thus, the productivity growth in agriculture plays a more important role than that in non-agriculture on structural change. Intuitively, the complementarity between capital and labor creates a "hold-up" effect to postpone the labor reallocation from the agricultural sector to the non-agricultural sector in the process of structural change. Such an effect does not prevail in a model where capital is not used in the agricultural sector. As a result, the structural change generated by the model with capital in both sectors matches with the slow change in the data, by comparison, reasonably better than that generated by the model without capital or without capital in agriculture.

Our paper is related to recent studies of structural change which investigated the connections between productivity growth and uneven growth. Two competing approaches have been put forward for structural change. The first approach is based on differential productivity changes among sectors; see, e.g. Baumol (1967), Ngai and Pissarides (2007) and Acemoglu and Guerrieri (2008).[5] The second approach is a utility-based explanation rooted in non-homothetic preferences resulted from the presence of subsistence agricultural consumption; see, e.g. Echevarria (1997), Laitner (2000), Kongsamut et al. (2001) and Gollin et al. (2004).[6] Our model includes differential productivity changes and subsistence agricultural consumption and may be thought of as an integration of these two approaches.

Our paper is particularly close to Ngai and Pissarides (2007) and Gollin et al. (2002, 2007). First, our results lend support to Ngai and Pissarides (2007) in that the agricultural sector has a higher growth rate of productivity but it eventually loses the employment share in the course of structural change. However, without subsistence agricultural consumption, Ngai and Pissarides (2007) obtain the results only when the elasticity of substitution between consumption is smaller than one. By contrast, with subsistence agricultural consumption, we obtain the results even if the elasticity of substitution equals one like that in the common Cobb–Douglas utility function.[7] Next, our results corroborate Gollin et al. (2002, 2007) in that agricultural productivity growth is important for economic development. However, in Gollin et al. (2002, 2007), agricultural technology progress determines when an economy takes off. If the economy has taken off, agricultural technology plays no role, and structural change is driven entirely by non-agricultural technology progress. By contrast, because capital is used in both sectors in our model, agricultural technology progress plays an important role on long-term and massive structural change.[8]

A roadmap is as follows. In section 2, we set up an otherwise standard two-sector growth model with non-homothetic preferences. Then, we study the optimization problems, analyze the equilibrium and carry out the comparative-static exercises of sectoral technological progress. In section 3, we investigate the effects of sectoral productivity growth on structural transformation. Finally, concluding remarks are offered in section 4.

2. The Model

We consider an economy with two sectors: the agriculture and the non-agriculture sectors. Following conventional wisdom, we associate the non-agricultural sector with the full range of activities in manufacturing and services. The subscript a refers to agriculture variables and m refers to non-agriculture variables. Both goods are consumable, but only non-agricultural goods can be used to accumulate capital.

Production

The two goods are produced using capital and labor as input. Following existing literature, the Cobb–Douglas technology is used and given as follows.

$$y_{i,t} = A_{i,t} k_{i,t}^{\alpha_i} l_{i,t}^{1-\alpha_i}, \quad i = a, m, \tag{1}$$

where $k_{i,t}$ and $l_{i,t}$ are, respectively, the capital and labor used in sector i, and $A_{i,t}$ is an exogenous, sector-i specific technology parameter in period t. Parameter $\alpha_i \in (0, 1)$ is the share of capital in sector i. We assume the agricultural sector is less capital-intensive than the non-agricultural sector, i.e. $\alpha_m > \alpha_a$, as in Caselli and Coleman (2001) and Gollin et al. (2004, 2007). Both the goods market and the factor market are competitive. Using agriculture as a numeraire, the price of non-agriculture, the wage rate and the capital rental rate are denoted as p, w and r, respectively.

Our choice of using the Cobb–Douglas sectoral production functions is in line with the existing studies including capital on structural transformation. Yet, there is one restriction in that there is no difference in the elasticity of substitution between capital and labor across sectors. Recently, economists have documented the decline of the labor income share in the USA and other countries. Alvarez-Cuadrado et al. (2014) have found that differences in the elasticity of substitution between capital and labor across sectors are critical for understanding the evolution of sectoral and aggregate factor income shares. However, as shown by Herrendorf et al. (2013), the Cobb–Douglas sectoral production functions that differ only in technological progress capture the dominant force behind the postwar US structural transformation, whereas other differences across sectoral technology are of second order importance. Since the focus of our paper is to uncover the key for understanding the US structural transformation, not the evolution of the factor income share, the use of the Cobb–Douglas sectoral production functions is proper.

Given factor prices and goods prices, the optimal decisions of the representative firm are standard. The representative firm chooses capital and labor in a sector so that their marginal cost is equal to their marginal product. Moreover, the sectoral allocation of capital and labor between the non-agricultural sector and the agricultural sector is determined by equating the value of the marginal product in both sectors for each factor.

Preferences

The representative household consumes both agricultural (c_a) and non-agricultural (c_m) products. The preference is represented by the following Stone–Geary utility.

$$u(c_{a,t}, c_{m,t}) = \ln(c_{a,t} - \xi) + \gamma \ln c_{m,t}, \tag{2}$$

where $\gamma/(1 + \gamma)$ is the share of non-agriculture in consumption. Parameter $\xi > 0$ is the subsistence level of agricultural consumption. With subsistence agricultural consumption, the preference is non-homothetic. The assumption of subsistence agricultural consumption is consistent with the Engel's Law that the fraction of household expenditures on food declines as income rises. The utility (2) indicates that the elasticity of substitution between consumption is unity. The representative household's lifetime utility is thus $U = \sum_{t=0}^{\infty} \beta^t u(c_{a,t}, c_{m,t})$, where $\beta \in (0,1)$ is the discount factor.

In each period t, the representative household receives capital rentals and wages that are spent on consumption and investment. The household's flow budget constraint is given by

$$k_{t+1} = \frac{1}{p_t}(r_t k_t + w_t - c_{a,t}) - c_{m,t} + (1 - \delta)k_t, \tag{3}$$

where δ is the depreciation rate.

With constraint (3), the household's problem is to maximize the lifetime utility by choosing the two consumption goods and investment. Let λ_t denote the current-valued Lagrange multiplier in period t. In addition to the transversality condition, the optimal conditions for $c_{a,t}$, $c_{m,t}$ and k_{t+1} are standard. The optimal condition for agricultural consumption equates the marginal utility to the shadow price of capital in terms of non-agricultural goods, while the optimal condition for non-agricultural consumption equates the marginal utility to the shadow price of capital. Moreover, there is the Euler equation that governs how the shadow price of capital changes over time.

Equilibrium

We are ready to study the equilibrium. An equilibrium is a sequence of prices $\{\lambda_t, p_t, w_t, r_t\}_{t=0}^{\infty}$ and a sequence of allocation $\{c_{a,t}, c_{m,t}, k_{t+1}, k_{a,t}, k_{m,t}, l_{a,t}, l_{m,t}\}_{t=0}^{\infty}$ such that (i) given $\{p_t, w_t, r_t\}_{t=0}^{\infty}$, firms optimize; (ii) given $\{p_t, w_t, r_t\}_{t=0}^{\infty}$, households optimize; and (iii) prices adjust to clear the two factor markets, $k_{a,t} + k_{m,t} = k_t$ and $l_{a,t} + l_{m,t} = 1$, and the two goods markets as follows.

$$c_{a,t} = A_{a,t}(k_t - k_{m,t})^{\alpha_a}(1-l_{m,t})^{1-\alpha_a}, \tag{4a}$$

$$c_{m,t} = A_{m,t}k_{m,t}^{\alpha_m}l_{m,t}^{1-\alpha_m} - [k_{t+1} - (1-\delta)k_t]. \tag{4b}$$

There are a total of twelve equations, but the Walras' Law stipulates that one of the equations is implied by the factors and goods market clearing conditions. These equilibrium conditions solve for eleven variables. We can simplify these conditions into three equations with k_{t+1}, $k_{m,t}$ and $l_{m,t}$. In a steady state, all variables are stationary and do not change over time. These three equations are then obtained as

$$A_m k_m^{\alpha_m} l_m^{1-\alpha_m} - \delta k = \frac{\gamma[A_a(k-k_m)^{\alpha_a}(1-l_m)^{1-\alpha_a} - \xi][\alpha_m A_m k_m^{\alpha_m - 1} l_m^{1-\alpha_m}]}{\alpha_a A_a (k-k_m)^{\alpha_a - 1}(1-l_m)^{1-\alpha_a}}, \tag{5a}$$

$$\frac{l_m}{k_m}\frac{k-k_m}{1-l_m} = \frac{1-\alpha_m}{\alpha_m}\frac{\alpha_a}{1-\alpha_a}, \tag{5b}$$

$$\beta\alpha_m A_m k_m^{\alpha_m - 1} l_m^{1-\alpha_m} = 1 - \beta(1-\delta). \tag{5c}$$

Using (5a)–(5c), we can determine the steady-state values of k, k_m and l_m. With these values, we use the equilibrium condition for sectoral allocation of capital or labor between the two sectors and (4b) to determine p and c_m, respectively. Then we can substitute these variables into other equations and solve c_a, k_a, l_a, w, r and λ. Therefore, all endogenous variables are determined in a steady state.

Effects of Technology Progress in the Long Run

We now characterize the effect of sectoral technology progress (higher A_m and A_a) on capital accumulation and on the factor allocation across sectors in a steady state. First, the effect on capital accumulation in the economy in a steady state is

$$\frac{dk/k}{dA_m/A_m} = \frac{1}{\Delta}\frac{1-\frac{k_m}{k}}{1-l_m}k_m\left\{\frac{1}{\alpha_m} + \frac{\gamma}{\alpha_a}\left[1 - \frac{(1-\alpha_a)\xi}{y_a}\left(1 - \frac{l_m}{\frac{k_m}{k}}\right)\right]\right\} > 0, \tag{6a}$$

$$\frac{dk/k}{dA_a/A_a} = \frac{\Omega}{\Delta}\xi(1-\alpha_m)\frac{\frac{k_m}{k} - l_m}{1-l_m} \geq 0, \tag{6b}$$

where $\Omega \equiv \dfrac{\gamma(k-k_m)}{\alpha_a y_a} > 0$, $\Delta \equiv (1-\alpha_m)\left[\dfrac{k_m}{\alpha_m} + \dfrac{l_m}{1-l_m}\dfrac{\gamma(k-k_m)}{\alpha_a} - \dfrac{\frac{k_m}{k} - l_m}{1-l_m}\Lambda\right] > 0$ and $\Lambda \equiv \dfrac{\delta k k_m}{\alpha_m y_m} > 0$.

It is clear that when there is no subsistence agricultural consumption ($\xi = 0$), the agricultural technology progress has a null effect on capital accumulation, while the non-agricultural technology progress still increases capital accumulation. With subsistence agricultural consumption ($\xi > 0$), not only the non-agricultural technology progress but also the agricultural technology progress increases capital accumulation in the economy over the long run.

Next, the effects of the non-agricultural technology progress on the capital allocation across sectors in the steady state are

$$\frac{dk_m/k_m}{dA_m/A_m} = \frac{1}{\Delta}\left(\frac{1}{\alpha_m}+\frac{\gamma}{\alpha_a}\right)\frac{1-\frac{k_m}{k}}{1-l_m}k_m + \frac{1}{\Delta}\xi\gamma\frac{k-k_m}{y_a}\left(1-\frac{1}{\alpha_a}\frac{\frac{k_m}{k}-l_m}{1-l_m}\right) > 0, \tag{7a}$$

$$\frac{dk_a/k_a}{dA_m/A_m} = \underbrace{\frac{k}{k_a}\frac{dk/k}{dA_m/A_m}}_{(+)} - \underbrace{\frac{k_m}{k_a}\frac{dk_m/k_m}{dA_m/A_m}}_{(+)} = \frac{1}{\Delta}\left(\frac{1}{\alpha_m}+\frac{\gamma}{\alpha_a}\right)\frac{1-\frac{k_m}{k}}{1-l_m}k_m$$
$$+\frac{1}{\Delta}\gamma\xi\frac{k_m}{y_a}\left[\frac{1}{\alpha_a}\frac{\frac{k_m}{k}-l_m}{1-l_m}\left(1-(1-\alpha_a)\frac{k}{k_m}\right)-1\right]. \tag{7b}$$

Clearly, the non-agricultural technology progress increases non-agricultural capital, but it has an ambiguous effect on agricultural capital. Ambiguity in the agricultural sector emerges because two conflicting effects are at work. First, the non-agricultural technology progress increases capital accumulation in the economy, which increases agricultural capital. However, as we will see below, the non-agricultural technology progress releases labor from agricultural production to non-agricultural production, which, under the complementarity between labor and capital in production, reduces agricultural capital. As a result, the non-agricultural technology progress may increase or decrease agricultural capital.

Further, the effects of the agricultural technology progress on the capital allocation across sectors in the steady state are

$$\frac{dk_m/k_m}{dA_a/A_a} = \frac{\Omega}{\Delta}\xi(1-\alpha_m) \geq 0, \tag{8a}$$

$$\frac{dk_a/k_a}{dA_a/A_a} = \underbrace{\frac{k}{k_a}\frac{dk/k}{dA_a/A_a}}_{(+\text{ or }0)} - \underbrace{\frac{k_m}{k_a}\frac{dk_m/k_m}{dA_a/A_a}}_{(+\text{ or }0)} = \frac{\Omega}{\Delta}\xi(1-\alpha_m)\left(\frac{-l_m}{1-l_m}\right) \leq 0. \tag{8b}$$

Thus, as shown in (6b), when there is no subsistence agricultural consumption ($\xi = 0$), the agricultural technology progress has a null effect on not only capital accumulation but capital reallocation. When there is subsistence agricultural consumption ($\xi > 0$), the agricultural technology progress increases non-agricultural capital but decreases agricultural capital. Intuitively, the agricultural technology progress increases capital accumulation in the economy (cf. (6b)). Moreover, as will be described below, the agricultural technology progress releases labor from agricultural production to non-agricultural production. Because of the complementarity between labor and capital in production, the agricultural technology progress unambiguously increases non-agricultural capital. However, also owing to the complementarity between labor and capital in production whose effect is stronger, agricultural capital is unambiguously decreased.

Finally, the effects of sectoral technology progress on the labor allocation across sectors in the steady state are as follows.

$$\frac{dl_m/l_m}{dA_m/A_m} = \frac{\Omega}{\Delta}\xi\alpha_a \geq 0 \quad \text{and} \quad \frac{dl_a/l_a}{dA_m/A_m} = -\frac{l_m}{l_a}\frac{dl_m/l_m}{dA_m/A_m} \leq 0, \tag{9a}$$

$$\frac{dl_m/l_m}{dA_a/A_a} = \frac{\Omega}{\Delta}\xi(1-\alpha_m) \geq 0 \quad \text{and} \quad \frac{dl_a/l_a}{dA_a/A_a} = -\frac{l_m}{l_a}\frac{dl_m/l_m}{dA_a/A_a} \leq 0. \tag{9b}$$

Obviously, when there is no subsistence agricultural consumption ($\xi = 0$), progress in both types of technology has a null effect on the labor reallocation. With subsistence agricultural consumption ($\xi > 0$), progress in both types of technology increases non-agricultural employment and decreases agricultural employment. As the capital share is usually smaller than a half and thus $1 - \alpha_m > \alpha_a$, $\frac{dl_m/l_m}{dA_a/A_a}$ in (9b) is larger than $\frac{dl_m/l_m}{dA_m/A_m}$ in (9a). In consequence, the agricultural technology progress increases the non-agricultural employment share more than what the non-agricultural technology progress does. Thus, progress in both types of technology reduces the agricultural employment share. For the same reason, the agricultural technology progress decreases the agricultural employment share more than what the non-agricultural technology progress does.

It should be noted that with subsistence agricultural consumption, if capital is not an input in the agricultural sector as in Gollin et al. (2002, 2007), or if there is no capital in the economy as in Matsuyama (1992) and Restuccia et al. (2008), the effects of sectoral technology progress become different. In these two kinds of models, only the agricultural technology progress exerts effects, but the non-agricultural technology progress does not have any effect on employment across sectors. To see these results, first, suppose that only the non-agricultural sector uses capital, but the agricultural sector does not. This case gives the following results.

$$\frac{dl_m/l_m}{dA_m/A_m} = 0 \quad \text{and} \quad \frac{dl_a/l_a}{dA_m/A_m} = -\frac{l_m}{l_a}\frac{dl_m/l_m}{dA_m/A_m} = 0, \tag{10a}$$

$$\frac{dl_m/l_m}{dA_a/A_a} = \frac{\xi}{A_a - \xi} \geq 0 \quad \text{and} \quad \frac{dl_a/l_a}{dA_a/A_a} = -\frac{l_m}{l_a}\frac{dl_m/l_m}{dA_a/A_a} \leq 0. \tag{10b}$$

Next, suppose there is no capital in the model. It is straightforward to show that the comparative-static results are exactly the same as those in (10a) and (10b).[9]

Therefore, it does not matter if there is no capital or if capital is not used in the agricultural sector, the effect of the complementarity between capital and labor is not at work in at least one of the sectors. Then, only the progress in agricultural technology increases non-agricultural employment and thus decreases agricultural employment. The progress in non-agricultural technology has a null effect on the labor reallocation across sectors. The results are different from those in Gollin et al. (2002, 2007) wherein if an economy has taken off, agricultural consumption becomes fixed and the structural change is entirely driven by the progress in non-agricultural technology.

To summarize the steady-state effects in our two-sector model with subsistence agricultural consumption and with capital in both sectors, the progress in both agricultural and non-agricultural technology increases aggregate capital and non-agricultural capital. Moreover, the progress in agricultural and non-agricultural technology both increase non-agricultural employment and decrease agricultural employment. However, the progress in agricultural technology decreases agricultural capital, but the progress in non-agricultural technology may increase or decrease agricultural capital. Because the agricultural productivity progress decreases agricultural capital and increases non-agricultural capital, through the complementarity between capital and labor, it is expected that the agricultural productivity progress will lead to a negligible agricultural share of employment over time as experienced by today's richest countries. However, since the progress in non-agricultural productivity may increase agricultural capital, it is anticipated that non-agricultural productivity growth will generate structural transformation that does not result in a negligible agricultural share of employment.

3. Structural Change

In this section, we quantify the effects of growth in sectoral productivity on structural change in today's richest countries. We use the USA to represent today's richest countries because the USA has been the richest among Organisation for Economic Co-operation and Devevelopment (OECD) countries for most years in the post-World War II era, and it has data available from as early as the early 1800s.[10] By applying the data of the technology progress in different sectors to different models, we envisage what type of technology progress, agricultural or non-agricultural, in which kind of the model can better outline the structural transformation in the USA.

Data indicates that the USA has experienced structural transformation with a substantial amount of labor reallocation across sectors. As is well known, the process of structural transformation is slow (Lucas, 2000). While the structural transformation started in the late 1700s, available data suggests that in the early 1800s the share of labor employment in agriculture remained over 70% with the share in non-agricultural activity being less than 30% (cf. Figure 1). Over time, the employment share in agriculture shrank monotonically with an equally slow expansion with regard to the non-agricultural sector, or about 50% each by around 1878. The employment share in agriculture was still around 20% over the World War II period. In the early 2000s, the share in agriculture was eventually reduced to less than 2% with more than 98% being accounted for by non-agricultural endeavors.

Calibration and Solution Algorithm

To quantify the effects on structural change, we use a shooting algorithm to compute the effects of sectoral technology progress on the entire path of allocations of employment across sectors from 1820 to 2011.[11] We now describe our approach to calibrating the parameters used in our computation of the dynamic paths.

First, given the initial and the final values of the sector-specific technology series $\{A_{i,t}\}$, we solve the initial steady-state values and the final steady-state values. Then, we solve the dynamic equilibrium path by using a shooting algorithm, which is a standard method in non-linear numerical simulations. A similar shooting algorithm has been used by Conesa and Krueger (1999), Chen et al. (2006) and He and Liu

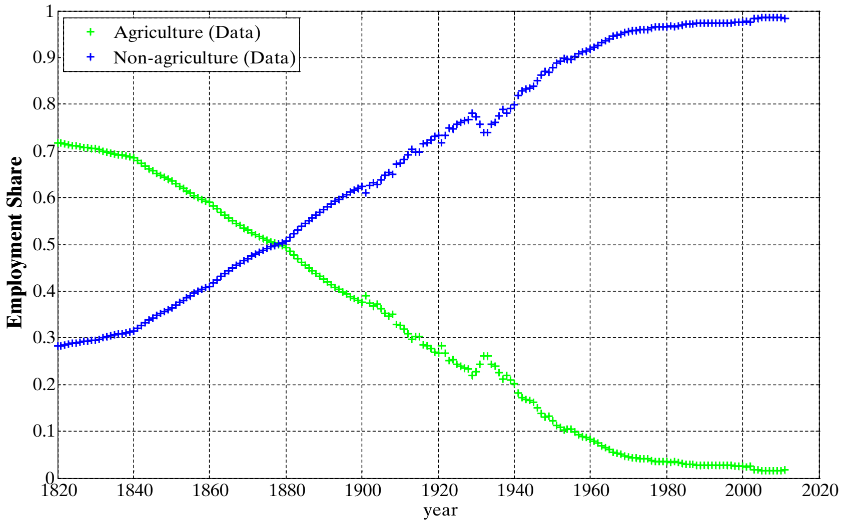

Figure 1. US Structural Transformation between Agriculture and Non-agriculture

Note: Non-agriculture includes both manufacturing and services.
Sources: US Bureau of the Census (1975); US Census Bureau (2004); US Bureau of Labor Statistics (2012).

(2008). We assume $t = 1$ for year 1820, $t = T$ for year 2011, and $t = 2, \ldots, T - 1$ for years in transitional periods. Since $T = 192$ is sufficiently large, the transitional dynamics between 1820 and 2011 in our model are not affected by small variations in T. A brief summary of the algorithm is as follows.

(i) Given the initial values of series $A_{i,1}$, $i = a, m$, we solve and save the initial steady-state values of the following 13 variables: $\{c_{a,1}, c_{m,1}, k_1, k_{a,1}, k_{m,1}, l_{a,1}, l_{m,1}, p_1, w_1, r_1, \lambda_1, y_{a,1}, y_{m,1}\}$.
(ii) Given the terminal values of series $A_{i,T}$, $i = a, m$, we solve and save the final steady-state values of the above-mentioned 13 variables in $t = T$.
(iii) Through linear interpolations between the initial steady state and the final steady state, we obtain sequences of each of the 13 unknowns in years $t = 2, \ldots, T - 1$. We use these sequences as an initial guess and solve the system of non-linear equations.

To carry out the quantitative effects of sectoral technology progress, we start by calibrating our model to the US economy at an annual frequency. Most structural parameters in the model are calibrated so that the resulting steady-state values of key variables can match with the long-term features of the US economy. The details of the data regarding TFP, output, employment and capital are described in the Appendix.

We set the annual discount factor β to be 0.96, so that the discount rate can be pinned down at 4%. Following Hansen (1985), the annual depreciation rate of capital is chosen to be $\delta = 0.1$. The capital share of the non-agricultural sector is set at $\alpha_m = 0.3$ to match with the average capital share in the non-agricultural sector in postwar USA. Following Hayami and Ruttan (1985), the capital share of the agricultural sector is set at $\alpha_a = 0.1$, so the agricultural sector is less capital-intensive.

We use the exogenous sectoral TFP to measure the progress in sectoral technology. Both TFPs grow as $A_{i,t} = (1 + g_i)^{t-1} A_{i,1}$, $g_i > 0$, $i = a, m$, $t = 2, \ldots, T$. In the data, the

Table 1. Baseline Parameter Values

Initial value of TFP in agriculture (normalized)	$A_{a,1}$	1
Initial value of TFP in non-agriculture (normalized)	$A_{m,1}$	1
Rate of the TFP growth in the agricultural sector	g_a	0.0140
Rate of the TFP growth in the non-agricultural sector	g_m	0.0134
Subjective discount factor	β	0.96
Capital share of the agricultural sector	α_a	0.1
Capital share of the non-agricultural sector	α_m	0.3
Depreciation rate of capital	δ	0.1
Consumption share for non-agricultural goods	γ	179.11
Subsistence level of agricultural consumption	ξ	0.648

Table 2. Comparison between Models

	Model with capital in both sectors			*Model without capital in agriculture*	*Model without capital*	*Data*
	A_a- and A_m-driven	*A_a-driven*	*A_m-driven*			
Non-agricultural share of employment	0.9620	0.9483	0.5339	0.9416	0.9460	0.9839

average annual growth rate of the agricultural TFP is $g_a = 0.0140$ and that of the non-agricultural TFP is $g_m = 0.0134$. Thus, the TFP in the agricultural sector on average grows faster than that in the non-agricultural sector, which confirms the findings in Jorgenson and Gollop (1992). With initial values of the agricultural and the non-agricultural technology level being normalized to unity ($A_{a,1} = A_{m,1} = 1$ in 1820), we can generate the two TFP series, $\{A_{i,t}\}_{t=2}^{T}$, $i = a, m$.

The two parameters γ and ξ are left to be calibrated so that the initial steady-state values in the model match with the following two moment conditions in the US data. The agricultural share of employment is 0.718 in 1820, and the output share of the agricultural sector in the economy is 0.344 in 1819.[12] By using these two data, our exercise ends up with the share of non-agricultural consumption at $\gamma = 179.11$ and subsistence agricultural consumption at $\xi = 0.648$. The benchmark parameter values are summarized in Table 1.

Table 2 summarizes the final steady states concerning the employment share of the non-agricultural sector in the economy ($l_{m,T}$). In the table, we report the data in 2011 and steady-state values in the three models; that is, the model wherein both sectors use capital, the model wherein only the non-agricultural sector uses capital and the model wherein neither sector uses capital. Further, in the table when we report in the case wherein both sectors use capital, we separate the case when technological progress is driven by both sectors from the case wherein technological progress is driven by one of the two sectors. As evident from the table, almost all values in the final steady states are close to the data. The exception is the model wherein capital is used in both sectors with progress in non-agricultural technology, in which the final steady state deviates from the data. All these results are consistent with the prediction posited in (9a) and (9b) wherein the non-agricultural TFP growth reallocates less employment from the agricultural sector to the non-agricultural sector than what the agricultural TFP growth does.

Effects of TFP Growth

We are now ready to quantify the dynamic effects of sectoral TFP growth upon the process of structural transformation. We feed the model with the sectoral TFP series $\{A_{i,t}\}_{t=1}^{T}$ and compute the resulting dynamic equilibrium paths from the initial steady state toward the final steady state. We illustrate the resulting structural transformation in the allocation of the employment share between the non-agricultural sector and the agricultural sector.

Models without capital in agriculture and without capital in both sectors Before quantifying the baseline two-sector model wherein capital is employed in both sectors, we present the effects in the model wherein capital is not used in the agricultural sector and the model wherein capital is not used in both sectors. First, in the model when capital is not an input in the production of agriculture, $\alpha_a = 0$ and $k_a = 0$.[13] The dynamic paths are illustrated in Figure 2, wherein the employment shares generated by the model are displayed against the employment shares in the data. As evident from (10a) and (10b), only the agricultural TFP growth affects labor reallocation, and the non-agricultural TFP growth has no effect on the labor reallocation across sectors.

According to the figure, in response to agricultural TFP growth, the non-agricultural share of employment increases, and the agricultural share of employment decreases. However, the paths of employment shares generated by the model are divergent from the US data. Figure 2 shows that in response to agricultural TFP growth, the employment share in the agricultural sector generated by the model is reduced more than the data, and in consequence, the employment share in the non-agricultural sector generated by the model is expanded faster than the data. Thus, the agricultural share of employment generated by the model is almost 20 percentage

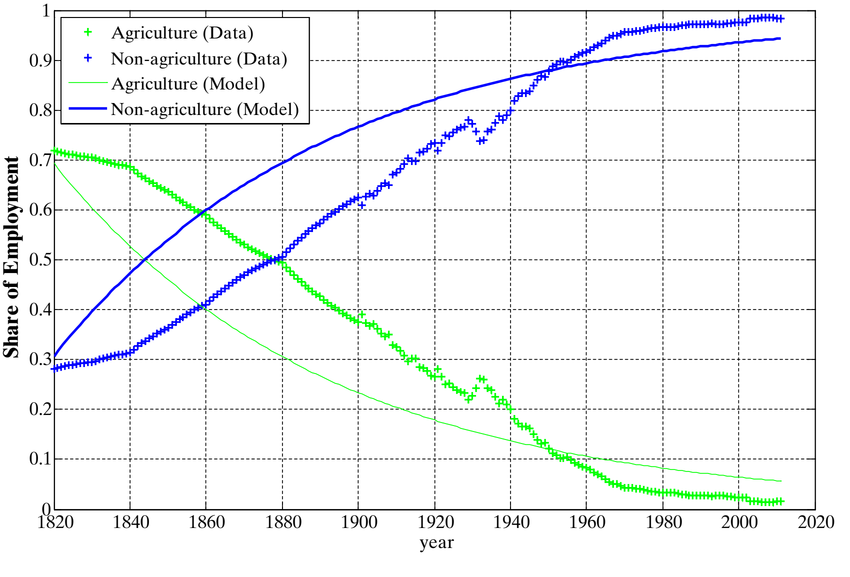

Figure 2. Structural Change in a Model without Capital in Agriculture: Agricultural TFP Growth

Note: In a model without capital in the agricultural sector, non-agricultural TFP growth does not affect the labor reallocation.

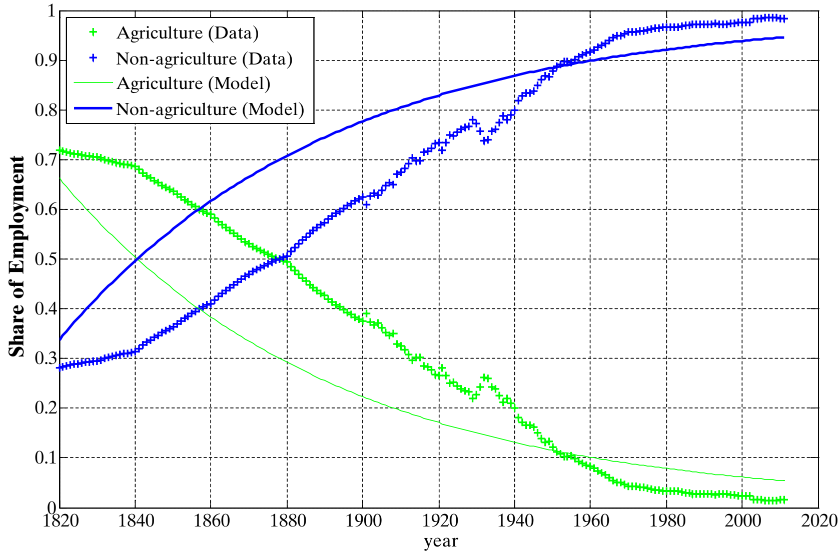

Figure 3. Structural Change in a Model without Capital in Both Sectors: Agricultural TFP Growth

Note: In a model without capital in both sectors, non-agricultural TFP growth does not affect the labor reallocation.

points lower than that in the data over 1840–1900. As a result of rapid transitions, the paths of the employment share in the two sectors generated by the model intersect in around 1844, which leads to about 34 years in the data wherein the employment paths in the two sectors intersect around 1878. As shown in Figure 2, in the model wherein capital is not employed in the agricultural sector, neither agricultural TFP growth nor non-agricultural TFP growth generates structural transformation that matches the US data over the past 200 years.

Next, we report the effects when there is no capital in the model, i.e. $\alpha_a = \alpha_m = 0$ and $k_a = k_m = 0$.[14] As can be seen from (10a) and (10b), when both sectors do not use capital, the non-agricultural technology progress has no effect on structural change. Only technological progress in agriculture affects the factor reallocation. In this model, the effects of agricultural TFP growth on structural transformation are illustrated in Figure 3, which is similar to Figure 2. As we can see in Figure 3, the paths of the employment share in the two sectors generated by the model intersect in around 1840, which leads the data for about 38 years.

Therefore, the results above indicate that in a two-sector growth model when capital is not used in the agricultural sector or not used in both sectors, the agricultural TFP growth generates structural transformation too fast to match what it outlines in the US data.

The model with capital in both sectors and effects of the TFP growth in agriculture

Now, we turn to the baseline model when capital is used in both sectors. We start by investigating the effects of the agricultural TFP growth on the process of structural transformation, which are illustrated in Figure 4. It can be seen from the figure, the agricultural share of employment generated by the model shrinks gradually over time.

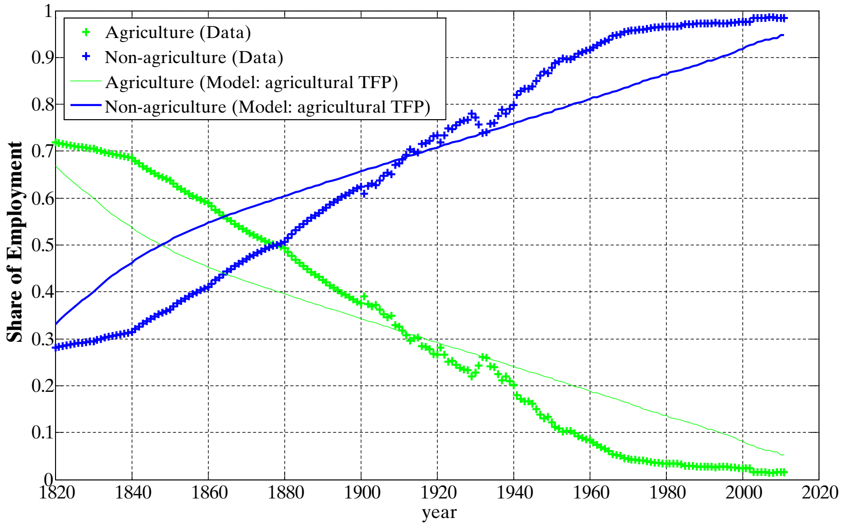

Figure 4. Structural Change in a Model with Capital in Both Sectors: Agricultural TFP Growth

The employment share generated by the model differs from that in the data by less than 10 percentage points for most years.

Compared with the results in Figures 2 and 3 wherein the agricultural TFP growth leads to overly fast structural transformation, in Figure 4 the agricultural TFP growth causes slower structural transformation, which fits the data much better. Indeed, if we use the mean squared error to measure the difference in the employment share between the model and the data, we find the value of 0.0082 in Figure 4.[15] This value of the mean squared error is smaller than the corresponding values in Figures 2 and 3, which are 0.0132 and 0.0160, respectively.

The reasons for a better fit in Figure 4 than those in Figures 2 and 3 are easily understood. It does not matter whether in a model with capital in both sectors (cf. (9b)) or in a model when capital is not used either in the agricultural sector or in both sectors (cf. (10b)), the agricultural TFP growth releases labor from the agricultural sector to the non-agricultural sector. However, the model with capital in both sectors has an additional force, that is, the complementarity between capital and labor in production in both sectors. Through the complementarity effect, the labor reallocation toward the non-agricultural sector raises the marginal productivity of capital in the non-agricultural sector and lowers that in the agricultural sector. This induces a fall in the relative price of non-agriculture, which postpones the labor reallocation from the agricultural sector to the non-agricultural sector. This creates a "hold-up" effect on the labor reallocation, an effect which does not prevail in a model where capital is not used in the agricultural sector. The "hold-up" effect makes the employment share in the agricultural sector shrink more slowly than those findings offered in Figures 2 and 3. As a result, the structural transformation generated by the model in Figure 4 is slower, by comparison, than that in Figures 2 and 3. Given that the structural transformation is slow in the data, a slower model-generated structural transformation in Figure 4 matches with the data reasonably well.

The model with capital in both sectors and effects of the TFP growth in non-agriculture We next investigate the effects of the non-agricultural TFP growth in the

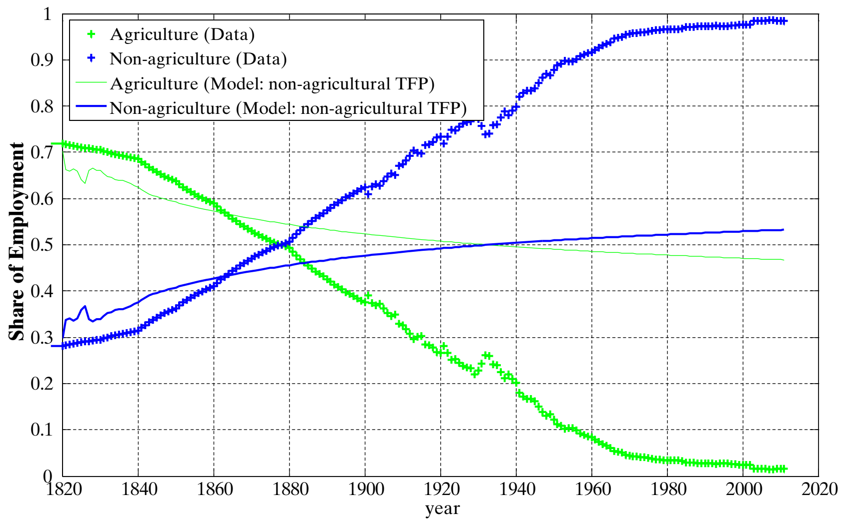

Figure 5. Structural Change in a Model with Capital in Both Sectors: Non-agricultural TFP Growth

model where capital is used in both sectors. Figure 5 indicates that in response to non-agricultural TFP growth, the employment share changes too slowly over the past two centuries. One should be reminded that in Table 2, in the model with capital in both sectors, non-agricultural TFP growth cannot generate a final steady state close to the data, as predicted by (9a) and (9b). In consequence, the paths of the employment share generated by the model do not cross until 1935, which lags behind the data by 57 years.[16] The results suggest that non-agricultural TFP growth appears to generate a too slow structural transformation to match the US data.

Our results above indicate that in the model with capital in both sectors, growth in agricultural productivity generates the structural transformation that reasonably well matches with the data, but growth in non-agricultural productivity generates the structural transformation that deviates far from the data.

4. Conclusions

This paper studies a two-sector neoclassical growth model to envisage which sectoral technological progress in which kind of the model can motivate sectoral reallocation and quantitatively generate structural change close to the data. First, in the long run, growth in agricultural productivity increases non-agricultural capital and decreases agricultural capital and, through the complementarity between capital and labor, it eventually causes a negligible agricultural employment share. However, growth in non-agricultural productivity cannot lead to a negligible agricultural employment share because it may increase agricultural capital. Next, by applying the US data of sectoral technological progress between 1820 and 2011, we find that in the model with capital in both sectors, via the complementarity between capital and labor, agricultural productivity growth can generate structural change that matches reasonably well with the data, but non-agricultural productivity growth cannot. Thus, growth in agricultural productivity is crucial to governing long-term and massive structural change in today's richest countries.

Appendix

Data Sources

Employment data Employment data for the periods of 1820–1900 and 1901–1928 are from Series D 75-77 and Series D 5-7 in "Historical Statistics of the United States, Colonial Times to 1970" (the US Bureau of the Census, 1975). Employment data over 1929–2002 come from No. HS-29, the "2003 Statistical Abstract of the United States" (the US Census Bureau, 2004). Employment data in 2003–2011 are from the "Current Population Survey" (the US Bureau of Labor Statistics, 2012). Note that the employment data in 1820–1900 are available every ten years, so we use linear interpolation to estimate the within-period employment.

TFP data for agriculture TFP data for agriculture in 1889–1950 are from Table B-II in Kendrick (1961), and those in 1950–2009 are from Table B-99 in the "2012 Economic Report of the President" (the US Government Printing Office, 2012). We employ the estimate of pre-1899 average annual rate of change in the agricultural TFP in Kendrick (1961) as the annual growth rate of the agricultural TFP in 1821–1889. The TFP growth rate in 2010–2011 is represented by taking the average of TFP growth rates in years 2000–2009.

TFP data for non-agriculture TFP data for non-agriculture in 1948–2011 are from the website of the Multifactor Productivity in the US Bureau of Labor Statistics. The non-agricultural TFP data are not available before 1948. Our Cobb–Douglas production technology indicates that the non-agricultural TFP can be computed from formula $A_{m,t} = y_{m,t}/(k_{m,t}^{\alpha_m} l_{m,t}^{1-\alpha_m})$. To this end, other than employment data, we need output data and capital stock data.

Output data The gross private domestic product and farm gross domestic product in 1889–1948 are obtained from Table A-III in Kendrick (1961).

Capital data Total real capital stock and total farm capital stock in 1889–1948 come from Table A-XV in Kendrick (1961). By subtracting the quantity in the agricultural (farm) sector from the aggregate quantity, we obtain the data for non-agriculture. Then, the non-agricultural TFPs in 1889–1948 can be obtained by using formula $y_{m,t}/(k_{m,t}^{\alpha_m} l_{m,t}^{1-\alpha_m})$. The data of capital stock in the non-agricultural sector is not available before 1889. Thus, the annual growth rate of the non-agricultural TFP in 1821–1889 is measured by taking an average of the annual growth rate of the non-agricultural TFP in 1889–1899.

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Notes

1. Structural change is interchangeable with structural transformation in the text.
2. See Kuznets (1966) and Maddison (1980), among others.
3. See, for instance, Jorgenson and Gollop (1992) for the USA over 1947–1985 and Martin and Mitra (2001) for OECD countries between 1967 and 1992.
4. See also Chen and Shimomura (1998) and Wang and Xie (2004) who studied when takeoff can be initiated within a poor country.
5. Baumol (1967) studied a model with non-progressive and progressive sectors and found a tendency for the non-progressive sector to decline. Ngai and Pissarides (2007) scrutinized a multi-sector model and derived the implications of different productivity growth rates for structural change. Finally, Acemoglu and Guerrieri (2008) explored a model with a final good that is produced by combining output of two sectors with different factor proportions and showed that as there is capital deepening, the reallocation of capital and labor behaves in a manner such that nonbalanced growth is consistent with an asymptotic equilibrium.
6. Echevarria (1997) and Laitner (2000) derived structural change in a two- or three-sector model economy. Kongsamut et al. (2001) obtained simultaneous constant aggregate growth and structural change by imposing a restriction that maps some of the parameters of their utility function into the parameters of the production functions. Finally, Gollin et al. (2004) studied a neoclassical growth model with the home production sector and showed that their model can account for structural change better than the neoclassical growth model.
7. Ngai and Pissarides (2007) is a multi-sector model with multiple consumption goods and only one manufacturing good. There is no subsistence agricultural consumption. These authors characterized the conditions under which structural change emerges. In particular, if the elasticity of substitution is smaller than one, the sector with a lower productivity growth rate gains a bigger labor share in the course of structural change.
8. Gollin et al. (2002, 2007) is a model with the agricultural and the non-agricultural sectors. There is more than one kind of agricultural production technology. When subsistence agricultural consumption is not met, labor in the economy is allocated entirely to the agricultural production that uses only labor. Another kind of the agricultural technology in Gollin et al. (2007) uses both capital and labor, which is used only when total output in the economy can meet subsistence agricultural consumption. Non-agricultural production technology is the sum of two parts: one part is the standard part that uses labor and capital, and the other part is an additional term that is linear in labor, so capital can be accumulated once the economy has taken off.
9. It is clear to note that if there is no subsistence agricultural consumption, even the agricultural technology progress does not have any effect on employment across sectors (cf. (10b)).
10. Gollin et al. (2002, 2007) used the UK data since 1800. However, these data cannot represent a massive structural change in today's richest countries. In 1800, the agricultural share of UK employment had been reduced to a low ratio, 35%, so the economy had experienced structural change by a wide range.
11. We regard 1820 as the initial steady state since the data of the employment across sectors is available from 1820.
12. The data for the agricultural share of output is not available in 1820, and therefore, we used the data in 1819 as a substitute.
13. In this case, $\xi = 0.691$ and $\gamma = 130.33$.
14. In this case, $\xi = 0.66$ and $\gamma = 122.8$.
15. The mean squared error is defined as $\sum_{t=1}^{T}(l_{a,t} - \overline{l}_{a,t})^2/T$ where $\overline{l}_{a,t}$ is the agricultural share of employment in the data in period t.
16. The value of the mean squared error is 0.0790 in this case.