A Three-Sector Model of Structural Transformation and Economic Development

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Growth accounting exercises point to aggregate TFP differences as the dominant source of the large cross-country income differences. In this paper, I ask which sectors account for the aggregate TFP gap between rich and poor countries. Data limitations for developing countries have led researchers to use indirect methods for estimating sectoral TFPs. This paper proposes a new approach for estimating sectoral TFP using panel data on sectoral employment shares and GDP per capita. The approach builds a model of structural transformation and uses it to infer sectoral TFP time series consistent with the reallocation of labor between sectors and GDP per capita growth of a set of developing countries over a 40-year period. I find that relative to the US, developing countries are the least productive in agriculture, followed by services and then manufacturing. While these findings are consistent with empirical studies, they differ from findings in the growth literature.

Keywords: Productivity, Sectoral TFP, Structural Transformation, Economic growth, Economic Development

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1. Introduction

Income differences across countries are large: income per capita for the US in 2000 was about 30 times the average for the least developed countries. Growth accounting exercises point to differences in total factor productivity (TFP) as the biggest source of cross-country income differences[1]. In this paper, I ask which economic sectors account for this TFP gap. The answer to this question is important for two reasons. First, it can help us construct theories for explaining the low productivity in developing countries. Second, it can be useful for formulating policy recommendations.

The key challenge for measuring sectoral TFP in developing countries is data availability. A simple sectoral growth accounting exercise requires comparable data for sectoral value added in constant prices, sectoral capital stock and sectoral employment. Only data for sectoral employment is available for developing countries. This data limitation has led researchers to use indirect methods for estimating sectoral TFPs. The existing literature uses data on cross-section prices in a multi-sector growth model to infer sectoral relative TFPs[2].

A key contribution of this paper is to show how data on structural transformation, i.e., the reallocation of labor across sectors as an economy develops, can be used to uncover sectoral TFP differences. Kuznets included the process of structural transformation as one of six stylized facts of economic development. He found that developed countries all followed a similar process. However, as Bah (2007) documents, many developing countries are following processes that are very different from the path of developed countries. It is then natural to think that cross-country differences in the process of structural transformation provide information about cross-country differences in aggregate income and productivity.

Specifically, I develop a version of the neoclassical growth model with three sectors (agriculture, manufacturing and services) and use it to infer sectoral TFP time series consistent with GDP per capita growth and structural transformation in each of several

[1] Examples include Hall and Jones (1999), Prescott (1998), Klenow and Rodriguez-Clare (1997), Parente and Prescott (1994, 2000), Hendricks (2002), Caselli (2005).

[2] See Hsieh and Klenow (2007) and Herrendorf and Valentinyi (2006).

countries over a 40-year period[3]. To allow for labor reallocation between the sectors associated with structural transformation, the model incorporates the following features. First, non-homothetic preferences and agricultural TFP drive labor out of agriculture[4]. Second, a TFP growth differential and the elasticity of substitution between the manufacturing and service sectors drive the reallocation of labor between those two sectors[5]. This kind of hybrid model has been used by Rogerson (2007) to analyze labor market outcomes in Europe[6].

I calibrate the model to match the structural transformation and per capita GDP growth for the US over the period of 1950-2000. I then use the calibrated model to infer sectoral TFP time series that are consistent with the structural transformation and economic development experiences of a sample of developing countries: Brazil, Korea, and an average of 11 African countries.

In this exercise, I assume that preference parameters are the same for all countries but allow all sectoral TFPs to vary. I show that given data on sectoral employment and aggregate GDP per capita, the model can be used to infer the time series for sectoral TFPs. The actual implementation of the approach is somewhat complex because of the dynamics associated with capital accumulation, but at a heuristic level, the approach works as follows. Given the calibrated preference parameters, observed employment in agriculture determines the level of agricultural TFP. Relative employment in manufacturing and services determines the relative TFPs of manufacturing and services. Finally, aggregate GDP per capita determines the levels of TFP in manufacturing and services.

Using this approach, I find that relative to the US, developing countries are the least productive in agriculture, followed by services and then manufacturing. Korea had high TFP growth in all 3 sectors and it was catching up to the US during the 40-year period. Relative to the US, Africa and Brazil did not improve their productivities in agriculture and they fell behind in services. In manufacturing, Africa lost ground to the US while

[3]Note that instead using cross-section price data, this approach uses panel data on sectoral employment shares and GDP per capita.

[4]Example of papers using this feature include: Echevarria (1997), Kongsamut et al. (2001), Laitner (2000), and Gollin et al. (2002, 2007).

[5]This feature is used by Ngai and Pissarides (2007).

[6]However, his model did not include capital and have two sectors.

Brazil experienced a modest catch-up especially between 1960 and 1980.

This paper is related to papers in the development literature, the growth literature and empirical studies. The development literature generally divides the economy into agriculture and non-agriculture and consistently finds that agriculture is relatively the least productive[7]. This is consistent with my findings. Moreover, my finding that developing countries are relatively less productive in services than in manufacturing is consistent with the empirical studies of Lewis (2004) and the McKinsey Global Institute.

However, my finding that developing countries are relatively less productive in services than manufacturing seems to contradict the findings of papers in the growth literature by Hsieh and Klenow (2007) and Herrendorf and Valentinyi (2006). These papers also assume that countries differ in sectoral TFP and seek to understand which sectors make aggregate TFP low in developing countries. Both papers use cross-section relative prices to infer cross-section relative sectoral TFPs. In Hsieh and Klenow (2007), there are two sectors: investment and consumption. They find that relative TFP is lower in investment than consumption. Herrendorf and Valentinyi (2006) has four sectors: services, consumption goods, construction and equipment goods. They find that relative TFP differences in services are small compared to the other sectors. They also aggregate the four sectors into two sector-splits and find that relative TFP is lower in investment than consumption. Because my sectoral subdivision is different, I cannot make a direct comparison of our findings. However, given that agriculture and services (the two least productive sectors) produce the largest share of consumption, my findings suggest that developing countries are more productive in investment than in consumption.

A policy implication of my findings is that governments in developing countries who neglected the service sector in the past should find ways to increase productivity in that sector. As shown in a later section, the stagnation that started in Brazil in the 1980s can be explained primarily by decreases in service TFP.

The rest of the paper is organized as follows. Section 2 describes the model and characterizes the competitive equilibrium. Section 3 calibrates the model to the US

[7]See Kuznets (1971), Gollin et al. (2002, 2007), Cordoba and Ripoll (2005), Restuccia et al. (2007).

economy. Section 4 applies the model to a sample of developing countries and find their sectoral TFP time series. Section 5 discusses how the paper fit within the literature and section 6 concludes.

2. A Three-Sector Model of Structural Transformation

This section develops a three-sector model of structural transformation, which is characterized as follows. Early in the development process, the majority of the labor force is engaged in food production. As food output rises, labor moves from agriculture into manufacturing and services. This is the first phase of structural transformation. In the second phase, labor moves from agriculture and manufacturing into services. This process of structural transformation has been followed by current developed countries but as as Bah (2007) documents, many developing countries are following processes that are very distinct from the above process. The share of services in output is high at relatively low income per capita in many developing countries in Africa and Latin America. This is not the case for Asian countries who are mostly following the path of developed countries. The model developed here will emphasize differential in sectoral productivity growth as the main feature explaining differences in structural transformation processes. The model will be calibrated to the match the growth and structural transformation of the US economy for the period 1950-2000. In the next section the calibrated model will be used to infer sectoral TFPs for a select of developing countries.

2.1. Model

At each period, the economy has three sectors that produce each one good: agriculture, manufacturing and services. A key for the model developed here is to replicate the labor reallocation across different sectors of the economy. Following Rogerson (2007)[8], the model has two features to achieve this outcome: non-homothetic preferences and techno-

[8]Duarte and Restuccia (2007) uses a similar model to account for the role of structural transformation in aggregate productivity. In their analysis, they use measured sectoral labor productivity differences to account for the catch-up and decline of aggregate productivity relative to the US.

logical growth differential across sectors. If income elasticities are not all unitary, then resources are reallocated across sectors as the income increases. Examples emphasizing this feature include Echevarria (1997), Kongsamut et al. (2001), Laitner (2000), and Gollin et al. (2002, 2007). Technological growth differential and non-unitary elasticities of substitution across goods lead to resource reallocation across sectors. This feature has been emphasized by Beaumol (1967) and Ngai and Pissarides (2007).

To simplify the analysis, I assume closed economies. Given the structure of my model, this assumption seems reasonable[9].

Preferences

There is a representative household who lives forever. For simplicity, I assume the size of the household is constant. The household supplies labor to the three sectors and uses its wage compensation to consume three final goods: an agricultural good, an manufactured good and a services. Lifetime utility is given by:

$$\sum_{t=0}^{\infty} \beta^t U(\Phi_t, A_t), \quad \beta \in (0,1) \tag{1}$$

Instantaneous utility is defined over the agricultural good (A_t) and a composite consumption good (Φ_t) which is derived from the manufacturing and service sectors. The instantaneous utility is is given given by:

$$\log(\Phi_t) + V(A_t) \tag{2}$$

$V(A_t)$ is non-homothetic and following Rogerson (2007) and Duarte and Restuccia (2007), $V(A_t)$ it is given by:

$$V(A_t) = \begin{cases} -\infty & \text{if} \quad A_t < \overline{A} \\ min(A_t, \overline{A}) & \text{if} \quad A_t \geq \overline{A} \end{cases} \tag{3}$$

This specification assumes that there is a subsistence level $\overline{A}$ below which the household

[9]Gollin et al. (2007) documents that developing countries engage in little trade in food products. Given that services are generally non-tradables and I assume a single manufactured good, trade in that single good is not possible under trade balance.

cannot survive. This feature has been shown to be quantitatively important for driving labor out of agriculture[10]. While the specification seems to simplify the analysis of the model, we will see later that it also describes the data reasonably well.

The composite good is a CES aggregate of the manufactured good (M_t) and the services (S_t)[11].

$$\Phi_t = \left(\lambda M_t^{\frac{\epsilon-1}{\epsilon}} + (1-\lambda) S_t^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon}{\epsilon-1}}, \quad \epsilon \in (0,1) \quad \text{and} \quad \lambda \in (0,1) \tag{4}$$

Endowments

In each period the household is endowed with one unit of time, all of which is devoted to work. Also, the household is endowed with initial capital stock at time 0 and the total land for the economy. I normalize the size of land to 1 and assume that land does not depreciate.

Technologies

Agriculture:

The agricultural good is produced using a Cobb-Douglas production function with labor (N) and land (L) as the only inputs[12]. The agricultural good is only used for consumption so the resource constraint is given by:

$$A_t = A_{at} N_{at}^{\alpha} L_t^{1-\alpha} \tag{5}$$

where the TFP evolves according to:

$$A_{at} = A_a (1+\gamma_{at})^t \tag{6}$$

The TFP parameter A_a and γ_{at} in the equation above are assumed to be country specific. There are many sources of cross-country differences in agricultural efficiency. One source is government policies and institutions that have an impact on agricultural activity. As an example, it has been shown that marketing boards, present in many African countries

[10] See Echevarria (1997), Kongsamut et al. (2001), Laitner (2000), and Gollin et al. (2002, 2007)

[11] Here, I abstract for services produced at home that Rogerson (2007) finds important for explaining why European countries substitute away from market services in the face of higher taxes.

[12] This formulation assumes that capital is not used in the agricultural technology. In the applications of the model, the effect of capital is implicitly captured by agricultural TFP.

until the 1990s, were inhibiting the development of the agriculture sector[13]. Another source of variation is the quality of land available per person and the climate(s) prevailing in the country. For example, a variety of seed developed for one region will not necessarily be suited for another.

Manufacturing and Services:

The manufacturing and service sectors produce output using standard Cobb-Douglas production functions with capital and labor as inputs. Following the literature, I assume identical capital shares in both sectors[14]. The manufacturing sector's output is used for consumption (M_t) in the composite good and investment (X_t). The manufacturing sector resource constraint is:

$$M_t + X_t = A_{mt} K_{mt}^{\theta} N_{mt}^{1-\theta} \tag{7}$$

where TFP evolves as:

$$A_{mt} = A_m (1 + \gamma_{mt})^t \tag{8}$$

The law of motion of the aggregate capital stock (K_t) in the economy is given by:

$$K_{t+1} = (1 - \delta) K_t + X_t \tag{9}$$

where δ is the depreciation rate.

The output of the service sector is only used for consumption through the composite good. Therefore, the service sector resource constraint is given by:

$$S_t = A_{st} K_{st}^{\theta} N_{st}^{1-\theta} \tag{10}$$

where TFP evolves as:

$$A_{st} = A_s (1 + \gamma_{st})^t \tag{11}$$

In the equations above, the TFP parameters A_m, A_s, γ_{mt} and γ_{st} are also assumed to be country specific. Recovering how these differ across countries is the main contribution

[13] These are governmental institutions that buy export crops from farmers at fixed low prices, then resell them aborad at world prices. See Sachs and Warner (1995), Wacziarg and Welch (2003) for details.

[14] See for example Hsieh and Klenow (2007) and Ngai and Pissarides (2007).

of this paper. Again, a country's institutions and policies affect its productivity in these economic activities.

2.2. Equilibrium

In this section, I describe how to solve for the competitive equilibrium of the model economy from the start of structural transformation[15].

Note that there are no distortions in the economy, therefore the equilibrium allocations can be obtained by solving a social planner's problem. Let T be the first period in which the economy can move labor out of agriculture. From period T on, a social planner chooses the allocations $(K_t, K_{mt}, K_{st}, N_{at}, N_{mt}, N_{st}, S_t, L_t)$ to solve the following maximization problem:

$$\max \sum_{t=T}^{\infty} \beta^{t-T}(\log(\Phi_t) + V(A_t))$$

s.t

$$\Phi_t = \left(\lambda M_t^{\frac{\epsilon-1}{\epsilon}} + (1-\lambda) S_t^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon}{\epsilon-1}}$$

$$\overline{A} = A_{at} N_{at}^{\alpha} L_t^{1-\alpha}$$

$$S_t = A_{st} K_{st}^{\theta} N_{st}^{1-\theta}$$

$$M_t + X_t = A_{mt} K_{mt}^{\theta} N_{mt}^{1-\theta}$$

$$K_{t+1} = (1-\delta) K_t + X_t$$

$$K_{mt} + K_{st} = K_t$$

$$N_{at} + N_{mt} + N_{st} = 1$$

In what follows, I develop a solution method similar to the one sector growth model. Recalling that we normalized land to be one, and given the preferences over food consumption, we can easily solve for employment in agriculture; which depends only on

[15] The definition of competitive equilibrium is standard so I do not reproduce it here.

productivity in the agriculture sector:

$$N_{at} = \left(\frac{\overline{A}}{A_{at}}\right)^{\frac{1}{\alpha}} \tag{12}$$

Let $N_t = 1 - N_{at}$ be the total time that can be allocated between the manufacturing and service sectors. Then the problem is reduced to solving the following two-sector planner's problem:

$\max \sum \beta^t \left(\frac{\epsilon}{\epsilon - 1}\right)$

$\log \left[\lambda \left(A_{mt} K_{mt}^{\theta} N_{mt}^{1-\theta} + (1-\delta)K_t - K_{t+1}\right)^{\frac{\epsilon-1}{\epsilon}} + (1-\lambda) A_{st}^{\frac{\epsilon-1}{\epsilon}} K_{st}^{\frac{\epsilon-1}{\epsilon}\theta} N_{st}^{\frac{\epsilon-1}{\epsilon}(1-\theta)}\right]$

$s.t$

$$K_{mt} + K_{st} = K_t \tag{13}$$

$$N_{mt} + N_{st} = N_t \tag{14}$$

The F.O.C for this problem are given by:

$$\lambda A_{mt} K_{mt}^{\theta-1} N_{mt}^{1-\theta} M_t^{-\frac{1}{\epsilon}} = (1-\lambda) A_{st}^{\frac{\epsilon-1}{\epsilon}} K_{st}^{\frac{\epsilon-1}{\epsilon}\theta - 1} N_{st}^{\frac{\epsilon-1}{\epsilon}(1-\theta)} \tag{15}$$

$$\lambda A_{mt} K_{mt}^{\theta} N_{mt}^{-\theta} M_t^{-\frac{1}{\epsilon}} = (1-\lambda) A_{st}^{\frac{\epsilon-1}{\epsilon}} K_{st}^{\frac{\epsilon-1}{\epsilon}\theta} N_{st}^{\frac{\epsilon-1}{\epsilon}(-\theta)} \tag{16}$$

$$\frac{M_{t-1}^{-\frac{1}{\epsilon}} \varphi_{t-1}^{-1}}{M_t^{-\frac{1}{\epsilon}} \varphi_t^{-1}} = \beta \left[1 - \delta + \theta A_{mt} \left(\frac{K_t}{N_t}\right)^{\theta-1}\right] \tag{17}$$

where

$$\varphi_t = \lambda M_t^{\frac{\epsilon-1}{\epsilon}} + (1-\lambda) S_t^{\frac{\epsilon-1}{\epsilon}} \tag{18}$$

Equations (15) and (16) equate marginal products of capital and labor in manufacturing and services. Equation (17) states that the marginal rate of intertemporal substitution of the consumption good equals to the marginal rate of transformation of current consumption to future consumption.

Dividing equation (15) by (16) and combining with (13) and (14), yields:

$$\frac{K_{mt}}{N_{mt}} = \frac{K_{st}}{N_{st}} = \frac{K_t}{N_t} \tag{19}$$

i.e.; capital to labor ratios are equalized across sectors.

Using equation (19) in (15) leads to:

$$\frac{1-\lambda}{\lambda}\left(\frac{M_t}{S_t}\right)^{\frac{1}{\epsilon}} = \frac{A_{mt}}{A_{st}} \tag{20}$$

This equation gives the relative consumption of services and the manufactured good. Note that this ratio depends only on current period productivities.

Let C_t be the non-agricultural aggregate expenditures. I show in the appendix that:

$$C_t = \frac{\varphi_t M_t^{\frac{1}{\epsilon}}}{\lambda} \tag{21}$$

where φ_t is as defined in equation (18).

Equations (17) and (21) then imply:

$$\frac{C_t}{\beta C_{t-1}} = 1 - \delta + \theta A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta-1} \tag{22}$$

This equation is similar to the standard Euler equation for the one sector growth model if one notes that the manufacturing and service sectors can be aggregated to one sector with production function:

$$F(K_t, N_t) = A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta} N_t \tag{23}$$

Equations (12), (19), (20), (22) and the resource constraint equations (13) and (14) completely characterize the equilibrium allocations.

I show in the appendix that one can reduce the problem of solving for the equilibrium allocations to a unique dynamic equation of capital.

$$\begin{aligned} K_{t+1} \quad = \quad & A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta} N_t + (1-\delta)K_t - \beta\left[1 - \delta + \theta A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta-1}\right] \\ & \left[A_{mt-1}\left(\frac{K_{t-1}}{N_{t-1}}\right)^{\theta} N_{t-1} + (1-\delta)K_{t-1} - K_t\right] \end{aligned} \tag{24}$$

Given the initial capital stock and transversality condition, we can solve for the path of aggregate capital stock for the economy using equation (24). Once capital is known, all other allocations can be easily derived. In particular, I show in the appendix that the quantity of labor used in the service sector is given by:

$$N_{st} = \frac{C_t}{A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta}\left[1 + \left(\frac{\lambda}{1-\lambda}\right)^{\epsilon}\left(\frac{A_{st}}{A_{mt}}\right)^{1-\epsilon}\right]} \tag{25}$$

where C_t is given by:

$$C_t = A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta} N_t + (1-\delta)K_t - K_{t+1} \tag{26}$$

The strategy for computing the equilibrium allocations can be summarized as follows. Non-agricultural labor using equation (12). From equation (24), I compute the path of aggregate capital in the economy. Equation (26) yields the sequence of the composite consumption good. Finally, (25) yields the hours in the service sector. The other series: sectoral capital, labor in manufacturing and sectoral outputs are then easily derived.

For the equilibrium prices, I normalize the price of the manufactured good to 1 in each period and let p_{at}, p_{st} be respectively the prices of the agricultural and service goods relative to the manufactured good. The wage rate and rental rate of capital are the marginal physical products of labor and capital of the manufacturing sector technology. Given wage equality between sectors, we have:

$$p_{st} = \frac{A_{mt}}{A_{st}} \tag{27}$$

This equation results from the equality of capital share in manufacturing and services which leads to the same capital to labor ratio across the two sectors. The relative price of the agriculture good is the wage rate divided by the marginal product of labor of the modern agriculture technology:

$$p_{at} = \frac{w_t}{\alpha A_{at} N_{at}^{\alpha-1}} \tag{28}$$

2.3. Asymptotic Balanced Growth Path with Structural Transformation

In this section, I show conditions for the existence of an asymptotic aggregate balanced growth path with structural transformation. Notice that the equation defining the equilibrium allocation for capital is similar to the equation that one obtains from the one sector growth model. Asymptotically, the agriculture sector will disappear (in the sense that $N_{a,t} = 0$). Let Y_t be the aggregate non-agriculture output. We already saw from equation (23) that Y_t can be written as:

$$Y_t = A_{mt} \left(\frac{K_t}{N_t} \right)^{\theta} N_t \tag{29}$$

An asymptotic balanced growth path is a set of allocations such that Y_t, K_t and C_t grow asymptotically at the same constant rate g. Asymptotically, $N_t = 1$ and equation (29) implies:

$$g = (1 + \gamma_{mt})^{\frac{1}{1-\theta}} - 1 \tag{30}$$

where γ_{mt} is the TFP growth rate in the manufacturing sector. This equation states that in the limit, aggregate growth depends only on TFP growth in manufacturing. This implies that the existence of asymptotic balanced growth requires only constant TFP growth rate in manufacturing[16], $\gamma_{mt} = \gamma_m, \forall t$. The intuition for this result is that the relative price of services is inversely proportional to service TFP. Therefore, growth in service output due to TFP will be neutralized by a decrease in its relative price.

Notice that there is structural transformation along the asymptotic balanced growth path. The necessary and sufficient conditions are:

$$\epsilon \neq 1 \text{ and } \gamma_m \neq \gamma_{st}$$

[16] I assume this holds below.

This result can be seen from the following equation derived in the appendix:

$$\log(N_{st+1}) - \log(N_{st}) \approx \left(\frac{\lambda}{1-\lambda}\right)^{\epsilon} \left(\frac{A_{st}}{A_{mt}}\right)^{1-\epsilon} \left[1 - \left(\frac{1+\gamma_{st}}{1+\gamma_m}\right)^{1-\epsilon}\right] \tag{31}$$

This expression is different from zero if $\epsilon \neq 1$ and $\gamma_m \neq \gamma_{st}$. If $\gamma_m > \gamma_{st}$, labor flows from manufacturing into services. This result is similar to the one obtained by Ngai and Pissarides (2007) in a more general model[17].

3. Calibration to the US Economy

In this section, I calibrate the model to the US economy for the period 1950-2000. The sources and detail of the data series are explained in the appendix.

3.1. Parameter Values

The model is calibrated to match the U.S structural transformation and GDP growth from 1950 to 2000. The model period is 1 year. The natural counterpart for labor input in the model is sectoral shares of hours worked, this will be used for the calibration[18]. The parameter values to determine are $\overline{A}, \beta, \delta, \epsilon, \lambda$ and the time series for A_{at}, A_{mt}, A_{st}. I assume constant TFP growth rates for manufacturing and services for the US.

Choosing values for the productivity levels $A_{i(i=a,m,s)}$ amounts to choosing units; therefore, I normalize those to 1 in 1950. I set the labor share in agriculture α to 0.7 to be consistent with the empirical findings of Hayami and Ruttan (1985) and Mundlank (2001). I also use the standard capital share value of 0.33 for θ.

Contrary to the the standard calibration method for growth rates, discount factor and depreciation rate parameters, I don't assume that the US economy is on a balanced growth path[19]. Instead, I calibrate the parameters ($\gamma_m, \gamma_s, \beta,$ and δ) jointly to match

[17]Their model has 1 capital producing sector and $n-1$ symmetric consumption sectors. Asymptotically, their economy also converges to two sectors: the capital producing sector and the slowest consumption sector.

[18]In the next session when applying the model to developing countries, I will use sectoral employment shares because data for sectoral hours is not available for all the countries considered in my sample.

[19]In 1950, the share of agriculture in total output was 7.9% and it decreased to 1.16% in 2000.

four averages in the data from 1950 to 2000: average growth rate of GDP per capita, average growth rate of the price of the service good relative to the manufactured good, average investment to output ratio and average capital to output ratio. Table 2 shows the targeted statistics from the model and the data.

The average GDP per capita growth rate is linked to the manufacturing TFP growth rate through equation (29) which shows that asymptotically GDP growth depends only on manufacturing TFP growth. The average growth rate of the price of the services relative manufacturing will be used to find the service TFP growth rate. From equation (27), we have:

$$\log(p_{st}) = \log(A_{mt}) - \log(A_{st}) \tag{32}$$

Differentiating this equation with respect to time, yields:

$$\Delta p_{st} = \gamma_m - \gamma_s \tag{33}$$

where Δp_{st} is the slope of the price of the service good relative to the manufactured good. From the Groningen 10-sector industry database, I calculated the relative price of services from 1950 to 2000[20]. On average, the price of services relative to manufacturing increased by 0.88% per year. Then, $\gamma_s = \gamma_m - 0.0088$. The last two targeted statistics will help determine the discount factor β and depreciation rate δ.

Next, I calibrate the agricultural productivity growth rate parameter γ_{at} and the subsistence level $\overline{A}$. The growth rate of agricultural productivity is set so that the model matches the employment share in agriculture in the US. I assume that the growth rate varies each decade starting in 1950[21]. The growth rate between two dates t_1 and t_2 is calculated as follows:

$$\gamma_{a_{t_1 t_2}} = \left(\frac{N_{at_1}}{N_{at_2}}\right)^{\frac{\alpha}{t_2 - t_1}} - 1 \tag{34}$$

where N_{at} is the agricultural share of employment at date t . The calibrated values of

[20]See the data appendix for details .

[21] I did not assume constant productivity growth rate in agriculture for the entire period because labor allocated to the manufacturing and service sectors is very sensitive to labor in the agriculture sector. Moreover, such assumption would be hard to justify in light of the agricultural technology formulation and the path of agricultural labor share.

γ_{at} are shown in table 3 in the appendix. The subsistence level is just the agricultural output in every period after the start of structural transformation. Because I normalized agricultural TFP to be 1 in 1950, it follows:

$$\overline{A} = N_{a1950}^{\alpha} \tag{35}$$

Lastly, I need to calibrate the initial capital k_0 and the parameters ϵ and λ. The parameter ϵ is the elasticity of substitution between the manufacturing and service goods and λ is the weight of the manufactured good in the production of the composite good. The initial capital is chosen to match the share of hours in manufacturing in 1950. The calibrated value is 2.8. The parameters ϵ and λ determine the labor reallocation between the manufacturing and service sectors. For labor to be reallocated from the high productive sector (manufacturing) to the low productive sector (services), ϵ has to be between 0 and 1. In other words, $\frac{\epsilon-1}{\epsilon}$ has to be negative. I choose values of ϵ and λ to minimize the quadratic norm of the difference between the predicted and actual manufacturing shares of hours worked between 1950 and 2000. The corresponding values are: $\epsilon = 0.45$ and $\lambda = 0.01$. Table 1 summarizes the calibrated parameter values.

Table 1: Calibrated Parameters

A_a	A_m	A_s	$\overline{A}$	α	β	δ	ϵ	λ	θ	γ_m	γ_s
1	1	1	0.24	0.7	0.97	0.04	0.45	0.01	0.33	0.014	0.0052

Table 2: Statistics in the Data and the Model

Statistics, average 1950-2000	Data (%)	Model (%)
Per Capita GDP Growth Rate	2.10	2.10
Capital to Output Ratio	2.40	2.40
Investment to Output Share	20.30	21.00
Growth Rate of Price of Services / Manufacturing	0.88	0.88

3.2. Structural Transformation of the US economy

This section provides some insights into how well the calibrated model fits the data. I use the calibrated model to compute the sectoral shares of hours of the US economy from 1950 to 2000 and compare them with the data series[22].

Figure 1 shows the structural transformation predicted by the model. It shows that the model does a good job at replicating the sectoral shares of hours worked. By construction, the model matches exactly the agricultural share of hours for the years used in the calibration. But the model also does a good job in the other years. Of greater interest is the fact that there is a close match between the model and the data in the other two sectors. In particular, the model traces very well the shares of hours in the manufacturing and service sectors until the early 1990s. However, starting in the mid 1990s, the data show a drop in manufacturing share of hours that is not well replicated by the model. This discrepancy is caused by two factors.

First, the model abstracts from increases in total hours worked. However, as Rogerson (2007) shows, there have been a substantial increase in total hours worked in the US starting from the mid 1980s and most of the increase occurred in the service sector. By abstracting from growth in total hours and using sectoral shares, the model does not capture the full increase in the share of services. I abstract from growth in total hours because such data is not available for the developing countries for which the model will be used to determine sectoral TPF paths in the next section.

The second issue is the assumption of constant growth rates for productivity in manufacturing and services. In fact, Brauer (2006) of the Congressional Budget Office reported that there was an acceleration of manufacturing productivity since 1979. In my model, this acceleration would lead to a decrease in the share of hours in manufacturing. Adding this improves the fit slightly but given that the model does fairly well, I avoid this to focus on the long run growth.

[22]The data series has been filtered to focus on low frequency time series.

4. Sectoral TFP Paths for Developing Countries

In this section, I use the calibrated model to infer sectoral TFP time series for a developing countries. Specifically, assuming all countries have the same preference parameters[23], I find series for sectoral TFP such that when fed into the model they replicate the structural transformation and path of GDP per capita of Africa (average), Brazil, and Korea for the period 1960-2000[24]. This exercise will allow me to compare paths of sectoral TFP and identify the least productive sectors as well as convergence or divergence to the US. The assumption of constant productivity growth rates in manufacturing and services for the entire period is not empirically plausible for all countries. Some of the countries show a clear change in the trend of income per capita, signaling a change in productivity[25].

The agricultural TFP level for country i at date t can be obtained as follows:

$$A^i_{at}(N^i_{at})^\alpha = \overline{A} = A^{us}_{at}(N^{us}_{at})^\alpha$$

Thus:

$$A^i_{at} = \left(\frac{N^{us}_{at}}{N^i_{at}}\right)^\alpha A^{us}_{at} \tag{36}$$

where A^{us}_{at} and N^{us}_{at} represent respectively the agricultural productivity and employment share for the US at time t.

I calculate A^i_{at} every 10 years starting in 1960, and assume constant growth rates within each decade[26]. With the calculated growth rates, I can deduce the yearly agricultural TFPs. Table 3 in the appendix shows the productivity growth rates in agriculture. Korea has the fastest productivity growth in agriculture among the developing countries. On the other end, Africa had the worst productivity growth in agriculture during the whole period.

The other two productivity series and the initial capital stock are calibrated to match

[23]This assumption is often made in the literature. See for example Hsieh and Klenow (2007); Duarte and Restuccia (2007) and Gollin et al. (2007).

[24]Bah and Brada (2008) uses this model to assess the productivity catch up in transition countries of Eastern Europe.

[25]An important issue is to identify the source of these productivity changes. This is left for future work.

[26]The employment data is available at 10-year intervals.

GDP per capita relative to the US in 1960, GDP per capita growth for the period 1960-2000 and the sectoral shares of employment in manufacturing and services. For the employment shares, I specifically target the labor reallocation to the service sector[27]. As I mentioned earlier, some countries show clear changes in the trend of GDP per capita, signaling a change in TFP growth rates in manufacturing and services. For these countries, I divide the period 1960-2000 into sub-periods corresponding to the different trends in per capita GDP. For each sub-period, I match the average GDP per capita growth rate. To compute real GDP for for the developing countries, I use the prices for the US in 2000.

Before showing the relative sectoral TFP time series for all 3 countries, I will present a detailed analysis of the structural transformation process and economic growth for each country. I will also discuss the sectoral TFPs necessary for the aggregate outcomes and show how the model with the inferred TFP time series compare to the data.

4.1. Growth and Structural Transformation of Africa

I use the model to find the sectoral productivities for the average of 11 African countries[28]. All countries in the sample are located in Sub-Saharan Africa. Several criteria were used in the selection of countries, the main one being data availability and quality[29]. Data for sectoral shares of employment is available for 14 countries. The second criterion excludes countries that had less than 1 million inhabitants in 1960. The third criterion excludes countries with a mining sector's share of GDP higher than 30% for more than 5 years. The final sample includes the following countries: Benin, Cameroon, Central African Republic, Chad, Cote d'Ivoire, Ghana, Madagascar, Mali, Senegal, Togo and Uganda. In what follows, I refer to the population weighted average of these 11 countries as Africa.

Africa had a poor economic performance between 1960 and 2000. Relative to the US,

[27] Since, I match agriculture almost perfectly, matching the labor reallocation to the service sector implies matching it for manufacturing also.

[28] I take the average because the countries are relatively small and the data may have a lot of measurement errors.

[29] The data quality criterion excluded Kenya; which had agriculture share of employment decline from 82.1% in 1970 to 23% in 1980. Even the countries with the fastest structural transformation, like Korea, didn't have such dramatic decline in a decade.

its GDP per capita declined from 9% in 1960 to 3% in 2000. However, the path of GDP per capita shows three sub-periods with different growth trends. The first sub-period runs from 1960 to 1971 and is characterized by a slight increase in per capita GDP. But in the second sub-period, which runs between 1972 and 1994, there is a big decline in GDP per capita. The third sub-period, which starts in 1994 is similar to the first sub-period. Thus, with constant productivity growth in manufacturing and services, I cannot replicate the path of income per capita for Africa. Instead, the model requires positive productivity growth rates in manufacturing and services in the first and third sub-periods, and negative rates in the second. The calibrated rates are 0.9% in manufacturing and 0.4% in services in the first sub-period. But they were respectively -1.12% and -4% in the second (1971-1994), and then 1.6% and 0.7% in the third sub-period (1994-2000). These changes in growth rates are treated as unexpected. That is in the first period, the household expects that the manufacturing and service TFP growth rates will be constant for ever. After they change in 1971, the household will believe that the new rates will be constant for ever, etc ....

Panel (A) of figure 2 shows the the path of GDP per capita relative to 1960. The model is able to replicate very closely the path of per capita GDP. The graph shows that the small GDP per capita growth in the period of 1960-1971 disappeared between 1971 and 1994. In fact, Africa was poorer in 1994 than it was in 1960. After 1994, there was a small recovery. Panel (B) shows the process of structural transformation that accompanied these 40 years of economic stagnation. The first observation from the graph is that Africa reallocated a very small percentage of its workforce out of the agriculture sector. Agricultural employment share declined from 84% to 70%. This implies that a major problem for Africa is agricultural productivity. As long as Africa doesn't improve its productivity in agriculture, it cannot move labor to the other two sectors of the economy. The sources of poor efficiency in the agricultural sector are diverse. They can be the result of poor soil fertility, lack of efficient farming techniques, lack of use of fertilizers and so on.

The second observation from the figure is that the employment share of the manufacturing sector increased very little compared to the increase in the service sector. manufacturing employment share increased from 4% to 8% while the share of the service sector increased from 11% to 22%. This means that most of the labor reallocation occurred between the agriculture and service sectors. In the model framework, the small increase in manufacturing employment share is due to the low productivity of the service sector relative to the manufacturing sector. Thus, the second biggest problem for Africa is productivity in the service sector.

4.2. Growth and Structural Transformation of Brazil

GDP per capita for Brazil increased nearly 2.5-fold between 1960 and 2000. But the time series shows two sub-periods with very different outcomes. From 1960 to 1980, Brazil experienced a rapid growth with an average growth rate of 4.2%. However, Brazil was almost stagnant between 1980 and 2000, growing on average by less than 0.8% per year[30]. Despite the fast growth in the first period, Brazil did not catch up to the US. Its GDP per capita was almost at 20% of the US during the period.

Despite this mixed growth performance, Brazil experienced big changes in sectoral employment shares. Agricultural employment share decreased from 52% in 1960 to 24% in 2000. During the same period, manufacturing employment share increased first from 15% in 1960 to 22% in 1985, and then decreased to 19% by 2000. The service employment share increased by 24 percentage points for the whole period and was at 57% in 2000. This indicates that Brazil transitioned from the first to the second phase of its structural transformation process around 1985. One observation we can take from the changes of labor shares is that Brazil did not allocate a large percentage of its labor force to the manufacturing sector. One reason would be that the service sector was highly unproductive compared to the manufacturing sector especially in the second sub-period.

Calibrating the model to match income per capita growth and the structural transformation yields productivity growth rates at respectively 2.2% in manufacturing and 1.8% in services in the first sub-period. In the second sub-period, the growth rates were

[30]It seems then appropriate to assume that there was a break in the rates of growth of the productivities in manufacturing and services.

respectively 1.13% and -2.4%. Again, the changes in the growth rates are treated as unexpected and are assumed to be permanent.

With the calibrated productivities, the model is able to trace very closely the path of per capita GDP as shown in panel (A) of figure 3. Panel (B) shows the structural transformation of Brazil. The model is able to replicate the changes of employment shares in all three sectors[31]. We can see that the employment share of services increased slightly more in the second sub-period than in the first. This is caused by the higher TFP growth differential between manufacturing and services in the second sub-period.

The analysis above shows that while the agriculture and manufacturing sectors were holding ground relative to the US, the service sector was not. In the second period, there was a dramatic decline in service TFP. This was the driving force behind income stagnation for those 20 years. In fact, manufacturing TFP growth was high in both sub-periods.

4.3. Growth and Structural Transformation of Korea

Korea is a growth miracle. It was able to achieve and sustain high output growth for many years. GDP per capita increased nearly 13-fold and it was catching up to the US. It went from 9% of the US in 1960 (the same as Africa) to 50% in 2000. It also experienced substantial structural transformation in the period 1960-2000. Empirically, the agricultural employment share declined from 66% in 1960 to only 10% in 2000. The manufacturing employment share first increased from 9% in 1960 to 35% in 1991 and then declined to 28% in 2000. On the other hand, the service share of employment increased by 37 percentage points in the 40-year period. It increased from 24% to 62% of total employment. Korea fits very well the structural transformation process accompanying economic development as described by Kuznets[32].

I choose manufacturing and service TFP time series to match the sectoral employment shares described above and the path of GDP per capita growth. The steady growth of

[31] The kinks that appear in the model's curves are due to the brusque changes in the sectoral TFP growth rates.

[32] See Bah (2007) for a discussion of this topic

GDP per capita from 1960 to 2000 is consistent with constant productivity growth rates both in the manufacturing and service sectors. The calibrated growth rates are 3.6% in manufacturing and 3.0% in services from 1960 to 2000. After 2000, I assume that these rates drop unexpectedly to the level of the US rates, implying that the catch up of Korea stops at this time. Figure 4 shows the GDP per capita growth and structural transformation of Korea. As can be seen in panel (A), the model replicates very well the the path of GDP per capita relative to 1960. We can also see in panel (B), the model's labor reallocation between manufacturing and services matches that of the data but the paths of sectoral employment shares in those sectors deviate somewhat from those of the data.

These two figures show that the calibrated sectoral TFP time series are consistent with the paths of GDP per capita and sectoral employment shares for Korea. In addition, from the model framework, we see that the underlying reason for Korea's fast income growth was the increased productivity in all three sectors[33]. The productivity increases were also sustained for long periods. This is a key difference between Korea and Brazil. While Brazil improved productivity in all 3 sectors between 1960 and and 1980, the trends did not continue after that. The service sector experienced a big decline in TFP.

4.4. Comparing Sectoral TFP Paths for Africa, Brazil and Korea

In the sections above, I discussed in detail the structural transformations and GDP per capita growths for Africa, Brazil and Korea. I also discussed the sectoral TFP time series necessary for the aggregate outcomes for each country. In this subsection, I will summarize the paths of sectoral TFP relative to the US for the 3 countries. This will highlight the least productive sectors in each country.

I plot in figure 5 the relative productivities in the three sectors. Panel (A) shows the relative TFP in agriculture. Between 1960 and 1970, the US had a high TFP growth in agriculture, therefore all other countries had downward slopping relative TFPs. However since 1970, US agricultural TFP growth was not so high and most of the countries

[33]This conclusion should be treated with care because the assumption of closed economy may be too strong for Korea.

had increasing relative TFPs. The highest productivity growth was for Korea, where relative TFP more than doubled increasing from 16% in 1970 to 40% in 2000. Brazil's relative TFP increased somewhat after 1970 but it was only around 21% as of 2000. As I mentioned earlier, Africa is very unproductive in agriculture. Its relative productivity declined from 12% to 10% of the US in the period 1970-2000.

As can be seen in panel (B), the relative TFPs in the manufacturing sector are better than those of the agriculture sector. Korea started with lower relative manufacturing TFP than Brazil but it ended up being the highest by 2000. It increased from 36% of the US in 1960 to 85% in 2000. Brazil had high growth in the first sub-period, which slowed down in the second. Despite of this, relative manufacturing TFP increased from 50% to 57% in the period 1960-2000. Africa had a decline relative manufacturing TFP for both subperiods with a much bigger in the second subperiod. Its manufacturing TFP declined from 35% of the US in 1960 to 19% in 2000.

For the service sector, the relative TFPs are shown in panel (C). Korea and Africa started almost at the same level (31% of the US) but had different paths. While Korea experienced a sustained growth and more than doubled its relative service TFP to 82% in 2000, Africa had a big decline decline in the whole period. It was around 11% of the US from 1994 to 2000. For Brazil, after a catch-up in the first sub-period, it experienced a big decline in the second. Service TFP increased from 45% of the US in 1960 to 53% in 1980 but declined to 30% in 2000.

Comparing the relative sectoral TFPs, all countries are the least productive in agriculture, followed by services and then manufacturing. Table 4 shows relative agricultural TFP divided by relative service TFP and relative service TFP divided by relative manufacturing TFP. Due to a big decline in productivity in services, Africa's relative agricultural TFP increased from 55.92% of relative service TFP in 1960 to 92.55% in 2000. A similar phenomenon occurred in Brazil where relative agricultural TFP increased from 52.95% of relative service TFP in 1960 to 71.62% in 2000. For Korea it was the contrary. Relative TFP increased in both sectors but faster in services. Relative agricultural TFP declined from 64.06% of relative service TFP in 1960 to 48.28% in 2000. The comparison between relative service TFP and manufacturing shows similar trends. For Africa and Brazil, there were bigger declines in relative productivity in services than manufacturing. Korea caught up to the US in both sectors but with a slightly higher rate in services. Africa's relative service TFP decreased from 88.57% of manufacturing TFP in 1960 to 57.93% in 2000. The decline was from 90.00% in 1960 to 52.42% for Brazil. Korea's relative service TFP increased from 86.11% of relative manufacturing TFP in 1960 to 96.73% in 2000.

A policy implication of my findings is that governments in developing countries who neglected the service sector in the past should find ways to increase productivity in that sector. As we saw for the case of Brazil, the stagnation that started in the 1980s is mainly accounted for by decreases in service TFP. For Africa, it needs to improve productivity both in the agriculture and service sectors[34].

5. Relation with the Literature

In this subsection, I compare my findings and method with the existing literature. The development literature generally divides the economy into agriculture and non-agriculture sectors[35] and consistently finds that agriculture is relatively the least productive. This is consistent with my findings. Moreover, my finding that developing countries are relatively less productive in services than in manufacturing is consistent with the empirical studies of Lewis (2004) and the McKinsey Global Institute. Also, looking at labor productivity, Duarte and Restuccia (2007) finds that relative to the US, most countries are the least productive in agricultural and services[36].

However, my finding is in contrast with those of Herrendorf and Valentinyi (2006) and Hsieh and Klenow (2007). In Hsieh and Klenow (2007), there are two sectors: investment and consumption. They find that relative TFP is lower in investment than consumption. Herrendorf and Valentinyi (2006) has four sectors: services, consumption

[34] As future research, it is interesting to find the sources of the low TFPs in these sectors. This will lead to specific policy prescriptions on how to improve the TFPs.

[35] See Kuznets (1971), Gollin et al. (2002, 2007), Cordoba and Ripoll (2005), Restuccia et al. (2007).

[36] Their data set include developed and developing countries.

goods, construction and equipment goods. They find that relative TFP differences in services are small compared to the other sectors. They also aggregate the four sectors into two sector-splits and find that relative TFP is lower in investment than consumption. Because my sectoral subdivision is different, I cannot make a direct comparison of our findings. However, given that agriculture and services (the two least productive sectors) produce the largest share of consumption, my findings suggest that developing countries are more productive in investment than in consumption.

The two above papers use consumer prices derived from the benchmark studies of the Penn World Table (PWT) to infer cross-section relative TFPs. The benchmark studies are conducted for a few select years, hence the use of cross-section data[37]. My paper complement these studies by computing the time series of sectoral TFPs for a period of 40 years. This is important because many developing countries experience large changes in GDP growth over time which suggest that their sectoral TFPs undergo large changes over time as well.

However the differences in our findings necessitate further investigation. A key factor for the discrepancy in findings is price measurements. The two above papers use consumer prices instead of producer prices[38]. Authors like Jorgensen argue that one should use producer prices for computing sectoral TFPs. Following the method explained by Herrendorf and Valentinyi (2006), I compute the prices of services relative to manufacturing from the benchmark data of the PWT in 1996 for Brazil and Korea. Relative to the US, the relative prices are 1.70 for Brazil and 4.30 for Korea[39]. From my model, the same relative prices are respectively 2.45 and 1.55[40].

A key innovation of my paper is the use of panel data on sectoral employment and GDP per capita, which allows me to compute time series for sectoral TFPs. With long time series, I can find not only the least productive sectors in developing countries, but also the

[37] Herrendorf and Valentinyi (2006) uses the 1996 benchmark data whereas Hsieh and Klenow (2007) uses data for 1980, 1985 and 1996. The 1996 study has the largest number of developing countries.
[38] Differences in consumer prices can come from many sources other than differences in productivity.
[39] To make the comparison valid, I divide the relative prices for Korea and Brazil with that of the US to eliminate the differences in units from the two sources.
[40] It would have been better to confront these relative prices with thoose of a different data source. Unfortunately, I am unable to find such data. The OECD data cannot be used because unlike the PWT, the prices in national currencies and international dollars are the the same.

sectoral sources of big changes in GDP per capita for a given country. Moreover, given that data for developing countries can have a lot of measurement errors, it is important to estimate sectoral TFPs using different data sets in addition to prices.

6. Conclusion

In this paper, I asked which sectors have the highest TFP gaps between rich and poor countries. Because of data limitations, direct methods are not useful for estimating sectoral TFPs. I argued that data on structural transformation can lead to information in sectoral TFP. I proposed a new approach for estimating sectoral TFPs. The approach extends the neoclassical growth model to three sectors and uses it to infer sectoral TFP time series consistent with the structural transformation and GDP growth of developing countries over a 40-year period. The calibrated model does a good job at replicating the structural transformation process of the US economy for period 19500-2000. Using the proposed approach, I find that developing countries have the highest TFP gap in agriculture, followed by services and then manufacturing.

The story in this paper was about sectoral productivity. But one can think of the sectoral residual as a combination of productivity and distortions like taxes. Then the next logical question is what's the magnitude of the two. Another related question is to understand how and why policies and institutions affects sectors differently. These questions are left for future research.

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A. Appendix A: Data Sources

The calibration of the model to the US economy requires data for GDP per capita, sectoral shares of hours worked, price of services relative to manufacturing, investment to output and capital to output. The data for GDP per capita, expressed in 1990 international Geary-Khamis dollars, is from the "Historical Statistics for the World Economy: 1-2003 AD" by Maddison. The shares of sectoral hours worked and the price of services relative to manufacturing are from the Groningen 10-sector manufacturing database. In the database, the economy is disaggregated into 10 sectors. The value-added of each sector is given in both constant and current prices. I aggregated those sectors into the 3 sectors used throughout this paper. manufacturing includes mining, manufacturing, utilities and construction. I calculate the price of a sector by dividing its value added in current prices by the value added in constant prices. The price of services relative to manufacturing is deduced form there. This database also contains the sectoral hours worked for the US between 1950 and 1997. For the period, 1998-2000, I use the 60-sector industry database. I obtained investment series from the NIPA tables and used the perpetual inventory method to calculate capital stocks.

For the application of the model to the developing countries, I need data on sectoral employment and GDP per capita. The employment shares data is obtained from the World Bank tables (1983) for the years 1960, 1965 and 1970 and World Development Indicators online database from 1971. The per capita GDP is from Maddison.

The GDP per capita and sectoral employment shares data series for the US and developing countries have been filtered using the H-P filter to focus on low frequency trends.

The data used in the comparison of relative price of services comes from the 1996 benchmark studies of the Penn World Table (PWT). The PWT has final per capita expenditures in national currencies and international dollars for 30 sectors. I aggregate these 30 sectors to 3 following the method described by Herrendorf and Valentinyi (2006). The price of a sector for a country is its sectoral expenditures in national currency divided by its expenditures in internal dollars.

B. Appendix B: Figures, Proofs and Tables

B.1. Proofs

Proof 1: Deriving equation for the non-agricultural aggregate expenditure C_t

$$C_t = M_t + p_{st} S_t \tag{37}$$

Using equation (27) yields:

$$C_t = M_t + \frac{A_{mt}}{A_{st}} S_t \tag{38}$$

We also know that $\Phi_t(M_t, S_t)$ is homogenous of degree 1, therefore:

$$\Phi_t(M_t, S_t) = \Phi_1 M_t + \Phi_2 S_t \tag{39}$$

$$\Phi_1 = \lambda M_t^{-\frac{1}{\epsilon}} \varphi_t^{\frac{1}{\epsilon}} \tag{40}$$

$$\Phi_2 = (1-\lambda) S_t^{-\frac{1}{\epsilon}} \varphi_t^{\frac{1}{\epsilon}} \tag{41}$$

But from equation (20), we have:

$$\frac{1-\lambda}{\lambda}\left(\frac{M_t}{S_t}\right)^{\frac{1}{\epsilon}} = \frac{A_{mt}}{A_{st}} \tag{42}$$

Then:

$$\Phi_2 = \frac{A_{mt}}{A_{st}}\Phi_1 \tag{43}$$

This implies:

$$\Phi_t = \Phi_1 M_1 + \frac{A_{mt}}{A_{st}}\Phi_1 S_t = \Phi_1\left(M_t + \frac{A_{mt}}{A_{st}}S_t\right) = \Phi_1 C_t \tag{44}$$

Replacing Φ_1 by its expression, yields:

$$C_t = \frac{\varphi_t M_t^{\frac{1}{\epsilon}}}{\lambda} \tag{45}$$

where φ_t is as defined in 18

Proof 2: Deriving the dynamic equation for capital

From equations (38) and (21):

$$C_t = M_t + A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta} N_{st} \tag{46}$$

Then:

$$C_t = A_{mt}\left(\frac{K_{mt}}{N_{mt}}\right)^{\theta} N_{mt} + (1-\delta)K_t - K_{t+1} + A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta} N_{st} \tag{47}$$

Since $\frac{K_{mt}}{N_{mt}} = \frac{K_t}{N_t}$, this reduces to:

$$C_t = A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta} N_t + (1-\delta)K_t - K_{t+1} \tag{48}$$

This implies:

$$K_{t+1} = A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta} N_t + (1-\delta)K_t - C_t \tag{49}$$

Combining equations (22) and (49), we get the following dynamic equation for the aggregate capital stock:

$$K_{t+1} = A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta} N_t + (1-\delta)K_t - \beta\left[1-\delta+\theta A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta-1}\right] \left[A_{mt-1}\left(\frac{K_{t-1}}{N_{t-1}}\right)^{\theta} N_{t-1} + (1-\delta)K_{t-1} - K_t\right] \tag{50}$$

Proof 3: Deriving labor used in services

From equations (20) and (19), we have:

$$M_t = A_{mt}\left(\frac{\lambda}{1-\lambda}\right)^{\epsilon}\left(\frac{A_{st}}{A_{mt}}\right)^{1-\epsilon}\left(\frac{K_t}{N_t}\right)^{\theta} N_{st} \tag{51}$$

Combining equations (46) and (51), we get:

$$C_t = M_t + A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta} N_{st} = A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta}\left[1+\left(\frac{\lambda}{1-\lambda}\right)^{\epsilon}\left(\frac{A_{st}}{A_{mt}}\right)^{1-\epsilon}\right] N_{st} \tag{52}$$

From equation (52) we can get the quantity of labor used in the service sector.

$$N_{st} = \frac{C_t}{A_{mt}\left(\frac{K_t}{N_t}\right)^{\theta}\left[1+\left(\frac{\lambda}{1-\lambda}\right)^{\epsilon}\left(\frac{A_{st}}{A_{mt}}\right)^{1-\epsilon}\right]} \tag{53}$$

Proof 4: Deriving the necessary and sufficient conditions for the existence of an asymptotic balanced growth path with structural transformation

Asymptotically, the agriculture sector disappears and $N_t = 1$. From equation (25):

$$\frac{N_{st+1}}{N_{st}} = \frac{C_{t+1}/C_t}{(A_{mt+1}/A_{mt})\left(\frac{K_{t+1}}{K_t}\right)^{\theta}\left[\frac{1+\left(\frac{\lambda}{1-\lambda}\right)^{\epsilon}\left(\frac{A_{st+1}}{A_{mt+1}}\right)^{1-\epsilon}}{1+\left(\frac{\lambda}{1-\lambda}\right)^{\epsilon}\left(\frac{A_{st}}{A_{mt}}\right)^{1-\epsilon}}\right]} \tag{54}$$

Along the balanced growth path, from equation (30), we have:

$$1+\gamma_m = (1+g)^{1-\theta} \tag{55}$$

Thus:

$$\frac{N_{st+1}}{N_{st}} = \frac{1 + \left(\frac{\lambda}{1-\lambda}\right)^{\epsilon} \left(\frac{A_{st}}{A_{mt}}\right)^{1-\epsilon}}{1 + \left(\frac{\lambda}{1-\lambda}\right)^{\epsilon} \left(\frac{A_{st+1}}{A_{mt+1}}\right)^{1-\epsilon}} \tag{56}$$

Taking logs and approximating, yields:

$$\log N_{st+1} - \log N_{st} \approx \left(\frac{\lambda}{1-\lambda}\right)^{\epsilon} \left(\frac{A_{st}}{A_{mt}}\right)^{1-\epsilon} - \left(\frac{\lambda}{1-\lambda}\right)^{\epsilon} \left(\frac{A_{st+1}}{A_{mt+1}}\right)^{1-\epsilon} \tag{57}$$

Or

$$\log N_{st+1} - \log N_{st} \approx \left(\frac{\lambda}{1-\lambda}\right)^{\epsilon} \left(\frac{A_{st}}{A_{mt}}\right)^{1-\epsilon} \left[1 - \left(\frac{1+\gamma_s}{1+\gamma_m}\right)^{1-\epsilon}\right] \tag{58}$$

If $\epsilon \neq 1$ and $\gamma_m \neq \gamma_s$,

$$\log N_{st+1} - \log N_{st} \neq 0$$

B.2. Figures and Tables

Table 3: Agricultural Productivity growth rates

Period	1950-1960	1960-1970	1970-1980	1980-1990	1990-2000
US	0.048	0.0413	0.0019	0.0153	0.0077
Korea		0.0189	0.0279	0.0478	0.0422
Brazil		0.0102	0.0194	0.0170	0.0082
Africa		0.0033	0.0043	0.0010	0.0042

Table 4: Comparing Relative Sectoral TFPs

	Ag. Rel. TFP / Serv. Relative TFP		Serv. Rel. TFP / Manuf. Rel. TFP	
	1960	2000	1960	2000
Africa	55.32	92.55	88.57	57.93
Brazil	52.35	71.62	90.00	52.42
Korea	64.06	48.28	86.11	96.73

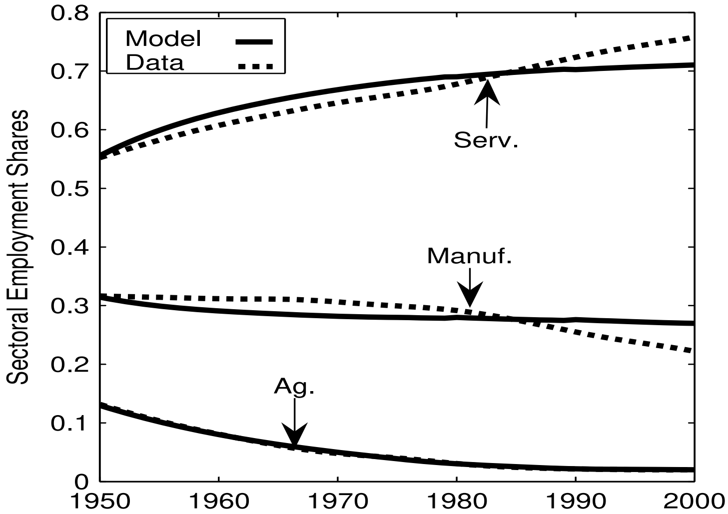
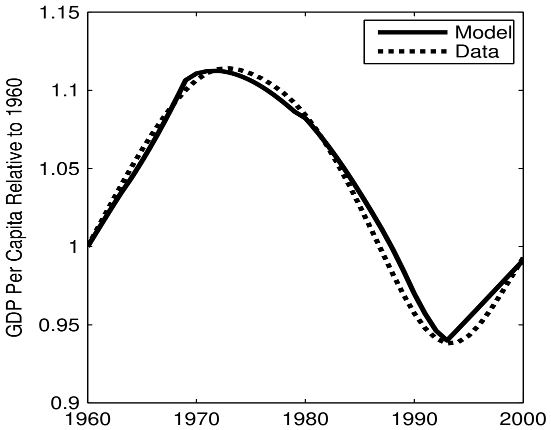
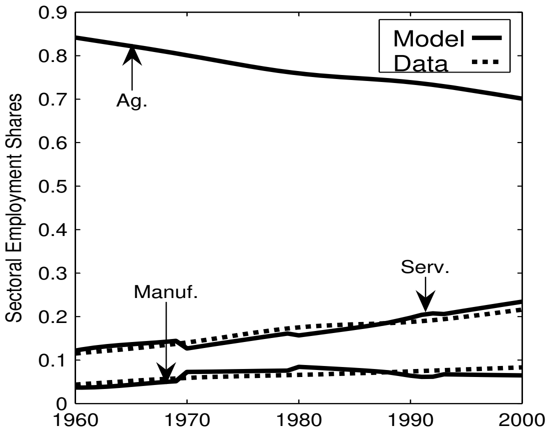


Figure 1: Structural Transformation for the US, 1950-2000

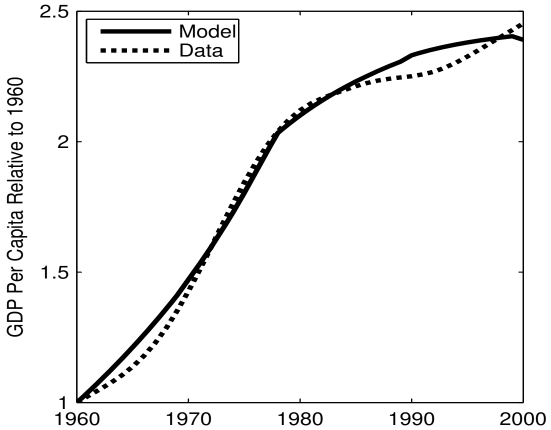


(A) Per Capita GDP

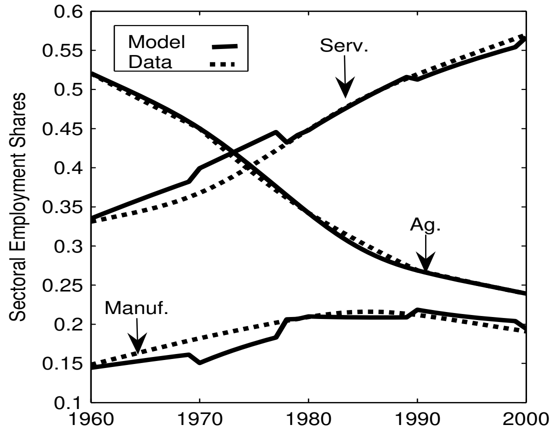


(B) Structural Transformation

Figure 2: Africa

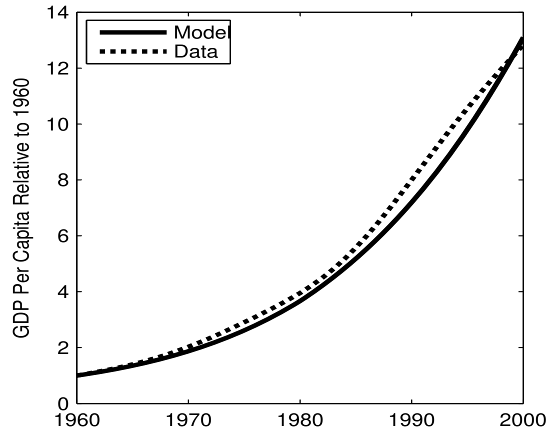


(A) Per Capita GDP

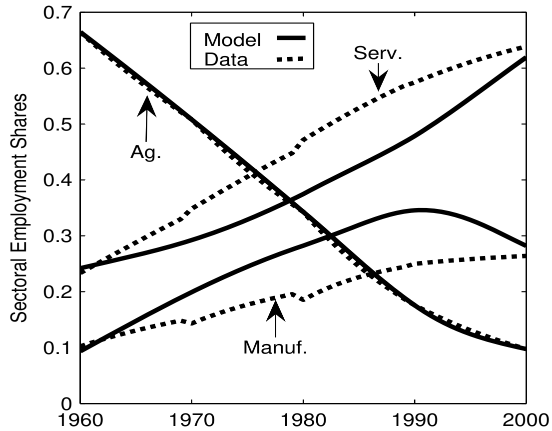


(B) Structural Transformation

Figure 3: Brazil

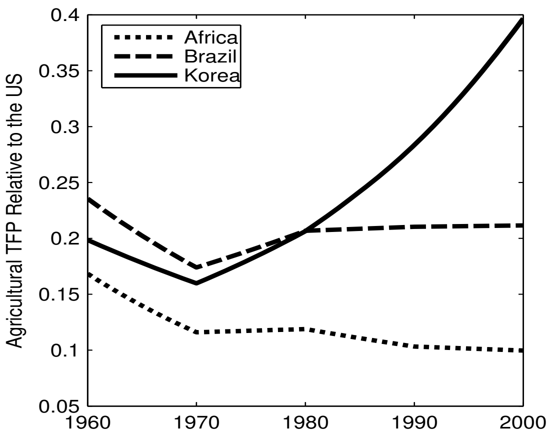


(A) Per Capita GDP

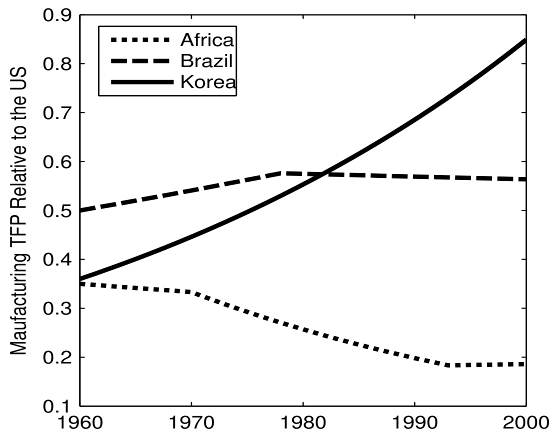


(B) Structural Transformation

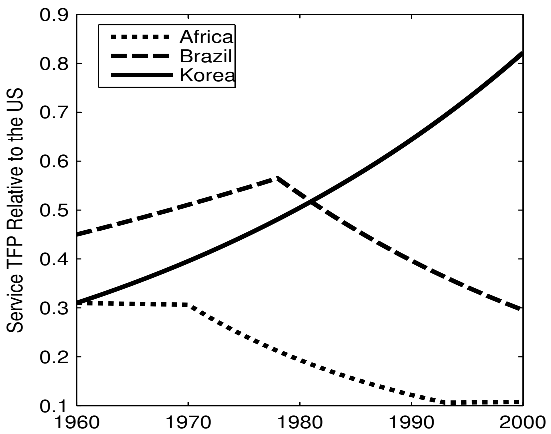
Figure 4: Korea



(A) Agriculture



(B) manufacturing



(C) Services

Figure 5: Sectoral TFP Paths