Agriculture and Aggregate Productivity: A Quantitative Cross-Country Analysis

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Abstract

A decomposition of aggregate labor productivity based on internationally comparable data reveals that a high share of employment and low labor productivity in agriculture are mainly responsible for low aggregate productivity in poor countries. Using a two-sector general-equilibrium model, we show that differences in economy-wide productivity and barriers to the use of modern intermediate inputs in agriculture generate large cross-country differences in the share of employment and labor productivity in agriculture. The model implies a factor difference of 10.8 in aggregate labor productivity between the richest and the poorest 5 percent of the countries in the world, leaving the unexplained factor at 3.2. Overall, this two-sector framework performs much better than a single-sector growth model in explaining observed differences in international productivity.

Keywords: Productivity, International Comparisons, Agriculture, Intermediate Inputs, Barriers, Two-sector Model

JEL classification: O4, O1

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1. Introduction

This paper examines the role of agriculture in accounting for international differences in output per worker. To see why agriculture is important, consider the following facts. In 1985, the average gross domestic product (GDP) per worker in the richest 5 percent of the countries in the world is 34 times that of the poorest 5 percent. This is an enormous difference in aggregate productivity. However, the labor productivity difference in agriculture is even larger: GDP per worker of the richest countries is 78 times that of the poorest countries. In contrast, the difference in GDP per worker in non-agriculture is a factor of 5. Despite very low productivity in agriculture, the poorest countries allocate 86 percent of their employment to this sector, as compared to only 4 percent in the richest countries.[1] These facts provoke two important questions. First, why do so many people in poor countries work in the extremely unproductive agricultural sector? Second, why is agricultural labor productivity so low in poor countries? Clearly, satisfactory answers to these questions are essential to understanding aggregate income differences across countries.[2]

The aim of this paper is to provide quantitative answers to the above questions using a general-equilibrium framework. At a qualitative level, there is an accepted answer to

[1] The data for aggregate GDP are from the Penn World Tables (PWT5.6); the data for agriculture are from the Food and Agricultural Organization of the United Nations (FAO). In our sample of 86 countries, the richest 5 percent are the United States, Canada, Switzerland, and Australia; the poorest 5 percent are Burundi, Tanzania, Burkina Faso, and Ethiopia. Figures 1 and 2 and Table 1 of the Appendix provide more detailed documentation of these observations. Appendix A-C, which are not for publication, are available from the authors upon request and can be accessed at: http://www.economics.utoronto.ca/diegor/research/research.html.

[2] The joint importance of employment share and sectoral productivity in accounting for cross-country productivity differences can be shown by the decomposition of aggregate GDP per worker (Y/N): $Y/N = Y_n/L_n\,(1 - L_a/N) + (Y_a/L_a)(L_a/N)$,where Y_i/L_i and L_i/N are per-worker GDP and share of employment in sector $i \in \{a, n\}$; a denotes agriculture and n non-agriculture. Consider a counterfactual scenario: if the richest 5 percent of the countries have the average employment share of the poorest countries (see Table 1 of the Appendix), aggregate productivity of the richest countries relative to this hypothetical case would be 2 to 1, only 1/17 of the actual difference between the richest and the poorest countries. Alternatively, if the richest countries have the sectoral productivity of the poorest countries, the productivity gap would be 5 to 1, about 1/7 of the actual difference between the richest and the poorest. Hence, both sectoral productivity and employment share are essential in understanding the differences in aggregate productivity across countries.

the first question: poor countries have a large share of employment in agriculture because they have what T.W. Schultz (1953) characterized as the "food problem." Due to low labor productivity, these countries have to allocate a large share of employment to farming in order to meet basic food requirements.[3] To address the second question, we formulate a two-sector general-equilibrium model that explicitly takes into account the role of agriculture and subsistence food requirements. In the model, agricultural labor productivity is determined, among other factors, by: (1) economy-wide productivity and (2) barriers to the use of modern intermediate inputs in agricultural production.[4] Simulation of the calibrated model implies that these two factors can account for large shares of employment and low labor productivity in agriculture in poor countries, thus explaining much of the observed differences in aggregate labor productivity across countries. Our analysis suggests that removing barriers to adopting modern inputs in agriculture could substantially raise agricultural and aggregate productivity in poor countries.

Admittedly, the key insight we build into the two-sector model has long existed in the economic development literature: traditional agricultural systems cannot generate high labor productivity in agriculture; opportunities for rapid productivity growth may become available only through advancement in science-based technology (e.g., Schultz, 1964; Hayami and Ruttan 1985; Huffman and Evenson, 1993). Since modern agricultural technology is often embodied in industry-supplied intermediate inputs – such as chemical fertilizers, better seed varieties, and more efficient sources of power – the extent of technical input use would generally indicate the level of agricultural modernization as well as labor productivity. Cross-

[3] The relationship between low agricultural productivity and its high share of employment does not have to hold if a country can import food. In reality, however, poor countries rarely import food. As Schultz points out, low-income countries must produce the bulk of their own food to satisfy subsistence needs since imports are costly and these countries have limited resources and products to exchange for food.

[4] Throughout the paper, intermediate inputs or modern inputs in agriculture refer to those factors that are provided outside the agricultural sector, such as chemical fertilizers, pesticides, machine services, processed seeds, fuel, and energy. FAO statistics also refer to these factors as non-agricultural inputs, which are distinguished from feeds and seeds provided within the farming sector.

country data corroborate this established view in the development literature. Using common international prices, Figure 3 plots final output per worker in agriculture against the ratio of expenditures on intermediate inputs to the value of final output in agricultural production. The plot reveals a clear pattern: high agricultural labor productivity is positively associated with the extent of intermediate input use, with a correlation coefficient in logs at 0.85. In the richest 5 percent of the countries, average expenditure on intermediate inputs is 38 percent of final output value, whereas it is only 12 percent in the poorest 5 percent of the countries.

We argue that certain distortions in factor markets may severely dampen the incentives of farmers for adopting modern inputs, thus leading to low agricultural labor productivity in poor countries.[5] This paper examines two kinds of barriers to the use of intermediate inputs. The first are direct barriers in poor countries that are reflected in the cost of modern inputs. For instance, protection of domestic industries, such as fertilizer production, may raise factor prices directly through tariffs and import quotas or indirectly by allowing the survival of inefficient domestic producers (e.g., Krueger et al., 1991). The lack of investment in market infrastructure, such as roads and distribution systems, may also raise significantly the costs of using technical inputs by geographically-dispersed rural households. The second are indirect barriers associated with labor market distortions. Obstacles to migration reduce labor flows from the agricultural to non-agricultural sector, and when combined with institutionally protected urban wages, often suppress agricultural wages to very low levels (e.g., Rosenzweig, 1988). This distortion encourages farmers to substitute cheap labor for other inputs, and therefore is an indirect barrier to intermediate input use.[6]

The quantitative analysis uses data from the Penn World Tables (PWT5.6) and the

[5] Presumably, other institutions and policies, such as heavy taxation on agricultural output and biased trade and exchange rate policies, may also suppress farmers' incentives to adopt modern inputs. However, because there is no cross-country information on agricultural taxes and trade policies that is comparable to data from FAO and Penn World Tables, we do not investigate these effects on productivity in this paper.

[6] See Manuelli and Seshadri (2003) for evidence that low labor costs were responsible for the initially slow adoption of one particular type of modern input − tractors − in U.S. agriculture.

Food and Agriculture Organization of the United Nations (FAO). To our knowledge, the FAO data are the best available information for studying labor productivity in agriculture across countries.[7] We measure economy-wide productivity in individual countries by their per-worker GDP in non-agriculture. Additionally, we measure direct barriers to using intermediate inputs by the price of the inputs relative to the price of non-agricultural output and measure indirect barriers of labor market distortions by the ratio of average wages in agriculture to non-agriculture. Taking these measures as exogenous, and using parameters values calibrated mostly to the U.S. data, the model generates quantitative predictions about the ratio of intermediate input to agricultural output, the share of employment and labor productivity in agriculture, as well as aggregate output per worker for all countries in the sample. The model generates implications for these variables that are consistent with observed cross-country differences. In particular, the model implies a ratio of 23.4 to 1 in agricultural final-output labor productivity between the richest and poorest countries, leaving the unexplained factor at 4.7. With regard to aggregate labor productivity, the model implies a factor difference of 10.8 between the richest and poorest countries, leaving the unexplained factor at 3.2. Overall, this two-sector framework performs much better than a single-sector growth model in explaining observed differences in international productivity.

This paper is closely related to the literature that applies a calibration approach to the neoclassical growth model to account for cross-country differences in labor productivity (e.g., King and Levine, 1994; Chari et al., 1996; Klenow and Rodriguez-Clare, 1997;

[7] These data are relevant for our purpose because the methodology of aggregating goods in agriculture follows a procedure similar to the PWT for the comparison of aggregate output across countries. The idea is to price a representative and common basket of goods across countries and convert output valued at domestic prices into a measure of output valued at a common set of prices (international prices), rendering comparable measures of output that are less subject to price distortions across countries. In addition, the FAO data are relevant for international comparisons of labor productivity in agriculture relative to the expenditure data in PWT because output of agricultural goods is aggregated using producer prices − prices received by farmers at the farm gate that exclude charges related to transportation, distribution, and marketing of products to the consumers. These expenses are service activities and should not be included in measures of agricultural output, especially since the price and quantity of services vary systematically with development (see Summers and Heston, 1991).

Prescott, 1998; Hall and Jones, 1999; Lucas, 2000; Parente and Prescott, 2000; Ngai, 2004; Hsieh and Klenow, forthcoming). These studies, however, do not formally model an agricultural sector that coexists with nonagricultural production. Recently, Gollin, Parente and Rogerson (2004 and forthcoming) present an extension of the neoclassical growth model that includes agriculture.[8] Their first paper incorporates home production in order to account for cross-country differences in agricultural and non-agricultural labor productivity. The second paper argues that low agricultural productivity may delay a country's timing of industrialization; hence, agricultural productivity may determine current international differences in output per worker. Our research complements, yet differs from, these two papers. While we also emphasize the significance of agriculture, we investigate specifically and quantitatively the role of economy-wide productivity and barriers to using modern agricultural inputs in explaining the share of employment and labor productivity in agriculture. These two factors are shown to be essential for understanding aggregate productivity differences between rich and poor countries.[9]

The rest of the paper is organized as follows. Section 2 presents the two-sector model that sets the basis for our quantitative analysis. Section 3 uses a simplified version of the model to illustrate analytically how barriers to the use of modern inputs in agriculture affect agricultural labor productivity and the allocation of employment across sectors. In Section 4, we calibrate the model, measure barriers to intermediate input use, present quantitative findings, and discuss the robustness of the results and possible extensions to the basic framework. Section 5 concludes the paper.

[8] Caselli and Coleman (2001) also examine the role of agriculture in the process of economic development, although their emphasis is on the evolution of relative incomes across regions in the United States. See also Caselli (2005) for an updated review of development accounting, including discussions on the relevance of sectorial differences in TFP for understanding cross-country income differences.

[9] Of course, our research is also closely related to the vast literature on the role of agriculture in economic development, along the lines of Johnston and Mellor (1961) and Timmer (1988). We depart from this literature mainly along two directions: (1) by building the Schultzian view of agricultural modernization in a two-sector general equilibrium model, and (2) by quantifying the role of agriculture in accounting for international differences in GDP per worker.

2. A Two-Sector Model

We consider a two-sector economy with the production and consumption of two final goods: an agricultural good and a non-agricultural good. Preferences in consumption are non-homothetic with a subsistence requirement of the agricultural good. Agricultural production uses an intermediate input, which is supplied by the non-agricultural sector, and there are two sources of barriers to using this modern input. This section incorporates the two barriers into a standard two-sector model and derives competitive equilibrium solutions to the use of intermediate input, share of employment and labor productivity in agriculture, as well as aggregate labor productivity.

2.1. Production Technologies

We posit the following production function for agriculture,[10]

$$Y_a = X^{\alpha} \left(Z^{1-\sigma} (\kappa A L_a)^{\sigma} \right)^{1-\alpha}, \quad 0 < \sigma < 1, \quad 0 < \alpha < 1, \quad \kappa > 0, \tag{1}$$

where the subscript a denotes agriculture (whereas n denotes non-agriculture). Y_a, Z, L_a, and X are agricultural output, land, labor, and the intermediate input provided by non-agricultural production. This intermediate input may consist of chemical fertilizers, pesticides, hybrid seeds, fuel, energy and other purchased factors. As a labor augmenting factor, A is an economy-wide productivity parameter that is influenced by factors such as the state of scientific knowledge, market institutions, property rights, public infrastructure, and government policies. Efficiency in agricultural production is linked to economy-wide productivity through parameter κ, which can be interpreted as measuring the integration of agriculture to the aggregate economy. For instance, institutions and policies affecting agricultural de-

[10] This Cobb-Douglas functional form is used extensively in the analysis of agricultural production; see, for instance, Hayami and Ruttan (1985) and Mundlak (2001) for discussions on related conceptual issues and empirical applications.

velopment may obstruct applications of general knowledge for the advancement of farming techniques, thus reducing the value of κ; in contrast, good transport infrastructure connecting rural and urban regions would raise the value of κ. We assume land is in fixed supply; hence, labor in agriculture exhibits decreasing returns.

The production function for non-agriculture is

$$Y_n = AL_n,$$

where Y_n and L_n denote output and labor input, respectively. Note that the input of capital services is omitted in the non-agricultural as well as the agricultural production function. This specification reflects the fact that neither the PWT nor the agricultural data from FAO contain by-sector information on the capital stock, thus precluding the possibility of analyzing capital in our quantitative exercise. The omission of capital will not affect the qualitative results to be presented below. In section 5 we discuss the implications of excluding capital for our quantitative findings.

Our formulation of production technologies differs from a standard two-sector model in two ways. First, we include an intermediate input (X) in agricultural production, reflecting the Schultzian view of agricultural modernization and the fact that the use of technical inputs varies systematically with the level of development across countries. We assume that one unit of non-agricultural output is needed to produce $1/\pi$ units of X; therefore, a low value of π implies high efficiency of producing the input. With this formulation in competitive factor and output markets, π is the price of intermediate inputs relative to non-agricultural goods. Second, we build a link between economy-wide productivity (A) and agricultural productivity (κA). While economy-wide productivity has an impact on production in both sectors, variations in κ across countries may join with A in determining labor productivity in agriculture, and hence aggregate output per worker.

The economy is populated with a large and constant number (mass N) of homogeneous households. Under competition, profit maximization of the representative firm in the non-agricultural sector requires $w_n = A$. The representative farmer maximizes profits by choosing labor inputs and the use of the intermediate input,

$$\max_{X,L_a} \left\{ p_a X^{\alpha} \left(Z^{1-\sigma} (\kappa A L_a)^{\sigma} \right)^{1-\alpha} - \pi X - w_a L_a \right\},$$

where p_a is the price of agricultural good relative to non-agricultural good; thus, the price of non-agricultural good is treated as the numeraire. The farmer needs an amount πX of non-agricultural goods in order to obtain X units of intermediate inputs. w_a is the wage in the agricultural sector. The first-order condition with respect to the intermediate input implies that,

$$X = \left(\frac{\alpha p_a}{\pi} \right)^{\frac{1}{(1-\alpha)}} Z^{1-\sigma} (\kappa A L_a)^{\sigma}.$$

Combining this equation with the agricultural production function, and taking prices as given, we obtain an expression for the optimal choice of intermediate input to output ratio for the representative farmer,

$$\frac{X}{Y_a} = \alpha \frac{p_a}{\pi}.$$

Therefore, the intensity of using intermediate inputs is determined by the elasticity of output to intermediate inputs (α) and by the price of the agricultural good relative to the cost of intermediate inputs. It will become clear that this ratio of intermediate input to output plays an important role in determining the share of employment and labor productivity in agriculture.

2.2. Preferences

The representative household derives utility from consuming the agricultural good (c_a) and non-agricultural good (c_n). We do not consider leisure in our analysis, so that N is associated with aggregate employment in the cross-country data. Preferences for the representative household are summarized by a Stone-Geary utility function, which incorporates the impact of income growth on the secular decline in agriculture's share of economic activity,

$$U = a \log(c_a - \bar{a}) + (1 - a) \log(c_n), \quad 0 \leq a < 1,$$

where $\bar{a}$ is subsistence level of consumption of agricultural good and a is a utility weight over the two goods. This specification implies that the representative household first allocates $p_a\bar{a}$ amounts of income to $\bar{a}$ units of agricultural good, and then allocates remaining income to the two goods proportional to their weights in the utility function. More specifically,

$$c_a = \bar{a} + a p_a^{-1}(y - p_a\bar{a}), \tag{2}$$

$$c_n = (1 - a)(y - p_a\bar{a}), \tag{3}$$

where y is the income of the household.

2.3. Barriers to Intermediate Input Use

We model two sources of barriers that affect the intensity to which farmers use non-agricultural intermediate inputs. First, consider direct barriers in the market for intermediate inputs X that in effect increase π, the resource cost of converting non-agricultural output into X. A high value of π represents a high level of direct barriers confronting farmers in using the technical input. Second, consider barriers or labor market distortions that in effect increase the cost of reallocating labor from agriculture to non-agriculture. We model this cost as a percentage of the wage rate in the non-agricultural sector, θ. The no-arbitrage condition in the labor market implies

$$w_a = (1-\theta)w_n, \;\; 0 \leq \theta < 1. \tag{4}$$

Therefore, institutions and distortions in the labor market suppress wages in agriculture, giving farmers an incentive to use labor more intensively relative to the use of modern technical inputs.

2.4. Competitive Equilibrium

A competitive equilibrium in this economy is a set of allocations $\{L_a, L_n, c_a, c_n, \; X\}$, prices $\{p_a, w_a, w_n\}$, and profits for firms in agriculture, such that: (i) Given prices and profits, $\{c_a, c_n\}$ solve the utility maximization problem of the representative household; (ii) Given prices, $\{L_a, \; X, \; L_n\}$ solve the profit maximization problem of firms in each sector; (iii) Condition (4) holds so that the representative household is indifferent between working in the two sectors; and (iv) All markets clear, i.e.,

$$N = L_a + L_n, \tag{5}$$

$$Y_a = Nc_a, \tag{6}$$

$$Y_n = Nc_n + \pi X. \tag{7}$$

To explain cross-country differences in productivity, we focus on four key variables of the competitive equilibrium: the intermediate input ratio X/Y_a, the share of employment in agriculture L_a/N, labor productivity in agriculture Y_a/L_a, and aggregate labor productivity Y/N. Manipulation of the agricultural production function in equation (1) suggests the following decomposition of agricultural final output per worker:[11]

$$\frac{Y_a}{L_a} = (\kappa A)^{\sigma} \left(\frac{Z}{N}\right)^{1-\sigma} \left(\frac{X}{Y_a}\right)^{\frac{\alpha}{1-\alpha}} \left(\frac{L_a}{N}\right)^{\sigma-1}. \tag{8}$$

Labor productivity in agriculture depends positively on economy-wide productivity A, agricultural productivity parameter κ, land-to-employment ratio Z/N, and the intensity of technical input use X/Y_a; however, it relates negatively to the share of employment L_a/N in agriculture.

Using equation (8) and other conditions of the competitive equilibrium, we can solve for the following variables (see Appendix C for details of derivation):

$$\frac{X}{Y_a} = \left[\frac{\alpha}{\sigma(1-\alpha)} \frac{(1-\theta)}{\pi} \frac{A^{1-\sigma}}{\kappa^{\sigma}(Z/N)^{1-\sigma}}\right]^{1-\alpha} (L_a/N)^{(1-\alpha)(1-\sigma)}, \tag{9}$$

$$\frac{Y_a}{L_a} = A^{\sigma+\alpha(1-\sigma)} \kappa^{\sigma(1-\alpha)} \left[\frac{\alpha}{\sigma(1-\alpha)} \frac{(1-\theta)}{\pi}\right]^{\alpha} \left[\frac{(Z/N)}{(L_a/N)}\right]^{(1-\alpha)(1-\sigma)}, \tag{10}$$

where X/Y_a and Y_a/L_a are functions of L_a/N and other exogenous variables and parameters. Appendix C also shows how to derive the following equation for the share of employment in agriculture,

$$\frac{L_a}{N} = \frac{(1-a)(1-\theta)}{a(1-\alpha)\sigma + (1-a(1-\alpha))(1-\theta)} \frac{\bar{a}}{Y_a/L_a} + \frac{a(1-\alpha)\sigma}{a(1-\alpha)\sigma + (1-a(1-\alpha))(1-\theta)} \tag{11}$$

After substituting equation (10) into equation (11), we get an implicit function for L_a/N that can be solved numerically. We can then substitute the solution into equations (9) and

[11] In our quantitative analysis, we focus on the implications of the model for final output per worker in agriculture (as opposed to GDP per worker) because this measure incorporates the role of intermediate inputs in agricultural production. Nevertheless, the model has implications for GDP per worker in agriculture; those results are available from the authors upon request.

(10) to solve for X/Y_a and Y_a/L_a. Finally, aggregate GDP per worker can be derived as:

$$\begin{aligned} \frac{Y}{N} &= \frac{GDP_a + GDP_n}{N} \\ &= \frac{p_a^* Y_a - \pi^* X + A(N - L_a)}{N} \\ &= \frac{Y_a}{L_a}\frac{L_a}{N}\left(p_a^* - \pi^* \frac{X}{Y_a}\right) + A\left(1 - \frac{L_a}{N}\right), \end{aligned} \tag{12}$$

where $\{p_a^*, \pi^*\}$ denote international prices for agricultural output and intermediate input. Equations (9), (10), (11), and (12) form the basis for subsequent quantitative analysis.

3. The Effects of Barriers on Agriculture

Before conducting our quantitative analysis of the model, it is useful to further examine the main feature of our model: the mechanisms through which the two barriers and economy-wide productivity affect various aspects of agricultural production. For the simplicity of exposition, we consider a special case of $a = 0$, which sets the demand for agricultural good at the subsistence level, i.e., $U(c_a, c_n) = U(\overline{a}, c_n)$ if $c_a \geq \overline{a}$. Hence, we can explore analytically the determinants of intermediate input use, the share of employment in agriculture, and agricultural productivity.

To begin with, consider how barriers $\{\pi, \theta\}$ affect the use of the intermediate input. Setting $a = 0$ in equation (11), we can solve for L_a/N. Then, by substituting L_a/N into equation (9), we obtain,

$$\frac{X}{Y_a} = \left[\left(\frac{(1-\theta)}{\pi\kappa}\frac{\alpha}{(1-\alpha)\sigma}\right)^{\sigma}\left(\frac{\bar{a}}{(Z/N)}\right)^{1-\sigma}\right]^{\frac{(1-\alpha)}{\alpha+\sigma(1-\alpha)}}. \tag{13}$$

Equation (13) suggests several potential reasons for limited use of intermediate inputs in poor countries, among them: (a) high direct barriers (π), which reflect high costs of using technical inputs; (b) high indirect barriers (θ), which are associated with labor market distortions; and (c) high per-worker land endowment. In the next section we show that π and θ are indeed systematically higher in poor countries than in rich countries.

Limited use of modern technical inputs in agriculture may in turn affect the share of employment and labor productivity in agriculture, and thus aggregate productivity. With subsistence food consumption, market clearing for agricultural output implies $Y_a = N\bar{a}$, where $\bar{a}$ is subsistence requirement per person. This market clearing condition implies $Y_a/L_a = \bar{a}(L_a/N)^{-1}$, suggesting that factors leading to low agricultural labor productivity would lead to high share of employment in agriculture, a result that is independent of the specific setup of the model. Combining market clearing with equation (8) gives the following expressions:

$$\frac{L_a}{N} = \frac{1}{\kappa A}\left(\frac{\bar{a}}{(Z/N)^{1-\sigma}(X/Y_a)^{\frac{\alpha}{1-\alpha}}}\right)^{1/\sigma}, \tag{14}$$

$$\frac{Y_a}{L_a} = \kappa A\left(\frac{(Z/N)^{1-\sigma}(X/Y_a)^{\frac{\alpha}{1-\alpha}}}{\bar{a}^{1-\sigma}}\right)^{1/\sigma}. \tag{15}$$

Equations (14) and (15) show that the use of technical input X/Y_a is positively related to agricultural labor productivity but negatively related to the share of employment in agriculture; these results are consistent qualitatively with cross-country evidence presented in the introduction. Agriculture-specific and economy-wide productivity $\{\kappa, A\}$, as well as high land-to-employment ratio Z/N, raise agricultural labor productivity and thus reduce the share of employment in agriculture required to satisfy subsistence food consumption. Moreover, if low productivity in agriculture stems from a low land-to-employment ratio or intermediate input ratio, the share of employment required for agriculture would increase with the extent of decreasing returns to labor (σ) in agricultural production.

We note that the use of intermediate inputs in agriculture is a key mechanism through which the direct and indirect barriers (π, θ) realize their effects on the share of employment and productivity in agriculture. This can be demonstrated by setting $\alpha = 0$ in equations (14) and (15). Without modern inputs in agricultural production, the two barriers would have no impact on L_a/N and Y_a/L_a for the special case.[12]

4. Quantitative Analysis

This section assesses quantitatively the role of economy-wide productivity (A) and barriers to intermediate input use (π, θ) in generating observed cross-country patterns in the intermediate input ratio, the share of employment and labor productivity in agriculture, and aggregate labor productivity. We find that the model generates substantial differences in the sectoral allocation of employment and labor productivity between rich and poor countries.

4.1. Calibration

We assume a benchmark economy with no direct barriers to intermediate input use $(\pi = 1)$ and calibrate this economy to data for the United States in 1985. We normalize the relative price of agricultural goods to one for the benchmark economy. We need to determine eight parameter values: a, $\bar{a}$, α, σ, Z/N, A, κ, and θ. The land-to-employment ratio Z/N is taken directly from the U.S. data; according to FAO statistics, the ratio of arable land (in hectares) per employed person in the U.S. economy is 1.6. The income share of labor in agriculture σ is set at 0.7, broadly consistent with the estimates of agricultural production functions reported by Hayami and Ruttan (1985) and Mundlak (2001). Given our normalization of the relative price of agriculture and $\pi = 1$, the intermediate-input

[12] Admittedly, for the general case of $0 \leq a < 1$, labor mobility barrier (θ) could affect L_a/N through channels other than the use of intermediate inputs. From equation (11) we can see that, as long as a is positive, θ increases the share of employment in agriculture, independent of its effect on agricultural labor productivity, Y_a/L_a. In the presence of intermediate inputs, the effect of θ on L_a/N is even larger, as a more severe indirect barrier reduces intermediate input use and thus lowers labor productivity Y_a/L_a, which further increases the share of employment in agriculture.

elasticity of output in agriculture α determines the intermediate input to output ratio in the benchmark economy. We select this elasticity value to match the intermediate input ratio for the U.S. economy $\alpha = 0.4$. Again, because of the normalization of the relative price of agriculture, the ratio of marginal product of labor in agriculture to that in non-agriculture equals $(1-\theta)$ in the benchmark economy. For the benchmark economy, this ratio is 0.385, which implies that θ equals 0.615.

The technology parameters (A, κ) are chosen from sectoral residual calculations for the U.S. economy using the specified production functions, which result in $A = 34,206$ and $\kappa = 34.1$. Finally, the values of preference parameters a and $\bar{a}$ are selected to match two targets for the share of employment in agriculture. Roughly speaking, a determines the long-run share of employment in agriculture (the share implied by the model when the subsistence food constraint is not binding) and $\bar{a}$ determines the share of employment in agriculture at a point in time given the other preference and technology parameters. We assume a long-run share of employment in agriculture of 0.5 percent; in 1985, the share of employment in agriculture for the U.S. economy is 2.8 percent. These targets imply $a = 0.0046$ and $\bar{a} = 752.6$.[13] While our target for long-run share of employment in agriculture is somewhat arbitrary, it is consistent with the declining trend of the share of employment in the United States, which dipped below 2 percent in the late 90s. Several papers in the related literature (e.g., Caselli and Coleman, 2001; Gollin et al., forthcoming) actually assume lower values of employment shares than ours. We show later in this section that a lower value of a would imply stronger quantitative results in explaining aggregate productivity differences between rich and poor countries. To summarize, Table 1 presents values of the calibrated parameters

[13] It should be noted that, if employment-to-population ratios differ systematically between rich and poor countries, there would be a need to distinguish total employment from total population in the calibration of $\bar{a}$ and measurement of Z/N. However, the 1985 Penn World Tables indicate an employment-to-population ratio of 0.490 for the U.S., an average of 0.489 with standard deviation of 0.014 for the richest 5 percent of the countries, and an average of 0.493 with standard deviation of 0.050 for the poorest 5 percent of the countries. The sample means of the ratios are not statistically different across the two groups.

and the targets for parameter selection.

4.2. Measuring Barriers to Intermediate Input Use

The FAO data provide country-specific prices of intermediate inputs used in agricultural production (including pesticides, fertilizers, fuel and energy, electricity and other miscellaneous items) that are paid by farmers at their farm gates. Roughly speaking, these purchasing power parity (PPP) prices are the ratio of expenditures on these items in local currency for each country ($X\pi$) relative to the expenditures in international prices (common set of prices across countries, $X\pi^*$). Following the model, we use the price of non-agricultural output as the numeraire and compute the price of intermediate inputs relative to the price of non-agricultural output for each country. Figure 4 plots these prices relative to the United States.[14] against relative GDP per worker for individual countries. The figure shows that the relative price of modern inputs is systematically higher in less developed economies. For instance, the relative prices in Ethiopia, Nepal, Mali, and Mozambique are 5 to 6 times higher than the U.S. price. We interpret these differences in the relative price as a measure of direct barriers to using intermediate inputs (π). In a similar approach, other authors (see e.g., Jones, 1994; Restuccia and Urrutia, 2001) have used the price of investment relative to consumption as a measure of barriers to investment in one-sector growth models.

In an environment with perfect labor mobility, wages for comparable labor are equalized across sectors. As earlier discussions suggest, however, labor market institutions and distortions in poor countries may suppress wages in the agricultural sector, inducing farmers to use labor more extensively relative to the use of modern technical inputs. To investigate

[14] Symbolically the PPP price of X reported by FAO can be represented as $(X\pi/X\pi^*)$, where $\{X, \pi, \pi^*\}$ are not reported individually. Similarly, the PPP price of non-agricultural output is the ratio of domestic to international value of non-agricultural goods. Therefore, the relative price reported in Figure 4 is: $[(X\pi/X\pi^*)/(p_nY_n/p_n^*Y_n)]/[(X\pi/X\pi^*)/(p_nY_n/p_n^*Y_n)]^{US} = (\pi/p_n)/(\pi/p_n)^{US}$. Notice that in this simple form, the ratio of relative prices to a benchmark country eliminates the potential measurement bias of international prices.

this hypothesis, we construct a measure for indirect barriers to using intermediate inputs (θ) across countries based on the no-arbitrage condition stated in equation (4). We adopt this model-based construction of indirect barriers in the labor market because direct records of sectoral wages are not available for a large sample of countries.[15] More specifically, the indirect barrier for country i is measured relative to the United States (i.e., $(1-\theta_i)/(1-\theta_{us})$), where $(1-\theta)$ is computed as the ratio of the relative price of agricultural good times the average product of labor in agriculture to the average product of labor in non-agriculture. Since $(1-\alpha)\sigma$ is modeled to take equal value across countries, the ratio of sectoral average product of labor in country i relative to the United States is identical to the ratio of sectoral marginal product of labor in country i relative to the United States. Figure 4 plots these relative measures of labor market distortions against the relative GDP per worker for individual countries. While there are large variations in the degree of distortions across countries, the most severe indirect barriers are found in the poorest countries.

4.3. Quantitative Results

Countries are treated as closed economies and are identical to the benchmark economy except in economy-wide productivity (A), which is measured by labor productivity in non-agriculture (see Figure 2),[16] barriers to intermediate input use (π, θ) (see Figure 4), and land-to-employment ratio (Z/N). For every country in the sample, we compute their equilibrium share of employment in agriculture (L_a/N), the intermediate input ratio (X/Y_a), labor productivity in agriculture (Y_a/L_a), and aggregate labor productivity (Y/N). In comparing aggregate output across countries in the model, we use the relative price of agriculture

[15] This approach shares a similar methodology used by other authors (e.g., Mulligan, 2002; Chari et al., forthcoming) who rely on first-order conditions to back out implied distortions in the labor market.

[16] We take labor productivity in non-agriculture as given, as our focus is on labor productivity differences in agriculture between poor and rich countries. There is a large literature that emphasizes the role of capital accumulation and total factor productivity in explaining international income differences; see, for instance, McGrattan and Schmitz (1999) and Parente and Prescott (2000) for surveys of this literature.

in the benchmark economy as the international price.[17] The key question is: with exogenous variations in A, π, θ, and Z/N, how much of the cross-country differences in L_a/N, X/Y_a, Y_a/L_a, and Y/N can be accounted for by the model?

Table 2 presents the main simulation results of the model: for each of the variables $\{X/Y_a, Y_a/L_a, Y/N\}$, we report the ratio of their equilibrium outcomes between the richest 5 percent of the countries and the poorest 5 percent of the countries in the sample; but, for L_a/N, we report the average equilibrium values directly for the two country groups. In order to isolate the contribution of each individual factor to explaining observed differences in the four outcome variables between the richest and poorest countries (as reported in the first row), we present seven different versions of the model: (1) a one-sector model with only non-agriculture, (2) a linear two-sector model with L_a as the only input in agriculture, (3) a two-sector model with $\{L_a, Z\}$ as inputs in agriculture, (4) a two-sector model with $\{L_a, Z, X\}$ as inputs in agriculture but no barriers, i.e., $\theta = \theta_{US}$ and $\pi = 1$, (5) introduce indirect barriers θ into (4), (6) introduce indirect barriers π into (4), and (7) the baseline model with both barriers $\{\theta, \pi\}$.

Table 2 shows that the explanatory power of the model increases substantially from the single-sector framework towards the baseline model that takes into account the effects of barriers to the use of modern technical inputs. A one-sector (non-agriculture) model with exogenous economy-wide productivity would imply that the aggregate labor productivity difference between the richest and the poorest countries is the same as that of the economy-wide productivity, a difference of factor 5. Versions (2)-(4) are all two-sector models in which labor, land, and intermediate inputs are added incrementally to the agricultural production technology. Moving from version (1) to (4), the share of employment in agriculture in poor countries rises far above the level in rich countries, as the gap in agricultural labor

[17] We obtain similar results if, instead, we use the international price of agriculture in the FAO data or the geometric average of relative prices across countries in our sample.

productivity widens. This finding reflects the "food problem" facing poor countries: with low agricultural productivity, they have to allocate higher shares of employment to agriculture. Note that in version (4), rich countries actually use less technical inputs in agriculture than poor countries, $(X/Y_a)^R/(X/Y_a)^P = 0.9$, which is mainly a consequence of a higher land-to-employment ratio in rich countries. As equation (13) suggests, abundant land endowment reduces farmers' incentives for intermediate input use. It is clear, however, that a standard two-sector model without barriers as in (4) still cannot explain well the patterns revealed in the data.

The results in (5) and (6) show that both direct and indirect barriers are important factors in accounting for observed differences in the intermediate input ratio between the richest and poorest countries. When the model considers one barrier at a time, as in version (5) or (6), it generates an input ratio of 1.5, accounting for about 50 percent of the differences in the use of intermediate inputs between the two groups. The simulated equilibrium outcomes for L_a/N, Y_a/L_a and Y/N are also improved substantially; for instance, the agricultural labor productivity gap is raised from a factor of 6.3 to 13.8 and 10.2, respectively, much closer to the observed differences.

Our baseline model, which takes into account the effects of both barriers simultaneously, replicates well the observed patterns of the four variables. In particular, it implies a factor difference of 10.8 in aggregate labor productivity between the rich and poor countries. This result indicates an amplification mechanism through agriculture, which turns the initial factor difference of 5 from a one-sector growth model into a disparity more than 2 times larger than the initial gap with the same exogenous differences in A. The evidence suggests that the large difference in aggregate productivity between the two groups implied by the model stems from very different cross-country economic structures: poor countries have on average 68 percent of their employment in agriculture relative to only 4 percent in rich countries; however, their agricultural labor productivity is only 1/23.4 of agricultural labor productivity in rich countries. Overall, the baseline model accounts for large percentages of the observed differences in the data, leaving the unexplained share of labor in agriculture in poor countries at 18 percent and the unexplained factors of L_a/N, Y_a/L_a and Y/N at 1.1, 4.7 and 3.2, respectively.

Table 3 presents additional simulation results of the baseline model covering all countries in the sample. We group the economies by deciles based on observed aggregate output per worker, and compare equilibrium outcomes of the four variables implied by the model with data. For the richest 10 percent of the countries reported in the first row, the model matches closely with the data. For the poorest 10 percent of the countries, the model replicates well the intermediate input to output ratio (both at 12 percent), and the share of employment in agriculture (71 percent in the model vs. 82 percent in the data). There are still gaps in accounting for agricultural labor productivity in this poorest decile of countries (1141 vs. 233) and for aggregate labor productivity (2794 vs. 1020); presumably, other institutional, policy and economic variables not covered in the model may significantly influence agricultural and aggregate productivity. Note that the ratio of agricultural labor productivity between the top decile and the bottom decile are 18.5 in the model vs. 86.9 in the data; and the corresponding ratios of aggregate labor productivity are 10.5 and 28.9. These results, covering a broader distribution of countries, are consistent with the findings for the richest and poorest countries in Table 2.

The quantitative analysis presented so far is based on the assumptions that (a) economy-wide productivity A takes country-specific values, and (b) agriculture-specific productivity parameter κ takes a common value across rich and poor countries. To further investigate the importance of efficiency parameters in accounting for key variables across countries, we perform two additional experiments. First, we perform an experiment in which the countries still have the same exogenous factors as in the baseline model except that we set their economy-wide productivity parameter equal to the level of the benchmark economy (the

United States). In the baseline model, we set $A_a = \kappa A_n$ for each country, where $A_n = A$ is non-agricultural labor productivity in that country. In this experiment, we maintain the value of A_a for each country as calculated before, but instead we set $A_n = A(US)$ for all countries. Experiment (1) in Table 4 presents the results. In comparison with the baseline model, a higher A in poor countries results in a massive movement of labor out of agriculture (the share of employment drops from 68 to 30 percent), substantial improvement in agricultural labor productivity (declining from a factor difference of 23.4 to 10.1, driven mainly by more intensive use of intermediate inputs), and dramatic improvement in aggregate labor productivity (declining from a factor difference of 10.8 to 1.4). A striking aspect of these results is that substantial improvements in labor productivity occur in poor countries despite their high barriers to intermediate inputs (π, θ) and low efficiency in agriculture (A_a).

In the second experiment, we allow poor countries to have lower values of κ relative to rich countries, which, for instance, may reflect the prevailing institutions and policies that obstruct the applications of general knowledge to farming. In the context of our model, we identify the differences in κ between the richest and the poorest 5 percent of the countries that would match either the share of employment in agriculture in the poor countries $(2a)$ or observed aggregate productivity differences between these countries $(2b)$, as reported in Table 4. In comparison with the baseline model in which κ is constant across countries, lower values of κ in poor countries imply an even larger share of employment in agriculture, lower labor productivity in agriculture, and a more substantial difference in aggregate labor productivity between the two country groups. These results suggest that research efforts on finding the determinants of total factor productivity in agriculture may further contribute to the understanding of aggregate productivity differences across countries.[18]

[18] In addition to the two experiments, we have also conducted sensitivity analysis; the results are presented in Appendix D. Overall, the main quantitative results are quite robust to changes in parameter values.

4.4. Discussion

We have so far presented a highly stylized model involving certain assumptions that may cause biases to the quantitative results. Therefore, before we proceed to the conclusions, it seems prudent to address a few potential concerns.

To begin with, due to constraints on data availability, we have abstracted physical capital from our analysis. We use labor productivity in non-agriculture as economy-wide productivity (A) for each country, a large component of which may actually reflect capital accumulation. In the baseline model, the potential role of capital is specified to affect agricultural and nonagricultural production through a linear form, A and κA, which translates into a linear relationship between labor productivity in agriculture and non-agriculture. If capital is introduced explicitly into the model, how would it affect the relationship of labor productivity between the two sectors? We can show that, for the case of $a = 0$, labor productivity in agriculture and non-agriculture remains linearly related as in the baseline model, if the income share of capital in agriculture and non-agriculture are equal, or if variations in labor productivity in non-agriculture stems primarily from differences in total factor productivity, rather than from differences in capital-to-output ratio. Of course, if there are frictions to capital mobility across sectors that result in low level of capital utilization in agriculture in poor countries, the inclusion of capital into the model would provide an additional source of differences in agricultural labor productivity between rich and poor countries. Although the measurement issues associated with constructing comparable measures of capital stock across sectors for a large number of countries are enormous, available evidence suggests that cross-country differences in capital-to-labor ratios are larger in agriculture than in non-agriculture, supporting the role of capital in accounting for labor productivity differences in agriculture between rich and poor countries (see, e.g., Crego et al., 1997; Chanda and Dalgaard, 2005).

Following the tradition of neoclassical growth theory, we also assume the same technology in agriculture for all firms within a country and for all countries, except in labor augmenting productivity and land endowments. We view this aggregate production function as an envelope of many different technologies, which is a widely accepted approach in the empirical development literature (e.g., Hayami and Ruttan, 1985). However, the adopted functional form has a restrictive feature: it does not allow possible substitution among inputs, in particular between intermediate inputs and land. We could generalize the production function into a more flexible form, but the cost is one more free parameter that makes it difficult to impose discipline in the quantitative exercise. Instead, we have sought independent evidence that would help us decide the selection of functional forms. For instance, a strong negative correlation between intermediate inputs and land would motivate us to choose a production function with input substitutability. However, the cross-country correlation between the intermediate input ratio (X/Y_a) and the land-to-employment ratio (Z/N) in our sample is only 0.5 percent (in logs). This evidence provides an additional reason for using the conventional Cobb-Douglas form.

We treat countries as closed economies. Given the enormous differences in agricultural labor productivity across countries, there seems to be an important role for trade of agricultural goods. Why, then, don't poor countries import large quantities of agricultural goods from rich countries? One possible explanation lies in the determination of food prices and poor market distribution systems in less developed countries. Using the 1985 ICP benchmark price data reported in the Penn World Tables, we calculate the price of food at market exchange rates. We find that on average, the price of food in rich countries is higher than in poor countries, although the price of agricultural products relative to the price of non-agricultural goods in rich countries is not higher than in poor countries, a fact that is consistent with the labor productivity differences across sectors. There is evidence that final food prices include a substantial portion of distribution and marketing services. The U.S. Department of Agriculture reports that for every dollar spent on food, only 20 cents go to the farmer; the remaining 80 cents are distribution and marketing charges.[19] While excessive service charges may not be applied to exporting food to poor countries, inefficient distribution systems in those countries may prevent rural areas from benefiting from food trade.

Lastly, our analysis uses employment, rather than hours of work, as the measure of labor input in agriculture. This practice could introduce a downward bias on agricultural labor productivity in poor countries, as greater fractions of their rural labor force are likely part-time farmers. A rural worker who resides on a farm may spend much time on non-agricultural activities, but still be counted as an agricultural worker. In addition, both the quality of employment data and hours of work in agriculture may differ systematically across countries. Unfortunately, we cannot correct for these potential issues with existing data. We should emphasize, however, that since the productivity differences in agriculture between rich and poor countries are so large, they are unlikely to be solely the outcome of these measurement issues. Admittedly, improved data can certainly help tease out the measurement problems in accounting for international differences in agricultural labor productivity.

5. Conclusions

In this paper, we show that a simple two-sector general-equilibrium model with subsistence food requirements and decreasing returns to labor in agriculture can generate large differences in agricultural and aggregate labor productivity across rich and poor countries. These differences in productivity arise from differences in economy-wide productivity and barriers to the use of modern intermediate inputs in agriculture. Our emphasis on the role of agriculture in development has a long tradition in the development economics literature. We contribute to this literature by quantifying the role of agriculture in the aggregate economy and analyzing the importance of economy-wide productivity and barriers to intermediate in-

[19] See Adamopoulos (2006) for evidence on the role of the distribution sector in explaining cross-country price observations.

puts in generating differences in the use of modern inputs and the shares of employment and labor productivity in agriculture across countries. By generating substantial cross-country differences in agricultural productivity and employment, this paper provides a better understanding of aggregate productivity differences between rich and poor countries.

Our quantitative analysis suggests that it is important to understand economy-wide productivity differences across countries, as advocated by the work of Klenow and Rodriguez-Clare (1997), Prescott (1998), Hall and Jones (1999), and Parente and Prescott (2000). In our model, relatively small differences in economy-wide productivity translate into large differences in aggregate labor productivity across countries. Our results suggest that the productivity differences needed to account for the wealth of nations are smaller once the role of agriculture in development is taken into account.

Our analysis also highlights the role of barriers and the cost of government policies that impact systematically against agriculture. These barriers reduce the incentives of farmers in poor countries to use modern inputs that are crucial for improving agricultural productivity. These are the same problems that T.W. Schultz (1964) analyzed almost forty years ago in his influential work "Transforming Traditional Agriculture." Unfortunately, our quantitative analysis shows that for many poor countries in the world, barriers to transforming traditional agriculture are still pervasive. These barriers need to be removed in order to achieve substantial improvements in agricultural and aggregate productivity.

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Table 1: Calibration of Parameter Values to U.S. Data

Parameter	Value	Target
Z/N	1.6	Land-to-employment ratio
A	34,206	Labor productivity in non-agriculture
κ	34.1	Labor productivity in agriculture
σ	0.7	Hayami and Ruttan 1985
α	0.4	Intermediate input share
$(1-\theta)$	0.385	Value of relative marginal labor products
a	0.0046	Long-run share of employment in agriculture
$\bar{a}$	752.6	Share of employment in agriculture

Table 2: Effects of Barriers and Economy-Wide Productivity on Equilibrium Outcome Variables

	L_a/N	X/Y_a	Y_a/L_a	Y/N
	Rich/Poor	Ratio of Rich to Poor Countries		
Data	0.04/0.86	3.1	109.1	34.3
(7) Baseline model	0.04/0.68	2.7	23.4	10.8
Decomposing the Contribution of Individual Factors:				
(6) Add direct barriers π only	0.04/0.39	1.5	10.2	6.2
(5) Add indirect barriers θ only	0.03/0.38	1.5	13.8	7.0
(4) Two-sector with $\{L_a, Z, X\}$	0.04/0.20	0.9	6.3	5.5
(3) Two-sector with $\{L_a, Z\}$	0.04/0.24	–	8.2	5.4
(2) Linear two-sector with $\{L_a\}$	0.04/0.17	–	5.0	5.0
(1) One-sector	–	–	–	5.0
Unexplained % or factor	0.00/0.18	1.1	4.7	3.2

Table 3: Quantitative Results by Deciles of Countries: Model vs. Data

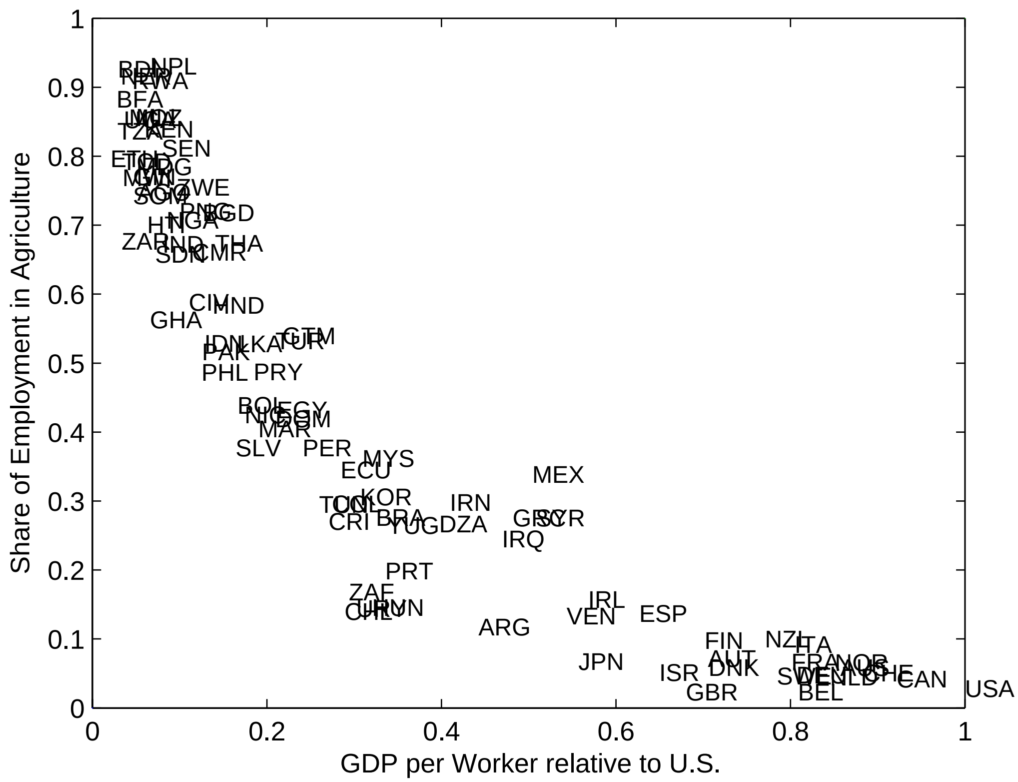
Distribution	L_a/N		X/Y_a		Y_a/L_a		Y/N	
of Y/N	Data	Model	Data	Model	Data	Model	Data	Model
0-10	0.05	0.05	0.41	0.44	20242	21109	29453	29368
10-20	0.07	0.05	0.36	0.40	15600	16198	25147	25352
20-30	0.18	0.09	0.35	0.33	5840	10968	18747	20726
30-40	0.23	0.11	0.27	0.24	3572	8402	12832	14999
40-50	0.33	0.18	0.25	0.22	2131	5055	8884	11147
50-60	0.49	0.27	0.20	0.15	1020	3063	5592	8228
60-70	0.62	0.34	0.19	0.15	586	2379	3915	7342
70-80	0.74	0.40	0.15	0.14	346	2057	2417	7417
80-90	0.82	0.51	0.14	0.13	309	1613	1559	4658
90-100	0.82	0.71	0.12	0.12	233	1141	1020	2794

Countries are ranked according to aggregate GDP per worker from PWT5.6. Each decile contains 8 countries (10 percent of countries in our sample) except decile 5, which contains 13 countries.

Table 4: Experiments with Alternative Values of A_n and κ

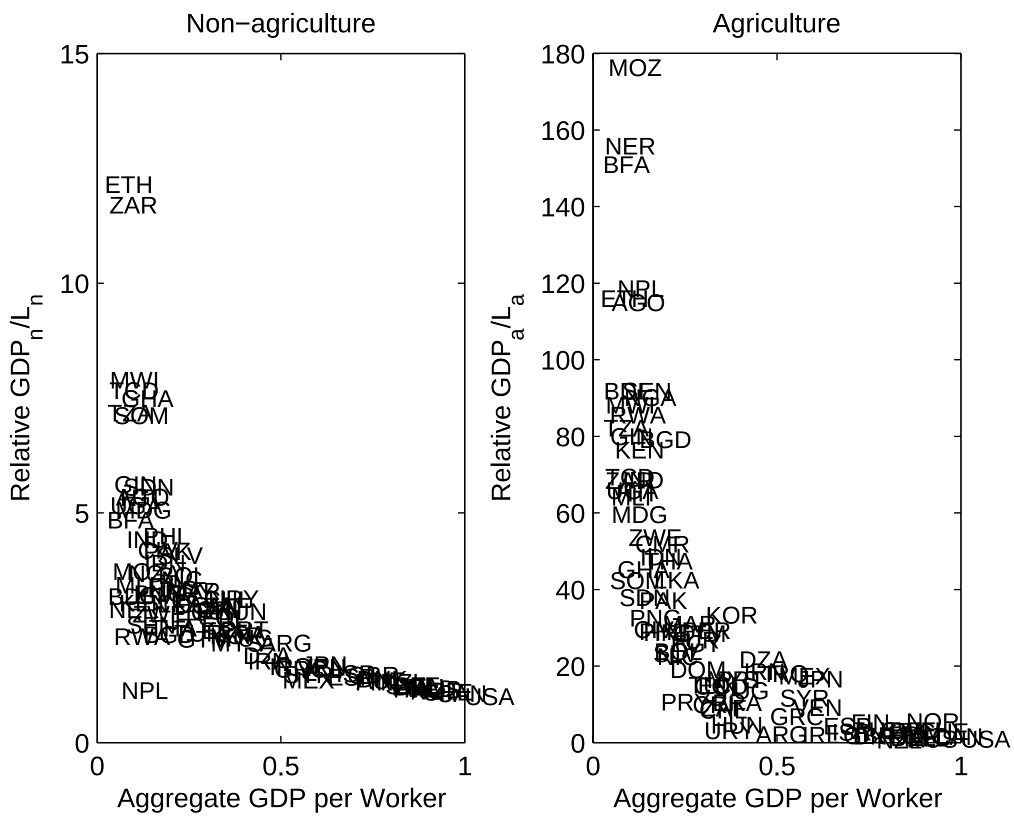
	L_a/N	X/Y_a	Y_a/L_a	Y/N
	Rich/Poor	Ratio of Rich to Poor Countries		
Data	0.04/0.86	3.1	109.1	34.3
Baseline Model	0.04/0.68	2.7	23.4	10.8
Experiments:				
(1) $A_n = A(US)$	0.04/0.30	1.0	10.1	1.4
(2) Differences in κ:				
$\kappa_{\text{poor}}/\kappa_{\text{rich}} = 0.60$	0.04/0.86	2.1	30.2	18.1
$\kappa_{\text{poor}}/\kappa_{\text{rich}} = 0.42$	0.04/0.96	1.8	35.5	34.2

Figure 1: Share of Employment in Agriculture − 1985



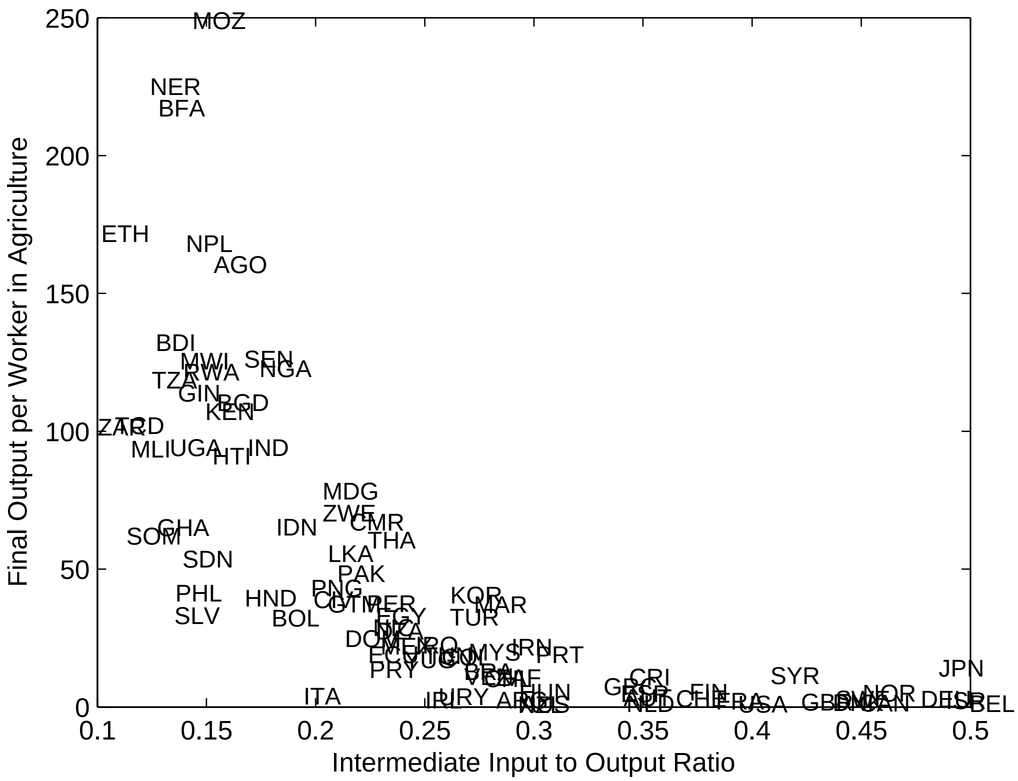
Aggregate GDP per worker from PWT5.6 is reported relative to the United States. The share of employment data is from FAO.

Figure 2: Sectoral Labor Productivity across Countries − 1985



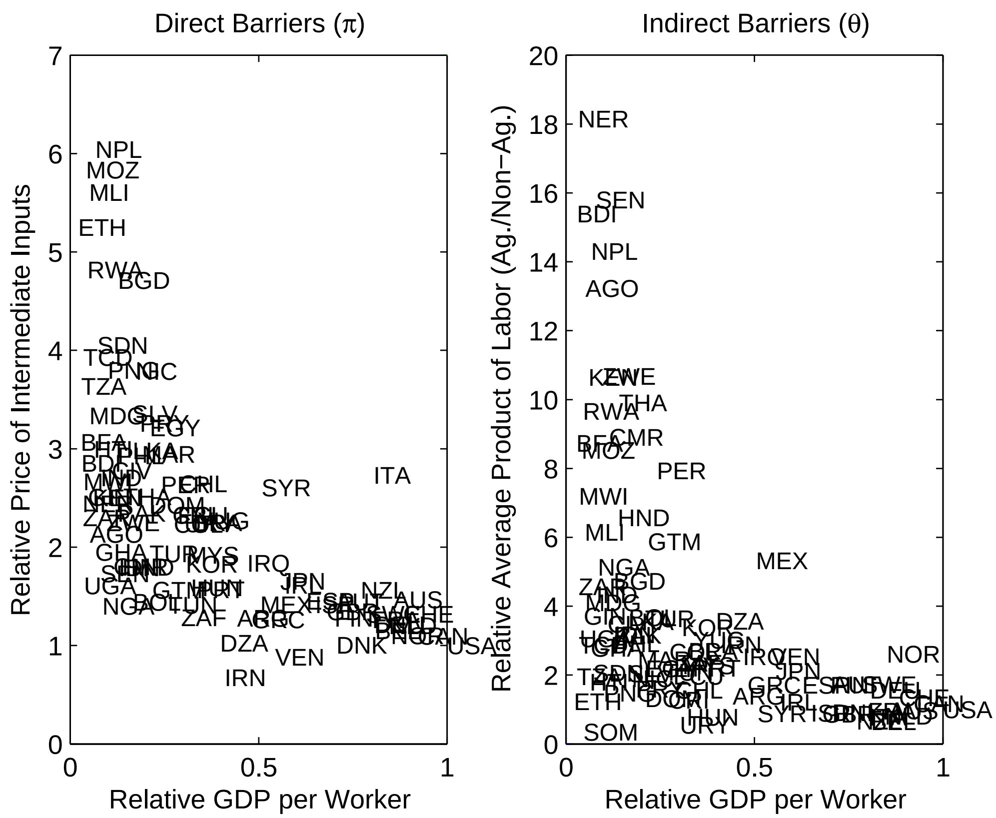
GDP_j/L_j is GDP per worker in sector $j \in \{a, n\}$ where a denotes agriculture and n non-agriculture. Sectoral labor productivity is reported as the United States relative to each country i. Aggregate GDP per worker from PWT5.6 is reported relative to the United States.

Figure 3: Intermediate Input Ratio and Labor Productivity in Agriculture − 1985



Labor productivity in agriculture is final output per worker in agriculture expressed as the United States relative to each country i. The intermediate input ratio is the amount of non-agricultural intermediate inputs relative to final output in agriculture, both measured in international dollars.

Figure 4: Barriers to the Use of Intermediate Input − 1985



(a) The relative price of intermediate inputs is the price of non-agricultural intermediate inputs in agriculture relative to the price of output in non-agriculture. The price of intermediate inputs in agriculture is the price paid by farmers at the farm gate. Relative prices are reported as the ratio to the U.S. relative price. (b) Aggregate GDP per worker from PWT5.6 is reported relative to the United States.

"Agriculture and Aggregate Productivity: A Quantitative Cross-Country Analysis"

Diego Restuccia, Dennis Tao Yang and Xiaodong Zhu

Appendix: Not for Publication

A. Data for Agriculture from FAO

This appendix explains the construction of statistics for agricultural output across countries. A more detailed description is in Prasada Rao (1993). The main source of data is the Food and Agriculture Organization of the United Nations (FAO).

Due to data limitations, agricultural activities include agriculture and hunting but exclude forestry and fishing. Within agricultural activities, only crop and livestock production is included because of the lack of reasonable cross-country data for agricultural services. Output is comprised of a large and representative set of commodities, and aggregation is done using prices. The FAO data have an important advantage for studying agricultural productivity relative to expenditure data in the Penn World Table: agricultural production is valued at producer prices, prices measured at the farm gate that exclude expenses such as costs of transportation, distribution and marketing.

Using data of N commodities indexed by i and M countries indexed by j, total agricultural output in country j is defined as,

$$T_j = \sum_{i=1}^{N} p_{i,j} q_{i,j},$$

where $q_{i,j}$ and $p_{i,j}$ are the quantity and price of commodity i in country j. Hence, this is a measure of total output in country j prices (currency). In order to obtain comparable measures of agricultural total production across countries, a common set of prices must be used. Let π_i be the international price of commodity i measured in a reference currency (dollars). Therefore, total agricultural output in country j at international prices is defined as,

$$T_j^* = \sum_{i=1}^{N} \pi_i q_{i,j}.$$

There are two measures of agricultural output considered: Final output and GDP. Final output comprises total output as defined above minus any intermediate agricultural inputs used in production such as feed and seed. GDP consists of final output minus any intermediate non-agricultural inputs such as fertilizer, pesticide, fuel and energy. Therefore, agricultural final output, F_j, is defined as,

$$F_j = \sum_{i=1}^{N} p_{i,j} q_{i,j} - \sum_{i=1}^{N} p_{i,j}^{s} s_{i,j} - \sum_{i=1}^{N} p_{i,j}^{f} f_{i,j},$$

where $s_{i,j}$ is the quantity of commodity i used as seed and $f_{i,j}$ is the quantity of commodity i used as feed. Notice that the prices of these inputs are allowed to differ from the producer price; that is, the general principle is that all prices are valued at the farm gate. Therefore, prices for inputs are the purchase price paid by farmers at the farm-gate including any distribution charges, such as transportation costs, and any taxes, subsidies and/or bulk discounts. Agricultural GDP is defined as,

$$Y_j = F_j - \sum_{k=1}^{K} w_{k,j} x_{k,j},$$

where $x_{k,j}$ and $w_{k,j}$ are the quantity and price of non-agricultural commodity k in country j. Again, the general pricing principle is that $w_{k,j}$ is the farm-gate purchase price paid by the farmer.

Both final output and GDP are converted in comparable units across countries using standard methods. These methods are discussed extensively in Prasada Rao (1993) and the references therein. A general principle of these aggregation methods is the property of country invariance and transitivity. This property produces results that are independent of the political subdivision of the world such that the comparison of any two countries is not affected by the comparison through a third country.

We present the basic aggregation procedure used: The Geary-Khamis (GK) method.

This method involves finding the fixed point of the following system of equations:

$$\pi_i = \sum_{j=1}^{M} \left(\frac{p_{i,j}}{PPP_j} \right) \gamma_{i,j},$$
$$PPP_j = \frac{\sum_{i=1}^{N} p_{i,j} q_{i,j}}{\sum_{i=1}^{N} \pi_i q_{i,j}},$$

where $\gamma_{i,j} = q_{i,j} / \sum_{j=1}^{M} q_{i,j}$ are quantity weights. The first N equations correspond to the determination of international prices for every commodity i, as a weighted average of prices in the world; the remaining M equations correspond to the determination of agricultural purchase power parities for every country j, as the ratio of output in domestic prices relative to output valued at international prices. A slightly different method is used to compute a comparable measure of agricultural GDP taking non-agricultural input prices into account.

The data is contained in the FAO Interlinked Computerized Storage and Purchasing System of Food and Agricultural commodities (ICS). The output data includes 185 commodities at a fairly detailed level (although it is not adjusted for quality differences), 58 commodities used as seed, and 146 commodities used as feed. Data on quantities and prices are collected for all benchmark years, 1970, 1975, 1980, 1985 and 1990. There are 103 countries in the sample, representing 99% of total world agricultural production and 98% of the world population. The sample of countries is fairly well distributed along the cross-country income distribution.

B. Sample Data

This paper uses data from the Penn World Table (PWT5.6) and FAO. Our sample includes 86 countries for which data for 1985 is available in both the PWT and FAO for all variables. The data are available in Excel and ASCII format at:

<http://www.economics.utoronto.ca/diegor/research/research.html>.

We use two measures of labor productivity in agriculture: GDP per worker (GDP_a/L_a) and final output per worker (Y_a/L_a) both from FAO. The share of employment in agriculture (L_a/N) is calculated as the ratio of employment to population in agriculture from FAO and employment to population from PWT. Labor productivity in non-agriculture (Y_n/L_n) is calculated using aggregate data from PWT and agricultural GDP and employment data from FAO. The land-to-employment ratio (Z/N) is calculated as arable land from FAO to total employment from PWT. The intermediate input to agricultural output ratio (X/Y_a) is calculated as the difference between final output and GDP relative to final output in agriculture from FAO. The PPP price of intermediate inputs is obtained directly through FAO.

In our sample, the richest 10 percent of the countries include the United States, Canada, Switzerland, Australia, Norway, Netherlands, Belgium, and Germany; the poorest 10 percent of the countries include Malawi, Chad, Zaire, Niger, Burundi, Tanzania, Burkina Faso, and Ethiopia.

C. Solution of the Equilibrium

From section 2, the maximization problem of the representative farmer yields the following first-order conditions:

$$\frac{X}{Y_a} = \alpha \frac{p_a}{\pi}, \tag{1}$$

$$p_a \sigma (1-\alpha) \frac{Y_a}{L_a} = w_a. \tag{2}$$

Substituting in the no-arbitrage condition $w_a = (1-\theta) w_n$ and the first-order condition of the non-agricultural firm's problem $w_n = A$, equation (2) becomes:

$$p_a \sigma (1-\alpha) \frac{Y_a}{L_a} = (1-\theta) A. \tag{3}$$

Using this equation to substitute for p_a in equation (1) and performing simple algebra manipulations, we obtain equation (E9),[1] an expression for the intermediate input to agricultural output ratio. Substituting (E9) into (E8) yields an expression for labor productivity in

[1] The letter E refers to equations in the original article; hence, E9 refers to equation 9 in the original paper.

agriculture, as stated in equation (E10).

The consumption allocation equations (E2) and (E3) of the representative household imply:

$$c_a = \bar{a} + \frac{a}{(1-a)} p_a^{-1} c_n.$$

Substituting the market clearing conditions for c_a in (E6) and c_n in (E7) into the above equation, we obtain:

$$\frac{Y_a}{N} = \bar{a} + \frac{a}{(1-a)} \frac{1}{p_a} \left(\frac{Y_n}{N} - \frac{\pi X}{N} \right). \tag{4}$$

Note that

$$\frac{Y_n}{N} = A(1 - \frac{L_a}{N}), \tag{5}$$

and from (1) we have

$$\frac{\pi X}{N} = \frac{\pi X}{Y_a} \frac{Y_a}{L_a} \frac{L_a}{N} = \alpha p_a \frac{Y_a}{L_a} \frac{L_a}{N}.$$

Using (3) to solve for p_a and substituting into the equation above we have

$$\frac{\pi X}{N} = \frac{\alpha(1-\theta)}{\sigma(1-\alpha)} A \frac{L_a}{N}. \tag{6}$$

Substituting (3), (5) and (6) into equation (4) and solve for L_a/N, we obtain equation (E11).

D. Sensitivity Analysis

We examine the robustness of our quantitative results with alternative values for $(1-\sigma)$ and a. The baseline model assumes a land elasticity of output in agriculture $(1-\sigma)$ of 0.3. This value is in the range of estimates in the empirical development literature. This literature documents a range of estimates for land elasticity between 0.1 and 0.4. (see Hayami and Ruttan, 1985; Mundlak, 2001) Table 2 reports the results of the model with alternative values for $(1-\sigma)$. When land is more important in agricultural production, σ is low, the extent of decreasing returns to labor is stronger, and the model implies larger aggregate productivity differences between rich and poor countries. The intuition for this result is that, for a given productivity difference between rich and poor countries, more labor is required to meet the subsistence constraint when there are stronger decreasing returns to labor in agricultural production. Indeed, when $\sigma = 0.6$, the average share of employment in agriculture in poor countries implied by the model is 81 percent instead of 68 percent in the baseline calibration. The opposite occurs when the extent of decreasing returns to labor is weaker ($\sigma = 0.8$). In both cases, the model with agriculture still implies substantial aggregate productivity differences between rich and poor countries relative to a one-sector model.

Our baseline model is calibrated to a long-run share of employment in agriculture of 0.5 percent, implying a preference parameter for agricultural goods a of 0.0046. Several analyses in the related literature assume a long-run share of employment in agriculture of zero. This alternative assumption would imply $a = 0$. Table 2 reports the results of the model when $a = 0$. Relative to the baseline calibration, the model with $a = 0$ implies a much larger aggregate productivity difference across countries (25.2 between the richest and poorest countries vs. 10.8 in our baseline calibration). The assumption that $a = 0$ implies that the share of employment in agriculture is much more responsive to changes in economy-wide productivity (a share of employment in agriculture of 0.83 in poor countries vs. 0.68 in the benchmark model), and therefore implies larger aggregate productivity differences than in the baseline calibration.

Table 1: Summary Data across Countries

Distribution	L_a/N	X/Y_a	Y_a/L_a	Y/N	Y_n/L_n	Z/N	π	$\frac{(1-\theta_i)}{(1-\theta_{us})}$
0-10	0.05	0.41	20242	29453	30306	1.60	1.19	0.93
10-20	0.07	0.36	15600	25147	26262	0.62	1.49	0.98
20-30	0.18	0.35	5840	18747	22269	0.81	1.54	0.66
30-40	0.23	0.27	3572	12832	16125	1.24	1.56	0.52
40-50	0.33	0.25	2131	8884	12848	0.86	2.14	0.54
50-60	0.49	0.20	1020	5592	10444	0.94	2.76	0.36
60-70	0.62	0.19	586	3915	10084	0.69	2.80	0.29
70-80	0.74	0.15	346	2417	11117	0.72	2.92	0.26
80-90	0.82	0.14	309	1559	8079	0.99	4.70	0.53
90-100	0.82	0.12	233	1020	6112	0.82	3.27	0.28
Rich 5	0.04	0.38	22969	30935	31701	2.95	1.22	0.91
Poor 5	0.86	0.12	211	902	6345	0.58	3.70	0.38
Rich 10	0.05	0.41	20242	29453	30306	1.60	1.19	0.93
Poor 10	0.82	0.12	233	1020	6112	0.82	3.27	0.28
Rich 20	0.06	0.38	17921	27300	28284	1.11	1.34	0.95
Poor 20	0.82	0.13	271	1289	7095	0.90	3.98	0.40
R 5/P 5	0.05	3.12	109.1	34.3	5.0	5.08	0.33	2.41
R 10/P 10	0.05	3.44	86.9	28.9	5.0	1.96	0.37	3.27
R 20/P 20	0.07	2.94	66.2	21.2	4.0	1.23	0.34	2.35
D 1/D 10	0.05	3.44	86.9	28.9	5.0	1.96	0.37	3.27
D 2/D 9	0.09	2.53	50.5	16.1	3.3	0.63	0.32	1.86

L_a/N is the share of employment in agriculture, X/Y_a is the intermediate input ratio, Z/N is the land-to-employment ratio, Y_i/L_i is labor productivity in sector i, a denotes agriculture and n non-agriculture, π is the relative price of intermediate inputs, and $(1-\theta)$ is the relative wage ratio. Rich x and Poor y refer to the rich x and poor y percent of the countries in aggregate GDP per worker in the data.

Table 2: Sensitivity Analysis with Alternative Parameter Values

	L_a/N	X/Y_a	Y_a/L_a	Y/N
Baseline Model	0.04/0.68	2.7	23.4	10.8
Alternative Specifications:				
$\sigma = 0.6$	0.04/0.81	2.4	29.2	15.6
$\sigma = 0.8$	0.04/0.58	3.1	19.4	8.9
$a = 0$	0.04/0.83	2.6	24.2	25.2

The baseline model assumes $\sigma = 0.7$ and $a = 0.0046$. The benchmark economy is re-calibrated to match the same targets from the U.S. economy as in the baseline model.