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The Agricultural Basis of Comparative Development

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Abstract

This paper shows, in a two-sector growth model with endogenous fertility, that long-run output per capita and industrialization depend upon the labor elasticity of agricultural production. A high labor elasticity, because the diminishing returns to labor are less pronounced, leads to a larger population density, lower output per capita, and a larger share of labor in agriculture in steady state. In response to an increase in industrial productivity, a higher labor elasticity in agriculture reduces the increase in output per capita. Cross-country estimates of agricultural production functions confirm that there is substantial variation in this elasticity across different climate zones and crop types. Consistent with relative development levels prior to the Industrial Revolution, regions in the tropics and/or with distinct winter dry seasons, as well as areas relying primarily on maize or rice production, are found to have higher labor elasticities. The results suggest that the *type* of agriculture practiced can provide an important explanation for relative development levels in historical, and potentially in contemporary, contexts.

JEL Codes: N10, N50, O41, O11, O13, Q10

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1 Introduction

Recent research has made it clear that long-run development depends on the trade-off between population and prosperity. For most of human history a Malthusian relationship appears to have held between population and income, leading to stagnant living standards. Sustained growth in income per capita began in several countries following the industrial revolution, which not only introduced new technologies to the production process but was closely followed by a demographic transition that changed the strict Malthusian relationship of income and human fertility.[1]

The importance of population processes for relative development holds even within the Malthusian regime. As Clark (2007) and Voigtländer and Voth (2009) point out, Malthusian stagnation does not imply that output per capita is always at minimum subsistence levels. Differences in the responsiveness of births and deaths to income can generate significant differences in living standards. Thus we have evidence from Maddison (2001) that per capita incomes in Europe were already two to three times higher than incomes in Asia, Africa, or Latin America in 1700, the eve of the Industrial Revolution.

This paper proposes that we can usefully explain output per capita, population density, and industrialization in the Malthusian era – and potentially in even more recent periods – by looking at the labor elasticity of agricultural output. The evidence presented in the paper establishes that this labor elasticity is related to the *type* of agriculture practiced, as captured by major crops produced and primary climate zones.

In a basic Malthusian model involving two sectors of production and a dependence of human fertility on the price of food, I show that this labor elasticity is a determinant of a) the steady state size of the population, b) the share of population employed in agriculture (industrialization), and c) output per capita.[2] In addition, it is shown that while changes in industrial productivity and fertility preferences will raise real output per capita, the size of the effect depends upon the labor elasticity in agriculture as well.[3]

The basic intuition is that when the labor elasticity is large the diminishing returns to labor in agriculture are less severe. This leads to a higher population density relative to the fixed factor of production, land, in the agricultural sector. If there were only one sector, then this would be the only effect of labor elasticity. Once a second sector is introduced, though, there are further consequences. A larger labor elasticity leads to a smaller average product of labor in agriculture

[1]The transition from Malthusian stagnation to growth has been explored by Galor and Weil (1999, 2000), Galor and Moav (2002), Hansen and Prescott (2002), Jones (2001), Doepke (2004), Fernández-Villaverde (2005) and others. See Galor (2005) for a complete survey of the facts and theories involved in unified growth.

[2]The basic two-sector specification is similar to Galor and Mountford (2008), who focus on the effects of international trade when productivity levels differ, but assume that labor shares in agriculture are identical. The explicit dependence of fertility on food prices is shared with work by Strulik and Weisdorf (2008).

[3]Recent work by Weil and Wilde (2009) and Wilde (2009) has focused on the substitutability of fixed factors of production to examine the importance of Malthusian mechanisms. The current paper presumes that production is Cobb-Douglas and therefore the elasticity of substitution between land and labor is exactly equal to one.

once the wage is pinned down by the non-agricultural sector. With a low average product, more individuals must be employed in agriculture to meet demand, and the average product is lower in the economy overall. Thus the type of agriculture practiced, to the extent that it influences labor elasticities, can have an effect on relative development levels even within a Malthusian equilibrium.

It is important to distinguish the approach of this paper from others focusing on the structural transformation and improvements in agricultural *productivity*. Gollin, Parente, and Rogerson (2007) provide an explanation for comparative development that depends upon differences in agricultural TFP, similar in spirit to the work of Schultz (1953), Johnston and Kilby (1975) and Timmer (1988). In this type of "push" model, countries with high agricultural productivity release labor into industry and enjoy higher incomes per capita due to the higher productivity of the industrial sector. These models typically assume that population is fixed in size and agricultural production functions are identical across countries. What I show here is that when these assumptions are relaxed, differences in production functions – the *type* of agriculture used – can generate long-run differences in output per capita even while holding the *productivity* of agriculture constant.

For this to be a meaningful way of thinking about long-run development, we need to establish that labor elasticities in agriculture vary and that they vary in a manner consistent with the evidence on relative development levels. To address these questions, I estimate agricultural production functions using country-level data from the years 1961-1999, breaking down the sample by major crop type as well as climate characteristics.

The results indicates clear differences in labor elasticity across different biological zones of the world. In tropical and rice-producing zones, as well as those areas that experience a distinct winter dry season during the year, elasticities are between 0.55 and 0.77. In contrast, mid-latitude regions, wheat-producing areas, and those places without dry seasons have elasticities in the range 0.35 to 0.40. Regions without significant livestock production have elasticities two to three times larger than those that do produce livestock as a major output.

These estimates must be taken with the caveat that they are drawn from contemporary data, and labor elasticities may have been different in the past, or are a response to development itself. Historical evidence is reviewed, though, that indicates labor shares in agricultural output were very persistent over the last four-hundred years. In addition, including controls for income per capita directly or making estimates while excluding all of the highly-developed nations of today yields nearly identical results regarding the relationship of climate and labor elasticity. The results are also consistent with micro-level data on the fraction of output earned by agricultural laborers involved in different types of crop production.

With this in mind, the estimates suggest that differences in agricultural type can provide an interesting perspective on sources of comparative development. Just prior to the Industrial Revolution, Europe had a relatively high standard of living and a large urban sector. As mentioned, Maddison's evidence suggests Europe was relatively well-off compared to Asia and Africa in 1700.

Similarly, urbanization rates averaged about 10-15% for western Europe in 1700 (Bairoch, 1988) while areas such as the Netherlands had rates as high as 40%. In contrast, in 1700 China's overall urbanization rate was about 2% and that of India only 1%. The argument here is that these differences were related to the fact that Europe's climate endowed them with a low labor-elasticity agriculture (wheat and dairy) while India and China (the southern regions, at least) employed the more labor-intense techniques associated with rice. Even though India and China had very productive agricultural sectors, as evidenced by their large populations and high densities, the type of agriculture practiced created individual incentives that led to low average products per worker.

The emphasis here on the role of biological or geographic factors in development is related to the work of Diamond (1997) and Jones (1987), who argue that endowments of crops and livestock were important in determining relative development levels.[4] This paper suggests that the salient aspects of these endowments was their influence on labor's role in agricultural production. This view is different from the one in Sachs (2001), Bloom and Sachs (1998), or Gallup, Mellinger and Sachs (1998), which all look at direct effects of geography on income working through disease environments or inherent agricultural productivity.

In contrast, there is a prominent literature that emphasizes the role of economic and political institutions over geography or biology in comparative development. Acemoglu, Johnson, and Robinson (2001, 2002, 2005) look at the role of institutional structure in determining income levels across ex-colonies, following the work of North and Thomas (1973) studying the role of property rights in European development. The current paper does not contradict the idea that institutions are relevant for economic development, but fits into the paradigm that geographic factors may be significant influences on those institutions (see also Engerman and Sokoloff, 1997).

More specifically, Acemoglu et al (2002) document a "reversal of fortune" among former colonies and attribute this to institutional differences imposed by the European colonizers. The evidence of this paper suggests a reason why it was Europe that was colonizing the Americas, Africa, and Asia, rather than the other way around. The source of the European advantages, from this perspective, were the low labor elasticity of agriculture that led to higher levels of income per capita and industrialization relative to these other areas. These biological advantages, as in Diamond (1997) and Jones (1987), gave Europe the upper hand.

More broadly, the relevance of the Malthusian mechanism for comparative development levels has been recently documented by Ashraf and Galor (2008). The current study offers a complementary approach to understanding variation within the Malthusian world, while also providing an explanation for how the type of agriculture practiced could have long-run consequences for growth. After introducing the model defining the role of labor elasticity, the empirical evidence is presented to support the idea that this elasticity varies widely by climate zone.

[4]Other recent research concerned with biological elements of long-run development include Ashraf and Galor (2009), Dalgaard and Strulik (2007), Galor and Michalopoulos (2006), Galor and Moav (2002), Lagerlöf (2003), Michalopoulos (2008), and Olsson and Hibbs (2005).

2 Agricultural Production and Development

The model presented here is a relatively simple two-sector model of development that includes an endogenous fertility decision by individuals. It focuses on the allocation of labor between the two sectors (agriculture and industry) and how the shape of the agricultural production function ultimately determines output per capita and industrialization.[5]

2.1 Individual Optimization

Utility for each of the L_t adults in the economy is over both consumption, c_t, and fertility, n_t,

$$U_t = U(c_t, n_t) \tag{1}$$

and the function $U(\cdot)$ has the properties

$$U_c > 0,\ U_{cc} < 0,\ U_n > 0,\ U_{nn} < 0 \tag{2}$$

and there is no restriction on the cross-partial derivative.

The budget constraint depends on income, I_t, in terms of manufacturing output, the price of agricultural goods relative to manufacturing output, p_{At}, and the subsistence amount of food each adult and child must be fed. This amount is $\overline{a}$ for the adult, and $\theta\overline{a}$ for each child with $\theta \in (0, 1)$. Income not spent on food is consumed, so that the overall constraint is

$$I_t = c_t + p_{At}\overline{a}(1 + \theta n_t). \tag{3}$$

The optimal solution for fertility is

$$n_t = s\frac{(I_t - p_{At}\overline{a})}{p_{At}\theta\overline{a}} \tag{4}$$

where the term $s \in (0, 1)$ is the share of net income, $I_t - p_{At}\overline{a}$, that is spent feeding children.[6] For a fixed s, fertility is Malthusian in the sense that a decrease in the price of food increases n_t. The main results can be developed without having to specify the nature of s any further.

[5] The model is strictly Malthusian in that it generates a positive relationship between income and fertility and does not include an endogenous quantity/quality trade-off. This highlights the role of the agricultural production function. One could enrich the model with more complex fertility decisions, but this would complicate the analysis without fundamentally changing the role of agricultural production. Kogel and Prskawetz (2001) provide a unified growth model involving agricultural productivity and endogenous fertility, but do not consider relative development levels.

[6] If utility is a typical Cobb-Douglas function of consumption and fertility, then s is constant.

2.2 Production and Individual Income

Only the L_t adults are productive. Agricultural goods are produced by a combination of land, R, and labor, $L_{At} \leq L_t$, and output in that sector is defined as

$$Y_{At} = A_{At} R^{1-\beta} L_{At}^{\beta} \tag{5}$$

where A_{At} is total factor productivity and Y_{At} is aggregate output.

The parameter β will be of central importance in this model. Typically one would assume that β is a technological constant. In particular, one would presume that β is the same for different countries under investigation. This model shows that if β is *not* the same across economies, it can have a significant influence on long-run development levels. The empirical work later in the paper establishes that β in fact *does* vary across countries by climate zone and crop type.

The agricultural sector is presumed to be perfectly competitive, so that land and labor are paid their value marginal products

$$\begin{aligned} w_{At} &= p_{At}\beta \frac{Y_{At}}{L_{At}} \\ r_{At} &= p_{At}(1-\beta)\frac{Y_{At}}{R} \end{aligned} \tag{6}$$

where w_{At} is the agricultural wage rate and r_{At} is the rental rate for land, both in terms of manufactured goods.

The manufacturing sector is presumed to be linear in labor, for simplicity, and the wage rate this yields is denoted w_{Mt}. Perfect mobility between sectors ensures that the wage rates are equalized and therefore

$$\begin{aligned} w_{At} &= w_{Mt} \\ p_{At}\beta \frac{Y_{At}}{L_{At}} &= w_{Mt}. \end{aligned} \tag{7}$$

Individuals are presumed to be identical in their endowments of labor. Additionally, all individuals are presumed to hold an equal amount of land, regardless of their actual sector of employment.[7] Given these assumptions, I_t for any individual can be written as

$$I_t = p_{At}\beta \frac{Y_{At}}{L_{At}} + p_{At}(1-\beta)\frac{Y_{At}}{L_t}. \tag{8}$$

[7]Because of the linear nature of fertility, allowing for some distribution of land over individuals will result in an identical solution for aggregate fertility despite individuals having differential fertility based on their land holdings.

2.3 Equilibrium and Dynamics

We can now establish two conditions that will determine the equilibrium allocation of labor to agriculture and the fertility rate. First, total demand for agricultural goods must equal their total supply,

$$\overline{a}(1+\theta n_t)L_t = Y_{At} \tag{9}$$

which tells us implicitly what level of fertility can be supported by the economy for any given level of agricultural employment, L_{At}, and population L_t. Given the nature of the production function, n_t is increasing in L_{At}, holding L_t constant.

The second condition is the optimal fertility level from equation (4). Combining this with the income level in (8) we have

$$n_t = \frac{s}{\theta\overline{a}}\left(\beta\frac{Y_{At}}{L_{At}} + (1-\beta)\frac{Y_{At}}{L_t} - \overline{a}\right) \tag{10}$$

where the price level of agricultural goods has canceled out. From this equation, we see that n_t depends on L_{At} to the extent that it affects income relative to the price of the subsistence consumption of food for the adult.

The equilibrium levels of L_{At} and n_t have to satisfy both the resource constraint in (9) and the individual optimality condition in (10). To capture this, consider that one can combine the optimal fertility condition in (10) and the resource constraint in (9) to solve for L_A. This gives us the following function G,

$$G(L_{At}|A_{At},R,L_t) \equiv \left(\frac{Y_{At}}{L_t} - \overline{a}\right) - s\left(\beta\frac{Y_{At}}{L_{At}} + (1-\beta)\frac{Y_{At}}{L_t} - \overline{a}\right) = 0 \tag{11}$$

which defines L_{At} as an implicit function of A_{At}, L_t, and R.

To examine the dynamics of the structural transformation, we need to establish how L_{At} responds to changes in population, L_t. The relationships

$$\frac{\partial L_{At}}{\partial L_t} > 0 \qquad \frac{\partial^2 L_{At}}{\partial L_t^2} > 0 \tag{12}$$

can be found by applying the Implicit Function Theorem using $G(\cdot)$, along with the nature of the Cobb-Douglas production function.

Figure 1 shows graphically the long-run equilibrium. The x-axis measures the size of the population at time t, while the y-axis measures the size of the agricultural population. Along the 45 degree line, the share of population in agriculture is equal to one. Below this line, the agricultural share of population, L_{At}/L_t is less than one.

$G(L_{At}|L_t, A_{At}, R) = 0$ represents the equilibrium level of L_{At} given the size of L_t, holding

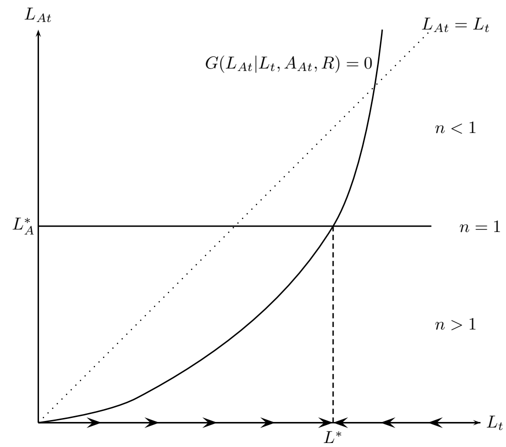

Figure 1: Equilibrium Population Structure

Note: The $G(L_{At}|L_t, A_{At}, R) = 0$ curve represents the number of workers in equilibrium in agriculture for a given L_t, holding A_A and R constant. The $n = 1$ line represents the level of L_{At} that sets the optimal fertility decision of individuals to one. Above this line fertility is less than one, while below this line fertility is above one. The economy converges along the optimal allocation curve to the point (L^*, L_A^*).

constant A_{At} and R. The economy is always on this curve. As population increases, an increasing number of individuals have to be employed in agriculture. L_{At} increases with L_t at an increasing rate because of the diminishing marginal product of each new agricultural worker.

The horizontal line labeled L_A^* represents the number of agricultural workers that sets the optimal fertility choice of individuals in equation (10) equal to one. At levels of L_{At} below this line, the wage rate goes up and so optimal fertility is greater than one, implying an increase in population. Above the line, wages are low and so fertility is below replacement levels.

The intersection of the two curves represents the point at which the equilibrium number of agricultural workers, L_A^*, is exactly that level at which fertility is at replacement. This level of population is labeled L^*. At $L_t < L^*$, fertility is greater than one, and $L_{t+1} > L_t$. At $L_t > L^*$, fertility is less than one, and $L_{t+1} < L_t$. The point L^* is an absorbing steady state, and the economy will end up there regardless of the original population level.

More exact solutions for the long-run can be obtained given the functional forms assumed. In steady state, we must have that $n_t = 1$. Solving together (10) and (9) along with this condition yields the following steady state share of labor in agriculture

$$\frac{L_A^*}{L^*} = \frac{\beta}{\beta + \Omega}. \tag{13}$$

where $\Omega = \theta(1 - s)/(1 + \theta)s$. This shows that in steady state the fraction of labor employed in the agricultural sector is increasing in labor's share of production. For economies with large labor elasticities in agricultural production, a greater share of individuals will remain in that sector. The explanation for this is that a high elasticity implies a large marginal product of agricultural labor. The only way for the labor market to clear, given the manufacturing wage, is for the average product of labor to be very low. To provide sufficient food for the population, then, a larger number of individuals will have to remain in the agricultural sector.

Note that the L_A^*/L^* ratio does *not* depend on productivity or the resource base. The reason is that productivity also induces higher fertility due to lower food prices and that requires a greater number of agricultural workers to support. Any long-run changes in the share of labor in agriculture would have to come from changes in either the share of time spent raising children (s) or in the relative cost of children (θ). It is not possible the "push" labor into industry in the long run by raising agricultural productivity.

The important influence of β can also be seen in the levels of consumption per person. In steady state, with $n = 1$, it must be that agricultural output per adult is

$$y_A^* = \frac{Y_A^*}{L^*} = 1 + \theta \tag{14}$$

which is identical regardless of β. However, the consumption of manufacturing goods per adult is

$$y_M^* = \frac{Y_M^*}{L^*} = w_M \frac{\Omega}{\beta + \Omega} \tag{15}$$

and this is clearly decreasing in β. Essentially, a large β means that the *average* product of a agricultural workers must be small, and therefore a large fraction of adults must work in agriculture to feed everyone. This leaves fewer individuals producing manufacturing goods. While manufacturing output per worker in that sector is unchanged, manufacturing output per adult is lower when β is large.

In other words, two economies that have identical endowments of resources and productivity (R, A_A, w_M) may have different output per person, industrialization, and population levels because their underlying agricultural production function is different.

2.4 Productivity Changes

A standard explanation of the structural transformation in the process of development involves increasing agricultural productivity combined with a low income-elasticity for agricultural goods. As productivity increases labor can be released into the industrial sector as agricultural demand does not rise one-for-one with income. The model illustrated here shows that this may only be relevant in the short-run, and that once we allow for a long-run response of fertility the allocation of labor across sectors is unaffected by agricultural productivity.

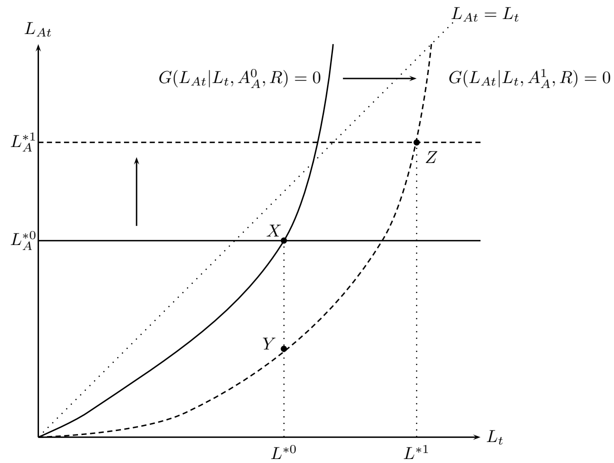

Figure 2: Effects of Improving Agricultural Production

Note: The economy begins in equilibrium at point X. An improvement of agricultural productivity from A_A^0 to A_A^1 increases the population sustainable at any given level of L_{At}, indicated by the rightward shift of the $G(\cdot)$ function. The level of L_{At} consistent with $n = 1$ also increases. Immediately after the shift, the economy moves to point Y, as fewer workers are necessary in agriculture. Over time, the increase in fertility moves the economy up the resource constraint from point Y to point Z. Long-run population is larger at L^{*1}, but the proportion of population in agriculture, L_A^{*1}/L^{*1} is unchanged.

Figure 2 shows how an economy will respond in the short-run and long-run to a change in agricultural productivity. Beginning with a productivity level of A_A^0, the economy is at a long-run equilibrium at point X. An increase of agricultural productivity to $A_A^1 > A_A^0$ moves both curves. First, the equilibrium condition shifts to the right as the economy can support a larger population with any given number of agricultural workers. Secondly, the increase in productivity increases wages, and therefore the number of agricultural workers consistent with replacement fertility increases.

Immediately after this change, the economy still has L^{*0} individuals. The increased productivity means that fewer people have to work in agriculture, and the economy drops to point Y. At this low number of L_{At}, fertility is very high, and the population begins growing. It grows until the new equilibrium at point Z is obtained. This equilibrium has a larger overall population of L^{*1}, as well as more agricultural workers, L_A^{*1}.

In many studies of the structural transformation the population size is held constant and the ratio L_A/L is found to fall as agricultural productivity increases. This is similar to the initial drop from point X to point Y in figure (2). As the current model shows, though, this is not the whole story. Agricultural productivity growth does not necessarily have to lead to structural transformation in the long run.

An additional point is that the short-run response of the economy to increasing productivity depends upon the labor elasticity β. Holding L_t constant, we can use the $G(L_{At}|L_t, A_{At}, R) = 0$ condition to ask how L_{At} responds to a change in A_{At}. Taking derivatives, it can be shown that

$$\frac{\partial L_{At}}{\partial A_{At}} < 0 \qquad \frac{\partial^2 L_{At}}{\partial A_{At} \partial \beta} > 0. \tag{16}$$

The first derivative shows that an increase in agricultural productivity will lower the number of workers in agriculture, holding L_t constant. The second part shows that the size of this effect depends upon the elasticity of output with respect to labor, β. As β gets larger, the drop in L_{At} becomes smaller following a productivity increase. That is, the negative effect of A_{At} on L_{At} becomes less powerful the higher is β.

Finally, in steady state, one can solve for the relative price of agricultural goods, and this will be

$$p_A^* = \frac{1}{1+\theta} \frac{w_M}{\beta + \Omega}. \tag{17}$$

As can be seen, the price is declining in β. An interesting implication of this involves international trade. Comparing two countries that differ only in β, it will be to the advantage of the high β country to specialize in food production, while the low-β country specializes in industrial production. Even without any distinction in industrial productivity w_M or agricultural total factor productivity A_A, we would see low-β countries industrializing more rapidly as they specialize.

2.5 The Response to Development

Similar effects can be seen when considering how an economy escapes from the Malthusian trap. As written, there is no endogenous mechanism in the model that will make this occur. However, we can consider two avenues through which the transition to sustained growth might happen: fertility habits and industrial productivity. From equation (15) we know that as β increases, manufacturing output per adult decreases. Note, though, that this also implies that the derivative of manufactured goods per adult with respect to industrial productivity (w_M) is decreasing in β, as $\partial y_M^* / \partial w_M = \Omega / (\beta + \Omega)$. In other words, a high labor elasticity of *agricultural* production will generate a small response to *industrial* productivity changes. Even if a technological improvement is perfectly shared across borders, countries with large β values will experience less of an increase in real manufacturing output per capita relative to low-β countries.

Another aspect of the transition to sustained growth is a drop in the share of time spent on fertility, s. When s falls, this increases the term Ω. From (**??**), this increases income per capita and from (13) it lowers the long-run share of individuals in agriculture, regardless of the initial value of β. Unlike changes in w_M, the gain in income from a fertility decline may be larger for countries with a high labor elasticity in agriculture. The exact effect of a drop in s depends on the relative size of β and Ω.

The model indicates the importance of the *type* of agriculture practiced in long-run development, as captured by the labor elasticity. Those places that practice labor-intensive agriculture will have lower output per capita, will be more populous, and will be less industrialized than economies using lower-intensity agriculture. This holds even if the absolute levels of productivity and resources are identical. Improvements in agricultural productivity will also do less to promote the structural transformation in places with highly labor-intense agricultural sectors, and the effect of technological changes on output per capita will be smaller.

3 Labor Elasticity in Agricultural Production

For this to be a useful way of thinking about long-run development, it requires evidence that β actually varies across economies in a way that matches the predictions of the model.

It would be ideal to have estimates of β over very long periods of time, for different countries or regions, in order to establish that it was relevant in the process of long-run development. Unfortunately, good data on agricultural production inputs do not exist for a wide array of countries from prior to 1960. The estimates will thus rely on contemporary data on agricultural production. The idea is that if estimates of β vary across countries or geographic regions *today*, then it is at least plausible that there were differences farther back in the past. At the end of the section a review of some related literature on labor shares suggests that these are relatively stable over long periods of time. Thus the contemporary estimates are felt to be a good indicator of fundamental differences in agricultural production over the long-run.

The estimations are performed for various groups of countries, differentiated by climate zones and primary agricultural products.[8] Gallup, Sachs, and Mellinger (1999) provide data on the share of cultivated area in each country that lay within each of the twelve primary Köppen-Geiger (KG) climate zones. There are two main dimensions upon which land is classified. First, a broad category determining the main climate. For our purposes, the three most interesting categories are zone "A" (Tropical), zone "B" (Dry), and zone "C" (Mid-latitude mild climate).[9] Intersecting these main categories are a classification based on the nature of the dry season. In the KG system, zone "f" denotes land without a distinct dry season, zone "s" denotes a summer dry season, and zone "w" denotes a winter dry season.[10]

[8] Wiebe, Soule, Narrod, and Breneman (2003) report production function estimates for agriculture by region, but do not break down their sample by climate zone or type of agriculture practiced.

[9] The other three main categories are zone D (Mid-latitude severe climate), zone E (polar), and zone H (highlands). Few countries have significant land located within these zones, and estimation of separate production functions for these areas are not possible.

[10] The combination of these dry season zones with the main climate zones provides the main KG system classification. Thus land may be denoted "Af", for tropical land that has no dry season, while other land may be denoted "Cs" for a mild mid-latitude climate with a summer dry season.

For each of six main regions, table 1 lists the average share of land in each of the six main classifications mentioned above.[11] Sub-saharan Africa has a majority of land in either the Tropical or Dry zones, and very little (9.8%) land does not experience a dry season. The Middle-East and North Africa are classified mainly as Dry or Mid-latitude, and are dominated by land with a summer dry season.

Asia and the Pacific islands are heavily Tropical (zone A) and also tend to have a dry season in the winter. The climate shares in this region are actually quite similar to Central and South America, which is also predominantly tropical and has a large proportion of land with a winter dry season. Relative to the other zones, Europe and the Neo-Europes (Australia, Canada, New Zealand, and the U.S.) are dominantly mid-latitude, and additionally have nearly all of their land in zones without a distinct dry season.

In addition to classifying countries by their climate zones, I also distinguish countries by the nature of their agricultural production. The FAO provides a breakdown of agricultural output data into different categories. The primary breakdown is to distinguish *crop* production from *livestock* production. Crop production refers, generally, to any output derived from plants, regardless of whether they are planted annually (like wheat) or planted permanently (like an orange tree). Livestock production involves any production (such as meat, milk, or eggs) that are derived from animals.[12]

As a further breakdown, one can consider primary cereal production. The FAO provides the share of total cereal production for several of the main cereal crops. The production of each cereal is converted into a rice-equivalent value so that output is comparable. I focus here on the three main cereals in production today: maize, rice, and wheat.

Referring back to table 1, the lower half provides the average share in agricultural production for crops, as well as the share of total cereal production accounted for by maize, rice, and wheat. Sub-Saharan Africa produces nearly 70% of it agricultural output from crops, and the Middle-East, Asia, and Latin America all have values between roughly 60% and 70%. In contrast, Europe and the Neo-Europes have under 50% of their agricultural production in crops, and have much larger shares of livestock products.

For cereal production, there is more variation across regions. Sub-Saharan Africa relies on maize to a great extent, as well as on other cereals not explicitly accounted for in the table (millet, for example). The Middle-East and North Africa are heavy wheat producers, while Asia is not surprisingly dependent on rice production. Central and South America have a more varied set of cereals, with maize and rice being predominant. Europe and the neo-Europes are mainly wheat

[11] The totals of land share in A,B,and C do not sum to one because there are other main categories that are excluded because of their small shares. The share in f,s, and w do not sum to one because not all land is given a dry season classification.

[12] A third category, *non-food* production, captures the value of output from fibre crops as well as drinks such as tea or coffee.

producers, but also have a large share of cereal production in maize.

3.1 Estimation of Labor Elasticity

To begin, production is assumed to be well described by a Cobb-Douglas function,

$$y_{it} = \gamma_0 + \beta l_{it} + \gamma_R r_{it} + \gamma_K k_{it} + \gamma_F f_{it} + \mu_i + v_t + \epsilon_{it} \tag{18}$$

where lower case letters refer to the log values, countries are denoted by i and time periods by t. y_{it} is gross agricultural output, l_{it} is agricultural labor, r_{it} is land area, k_{it} is the agricultural capital stock, and f_{it} is the supply of fertilizer used. The parameter ϵ_{it} is an i.i.d. error term, μ_i is a fixed effect by country and v_t is a fixed effect for each time period. β is the parameter of interest, while the γ coefficient represent the elasticity of output with respect to the other inputs.[13]

Estimating (18) has several issues typical to determining the coefficients of production functions. The main one is that we do not observe productivity, and given that inputs will be correlated with productivity, there will be some omitted variable bias present. Fixed-effects can deal with the unobserved value μ_i, but looking solely at within-country variation to estimate β raises an additional issue.

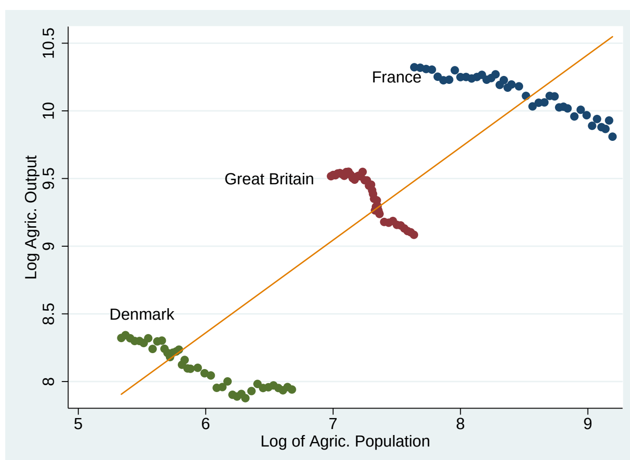

Figure 3: Within and Between Variation in Output and Labor in Agriculture

Notes: This figure plots the log of total agricultural output against the log of the agricultural population, both variables coming from the FAOSTAT database. The line plots the fitted values from the OLS regression across all data points.

[13]The Cobb-Douglas form of the agricultural production function has been found to be appropriate when examining cross-country agricultural production. Kawagoe, Hayami, and Ruttan (1985), Lau and Yotopoulos (1988), and Mundlak (2000) all confirm this as an appropriate assumption.

The problem is best illustrated by looking at data from a handful of countries, as in figure 3. Within Denmark, France, and Great Britain, it is clear that larger agricultural populations are associated with lower total agricultural output. This reflects that fact that as agricultural productivity goes up, more labor is released from the agricultural sector. This could provide information about the elasticity of agricultural output with respect to labor, but to tease this out requires some understanding of the general equilibrium effects at work. If we look across these three countries, though, we can infer something about how agricultural production is related to the size of the workforce. The strategy adopted here is to use random-effects estimation which combines the within-country variation with the between-country variation. An additional approach utilizing data on population size is discussed following the main results.

Regardless of the issues involved with the fixed effect, there remains unobserved productivity shocks in ϵ_{it}. There are techniques in the literature that attempt to deal with this by using data on intermediate good usage (Levinsohn and Petrin, 2003) and investment effort (Olley and Pakes, 1996). These techniques were designed for firm-level data, and require strong assumptions regarding competitive price-taking by these firms. The cross-country setting used here is just not an appropriate place to apply these techniques. While no specific method can be used to correct the issue with unobserved productivity, by estimating the model for small groups of countries with similar climates and/or similar output mixes, some of the variation in productivity should be reduced when compared to estimating over all countries. In other words, we could expect that variation in ϵ_{it} across only those countries producing rice is smaller than variation in ϵ_{it} across the whole world. This should reduce the bias within the smaller samples.

A final point regarding the estimation is the time-series treatment of ϵ_{it}. It seems likely that some serial correlation will be present in the productivity shocks. To deal with this possibility, it is assumed that $\epsilon_{it} = \rho\epsilon_{i,t-1} + \xi_{it}$ where ρ is the auto-regressive parameter and ξ_{it} is the unobserved shock in period t. Table **??** presents tests of serial correlation in the error terms of all the regressions done, and in every case the serial correlation is strongly supported. All the results account for the presence of serial correlation.

For the estimation, data on agricultural outputs and inputs are obtained from the United Nations Food and Agriculture Organization (FAO). Full details of this data are available in the appendix. Output is measured as the total value of agricultural production after deductions made to account for the use of output as feed for livestock and seed for subsequent planting. Inputs include the total area of agricultural land employed, a composite index capturing the value of all livestock, a count of the number of mechanical tractors employed, the total tonnes of fertilizer employed. The measure of agricultural labor is the total number of economically active agricultural workers. All these measures are the standard ones used in cross-country agricultural production research. A total of 98 countries are used, each with observations in the range 1961–1999, although not every country has the full 39 observations, so that the maximum number of observations is 3491.

One additional control variable is included in every regression, and that is the log of GDP per capita. This is used to address the possibility that the labor elasticity responds to the level of development itself. Relatively rich countries may optimally choose low labor intensity production technologies. The inclusion of GDP per capita will control for any correlation in the size of the agricultural workforce and the level of development holding constant the level of other agricultural inputs.

3.2 Cross-country Results

The results of the various baseline estimates of $\hat{\beta}$ by climate type or agricultural output can be found in table 2 under the column heading (A). Each row of the column represents a separate estimation, varying only in the countries included in the sample. Year dummies are included in all regressions, and the standard errors are calculated allowing for serial correlation. Note that the climate and agricultural output breakdown data are not included as control variables in the estimation, they are only used to define which countries are included in the regression.

The first row of table 2 reports $\hat{\beta}$ for the entire sample of 98 countries. The value of 0.399 is in line with the previous literature on cross-country agricultural production functions.[14] However, including all 98 countries in the same estimation assumes that the production function is actually identical for countries in all climate zones, and identical regardless of the type of agricultural goods produced.

The next four rows represent regressions run on sub-groups defined by the dominant cereal produced. The row labeled "> 50% Maize" thus includes the 29 countries for which maize makes up more than half of their total cereal output. In these countries, the estimated coefficient on labor is 0.453. For the 21 countries that rely mainly on rice, the coefficient is 0.584. In contrast, countries that are dominated by wheat production have a coefficient on labor or only 0.130, less than one-third the value of those other crops.

Recalling the theoretical section, these results indicate that rice and maize-growing areas will generally have lower output per capita, larger fractions of individuals engaged in agriculture, and will respond more sluggishly to industrial productivity improvements. To the extent that these elasticities are applicable to earlier periods, they could represent a reason that certain agricultural regions of the world remained relatively poor when compared to the temperate wheat-growing areas of western Europe. One caveat here is that maize production was not even possible for many areas prior to the European discoveries, so current maize-producing countries are not identical to those of the past. However, to the extent that the estimates are accurate, they can represent one reason why in the past the maize-dependent regions of the Americas were less developed.

Distinctions can also be drawn based on the share of crops (as opposed to livestock) in total

[14] See Mundlak (2000) for a review of this literature and the various estimates of labor elasticity.

agricultural output. For countries producing over 60% of output as crops, the estimated elasticity is 0.538, compared to an estimate of only 0.285 for those with larger shares in livestock. Output mix is, of course, endogenous, and richer countries will likely demand a larger share of output as meat and dairy products. However, as Diamond (1997) documents, the endowments of domesticable livestock varied greatly across regions of the world. It seems possible that the estimates represent a structural difference in agricultural production functions.

The final section of the table estimates $\hat{\beta}$ based on the dominant climate zone within countries. Tropical (A) and Dry (B) zones have very high estimated elasticities, with values of 0.613 and 0.773, respectively. This contrasts with a value of only 0.419 for the mild Mid-latitude zone. Countries that are predominantly located in areas with no dry season or with a summer dry season (as in the Mediterranean) show elasticities between 0.385 and 0.400, while areas that experience a winter dry season have an estimated elasticity of 0.552. The pattern of these results are consistent with the relative development of temperate zones in western Europe that did not experience dry seasons, as well as the subsequent development of places such as the United States and Canada. In contrast, those places in the tropics and dry regions have very high labor elasticities and are also relatively under-developed today.

An obvious concern here is that the low labor elasticities for some climate zones (C and f, in particular) and crop types (wheat) do not represent real structural differences, but some other facet of the high levels of development of the countries in them. As mentioned previously, the log of GDP per capita is included in each regression to control for a correlation of living standards with the labor force in agriculture. As an additional check, though, table 3 reports estimates of $\hat{\beta}$ for the same categories, only now excluding Europe and the Neo-Europes from the sample entirely. We are mainly checking whether it was simply the presence of highly developed nations that led to the relatively low labor elasticity estimates for those zones.

Overall, the remaining 73 developing countries have an estimated elasticity of 0.527. This is higher than when all countries are included, and indicates that the European countries were driving down the estimate due to their much lower labor elasticities.

If we look at the various crops, though, we see a similar pattern to the results of table 2. Maize and rice producers have much higher estimated elasticities than wheat producers. Note that the wheat producers in this estimation are not a sub-sample of particularly developed countries - it includes Algeria, Morocco, Syria, and Tunisia.

Comparing countries that produce more than 60% of output as crops with the remainder of countries yields again the estimate that crop production is more labor-intense. The difference in estimates is not as dramatic as in the whole sample, but given the very low standard errors it is impossible to reject the hypothesis that the estimates are actually identical.

If we look at the various climate zones, though, some of the variation in the whole sample has disappeared. The Tropical and Dry zones have identical estimates as no European or Neo-European country fell mainly within these zones in the first place. However, if we look at zone C, the mild mid-latitude zone, the estimate excluding Europe is now 0.520, slightly higher than before, but still smaller than the estimated values for the Tropical or Dry zones. The biggest change seen in table 3 is that countries with winter dry seasons do not appear to be significantly different any more than places without them. However, the distinction with tropical and dry regions remains.

Taken together, tables 2 and 3 indicate that there are distinct differences in the agricultural production function between different climate zones and types of agriculture. The elasticity of production with respect to labor is higher, in general, for tropical or dry places with a distinct dry season. Places that do not have significant livestock production have higher labor elasticities, as do places that rely more on maize or rice versus wheat.

3.3 Population-based Estimation

As noted previously, an issue with estimating β is that within countries the relationship of y_{it} and l_{it} involves not just the supply side but also the demand for agricultural goods. Thus we can see a negative relationship between the two as in figure 3.

One way of working around this problem is to account more clearly for the demand for agricultural output. If log population in a country is n_{it} at time t, then similar to the resource constraint in the model, one could write

$$\alpha + \phi n_{it} = y_{it} \tag{19}$$

which says that log output of agricultural goods is related to population size with an elasticity of ϕ (in the model, I presumed that this elasticity was one for simplicity), scaled by the factor α.

Combining equation (19) with the production function in (18) suggests the following relationship

$$n_{it} = \frac{\gamma_0 - \alpha}{\phi} + \frac{\beta}{phi} l_{it} + \frac{\gamma_R}{\phi} r_{it} + \frac{\gamma_K}{\phi} k_{it} + \frac{\gamma_F}{\phi} f_{it} + \frac{\mu_i}{\phi} + \frac{v_t}{\phi} + \frac{\epsilon_{it}}{\phi} \tag{20}$$

so that total population should be related to the agricultural labor force with an elasticity of β/ϕ. Estimating this relationship should eliminate some of the within-country issues as it explicitly accounts for agricultural demand (at least to some extent). The drawback is that we will have estimates of β/ϕ, not β. However, the goal is to compare β across different crop types and climate zones, and if we are willing to assume that ϕ is a behavioral parameter similar across countries, then we can still infer something about how β varies between zones from the β/ϕ estimates.

Again using random-effects estimation with explicit control for serial correlation, table 2 shows in column (B) the estimates in various samples using n_{it} as the dependent variable. As can be seen the general pattern of results is similar to those using output. Wheat production is found to have a lower estimated elasticity, while rice and maize are generally higher.

Places that rely more heavily on crops also retain a higher elasticity than places that don't. The final section of table 2 shows that, to a lesser degree than before, mild mid-latitude areas and those with no or a summer dry season have lower labor elasticities in agriculture.

In table 3, the estimation again excludes all European and Neo-European countries, and once again the patterns remain similar. Wheat production, a low reliance on crops, and begin mid-latitude without winter dry seasons yields a low elasticity of agricultural output with respect to labor.

One thing to note in table 3 is that the estimates in column (B) are all lower than the estimates in column (A). This would imply, if we believe the estimates in column (A) are accurate, that the parameter ϕ is greater than one, as column (B) is estimating β/ϕ.

While not a perfect control for the general equilibrium relationship of agricultural labor and output, estimation using population as the dependent variable does provide consistent information regarding the relative size of β across different crop types and climate zones.

3.4 Relationship to Other Evidence

The cross-country estimates here are consistent with several studies of labor shares in agriculture output. For Zimbabwe, Masters (1994) gives a labor share of 0.60. This relatively large value is consistent with the cross-country estimates, as Zimbabwe is split almost evenly between zone B (Dry) and zone C (mid-latitude), but about half of its land experiences a winter dry season. In addition, Zimbabwe grows maize as its primary cereal (83% of all cereal output) and crops make up approximately 75% of its agricultural output.

Hayami, Ruttan, and Southworth (1979) report labor shares for the Philippines of approximately 0.55 and Taiwan of 0.54. The Philippines lies entirely in zone A (Tropical) and produces over 75% of its agriculture as crops, dominantly rice. The reported value of 0.55 fits right at cross-country estimates of 0.585 for rice producers. Taiwan is mainly tropical and also relies heavily on crop production for its agricultural output. The cross-country evidence also seems consistent with the reported value of 0.54.

For China, Brandt, Hsieh, and Zhu (2008) suggest that the labor share in China is approximately 0.50 when estimated using household surveys. Provincial data from Hsueh and Li (1999) yields a labor share of 0.76. China spans a wide range of climate zones, but has a plurality of land in zone C (mid-latitudes) while approximately 70% of its land experiences some kind of dry season. It produces nearly 70% of its output as crops, rice making up about 46% of cereal output and maize and wheat each coming in at about 25%. Despite the wide variation within Chinese climate zones, the cross-country estimates are not wildly out of line with a value of 0.50-0.75 for a country that experiences winter dry seasons and relies so heavily on maize and rice production.

On the other end of the scale, estimated labor shares for the U.S. in 1980 from Capalbo and Vo (1988) are about 0.11, consistent with the cross-country estimates for a country that lies mainly in the mid-latitude zone C and has almost no dry seasons to speak of. Additionally, the U.S. has a much lower reliance on crops (55% of total output) and a much higher reliance on wheat than the previous examples.

Historical estimates for England from Clark (2002) suggest a higher value there of between 0.36-0.40. These numbers are similar to what we have from the cross-country estimates for a country that lies so squarely in the mid-latitude zone C and certainly has nothing resembling a dry season. Perhaps the most important aspect of Clark's estimates are that they are available for a period spanning nearly 300 years. In that time the share of output going to labor was consistently in the 0.36-0.40 range, suggesting that there is persistence in this value. Allen (2005) reports similar results, with the share of agricultural output going to labor fluctuating between 0.34 and 0.39 from 1700–1850. Thus there is some evidence that the contemporary cross-country data presented previously has some applicability to studying long-run development prior to 1960. In addition, this evidence suggests that labor intensities were relatively low in England as compared to East Asian countries.

All of these estimates accord with broader studies of the difference in labor intensity across different types of agriculture. Grigg (1974) states, "Compared with most farming systems, wet-rice cultivation is labour-intensive," (p. 81). The high intensity is corroborated by information on the average number of days labor per hectare to cultivate different crops, reported in Boserup (1965). Wet paddy rice requires approximately 125 days per hectare in India, while dry wheat production in the same country takes somewhere between 33-47 days per hectare (pages 40 and 50). Grigg (1974) reports that wheat production in southern Europe required approximately 30 days of labor per hectare as of the 1950's (p. 141). Overall, the cross-country results and labor share information suggest that there are likely distinct differences in agricultural labor elasticity across regions of the world. More importantly, these differences appear consistent with relative development levels prior to the Industrial Revolution and to some extent even after this event.

4 Implications

The evidence appears to indicate that β is distinctly different across different biological zones. The effect of this on relative development levels can be assessed in light of the model presented.

Table 4 presents the steady state values derived from the model based on different levels of β. Panel A, for example, shows the share of labor in agriculture, L_A/L, calculated from equation (13). The value of Ω in this equation depends on the food cost of children relative to adults, θ, and the share of resources spent on fertility, s. For the purposes of the table, it is assumed always that $\theta = 0.5$, while the different columns of the table report the outcomes under different assumptions regarding s.

From panel A, then, one can see how different levels of β change the steady state allocation of labor in agriculture. If the share of resources spent on fertility, s, is equal to 90%, as in the final column, then regardless of the value of β the economy has a very large portion of individuals engaged in agriculture to feed the population. However, note that if the elasticity is only 0.15, similar to the values estimated for wheat producing regions, then the share is relatively small at 80%, compared to 95% for an economy with an elasticity of 0.75, similar to that estimated for the tropical regions.

If the resource share to children, s, falls to 0.7, then for any level of β the labor share in agriculture falls. But note that the fall is much larger for the low elasticities. The drop in s leaves only 51% of labor in agriculture when $\beta = 0.15$ while 84% of labor remains in that sector if $\beta = 0.75$. Without appealing to any differences in productivity across economies, the difference in labor elasticity can generate very large differences in the share of labor engaged in the non-agricultural sector. If the share s falls all the way to 0.10, then the agricultural share drops in all cases, but remains much larger in relative terms when β is large.

Panel B reports the population density, assuming that $A_A(1+\theta)\overline{a} = 2$. This term dictates the actual size of the population, and an increase in A_A would increase density regardless of the value of s or β. The value of 2, and hence the density values, are not meant to match any specific data. Rather, they simply show how population density can vary by β even when the productivity level is held constant. As can be seen, for any given level of β, density is declining in s. In other words, as people expend fewer resources on children, the population size relative to the fixed factor will decline.

At high levels of s, note that density is increasing in β. However, as s declines this relationship flips, so that when $s = 0.10$ density is higher in the low labor elasticity situation. Recall that as β goes up, the average product of an agricultural laborer is falling. However, as β goes up we also know from panel A that the share of labor in agriculture is rising. As s falls, the former effect dominates and even with a relatively large fraction of workers in agriculture, they are producing less food in aggregate. At large levels of s the latter effect is dominant, and aggregate production is sufficient to sustain a very dense population.

Finally, panel C reports the value of industrial output per capita, assuming that $w_M = 10$. What can be seen is that manufacturing output is always lower for the high β situation. At high levels of s, panel C shows that output is about four times as large when $\beta = 0.15$ as when $\beta = 0.75$. Note that this difference holds even though all productivity levels are identical. It provides a way of understanding why relatively temperate, wheat-producing regions like Europe (with low β values) may have had an advantage in development even before the Industrial Revolution or Demographic Transition. Tropical and/or rice-producing regions, which had values of β between 0.60 and 0.75, would have been relatively poor, dense, and agricultural even though they had access to identical technologies as Europe. The high level of β increased the marginal return to labor, inducing higher fertility, and thence driving down the average return.

Of course, the values in table 4 are arbitrary, and different assumptions could mute the differences in density, labor allocation, and output per capita. However, it seems plausible at least that variation in β, which appears quite strongly in the data, could be a useful way of explaining and interpreting relative development levels.

5 Conclusion

When comparing development across countries, it is hard to escape the correlation with geography. Today, as well as three-hundred years ago, the temperate areas of Europe were well-off compared to the tropical and sub-tropical regions of Africa, Asia, and the Americas.

This paper has argued that this correlation is more than a coincidence. In particular, evidence shows that the labor elasticity of agriculture varies greatly depending on the climate zone and type of agriculture pursued. Tropical and sub-tropical regions have very large elasticities of agricultural output with respect to labor, depending on crops more than livestock and working with labor-intense crops such as rice. Mild latitude areas with access to livestock and crops such as wheat display a much lower elasticity.

These differences in labor elasticity were shown to be relevant to development levels within a simple Malthusian model that included two sectors of production and an endogenous fertility decision. With high labor elasticities, the limitations of fixed factors of production are less severe and populations grow more quickly. However, this drives down the average product of labor to the point that a larger fraction of workers are required to work in agriculture and output per capita is low. Low-elasticity agriculture supports an economy, in contrast, that has relatively high standards of living while allowing a greater share of workers to engage in non-agricultural work. These differences can exist even though the total factor productivity of the two sectors is identical across economies.

These results can potentially explain why Europe, and eventually North America after the introduction of the European agricultural system, were relatively rich even prior to the onset of the Industrial Revolution. The model also suggests that the marginal effect of technological changes in the industrial sector on output per capita would be larger in the temperate, low labor-elasticity areas, offering an explanation for why growth in these areas was more rapid following the Industrial Revolution as well.

Appendix

Production Data

Total agricultural output is obtained from the FAOSTAT (United Nations, 2009) database and is the total value of all agricultural production after deductions for feed and seed. This value is a price-weighted sum of the quantity of all agricultural outputs given in terms of international dollars. The international dollar was developed by the FAO to avoid having to use market exchange rates to compare the value of output across countries. It is derived from the Geary-Khamis fomula that calculates simultaneously the relative price of each component of output and the implicit exchange rate of each country's currency with respect to the international dollar.

The breakdown of output used to divide countries in the empirical analysis is based on output data from the year 2000. The FAO reports the value of all crop production (all food items grown), livestock production (food derived from animals including meat, eggs, and milk), and non-food production (fibre products as well as coffee, tea, and tobacco). The share of output in crops is simply total crop production relative to total output.

Cereal production is a subset of crop production. The FAO reports total production, in tonnes, of each of the major cereals. The raw tonnage of each cereal is converted by the FAO to milled rice equivalents. This converts the tonnes of each cereal into a nutritionally-equivalent number of tonnes of rice.

Data on inputs are from the FAOSTAT database. The measure of *land* is the total hectares of agricultural land, which consists of arable land, permanent crop land and permanent pasture land. *Livestock* is the number of cow equivalents, a measure commonly used in the cross-country literature. It is calculated from FAO data on stocks of types of animals using weights from Hayami and Ruttan (1985). The weighting is: 1 horse = 1 mule = 1 buffalo = 1.25 cattle = 1.25 asses = 0.9 camels = 5 pigs = 10 sheep = 10 goats = 100 chickens = 100 ducks = 100 geese = 100 turkeys. *Tractors* is measured as the number of agricultural tractors in use and are all assumed to be 30 horsepower. This measure excludes two-wheeled tractors and garden tractors and is not a perfect measure of capital services available. Unfortunately, this is the only series on physical capital available for a wide range of countries over the time frame covered. *Fertilizer* is the total metric tons used of nitrogen, phosphate, and potash fertilizer. *Labor* is measured as the total economically active population in agriculture.

The countries included in the data-set all have observations in each year from 1961 to 1999, inclusive. Countries with fewer observations were excluded. This mainly excluded the individual states created from the break-up of the Soviet Union and Yugoslavia.

Countries, by Region

The regional break-down is based upon the FAO's classification, with some modifications. In particular, Australia and New Zealand have been removed from the Asia and Pacific group and added to the European group. The European group was merged with the North American group (Canada and the U.S.) to form the Europe and Neo-Europe group.

Sub-Saharan Africa: Angola, Benin, Botswana, Burkina Faso, Cameroon, Central African Republic, Chad, Republic of Congo, Côte d'Ivoire, The Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe

Middle-East and North Africa: Afghanistan, Algeria, Egypt, Iran, Iraq, Jordan, Morocco, Saudi Arabia, Syria, Tunisia, Yemen

Asia and Pacific: Bangladesh, China, India, Indonesia, Japan, Rep. of Korea, Malaysia, Myanmar, Pakistan, Philippines, Sri Lanka, Thailand

Central and South America: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Suriname, Trinidad and Tobago, Uruguay, Venezuela

Europe and Neo-Europes: Australia, Austria, Belgium-Luxembourg, Bulgaria, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States

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Table 1: Country Level Summary Statistics, by Region

Region:	Sub-Saharan Africa	Middle-East and N. Africa	Asia and Pacific	Central and S. America	Europe and Neo-Europes
Share of cultivated land in Köppen-Geiger Climate Zone:					
Tropics (A)	0.467	0	0.554	0.652	0.002
Dry (B)	0.352	0.416	0.129	0.024	0.058
Mild mid-latitude (C)	0.166	0.320	0.196	0.147	0.752
No dry season (f)	0.098	0	0.279	0.273	0.689
Summer dry season (s)	0.308	0.526	0.056	0.035	0.260
Winter dry season (w)	0.577	0.210	0.510	0.472	0.007
Agricultural Production Shares, 2000					
Crops in total output	0.687	0.612	0.740	0.578	0.464
Maize in total cereals	0.445	0.096	0.083	0.479	0.196
Rice in total cereals	0.174	0.060	0.786	0.366	0.011
Wheat in total cereals	0.026	0.614	0.114	0.071	0.435

Notes: Data on the land shares is from Gallup, Sachs, and Mellinger (1999), while the regional categories are described in the appendix. Agricultural production shares are authors calculations from the FAOSTAT database for the year 2000.

Table 2: Estimates of Elasticity of Output with respect to Labor, by Various Samples

	Dep. Variable:					
	(A)		(B)			
	log Ag. Output		log Pop.			
Sample	$\hat{\beta}$	S.E.	$\hat{\beta}$	S.E.	Countries	Obs.
World	0.399	(0.023)	0.391	(0.006)	98	3491
Cereal production:						
> 50% Maize	0.453	(0.048)	0.409	(0.012)	29	1028
> 50% Rice	0.584	(0.033)	0.368	(0.015)	21	783
> 50% Wheat	0.130	(0.046)	0.255	(0.020)	16	581
Agricultural output:						
> 60% Crops	0.538	(0.031)	0.487	(0.009)	51	1813
< 60% Crops	0.285	(0.035)	0.368	(0.010)	47	1678
Cultivated land:						
> 60% Zone A (Tropical)	0.613	(0.039)	0.521	(0.015)	32	1124
> 60% Zone B (Dry)	0.773	(0.042)	0.593	(0.032)	9	331
> 60% Zone C (Mid-lat mild)	0.419	(0.040)	0.396	(0.011)	29	1045
> 60% Zone f (No dry season)	0.400	(0.038)	0.349	(0.012)	26	913
> 60% Zone s (Summer dry season)	0.385	(0.063)	0.385	(0.015)	17	609
> 60% Zone w (Winter dry season)	0.552	(0.041)	0.471	(0.014)	33	1154

Notes: Headings (A) and (B) refer to the dependent variable used in each regression in the table. Each row of the table represents a separate regression over the panel of countries that fit the sample definition. The reported coefficient is the elasticity of agricultural output with respect to labor. The time frame is 1961–1999, although some countries have data that begins later than 1961. Each regression includes year dummies and a control for log GDP per capita. Estimation and standard errors are calculated assuming that the residuals follow an AR(1) process.

Table 3: Estimates of Elasticity of Output with respect to Labor, Excluding Europe and Neo-European Countries

	Dep. Variable:					
	(A)		(B)			
	log Ag. Output		log Pop.			
Sample	$\hat{\beta}$	S.E.	$\hat{\beta}$	S.E.	Countries	Obs.
World	0.527	(0.029)	0.397	(0.009)	73	3491
Cereal production:						
> 50% Maize	0.510	(0.046)	0.385	(0.015)	27	950
> 50% Rice	0.585	(0.033)	0.368	(0.015)	21	783
> 50% Wheat	0.199	(0.074)	0.059	(0.035)	8	299
Agricultural output:						
> 60% Crops	0.604	(0.035)	0.542	(0.012)	47	1664
< 60% Crops	0.475	(0.047)	0.298	(0.016)	26	955
Cultivated land:						
> 60% Zone A (Tropical)	0.613	(0.039)	0.521	(0.015)	32	1124
> 60% Zone B (Dry)	0.773	(0.042)	0.593	(0.032)	9	331
> 60% Zone C (Mid-lat mild)	0.520	(0.074)	0.354	(0.021)	13	484
> 60% Zone f (No dry season)	0.583	(0.064)	0.493	(0.025)	10	371
> 60% Zone s (Summer dry season)	0.587	(0.075)	0.195	(0.027)	11	396
> 60% Zone w (Winter dry season)	0.552	(0.041)	0.471	(0.014)	33	1154

Notes: All countries in Europe and the "Neo-Europes" are excluded (see appendix for full list of countries in this category). Headings (A) and (B) refer to the dependent variable used in each regression in the table. Each row of the table represents a separate regression over the panel of countries that fit the sample definition. The reported coefficient is the elasticity of agricultural output with respect to labor. The time frame is 1961–1999, although some countries have data that begins later than 1961. Each regression includes year dummies and a control for log GDP per capita. Estimation and standard errors are calculated assuming that the residuals follow an AR(1) process.

Table 4: Steady State Outcomes at Different Labor Elasticities in Agriculture

Panel A: Share in Ag. (L_A/L)

	Fertility (s):				
β	0.10	0.30	0.50	0.70	0.90
0.15	0.05	0.16	0.31	0.51	0.80
0.30	0.09	0.28	0.47	0.68	0.89
0.45	0.13	0.37	0.57	0.76	0.92
0.60	0.17	0.44	0.64	0.81	0.94
0.75	0.20	0.49	0.69	0.84	0.95

Panel B: Pop. Density (L/R)

	Fertility (s):				
β	0.10	0.30	0.50	0.70	0.90
0.15	1.32	1.64	1.84	2.01	2.17
0.30	0.96	1.56	1.95	2.28	2.56
0.45	0.67	1.55	2.24	2.81	3.31
0.60	0.38	1.63	2.92	4.11	5.17
0.75	0.13	1.89	5.31	9.48	13.85

Panel C: Industrial Output p.c. (y^M)

	Fertility (s):				
β	0.10	0.30	0.50	0.70	0.90
0.15	9.52	8.38	6.90	4.88	1.98
0.30	9.09	7.22	5.26	3.23	1.10
0.45	8.70	6.33	4.26	2.41	0.76
0.60	8.33	5.65	3.57	1.92	0.58
0.75	8.00	5.09	3.08	1.60	0.47

Notes: The panels represent the steady state outcomes of the model under different assumptions regarding the labor elasticity of agriculture (β) and the time allocated to fertility (s). In each panel, the assumed value of θ (the relative food use of children) is 1/2. For panel B, the value of $A_A(1+\theta)\overline{a}$ is set equal to 2. Scaling this up will increase density in every case, and vice versa. In panel C, w_M is assumed to be equal to 10, while $p_A(1+\theta)\overline{a}$ is assumed to be equal to 1.