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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 intensity of agricultural production. Because the diminishing returns to labor are less pronounced, a high labor elasticity in agriculture leads to a larger population density as well as lower output per capita and a larger share of labor in agriculture. Development is slower when the labor intensity is high as increases in income are skewed towards higher population versus higher living standards. Historical evidence and cross-country estimates of agricultural production functions confirm that there is substantial variation in labor intensity across different crop types and climate zones. Consistent with relative development levels prior to the Industrial Revolution, regions in the tropics and/or with distinct dry seasons, as well as areas relying primarily on rice production, are found to have labor-intense agricultural systems. Simulations show that small differences in agricultural labor intensity can have a significant impact on the timing of long-run development. 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 1750, 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 – as well as the timing of the escape to sustained growth – by looking at the labor intensity of agricultural output. The evidence presented in the paper establishes that this labor intensity is related to the *type* of agriculture practiced, as captured by major crops produced and primary climate zones.[2]

In a basic Malthusian model involving two sectors of production and a dependence of human fertility on the price of food, I show that labor intensity 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.[3] In addition, it is shown that while changes in industrial productivity and fertility preferences can raise real output per capita, the size of the effect depends upon the labor intensity in agriculture as well.[4]

Intuitively, the economy is deciding how to allocate labor across two uses: non-agriculture and agriculture. As the labor intensity of agriculture goes up the opportunity cost of non-agricultural goods is larger – it costs more in lost food output to produce one additional unit of manufactured

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[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] Recent work by Voigtländer and Voth (2009) uses differences in labor intensity between grain crops and pastoralism, combined with differences in females and males comparative advantage in production to explain the emergence of the European marriage pattern following the Black Death.

[3] 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).

[4] 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.

goods by shifting a worker between sectors. In equilibrium with a labor-intense agricultural sector, the relative price of agricultural goods will be small and a larger share of labor will be allocated to agricultural work. With low food prices fertility will be higher and in the long-run the population size will be larger when labor intensity is high, even if the endowments of land and technology are identical to a low-intensity economy. In general, a highly labor-intense agricultural sector will keep the cost of fertility low, and so improvements in productivity in either sector will tend to generate increasing population at the expense of higher living standards.

For this to be a meaningful way of thinking about long-run development, we need to establish that labor intensities 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 the elasticity of agricultural output with respect to labor across different biological zones of the world. In tropical and rice-producing zones, as well as those areas that experience a distinct dry season during the year, elasticities are between 0.58 and 0.69. In contrast, mid-latitude regions, wheat-producing areas, and those places without dry seasons have elasticities in the range 0.23 to 0.50. Regions without significant livestock production have elasticities two to three times larger than those that do produce livestock as a major output. These elasticities indicate, given a standard Cobb-Douglas production function for agriculture, differences in labor intensity across different types of agriculture.

These estimates must be taken with the caveat that they are drawn from contemporary data, and labor intensities may have been different in the past, or are a response to development itself. Historical evidence is reviewed, though, that indicates labor shares of output 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. The findings 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. A straightforward simulation of the model allowing for endogenous productivity growth in the agricultural and manufacturing sectors shows that even minor differences in the labor intensity in agriculture will have significant effects on Malthusian steady states and the take-off to growth. A low-intensity agricultural economy with an elasticity of 0.4 that matches the stylized facts of development in Western Europe over the very long run (roughly 1300-2000) would have seen the Industrial Revolution delayed by up to 200-250 years if the elasticity were raised to only 0.5. Even allowing the high-intensity economy with an elasticity of 0.5 to start with higher productivity levels does not reverse this difference. While not definitive, the results of the simulation show that one can generate realistic differences in development without having to appeal to technological or institutional differences. Thus the model can provide an explanation for the relatively early development of the Western Europe (with low-intensity agricultural production) compared to India, China, and other areas endowed with high-intensity techniques.

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. Most notably, in the long run when fertility depends on food prices, industrialization and output per capita are invariant with respect to agricultural productivity. Increases in agricultural productivity induce larger populations, but do not generate development.

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.[5] 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.

While focusing on geographic differences in agriculture and development, it is important to point out that this does not imply geography is the engine of development. In other words, industrialization and sustained increases in living standards are driven by improvements in manufacturing sector productivity, and I do not suggest that agricultural labor-intensity is what dictates those improvements. Productivity increases may be due to changes in economic and political institutions, as emphasized by Acemoglu, Johnson, and Robinson (2001, 2002, 2005) following the work of North and Thomas (1973). Alternatively, innovations in science and technology that took hold in northwestern Europe may have been the spur for development, as in Mokyr (1990) or Landes (1969). Accumulation of human capital as in Galor and Weil (2000), and Galor, Moav, and Vollrath (2009) or the evolution of preferences for human capital as in Galor and Moav (2002) and Clark (2007) have also been proposed as reasons for the take-off to sustained growth. Regardless of the actual

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[5] 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).

source, what the current paper emphasizes is that the agricultural context within which this growth occurs is vital. For places with a high labor intensity in agriculture improvements in productivity get translated more into new population than into increased living standards. Over long periods slight differences due to this effect are magnified into widely divergent levels of development. An important implication is that development levels may diverge between economies even if they share identical institutions, productivity levels, or human capital.[6]

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 intensity, the empirical evidence is presented to support the idea that this intensity varies widely by climate zone. The paper concludes with simulations demonstrating the role of agricultural intensities in long-run growth.

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.[7]

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.

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[6] The ideas in this paper are similar in spirit to the work of Engerman and Sokoloff (1997) who emphasize that geographic factors may have indirect effects on development, in their case because geography influences the distribution of economic and political power.

[7] 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.

The budget constraint depends on income, I_t, in terms of manufacturing output, the price of agricultural goods relative to manufacturing output, p_t, 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

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

The optimal solution for fertility is

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

where the term $s \in (0, 1)$ is the share of net income, $I_t - p_t\overline{a}$, that is spent feeding children.[8] 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.

2.2 Production and Individual Income

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

$$Y_{At} = A_t X^{1-\beta} L_{At}^{\beta} \tag{5}$$

where A_t 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. Given the Cobb-Douglas production funciton, β is the elasticity of output with respect to labor, and captures the labor intensity of agricultural production.

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

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

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

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[8] If utility is a typical Cobb-Douglas function of consumption and fertility, then s is constant. This general specification is used as the calibration in the final section of the paper is not Cobb-Douglas.

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

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

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.[9] Given these assumptions, I_t for any individual can be written as

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

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

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[9] 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.

the following function G,

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

which defines L_{At} as an implicit function of A_t, L_t, and X.

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.

$G(L_{At}|L_t, A_t, X) = 0$ represents the equilibrium level of L_{At} given the size of L_t, holding constant A_t and X. 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 labor employed in agriculture is increasing in the labor-intensity of agricultural work, measured by β. A high intensity implies

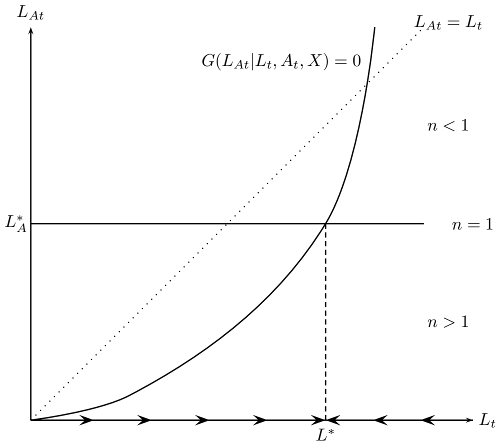

Figure 1: Equilibrium Population Structure

Note: The $G(L_{At}|L_t, A_t, X) = 0$ curve represents the number of workers in equilibrium in agriculture for a given L_t, holding A_t and X 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^*).

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 agricultural 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.[10]

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

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

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[10] As written, industrial productivity changes to w_M have no effect on the long-run allocation of labor, either. If one allows s to depend inversely on income, or allows for greater substitutability of fertility and consumption in the utility function, then L_A^*/L^* would depend negatively on w_M.

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 summary, two economies that have identical endowments of resources and productivity (X, 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 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^0, the economy is at a long-run equilibrium at point W. An increase of agricultural productivity to $A^1 > A^0$ 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 W 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.

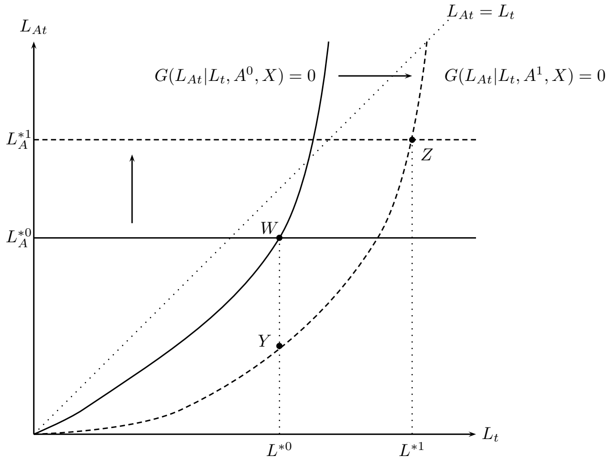

Figure 2: Effects of Improving Agricultural Production

Note: The economy begins in equilibrium at point W. An improvement of agricultural productivity from A^0 to 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.

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

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

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_t on L_{At} becomes less powerful the higher is β. Agricultural productivity improvements will do less to industrialize an economy in the short run the higher is β. Here it is important to note that this result is due to the production function elasticity, and not simply because labor is assumed to earn the fraction β of agricultural output.

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. Improvements to productivity may be due to institutions, human capital accumulation, or technological innovation. To the extent that these improvements influence s or w_M differentially will determine exactly how growth occurs, but here I simply examine the statics of the steady state with respect to these changes.

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 intensity in *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 adult 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 (15), this increases industrial output 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 intensity in agriculture. The exact effect of a drop in s depends on the relative size of β and Ω at the time of the change. Note that if s does depend on income per capita, then the effect of β is exaggerated. An economy with low labor intensity will be relatively rich, which will lower s, which makes the economy even richer, and so on. As will be seen in the simulations later in the paper, this type of interaction leads to earlier development for low labor intensity economies.

A final element to consider is the possibility of trade. One can solve for the relative price of agricultural goods in steady state, and this will be

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

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

The model indicates the importance of the *type* of agriculture practiced in long-run development, as captured by the labor intensity. 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.[11] 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).[12] 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.[13]

For each of six main regions, table 1 lists the average share of land in each of the six main classifications mentioned above.[14] Sub-saharan Africa has a majority of land in either the Tropical

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[11] 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.

[12] 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.

[13] 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.

[14] 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.

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.[15]

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

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

3.1 Estimation of Labor Intensity

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. β is the parameter of interest, while the γ coefficient represent the elasticity of output with respect to the other inputs.[16]

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. Country fixed-effects can deal with the unobserved value μ_i, but looking solely at within-country variation to estimate β raises an additional issue.

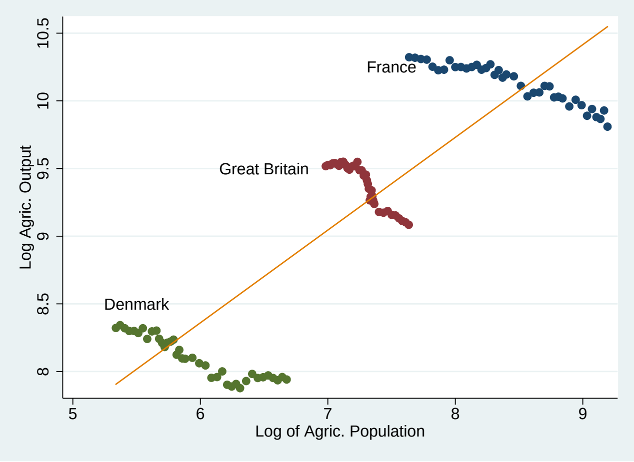

Figure 3: Within and Between Variation in Output and Labor in Agriculture

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.

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

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[16] 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.

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.

To avoid this issue, the estimation is done without country fixed effects, but including time fixed effects, v_t. Thus the estimates are based on within-time comparisons of different countries, which more closely captures how differences in the size of the agricultural labor force are related to total agricultural production. This means that invariant country characteristics are unaccounted for directly. However, the estimates will be done for sub-samples that share similar climate zones or agricultural types, eliminating one source of between-country variation. In addition, all the estimates include log GDP per capita as an additional control which will pick up some of the between-country variation as well. This control has the additional feature of picking up time-varying unobserved effects of development.

A final point regarding the estimation is the time-series treatment of ϵ_{it}. Specification tests (reported in the appendix) show that serial correlation is 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.

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.

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. An additional note is that table 2 only reports the estimated value of β, the coefficient on agricultural labor. Full results, including specification tests for serial correlation, are available in the appendix.

The first row of table 2 reports $\hat{\beta}$ for the entire sample of 98 countries. The value of 0.578 is in line with the previous literature on cross-country agricultural production functions.[17] 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 0.634. For the 21 countries that rely mainly on rice, the coefficient is 0.577. In contrast, countries that are dominated by wheat production have a coefficient on labor or only 0.227, less than one-half 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, for example, 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 indicate that maize production is also labor-intense and would lead to lower average levels of development in the Malthusian era.

Distinctions can also be drawn based on the share of crops (as opposed to livestock) in total agricultural output. For countries producing over 60% of output as crops, the estimated elasticity is 0.715, compared to an estimate of only 0.318 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 plausible 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 0.691 and 0.885, respectively. This contrasts with a value of only 0.503 for the mild Mid-latitude zone. Countries that are predominantly located in areas with no dry season show an elasticity of 0.422, while areas that experience a dry season have an estimated elasticity of between 0.666 and 0.757 depending on whether the dry season occurs in winter or summer. 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

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

contrast, places in the tropics and dry regions have very high labor intensities and are also relatively under-developed today. These results do not prove that this is the precise mechanism involved, but they are broadly consistent with comparative development levels.

An obvious concern here is that the low labor intensities 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 in column (A) 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 0.694. 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: 0.577-0.667 versus 0.250. 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 0.606, higher than before, but still smaller than the estimated values for the Tropical or Dry zones. Countries with no dry season now have an elasticity of 0.544, higher than in the full sample, but still lower than the reported estimates for those places with summer dry seasons (0.773) or winter dry seasons (0.666).

Taken together, the (A) columns of 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 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

An issue with the results so far is that the measure of agricultural output is based on imputed world values for each crop, and this may not be capturing the true nutritional value of agricultural output that is associated with subsistence needs, as in the model.

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 log 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. This eliminates the need to use the market value of agricultural outputs, but 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 between-time 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 (0.366), while rice and maize are generally higher (0.771 and 0.776, respectively).

Places that rely more heavily on crops also retain a higher elasticity than places that don't: 0.866 to 0.616. The final section of table 2 shows that, similar to before, mild mid-latitude areas (zone C) and those with no 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. One exception is that maize production is now found to have a relatively low value of β/ϕ compared to wheat and rice (0.305). The large gap between rice and wheat production, though, remains. We still have that heavy crop producers have higher labor elasticities, as do places in the Tropics (zone A) or Dry regions (zone B). One difference from the output-based regressions is that places without dry seasons, in this restricted set of countries, do not show a significantly lower elasticity that places with dry seasons.

One thing to note in table 2 and 3 is that the estimates in column (B) are almost all higher than the estimates in column (A). This would imply, if we believe the estimates in column (A) are accurate, that the parameter ϕ is less than one, as column (B) is estimating β/ϕ. This would indicate that demand for food has an elasticity of less than one with respect to total population. The implied values of ϕ are all around 0.75.

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 intensity 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, both cross-country and historical, appears to indicate that labor intensities vary across different climate zones and agricultural types. Theoretically, this could lead to differences in relative development, but the variation in estimated β values may only be on the order of 0.10-0.20. Are these differences really significant for long-run development? To see the influence of labor intensity, the model presented earlier is simulated under several different conditions. To do so, a specific functional form for the utility function is selected and a process for endogenous productivity growth is added.

The utility function is presumed to be quasi-linear, so that $U = c_t + \gamma \ln n_t$, a form originally due to Weisdorf (2008) and used by Strulik and Weisdorf (2008) in their unified growth model. This, in terms of the notation presented earlier, is equivalent to assuming that $s = \gamma/(I_t - p_{At}\overline{a})$. The share of income allocated to fertility is declining with income, and practically speaking this assumption means that fertility is determined only by the relative price of food. This in turn will imply that the relative productivity growth in the two sectors, which dictates the price of food, will drive the changes in fertility.

Productivity growth in the two sectors is characterized in a learning-by-doing manner, similar to Strulik (1997) and Matsuyama (1992), and consistent with the "reduced-form" version of endogenous productivity growth in Jones (1995). The specific functional forms are

$$A_{A,t+1} - A_{At} = \delta_A \left(A_{At} R^{1-\beta} L_{At}^{\beta} \right)^{\phi} \tag{21}$$

$$w_{M,t+1} - w_{Mt} = \delta_M \left(w_{Mt} L_{Mt} \right)^{\theta} \tag{22}$$

where δ_A and δ_M are scaling parameters, while ϕ and θ are both chosen to be less than one so that there is some decreasing return to productivity in generating new productivity growth.

The full analytical solution to the model and the specific parameter choices are detailed in the appendix. The parameter values and initial values were chosen so that the baseline simulation begins in period zero (normalized to year 1300) with a large fraction of individuals engaged in agriculture and relatively low fertility levels, and this is followed eventually by a structural transformation that includes a temporary spike in fertility and an increasing rate of industrial productivity growth.

Most importantly, the baseline simulation assumes that $\beta = 0.40$, in line with the historical work on the United Kingdom and consistent with the cross-country evidence for a country in temperate areas without distinct dry zones and relying on a wheat/livestock agriculture. This baseline can be seen in figure 4 on the curves denoted “Beta = 0.4”. The top panel plots the fertility rate, which begins slightly above replacement and climbs steadily over the simulation to a peak of about 1.01 towards the end of the 1800’s. From there fertility declines as industrial productivity growth proceeds and drives up the relative cost of children (i.e. food prices rise) until the economy in the long-run settles down to replacement fertility.

The share of labor employed in the agricultural sector begins at about 0.72. This value may seem rather low, but it should be noted that this is not intended to be the share of population in rural areas, but rather the share of labor engaged in non-subsistence activities. The starting value for this share will be modified in a second set of simulations to see if this initial value is crucial. Regardless, as the economy evolves productivity growth in industry is slow due to the small scale of the sector. Eventually, productivity growth in industry is sufficient to begin a structural transformation at around year 1800 that takes the share steadily down to nearly zero by 2100.

Finally, panel C of figure 4 plots the log of manufacturing output per capita. This value is low and stagnant at the early part of the simulation, but around 1800 this starts to climb in line with the structural transformation. The takeoff in manufacturing output per capita proceeds so that by the year 2000 it is 6 times higher than in 1800.

This baseline is meant to be similar to the experience of Western Europe, but is not calibrated to match any specific historical facts precisely. The reason is that accounting for long-run growth is not the purpose, but rather to compare how this baseline would change under different assumptions regarding labor intensity in agriculture.

In figure 4, the second set of curves plot the development of fertility, labor shares, and manufacturing output per capita with only a single change to the model. Rather than $\beta = 0.40$, the labor

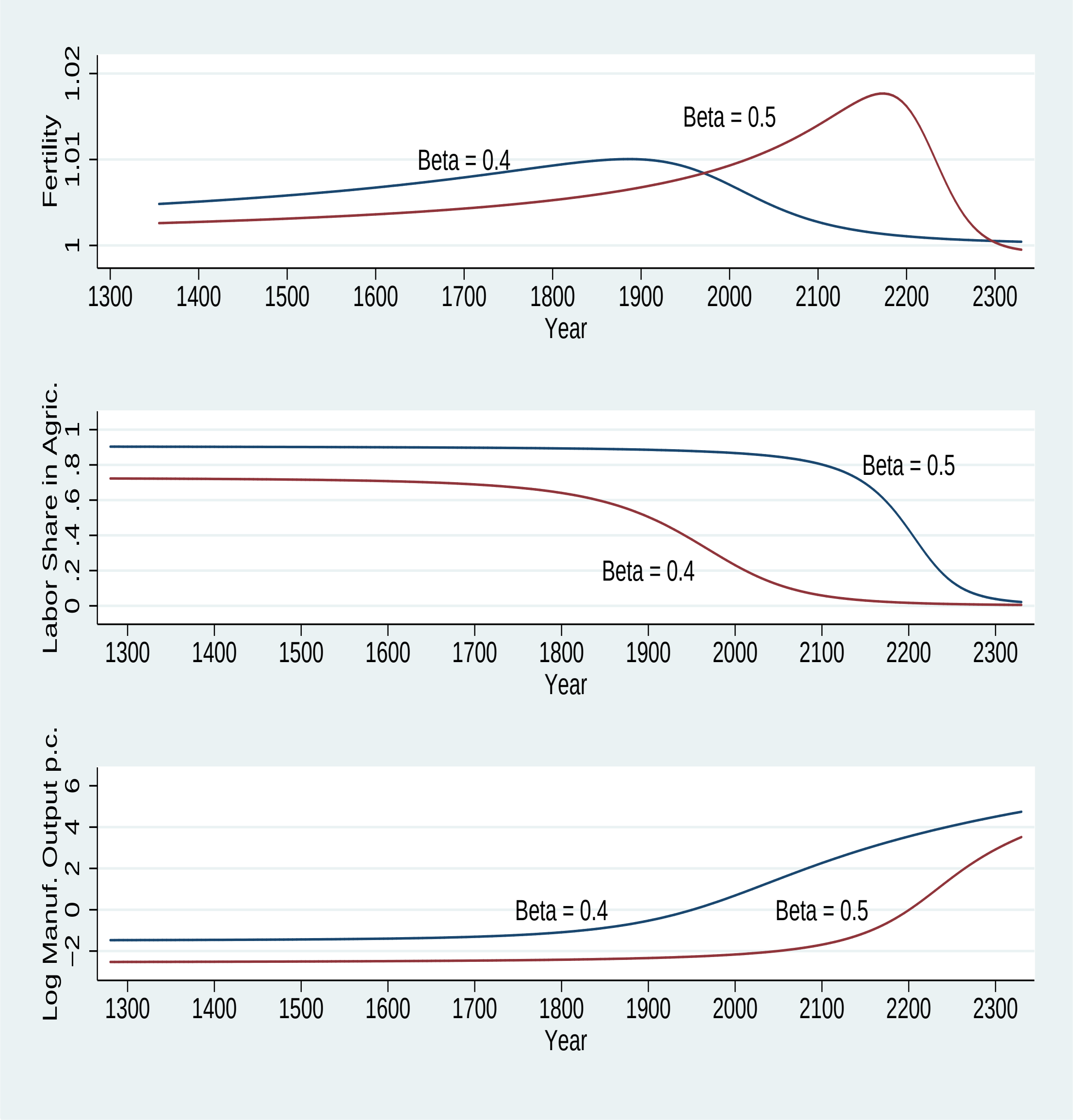

Figure 4: Comparative Development as only Labor Intensity Varies

Notes: Panel A shows how fertility rates (n_t) evolve over time. Panel B shows the labor share in agriculture and panel C shows the log of industrial output per capita. The only difference in the two runs of the simulation are the values of β indicated.

intensity of agriculture is now set to $\beta = 0.5$. This is closer to the values reported for China and other Asian countries, and is at the low end of values estimated for tropical zones or those with winter dry seasons.

It is important to note that this second simulation is not intended to be calibrated to the experience of Asia in general, but rather to show how a stylized Western Europe would have been different with a slightly higher labor intensity in agriculture. As can be seen, fertility is relatively low at the outset of the simulation, climbs in a similar manner, but achieves peak fertility only in 2200, nearly 300 years after the baseline. This fertility peak is also more severe in that maximum fertility is higher, and the fall in fertility is much steeper. This difference is due to the fact that β being higher makes fertility more responsive to changes in the economy, as income is more responsive to changes in agricultural productivity.

Similarly, the structural transformation in panel B is delayed by about 300 years, but once it begins it proceeds more rapidly. The initial share of labor in agriculture is larger (0.91 compared to 0.72), for the reason that the increased intensity drives up agricultural wages which increases fertility linearly and ultimately requires more individuals to provide the necessary food.

The take-off in manufacturing output per capita is also delayed but is converging towards the baseline case as the simulation runs to the end. The point of figure 4 is that the simple change in labor intensity of agriculture from $\beta = 0.4$ to $\beta = 0.5$ can have significant effects on the timing of long-run development. In the very long run, the two situations will converge, but the advantage of a low β value can generate significant differences in comparative development. In the year 2000, manufacturing output per capita is roughly 10 times higher in the $\beta = 0.40$ baseline economy compared to the otherwise identical economy with $\beta = 0.50$. The advantage of Europe and its relatively early development could be due to an agricultural difference that gave it a lower intensity style of agriculture.

One concern with the simulations in figure 4 is that the faster development of the $\beta = 0.40$ economy is due to the early advantage in the share of individuals in industry. This early advantage in moving individuals to industrial work is not, though, the source of the advantage. Figure 5 shows again the simulations for two economies with different labor elasticities, but the industrial productivity level is adjusted *down* for the baseline economy with $\beta = 0.40$. The productivity level is set lower so that it is optimal for more individuals to start working in agriculture, and the level is set so that in 1300 both economies begin with identical shares of 0.91 in that sector.

As can be seen, there is not much of a change in the outcome of the simulation. Fertility again peaks earlier and lower for the low-beta economy, and the structural transformation begins earlier. What is difficult to discern in the figure is that manufacturing output per capita is lower in the early years (due to the low productivity level) for the low-beta economy. In 1300, output per capita is roughly 20% higher for the $\beta = 0.50$ economy, but in about 1660 the low-beta economy overtakes the high-beta one, and from then on maintains a distinct advantage in manufacturing output per

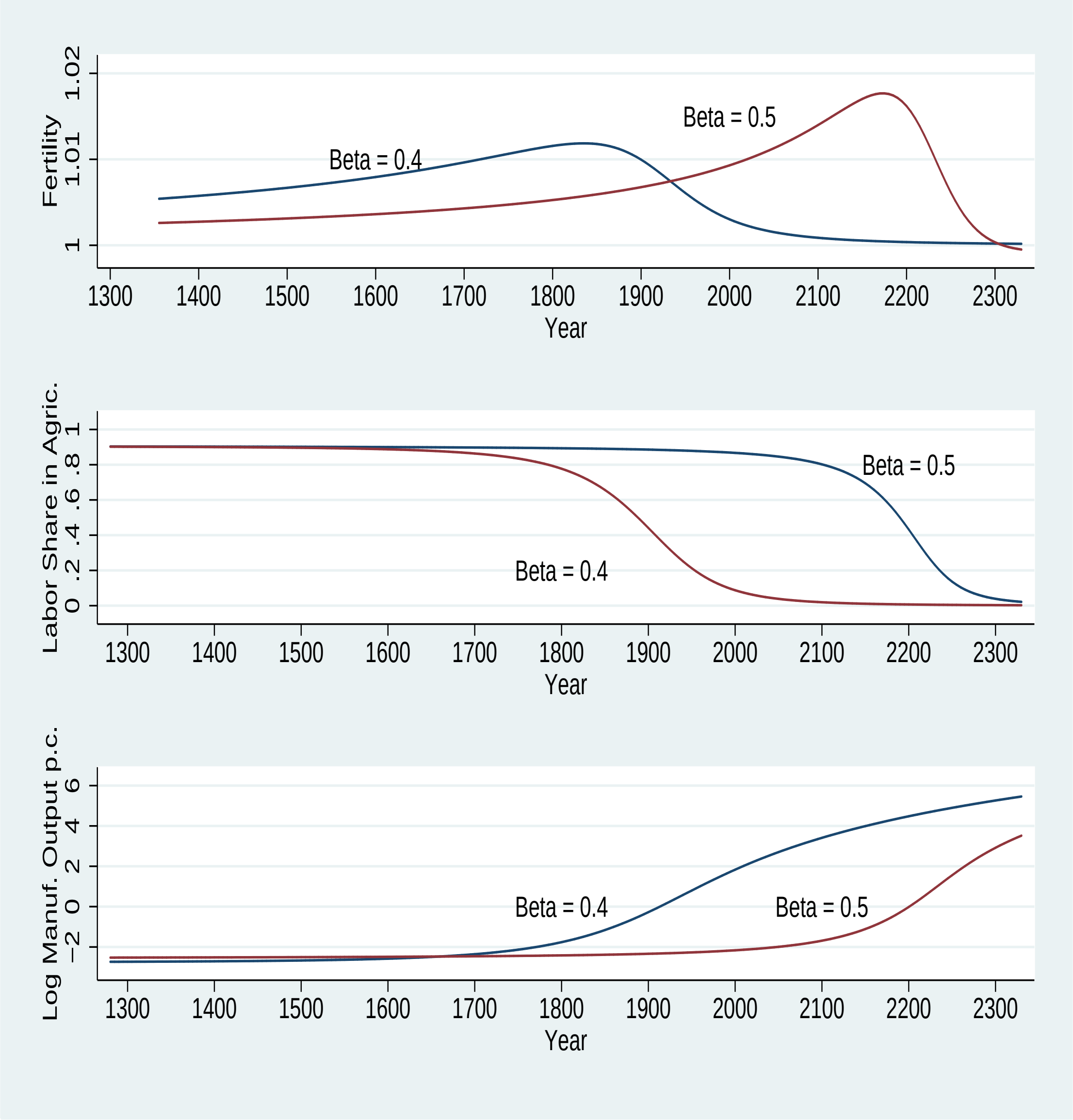

Figure 5: Comparative Development as Labor Intensity and Initial Productivity Vary

Notes: Panel A shows how fertility rates (n_t) evolve over time. Panel B shows the labor share in agriculture and panel C shows the log of industrial output per capita. The simulations vary in the value of β, as indicated, as well as in initial industrial productivity. When $\beta = 0.40$, initial productivity is relatively small so that the share of labor in agriculture in 1300 is identical in the two runs.

capita. Note that this is manufacturing output *per capita*. Manufacturing output *per worker* in that sector remains higher in the high-beta economy until roughly 1830, but because of the low beta value there are more workers in the manufacturing sector and so the per capita values are higher.

Overall, the simulations show that small differences in labor intensities in agriculture could potentially have large effects on comparative development. Obviously, it is not the only thing that matters, but it provides a means of explaining how different regions could experience different paths of economic growth without having to appeal to intrinsic differences in productivity in either the agricultural or industrial sectors.

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 intensity 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 labor intensity.

These differences 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 intensity, 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-intensity 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.

Simulations using realistic labor elasticities in agriculture show how these differences 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-intensity 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

Full Agricultural Production Estimation

Tables 2 and 3 only report values for β, the estimated coefficient on agricultural labor. Full results of all these regressions are available in appendix tables A.1, A.2, A.3, A.4.

Table A.1 presents the results using agricultural output as the dependent variable, and including all countries in the potential samples. The columns of this table correspond to the rows of table 2, so that each column is limited to countries matching the conditions listed across the top. For each column, the coefficient estimates on all the agricultural inputs are reported, as is the estimated value of ρ, the serial correlation parameter. Additionally, the implied scale of the production function is reported, by adding up the coefficients on labor, livestock, fertilizer, land, and tractor. In nearly every case, this is above 0.900, similar to prior studies that find production functions very close to constant returns. Given the tightly estimated coefficients, though, one rejects that the scale is exactly equal to one. One item to note is that for zone B (column 7), the estimated sum of coefficients is well above one. This may be a reflection of the relatively small sample size, or perhaps variation in agricultural type in this zone is too wide to zero in on accurate estimates.

Following Wooldridge (2002), the specification test for serial correlation in a panel setting is reported in the final two lines. As can be seen, in most cases the null hypothesis of no serial correlation is rejected. However, columns (3), (7), and (10) do reject this at typical levels of significance. Estimation of those specifications without serial correlation does not materially affect the estimated coefficients.

The remaining appendix tables report similar information, with table A.2 corresponding to the sample excluding the Europes and neo-Europes, while tables A.3 and A.4 reflect regressions using log population as the dependent variable.

Simulation of the Model

Similar to work by Strulik and Weisdorf (2008), utility is written in quasi-linear form as

$$U_t = c_t + \gamma ln n_t \tag{23}$$

which eliminates any explicit income-effect on the number of children. The only influence on the number of children will be their relative cost (in terms of consumption goods).

The budget constraint is assumed to be

$$I_t = c_t + p_t \overline{a} n_t \tag{24}$$

which differs from the more general model presented earlier in that individuals are not responsible for purchasing their own food. This is also not crucial to the simulation results that follow, but will make the analytical results clearer on what is driving long-run development. The solution to the optimization problem is therefore

$$n_t = \frac{\gamma}{p_t \overline{a}} \tag{25}$$

or fertility depends only on the relative price of food. The price of food will be driven by relative productivity in the two sectors. In terms of the original model, the assumptions made so far imply that $s = \gamma/(I_t - p_t\overline{a})$, or that the share of resources allocated to fertility is declining in income.

Production of agricultural goods is as before, $Y_{At} = A_t X^{1-\beta} L_{At}^{\beta}$, while manufacturing production is $Y_{Mt} = w_{Mt} L_{Mt}$. Labor is mobile between sectors as before so that

$$p_t \beta \frac{Y_{At}}{L_{At}} = w_{Mt} \tag{26}$$

and total agricultural demand is such that

$$Y_{At} = L_t \overline{a} n_t. \tag{27}$$

Solving (25), (26), and (27) together yields the following results for fertility and population density:

$$\begin{aligned} n_t &= \frac{(\gamma\beta)^{\beta}}{\overline{a} w_{Mt}^{\beta}} A_t \left(\frac{X}{L_t}\right)^{1-\beta} && (28) \\ \frac{L_{At}}{L_t} &= \frac{\gamma\beta}{w_{Mt}}. && (29) \end{aligned}$$

Fertility is increasing in agricultural productivity, as this decreases its relative price. The effect of β on fertility is ambiguous, as β acts directly to increase fertility, but also increases the elasticity of fertility with respect to w_{Mt}.

The dynamics of the model are assumed to be

$$\begin{aligned} L_{t+1} &= n_t L_t && (30) \\ A_{t+1} - A_t &= \delta_A \left(A_t X^{1-\beta} L_{At}^{\beta}\right)^{\phi} && (31) \\ w_{M,t+1} - w_{Mt} &= \delta_M \left(w_{Mt} L_{Mt}\right)^{\theta} && (32) \end{aligned}$$

so that population evolves in a typical manner, while productivity grows due to learning-by-doing effects.

The baseline simulation has the following parameter values: $\overline{a} = 20$, $\gamma = 1.5$, and $L_0/X = 0.00671$. Initial productivity is $w_{M,0} = 0.83$ and $A_0 = 1$. Productivity parameters are $\delta_A = 0.75$ and $\delta_M = 0.02$, while $\phi = 0.73$ and $\theta = 0.6$. As noted in the text, the initial value of β is 0.40 for the baseline, and 0.50 for the alternative scenario in figure 4.

In the second set of simulations, the parameters are adjusted so that initial allocations of labor to agriculture are identical between the $\beta = 0.40$ economy and $\beta = 0.50$ economy. This requires that $w_{M,0} = 0.66$ when $\beta = 0.40$ while $w_{M,0} = 0.83$ when $\beta = 0.50$. This delivers an identical solution for $L_{A,0}/L_0$ in the two economies.

Given the initial values, the simulation can be solved for directly. For purposes of clarity, time zero is equated to year 1300, and the fertility rate n_t is expressed as an average annual growth rate, assuming periods are equal to 10 years.

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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.	$\widehat{\beta/\phi}$	S.E.	Countries	Obs.
World	0.578	(0.013)	0.690	(0.006)	98	3491
Cereal production:						
$>$ 50% Maize	0.634	(0.028)	0.776	(0.012)	29	1028
$>$ 50% Rice	0.577	(0.014)	0.771	(0.010)	21	783
$>$ 50% Wheat	0.227	(0.030)	0.366	(0.014)	16	581
Agricultural output:						
$>$ 60% Crops	0.715	(0.019)	0.866	(0.007)	51	1813
$<$ 60% Crops	0.318	(0.015)	0.616	(0.010)	47	1678
Cultivated land:						
$>$ 60% Zone A (Tropical)	0.691	(0.023)	0.810	(0.009)	32	1124
$>$ 60% Zone B (Dry)	0.885	(0.029)	0.991	(0.014)	9	331
$>$ 60% Zone C (Mid-lat mild)	0.503	(0.026)	0.469	(0.011)	29	1045
$>$ 60% Zone f (No dry season)	0.422	(0.020)	0.517	(0.016)	26	913
$>$ 60% Zone s (Summer dry season)	0.757	(0.050)	0.758	(0.016)	17	609
$>$ 60% Zone w (Winter dry season)	0.666	(0.026)	0.875	(0.009)	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.	$\widehat{\beta/\phi}$	S.E.	Countries	Obs.
World	0.527	(0.029)	0.397	(0.009)	73	2619
Cereal production:						
> 50% Maize	0.667	(0.030)	0.305	(0.012)	27	950
> 50% Rice	0.577	(0.014)	0.771	(0.010)	21	783
> 50% Wheat	0.250	(0.061)	0.539	(0.020)	8	299
Agricultural output:						
> 60% Crops	0.729	(0.019)	0.892	(0.006)	47	1664
< 60% Crops	0.555	(0.020)	0.697	(0.013)	26	955
Cultivated land:						
> 60% Zone A (Tropical)	0.691	(0.023)	0.810	(0.009)	32	1124
> 60% Zone B (Dry)	0.885	(0.029)	0.991	(0.014)	9	331
> 60% Zone C (Mid-lat mild)	0.606	(0.044)	0.726	(0.015)	13	484
> 60% Zone f (No dry season)	0.544	(0.022)	0.826	(0.012)	10	371
> 60% Zone s (Summer dry season)	0.773	(0.047)	0.778	(0.021)	11	396
> 60% Zone w (Winter dry season)	0.666	(0.026)	0.875	(0.009)	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.

Appendix Table A.1: Full Results, Agricultural Production Function, by Sample

	Dep. Variable is log agric. output:										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	> 50%	> 50%	> 50%	> 60%	< 60%	> 60%	> 60%	> 60%	> 60%	> 60%	> 60%
	Maize	Rice	Wheat	Crops	Crops	Zone A	Zone B	Zone C	Zone f	Zone s	Zone w
Log ag. pop	0.634	0.577	0.227	0.715	0.318	0.691	0.885	0.503	0.422	0.757	0.666
	(0.028)	(0.014)	(0.030)	(0.019)	(0.015)	(0.023)	(0.029)	(0.026)	(0.020)	(0.050)	(0.026)
Log livestock	0.237	0.219	0.429	0.174	0.495	0.163	0.188	0.327	0.524	0.250	0.205
	(0.020)	(0.015)	(0.030)	(0.018)	(0.015)	(0.019)	(0.036)	(0.027)	(0.022)	(0.046)	(0.020)
Log fert.	-0.004	0.043	0.003	0.007	0.060	0.007	0.016	0.031	0.027	0.001	0.002
	(0.004)	(0.006)	(0.019)	(0.003)	(0.008)	(0.003)	(0.008)	(0.012)	(0.007)	(0.009)	(0.003)
Log land	0.005	0.029	-0.026	0.005	-0.030	0.016	0.063	0.046	0.023	-0.116	-0.007
	(0.013)	(0.011)	(0.014)	(0.010)	(0.009)	(0.010)	(0.023)	(0.023)	(0.010)	(0.027)	(0.011)
Log tractor	0.067	0.052	0.218	0.075	0.115	0.077	0.067	0.063	0.041	0.066	0.081
	(0.012)	(0.008)	(0.026)	(0.008)	(0.011)	(0.010)	(0.014)	(0.018)	(0.015)	(0.021)	(0.011)
Log GDP p.c.	0.406	0.302	0.234	0.481	0.310	0.345	0.334	0.509	0.261	0.633	0.325
	(0.025)	(0.014)	(0.035)	(0.018)	(0.017)	(0.024)	(0.039)	(0.033)	(0.027)	(0.047)	(0.024)
Obs.	1028	783	581	1813	1678	1124	331	1045	913	609	1154
Countries	29	21	16	51	47	32	9	29	26	17	33
ρ	0.926	0.877	0.872	0.944	0.878	0.945	0.716	0.926	0.934	0.886	0.957
Implied scale	0.939	0.920	0.851	0.976	0.958	0.954	1.219	0.970	1.037	0.958	0.947
Serial correlation test:											
F-stat	20.87	62.50	2.14	9.23	19.97	36.39	4.37	5.42	43.23	1.32	36.56
p-value	< 0.01	< 0.01	0.16	< 0.01	< 0.01	< 0.01	0.07	0.03	< 0.01	0.27	< 0.01

Notes: All countries in Europe and the “Neo-Europes” are excluded (see appendix for full list of countries in this category). The dependent variable is log of total population. Regressions vary in the countries included, which are determined by the condition listed in the heading. Each regression includes time dummies, and is estimated allowing for AR(1) correlation in the error terms. The value of ρ is the estimated AR(1) coefficient. The implied scale is the sum of the coefficients on the five agricultural inputs. The serial correlation test is from Wooldridge (2002), with a null hypothesis that no serial correlation exists. See the text for a description of the explanatory variables.

Appendix Table A.2: Full Results, Agricultural Production Function, by Sample, Excluding Europe and Neo-Europes

	Dep. Variable is log agric. output:										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	> 50%	> 50%	> 50%	> 60%	< 60%	> 60%	> 60%	> 60%	> 60%	> 60%	> 60%
	Maize	Rice	Wheat	Crops	Crops	Zone A	Zone B	Zone C	Zone f	Zone s	Zone w
Log ag. pop	0.667	0.577	0.250	0.729	0.555	0.691	0.885	0.606	0.544	0.773	0.666
	(0.030)	(0.014)	(0.061)	(0.019)	(0.020)	(0.023)	(0.029)	(0.044)	(0.022)	(0.047)	(0.026)
Log livestock	0.217	0.219	0.573	0.173	0.407	0.163	0.188	0.363	0.339	0.123	0.205
	(0.021)	(0.015)	(0.054)	(0.018)	(0.021)	(0.019)	(0.036)	(0.048)	(0.026)	(0.058)	(0.020)
Log fert.	-0.004	0.043	0.032	0.007	0.030	0.007	0.016	0.007	0.018	-0.001	0.002
	(0.004)	(0.006)	(0.029)	(0.003)	(0.007)	(0.003)	(0.008)	(0.017)	(0.008)	(0.011)	(0.003)
Log land	-0.013	0.029	-0.111	0.003	-0.104	0.016	0.063	-0.036	0.046	-0.124	-0.007
	(0.014)	(0.011)	(0.038)	(0.010)	(0.014)	(0.010)	(0.023)	(0.037)	(0.019)	(0.032)	(0.011)
Log tractor	0.057	0.052	0.076	0.066	0.073	0.077	0.067	0.052	0.039	0.108	0.081
	(0.013)	(0.008)	(0.031)	(0.008)	(0.011)	(0.010)	(0.014)	(0.028)	(0.020)	(0.021)	(0.011)
Log GDP p.c.	0.366	0.302	0.150	0.446	0.355	0.345	0.334	0.567	0.366	0.309	0.325
	(0.027)	(0.014)	(0.059)	(0.019)	(0.017)	(0.024)	(0.039)	(0.054)	(0.034)	(0.058)	(0.024)
Obs.	950	783	299	1664	955	1124	331	484	371	396	1154
Countries	27	21	8	47	26	32	9	13	10	11	33
ρ	0.938	0.877	0.792	0.941	0.885	0.945	0.716	0.927	0.897	0.821	0.957
Implied scale	0.924	0.920	0.820	0.978	0.961	0.954	1.271	0.992	0.986	0.879	0.947
Serial correlation test:											
F-stat	19.14	62.50	2.03	8.45	14.22	36.39	4.37	3.17	63.10	0.41	36.56
p-value	< 0.01	< 0.01	0.20	< 0.01	< 0.01	< 0.01	0.07	0.10	< 0.01	0.54	< 0.01

Notes: All countries in Europe and the "Neo-Europes" are excluded (see appendix for full list of countries in this category). The dependent variable is log of total population. Regressions vary in the countries included, which are determined by the condition listed in the heading. Each regression includes time dummies, and is estimated allowing for AR(1) correlation in the error terms. The value of ρ is the estimated AR(1) coefficient. The implied scale is the sum of the coefficients on the five agricultural inputs. The serial correlation test is from Wooldridge (2002), with a null hypothesis that no serial correlation exists. See the text for a description of the explanatory variables.

Appendix Table A.3: Full Results, Population Production Function, by Sample

	Dep. Variable is log total population:										
	(1) $> 50\%$ Maize	(2) $> 50\%$ Rice	(3) $> 50\%$ Wheat	(4) $> 60\%$ Crops	(5) $< 60\%$ Crops	(6) $> 60\%$ Zone A	(7) $> 60\%$ Zone B	(8) $> 60\%$ Zone C	(9) $> 60\%$ Zone f	(10) $> 60\%$ Zone s	(11) $> 60\%$ Zone w
Log ag. pop	0.776	0.771	0.366	0.866	0.616	0.810	0.991	0.469	0.517	0.758	0.875
	(0.012)	(0.010)	(0.014)	(0.007)	(0.010)	(0.009)	(0.014)	(0.011)	(0.016)	(0.016)	(0.009)
Log livestock	0.057	0.055	0.085	0.036	0.101	0.062	0.019	0.028	0.041	-0.009	0.049
	(0.008)	(0.008)	(0.010)	(0.005)	(0.008)	(0.007)	(0.009)	(0.006)	(0.009)	(0.012)	(0.006)
Log fert.	0.001	0.003	0.006	0.002	0.006	0.002	-0.001	0.004	0.001	0.003	0.002
	(0.001)	(0.002)	(0.003)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)
Log land	0.018	0.002	0.004	0.005	0.013	0.005	-0.003	0.000	0.001	-0.003	-0.002
	(0.005)	(0.003)	(0.004)	(0.002)	(0.003)	(0.003)	(0.005)	(0.005)	(0.002)	(0.008)	(0.003)
Log tractor	0.082	0.017	0.090	0.047	0.104	0.048	0.028	0.029	0.030	0.091	0.054
	(0.005)	(0.003)	(0.008)	(0.003)	(0.005)	(0.003)	(0.004)	(0.004)	(0.005)	(0.006)	(0.003)
Log GDP p.c.	0.148	0.088	0.046	0.081	0.145	0.068	0.054	0.034	0.060	0.168	0.092
	(0.009)	(0.010)	(0.011)	(0.006)	(0.009)	(0.008)	(0.009)	(0.007)	(0.010)	(0.012)	(0.008)
Obs.	1028	783	581	1813	1678	1124	331	1045	913	609	1154
Countries	29	21	16	51	47	32	9	29	26	17	33
ρ	0.966	0.985	0.988	0.978	0.977	0.977	0.981	0.997	0.997	0.935	0.963
Serial correlation test:											
F-stat	3756.21	18116.48	1520.31	1664.86	6438.27	1323.06	1729.55	7558.85	3296.78	4389.21	1174.76
p-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Notes: All countries in Europe and the "Neo-Europes" are excluded (see appendix for full list of countries in this category). The dependent variable is log of total population. Regressions vary in the countries included, which are determined by the condition listed in the heading. Each regression includes time dummies, and is estimated allowing for AR(1) correlation in the error terms. The value of ρ is the estimated AR(1) coefficient. The serial correlation test is from Wooldridge (2002), with a null hypothesis that no serial correlation exists. See the text for a description of the explanatory variables.

Appendix Table A.4: Full Results, Population Production Function, by Sample, Excluding Europe and Neo-Europes

	Dep. Variable is log total population:										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	> 50%	> 50%	> 50%	> 60%	< 60%	> 60%	> 60%	> 60%	> 60%	> 60%	> 60%
	Maize	Rice	Wheat	Crops	Crops	Zone A	Zone B	Zone C	Zone f	Zone s	Zone w
Log ag. pop	0.305	0.771	0.539	0.892	0.697	0.810	0.991	0.726	0.826	0.778	0.875
	(0.012)	(0.010)	(0.020)	(0.006)	(0.013)	(0.009)	(0.014)	(0.015)	(0.012)	(0.021)	(0.009)
Log livestock	0.004	0.055	0.227	0.028	0.055	0.062	0.019	0.081	0.115	-0.022	0.049
	(0.003)	(0.008)	(0.017)	(0.005)	(0.009)	(0.007)	(0.009)	(0.012)	(0.011)	(0.012)	(0.006)
Log fert.	0.000	0.003	0.013	0.002	0.003	0.002	-0.001	0.007	0.004	0.002	0.002
	(0.000)	(0.002)	(0.007)	(0.001)	(0.002)	(0.001)	(0.001)	(0.004)	(0.003)	(0.002)	(0.001)
Log land	-0.000	0.002	0.087	0.003	0.014	0.005	-0.003	0.013	0.007	-0.006	-0.002
	(0.002)	(0.003)	(0.010)	(0.002)	(0.005)	(0.003)	(0.005)	(0.011)	(0.005)	(0.008)	(0.003)
Log tractor	-0.000	0.017	0.022	0.041	0.074	0.048	0.028	0.053	0.054	0.073	0.054
	(0.002)	(0.003)	(0.011)	(0.002)	(0.006)	(0.003)	(0.004)	(0.009)	(0.008)	(0.006)	(0.003)
Log GDP p.c.	0.001	0.088	0.034	0.067	0.094	0.068	0.054	0.151	0.129	0.116	0.092
	(0.003)	(0.010)	(0.015)	(0.006)	(0.010)	(0.008)	(0.009)	(0.015)	(0.016)	(0.014)	(0.008)
Obs.	950	783	299	1664	955	1124	331	484	371	396	1154
Countries	27	21	8	47	26	32	9	13	10	11	33
ρ	0.999	0.985	0.899	0.972	0.984	0.977	0.981	0.958	0.972	0.966	0.963
Serial correlation test:											
F-stat	3768.92	18116.48	573.29	1652.71	5628.93	1323.06	1729.55	2591.11	946.58	3648.71	1174.76
p-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Notes: All countries in Europe and the "Neo-Europes" are excluded (see appendix for full list of countries in this category). The dependent variable is log of total population. Regressions vary in the countries included, which are determined by the condition listed in the heading. Each regression includes time dummies, and is estimated allowing for AR(1) correlation in the error terms. The value of ρ is the estimated AR(1) coefficient. The serial correlation test is from Wooldridge (2002), with a null hypothesis that no serial correlation exists. See the text for a description of the explanatory variables.