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The Agricultural Basis of Comparative Development

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ABSTRACT

This paper shows, in a two-sector Malthusian model of endogenous fertility, that output per capita, population density, and industrialization depend upon the labor intensity of agricultural production. Because the diminishing returns to labor are less pronounced, high labor intensity (as in rice production) leads not only to a larger population density but also to lower output per capita and a larger share of labor in agriculture. Agronomic, historical and cross-country evidence confirm that there are inherent substantial differences between rice and wheat production. A calibration of the model shows that a relatively small difference in labor intensity in agriculture can account for a large portion of the observed differences in industrialization, output per capita, and labor productivity between Asia and Europe prior to the Industrial Revolution. Significantly, these differences can be explained even though sector-level total factor productivity levels and the efficiency of factor markets are identical in the two regions.

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

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1 Introduction

Recent research has made it clear that long-run development involves a 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.[1] But as Clark (2007) and Voigtländer and Voth (2009) point out, stagnation does not imply that output per capita must be at minimum subsistence levels. One implication of this is that Malthusian equilibriums across regions need not be homogenous, and this is in fact what we see in data from the period prior to the Industrial Revolution.

In particular, preindustrial Europe had a relatively high per capita income compared to Asian countries such as China or India. The difference appears to be between a two- to four-fold advantage by 1800, but there is evidence of a European edge in living standards and urbanization for several centuries prior to that as well (Clark, 2007; Broadberry and Gupta, 2006; Jones, 1987; Landes, 1998).[2] A significant part of this advantage was the high labor productivity in agriculture in Europe, with each worker producing between 30-100% more than their Asian equivalent around 1800 (Boomgaard, 2002; Bairoch, 1999), freeing time and labor in Europe for the production of non-agricultural goods.

This was not due to some gulf in agricultural technology levels, as the difference in labor productivity was not reflected in yields. Boomgard (2002) finds output per hectare in Java nearly twice as high as yields in the United Kingdom around 1800, while Allen (2009) documents for the same time period a nearly eight-fold advantage in the Yangtze Delta in yields when compared to the English midlands.

The explanation for the high labor productivity and low yields in Europe relative to Asia is, on the face of it, trivial. Greater population densities in Asia, given a fixed factor of production, naturally account for the pattern. Around 1700 England and Wales were supporting 143 persons per hectare of arable land, and France approximately 83 (Grigg, 1980, p. 245). In comparison, densities in Asia in the same time period were on the order of 536 persons per hectare in China, 825 persons in Japan, and in India approximately 270 (Grigg, 1974).

While this explanation is logical, it is incomplete. Why did Asia have such a dense population? Why did fertility not rise in Europe and grind down living standards to Asian levels? Simple differences in agricultural total factor productivity differences are not sufficient to provide an answer. Higher productivity in Asia would

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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). See Galor (2005) for a complete survey of the facts and theories involved in unified growth.

[2] Allen (2005) summarizes evidence regarding real wages in Europe, Japan, India, and China, finding instead no advantage for Europeans in 1750. This real wage data refers to the returns to labor, but does not necessarily imply that average income per capita was identical across regions. While the real wage data give us information on the living standards of the median worker, average living standards may be more relevant for the study of long-run growth.

lead to higher densities, but does not by itself explain the relatively low level of output per capita in that region. Sustained differences in living standards require systematic differences in the population response to income. As Clark (2007, p. 267) states, "the Malthusian constraints seem to have operated much more tightly on England than on either Japan or China in the years 1300-1700."

In this paper I explore the idea that the tighter Malthusian constraints in Europe relative to Asia were due to the nature of agricultural production in these areas in the preindustrial era.[3] Differences in the labor intensity of agricultural production can provide a coherent explanation for variation in output output per capita, population density, and industrialization levels in the Malthusian world even holding constant technology levels, institutions, and the extent of markets.[4] To be clear about the mechanism at work, here I am concerned with labor intensity in the sense of the inherent *shape* of the agricultural production function, as opposed to differences in the actual endowments of land and/or labor.

Intuitively, the economy is deciding how to allocate labor across two uses: non-agriculture and agriculture. Low labor intensity in agriculture increases the opportunity cost of agricultural goods; it costs more in lost manufacturing output to produce one additional unit of food by shifting a worker between sectors. In equilibrium the relative price of agricultural goods will be large and a smaller share of labor will be allocated to agricultural work. With high food prices fertility will be lower and in the long-run the population size will be smaller, even if the endowments of land and sector-level total factor productivity are identical to a high-intensity economy. The Malthusian constraint *was* tighter in Europe because the inherent labor intensity of dry cereal crops (e.g. wheat) is relatively low, and this led to a low-density, high output per capita outcome relative to Asia, which relied on the highly labor-intense production of rice.[5]

Observations by agronomists confirm that wheat is, by nature, a much less labor intense crop than wet-paddy rice, independent of the actual labor/land endowment. Summaries by Grigg (1974) and Ruthenberg (1976) both support the idea that the diminishing returns to labor are much lower in rice than in wheat. Bray (1986) relates that rice output responds more to labor efforts than to the inherent soil quality or type, in the sense that sustained rice production can actually change and improve soil fertility. Even within individual

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[3] Clark provides evidence that an additional factor leading to high incomes in England was – similar to Galor and Moav's (2002) work on natural selection – a reproductive advantage for the wealthy. However, this cannot explain why the Malthusian constraints were so tight in Europe relative to Asia.

[4] 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 intensity in agriculture is identical across regions. The explicit dependence of fertility on food prices used here is shared with work by Strulik and Weisdorf (2008). Recent work by Voigtländer and Voth (2010) 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, a similar concept to this paper's focus.

[5] 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.

farms, farmers in tropical areas will expend much more effort on their rice fields compared to their upland (i.e. dry cereal) fields, even though the average product of the upland crops is much higher.

Contemporary and historical reports of labor's share of agricultural output are consistent with these technological differences. Rice-producing areas tend to see 50-60% of output going to labor, while evidence from England and China suggests that only about 35-40% was paid to labor in dry cereal-growing areas across several centuries of data.

As an alternative way of examining labor intensity, I estimate agricultural production functions using country-level data from the years 1961-1999, broken down by major crop type. Countries relying primarily on rice have an elasticity of agricultural output with respect to labor of about 0.55, while countries that are mainly wheat producers have an elasticity of only about 0.25. Breaking down the sample to exclude relatively rich countries, and controlling explicitly for development levels do not change these results. Overall, the body of evidence indicates a distinct difference in the *shape* of the agricultural production function between geographic regions of the world, and theoretically this leads to differences in how severely Malthusian constraints affect population growth and living standards.

A simple calibration shows the importance of even relatively small differences in labor intensities. Using values consistent with the observed data, the model predicts that a low-intensity "European" region will have agricultural labor productivity 25% larger than a stylized "Asia".[6] In addition, consumption of non-agricultural goods is four times higher and real output per capita is 25% higher in "Europe". The gaps are consistent with the variation identified in the historical literature regarding Malthusian-era output per capita in Asia and Europe. These results arise solely from differences in the labor intensity of agriculture, and hold constant productivity levels between the two regions. One significant value of this approach is that it provides a consistent explanation for the relative advantage of Europe in terms of industrialization and output per capita with the observations of Pommeranz (2000), Parthasarathi (1998), and others that emphasize how land, labor, and product markets were just as efficient in Asia as in Europe during the pre-Industrial Revolution era.

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,

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[6] The "European" economy is assumed to have an elasticity of output with respect to labor in agriculture of 0.4, while the "Asian" economy is assumed to have an elasticity of 0.5. Relative to the cross-country and historical evidence, this difference likely understates the case.

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.

The emphasis here on the role of biological or geographic factors in development is primarily 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.[7] This paper suggests that the salient aspects of these endowments was the inherent intensity of labor in agricultural production, regardless of initial factor endowments.[8]

While focusing on geographic differences in agriculture and development, it is important to point out that this does not imply geography is necessarily 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 dictates the timing or size of 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). Culture (and religion more specifically) may be operative, as suggested by Weber (2009[1904]) and modeled by Doepke and Zilibotti (2008). Alternatively, innovations in science and technology that took hold in north-western Europe may have been the spur for development, a matter discussed in detail by Mokyr (1990) and Landes (1969). Accumulation of human capital as in Becker, Murphy, and Tamura (1990), 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 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 skewed towards larger populations rather than increased living standards. Over long periods slight differences due to this effect can be magnified into widely divergent levels of development. Regions may diverge even if they share identical institutions, productivity levels, and preferences for fertility.[9]

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[7] 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).

[8] This paper differs from the work of Boserup (1965), even though she is interested as well in the intensity of agricultural labor use. Boserup is concerned with the transition from shifting cultivation systems to settled agriculture, whereas this paper is about the comparison across regions of economies that have reached the point of using settled agricultural techniques.

[9] 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.

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 across 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, empirical evidence is presented to support the idea that this intensity varies widely between the main crop types of the world, and then a calibration is performed on the basis of this evidence showing that the model contains significant explanatory power for preindustrial development levels.

2 Agricultural Labor Intensity and Development

The essential points regarding the role of labor intensity on long-run Malthusian steady-states can be seen in a simple two-sector model. After showing that the effects hold in a general setting, a specific version of the model is presented to provide some direction as to what kind of empirical evidence will be useful and to serve as the basis for the calibration exercise.[10]

2.1 The Role of Labor Intensity in General

Let utility for a representative individual be over children and manufactured goods so that

$$U = U(c_M, n) \tag{1}$$

where c_M is consumption of the manufactured (non-agricultural) good, and n is the number of children. The function $U(\cdot, \cdot)$ is assumed to be strictly quasi-concave, which assures that there is a single solution to the utility maximization problem. Stricter requirements are not necessary.

Children are assumed to need a specific amount of food to survive, and the number of children is positively and monotonically related to the total amount of food demanded by the parent. Specifically, let $n = n(c_A)$ with $\partial n/\partial c_A > 0$ and $n(0) = 0$. One can write an alternate utility function V as

$$V = V(c_M, c_A) = U(c_M, n(c_A)) \tag{2}$$

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[10] 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 or endogenous technological change. 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.

and the function V will inherit all of the properties of the function U, given that the function $n(c_A)$ is monotonically increasing.

Production takes place over two sectors. The production functions are, in per capita terms

$$\begin{aligned} y_A &= g\left(x, \frac{L_A}{L}\right) && (3) \\ y_M &= f\left(k, \frac{L_M}{L}\right) && (4) \end{aligned}$$

where both functions $g(\cdot,\cdot)$ and $f(\cdot,\cdot)$ are homogenous of degree one, and have the typical concave properties. Agricultural production requires land, and the per-capita amount of land is x, while L_A/L denotes the share of labor allocated to that sector. Manufacturing production takes capital, provided in the per-capita amount of k, while L_M/L is the share of labor working in that sector. As both technologies are concave in labor, all labor will be employed, so $L_M + L_A = L$.

The production possibility frontier (PPF) for an economy describes the potential bundles of output that can be produced given the resources available: x, k, and L. As labor is the only factor mobile between sectors, the slope of the PPF (the marginal rate of transformation) is given by

$$\frac{dy_M}{dy_A} = -\frac{f_L}{g_L} \tag{5}$$

where f_L and g_L are the marginal products of labor in the manufacturing and agricultural sectors, respectively.

To examine the effect of the labor intensity of agriculture, consider two different economies, denoted by 1 and 2. Assume economy 2 has a more naturally labor-intense agricultural system, which means that for any given allocation of factors to that sector, the marginal product of labor is higher than it would be in economy 1 with the same endowments. This implies that

$$\frac{f_L}{g_L^1} > \frac{f_L}{g_L^2} \tag{6}$$

or that the slope of the PPF in economy 1 is steeper than in economy 2. Practically speaking, increasing manufacturing output by a marginal amount in economy 2 requires a larger sacrifice of agricultural output than in economy 1.

Now, to compare these economies on even terms, hold utility constant at $\overline{V}$ and consider the equilibrium outcomes. Figure 1 shows the result of this comparison. The indifference curve for utility of $\overline{V}$ is shown with the convex shape implied by the properties of the V function, and is identical for both economies. The production possibility frontiers are shown as well, with PPF^1 being everywhere steeper than the PPF^2, consistent with the assertion that economy 2 has a more labor-intense agricultural sector.

[Figure 1 Here]

With those PPF's and utility of $\overline{V}$, the points Q^1 and Q^2 denote the equilibrium consumption bundles in the two economies. The bundle in economy 1 contains more manufacturing goods and fewer agricultural goods per person than that of economy 2. As this relationship holds for any given level of $\overline{V}$, by varying $\overline{V}$ one can trace out an "output expansion path" for both economy 1 and economy 2, denoted by the dashed OEP lines. Regardless of the level of $\overline{V}$, it must be the case that economy 1 consumes more y_M and less y_A, so $OEP^1 > OEP^2$ at every level of y_A.[11] The implied relative price of agricultural goods is lower in economy 2, consistent with the choice to consume more agricultural goods, and given the assumption that fertility is related to agricultural consumption, fertility is higher in economy 2 as well.

The result in figure 1 is static. What is the dynamic response of the economies to the difference in consumption bundles? To see this, recall that fertility depends on the amount of agricultural goods consumed. As these economies are closed, $c_A = y_A$ and therefore $n = n(y_A)$. Given the assumptions regarding the $n(\cdot)$ function, there must exist a value y_A^* such that $n(y_A^*) = 1$, or the population is constant from one generation to the next.

For either economy, if $y_A > y_A^*$ then population is growing. With a growing population, it is the case that land per capita (x) is falling, which will drive a typical Malthusian reduction in output per capita. Manufacturing production depends on capital per capita (k), and I will assume that the change in k given an increase is population is non-positive. That is, k need not decrease with population size, but it is not increasing. With k not increasing and x falling, output per capita must fall and the economy moves down the output expansion path.

What this means is that for any $y_A > y_A^*$, y_A is falling, and for y_A below the critical value, y_A is rising. The level y_A^* is therefore an absorbing steady state. On figure 2, this steady state level is denoted by the vertical line at y_A^*. The points at which this line intersects the output expansion paths of the two economies (points Z^1 and Z^2) are the steady states of the economies. Clearly, the manufacturing output per capita of economy 1 is larger than that of economy 2.

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[11] This outcome depends crucially on the assumption that total factor productivity (TFP) at the sector-level is identical in economy 1 and economy 2. OEP^2 could be higher than OEP^1 if economy 2 had sector-level productivity sufficiently larger than economy 1, but the goal is specifically to explain outcomes without having to appeal to such differences in TFP.

[Figure 2 Here]

Both economies converge to the point where agricultural consumption is exactly equal to the level that keeps population stable, the classic Malthusian result. However, the level of manufacturing output per capita that is consistent with this steady state consumption of agricultural goods depends crucially on the labor-intensity of the agricultural sector. A high intensity means that the trade-off in production favors agricultural goods, which drives up fertility. To reach the steady state where fertility is constant requires a lower average output per capita so that individuals find $n = 1$ optimal.

Note that the specific form of the utility function is not important, nor is the specific nature of the production functions provided that the two economies differ in labor-intensity. The essential assumption is that fertility depends positively on agricultural output, which seems uncontroversial. The labor intensity of the agricultural production function determines the relative value of manufactured and agricultural goods, which in turn determines the level of output per capita consistent with a stable population size.

2.2 A Specific Model

As mentioned previously, to provide direction for the empirical work and to frame the calibration, a specific application of the general model above is provided.

2.2.1 Individual Optimization

Individuals are presumed to gain utility from consumption of manufactured goods (c_{Mt}) and from the number of children they have (n_t). Each adult has a fixed subsistence consumption of food that produce no utility, while having children also requires an input of food.

The specific utility function employed is

$$U_t = c_{Mt} + \gamma \ln n_t \tag{7}$$

which is quasi-linear. This form of utility was examined by Weisdorf (2008) and shown by Strulik and Weisdorf (2008) to be useful in creating a simple unified growth model. What (7) implies is that there will be no income effect on fertility, and can be seen as a stripped-down version of the original Barro and Becker (1989) utility function over consumption and children. Here, changes in fertility will result from changes only in the relative price of food.

It must be made clear here that this choice in functional form is for convenience only, and the lack of an explicit income effect in the utility function is not driving the subsequent results. As the prior section highlighted, the influence of agricultural labor intensity is quite general and is not dependent on any specific forms for the utility or production functions.

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 subsistence amount is $\overline{a}$ for the adult, and $\theta\overline{a}$ for each child with $\theta > 0$.[12] Income not spent on food is consumed, so that the overall constraint is

$$I_t = c_{Mt} + p_t\overline{a}(1 + \theta n_t). \tag{8}$$

Along with the income constraint from (8), the optimal fertility level of individuals is

$$n_t = \frac{\gamma}{p_t\overline{a}\theta} \tag{9}$$

where one can see that fertility is driven by the relative price of agricultural goods.[13]

2.2.2 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

$$Y_{At} = A_t X^{1-\beta} L_{At}^{\beta} \tag{10}$$

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

β is the central parameter of interest here. Given the Cobb-Douglas production function, β is the elasticity of output with respect to labor, and captures the labor intensity of agricultural production. Higher values of β imply that the marginal product to labor falls more slowly as labor is added, meaning that the limit of the fixed factor of production is less severe. The value of β will be seen to drive the steady-state outcomes, and empirically we will be able to find evidence regarding this parameter in different agricultural zones.

Continuing, the agricultural sector is presumed to be perfectly competitive, so that land and labor are

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[12] In terms of the previous section, we could therefore write utility as $V = c_{Mt} + \gamma \ln(c_{At} - \overline{a})/(\overline{a}\theta)$ to express it in terms of consumption of manufactured and agricultural goods.

[13] One item to note here is that even though the quasi-linear utility function does not have an explicit income effect, because of the requirement that parents consume $\overline{a}$ units of food, there is still an Engel effect by which a decreasing fraction of income is spent on food as income increases.

paid their value marginal products

$$\begin{aligned} w_{At} &= p_t \beta \frac{Y_{At}}{L_{At}} \\ r_{At} &= p_t(1-\beta)\frac{Y_{At}}{X} \end{aligned} \tag{11}$$

where w_{At} is the agricultural wage rate and r_{At} is the rental rate for land, both in terms of manufactured goods.[14]

The manufacturing sector is presumed to be linear in labor, for simplicity, and the wage rate this yields is denoted w_{Mt}.[15] Perfect mobility between sectors ensures that the wage rates are equalized and therefore

$$\begin{aligned} w_{At} &= w_{Mt} \\ p_t \beta \frac{Y_{At}}{L_{At}} &= w_{Mt}. \end{aligned} \tag{12}$$

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

$$I_t = p_t \beta \frac{Y_{At}}{L_{At}} + p_t(1-\beta)\frac{Y_{At}}{L_t}. \tag{13}$$

2.2.3 Equilibrium and Dynamics

A final condition to impose is that the total supply of agricultural goods must equal the total demand,

$$Y_{At} = \overline{a}(1+\theta n_t)L_t \tag{14}$$

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[14] The assumption of perfect competition forces labor's share of agricultural output to be exactly equal to β. An objection may be that agricultural labor is often presumed to earn its *average* product. Two points suggest this objection is not relevant. First, assuming labor earns the average product implies that there are no property rights over land, something often done for theoretical convenience but at odds with historical experience. Clark's (2002) and Allen's (2005) work suggests an active rental market for land in England prior to the Industrial Revolution. The ability of land-owning lords to extract rents (at times in the form of labor service) is a major element of European economic history, as in North and Thomas (1973). Similarly, Perkins (1969) highlights the fact that landowners in 13th century China were already acting as landlords in all the modern senses. Secondly, we may observe a peasant earning the full output of their plot of land, but this does not imply that labor's share is 100% of output. To the extent that the peasant owns, or has rights over the land, they are acting as both labor and landlord and hence earn the full output. Peasants engaging their labor up to the point where the marginal return on that labor is equal to the outside option is entirely consistent with their also functioning as the landowner as well.

[15] w_M is assumed to be greater than $\gamma(1+\theta)/\theta$, which will assures that $c_t > 0$ and that the optimal allocation of labor to agriculture fulfils $L_{At} < L_t$.

[16] Because of the nature of optimal fertility, allowing for some distribution of land over individuals will result in an identical solution for individual fertility regardless of individual land holdings.

which tells us implicitly what level of fertility can be supported by the economy for any given level of agricultural employment, L_{At}. As the number of agricultural workers goes up (holding L_t constant) higher fertility is possible. Hence there is a positive relationship between L_{At} and n_t.

The second element of the equilibrium comes from the individual's optimal fertility solution in equation (9). Solving this together with the labor mobility condition in (12) we have that individual fertility can be written as

$$n_t = \frac{\gamma\beta}{\overline{a}\theta w_M} \frac{Y_A}{L_A}. \tag{15}$$

Given that agricultural production is concave in labor, this means that individual fertility is declining in L_{At}. The increase in the number of agricultural workers lowers the average product of a worker, and to offset this drop and keep labor from wanting to move out of agriculture the price of food must rise, which lowers fertility.

The equilibrium values of n_t and L_{At} can be found by combining the aggregate constraint in (14) with the individual fertility rate in (15). Note that for a given level of labor productivity in agriculture, a higher size of β implies a higher fertility level. This arises because, at a given average productivity level, a large β implies a higher marginal product of agricultural labor, and hence a lower price of agricultural goods, raising fertility. This equilibrium is capturing the features of the general case discussed in figure 1.[17]

Given the equilibrium in period t, the economy evolves based on the change in population size. Letting $L_{t+1} = n_t L_t$, the population size increases (decreases) if $n_t > 1$ (< 1). An increase in population size affects directly the aggregate constraint in (14), reducing the number of children that can be supported for any given number of agricultural workers. The Malthusian mechanism operates here to reduce fertility as population size increases, and vice versa.

The Malthusian steady state is the level of population L^* such that $n_t = 1$. By setting $n_t = 1$ in both (14) and (15) we can solve for steady state values. First, the allocation of labor to agriculture in steady state is

$$\frac{L_A^*}{L^*} = \beta \frac{\gamma}{w_M} \frac{1+\theta}{\theta}. \tag{16}$$

Note that the L_A^*/L^* ratio does *not* depend on agricultural productivity or the resource base X. The reason is that productivity increases induce higher fertility rates due to lower food prices and that requires a greater number of agricultural workers to support. While we cannot "push" labor out of agriculture in the long-run

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[17] The model does not say anything about how this higher fertility may manifest itself. One method of achieving this higher fertility could well be earlier marriage ages, as seen in Asia prior to the Industrial Revolution. The microeconomics of adjusting marriage ages to achieve fertility is where the paper of Voigtländer and Voth (2010) intersects with this paper.

of this model, an increase in w_M will "pull" labor into industry by raising the relative price of children.

More significantly, as β increases (agriculture gets more labor intense) the steady state share of labor engaged in agriculture goes up. By increasing the share of output that goes to labor, a lower relative price of agricultural goods is necessary to keep the labor market in equilibrium. The fertility rate is higher and to feed the resulting large population a greater share of workers must be engaged in agriculture.

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, from (14), that agricultural output per adult is

$$y_A^* = \frac{Y_A^*}{L^*} = \overline{a}(1+\theta) \tag{17}$$

which is identical regardless of β, as suggested in the general case of figure 2. However, the consumption of manufacturing goods per adult is

$$y_M^* = \frac{Y_M^*}{L^*} = w_M \left(1 - \frac{L_A^*}{L^*}\right) \tag{18}$$

and this is decreasing in β given (16), again consistent with the general outcome in figure 2. 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 by β, manufacturing output *per capita* is lower when agriculture is labor-intense (β is large).

We can also solve for the steady state population density knowing the allocation of labor from (16) and the resource constraint in (14). This yields

$$\frac{L^*}{X} = \left(\beta \frac{\gamma}{w_M} \frac{1+\theta}{\theta}\right)^{\beta/(1-\beta)} \left(\frac{A}{(1+\theta)\overline{a}}\right)^{1/(1-\beta)}. \tag{19}$$

The most interesting aspect of this is how population density is related to agricultural productivity. As β goes up, the elasticity of density with respect to productivity goes up. Increases in agricultural technology will have larger effects on population size when agriculture is labor-intense.[18] Hence an agricultural revolution, captured by an increase in A, will generate a larger population response when the agricultural sector is labor-intense.

What we have, then, is a way of describing differences in labor allocation, average real consumption,

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[18] An interesting implication of equation (19) is that fluctuations in agricultural productivity have more pronounced effects as β goes up. Drops in productivity due to poor weather or other reasons will cause larger drops in population when labor-intensity is high. This may be a useful way of thinking about why famines were more prevalent and devastating in Asia than in Europe in the period since 1300 (Clark, 2007).

and population density even holding constant technology levels (A_t, w_M) and resource endowments (X). By working with a labor-intense agriculture production system an economy will find it's Malthusian steady state skewed towards a larger population density and lower output per capita, and with a larger fraction of the population engaged in the agricultural sector. Within this specific model, it is the parameter β that dictates the labor-intensity of agriculture, and so evidence regarding this parameter is necessary to establish first that it varies across agricultural types, and second that it varies in a manner consistent with relative development levels.

3 Labor Intensity in Agricultural Production

There are distinct differences in the inherent labor intensity of different crops and geographic regions of the world. "Compared with most farming systems, wet-rice cultivation is labour-intensive," (Grigg, 1974, p. 81). This assertion is based not on observations of the number of workers per hectare in those regions, but rather on the minimum effort required to bring a crop of rice to harvest. More directly to the point, Ruthenberg (1976, p.189) finds that the production function of labor in rice production in the valleys of tropical areas are "as a rule, different from those in upland farming." Specifically, he concludes that the marginal returns to labor in upland farming (e.g. wheat or millet) are "lower and decrease more rapidly with greater employment of labor" when compared with rice production. In contrast, his work indicates that marginal returns to labor in rice production decrease very slowly or even remain constant as more labor is applied.

Bray (1986) discusses some of the features of rice production that lead it to be more labor-intense than dry cereal production. One particular aspect is the process of pozdolisation, by which the production of rice on a plot of land actually alters the soil chemistry, increasing its fertility over time. Because of this the rice yield has more to do with the application of labor than with the original nature of the land employed. In addition, the construction of paddies, which require dykes or bunds to retain water and must ideally be perfectly level, relies on the labor effort of farmers.

In terms of the simple Cobb-Douglas production function used above, the value of β captures the diminishing returns to labor. The evidence above indicates that β is relatively large for rice production when compared with wheat and/or other dry cereals. Their observations are based on unmechanized agriculture systems of East Asia and Africa prior to the widespread introduction of modern seeds, tools, and fertilizers. Hence these differences in the shape of the agricultural production function can serve as a useful indicator of what production was like in the pre-industrial era.

The high intensity of rice production is corroborated by information on the average number of days labor per hectare necessary 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). Allen (2009) shows that in 1800 the days of labor applied per acre were nearly 10 times higher in the Yangtze Delta as in England, even though the marginal product of a worker's time (as evidenced by the value of output produced per day) was almost identical. Ruthenberg (1976, p. 175) documents that these kinds of labor differences exist even *within* farms in tropical areas as farmers apply more labor to those crops with higher marginal returns (rice), implying that the evidence on days worked are not simply an indicator of differences in factor prices between rice-growing and wheat-growing areas.

Evidence from Bell (1992) indicates that in early 20th-century China, farmers employed their own labor across different crops in a manner consistent with rice having a high inherent labor intensity. Her evidence (see her tables 7.3 and 7.4) indicates that for a similar marginal return to labor (output per day of work), Chinese farmers employed roughly 12–25 days of work per *mu* planted with rice, while only 4–10 days of work per *mu* of wheat. Similarly, differences across regions of China are consistent with the differences in labor-intensity of crops. For northern China, where dry cereal production (millet and wheat) predominates, densities were on the order of 7-10 persons per *mu* in 1400 (Perkins, 1969, table B.5). In the same time period southern China, relying mainly on rice, had densities of 13–25 persons per *mu*.

This evidence indicates that differences in production functions across crops. To evaluate how important these differences were for Malthusian-era outcomes, we require some hard numbers on the values of β that are appropriate across regions and/or crops. The next two section provide two different approaches to getting these values, the first based on labor's share of output and the second on the elasticity of output with respect to labor employed. Both sets of evidence are consistent with the idea that rice production is more inherently labor-intense than wheat (or other dry cereal) farming.

3.1 Labor Share Evidence

Hayami, Ruttan, and Southworth (1979) report labor shares for the Philippines of approximately 0.55 and Taiwan of 0.54. Both are located in the tropics and rely most of their agricultural output is from crops (as opposed to livestock), dominantly rice (FAO, 2001). For China, Brandt, Hsieh, and Zhu (2008) suggest that the labor share in China is approximately 0.50 when estimated using household surveys from the period after the agricultural reforms of the late 1970's. Provincial data from Hsueh and Li (1999) yields a labor share of 0.76, although these values for China span several different agricultural zones. [19] Farm level data reported in Barker, Herdt, and Rose (1985) shows labor's share of output as 0.55 on traditional rice farms in Burma in 1932. Similarly, un-mechanized rice farmers in Sri Lanka earned 0.58 of output in 1972, while in the Philippines in 1974 similar rice farmers were earning up to 0.80 of total output. Historically, Chinese rice farmers appeared able to capture a significant fraction of output. Both Perkins (1969) and Huang (1990) speak of how tenants in rice-growing areas typically paid only half of their fall harvest as rent, but retained the full output of their other harvests during the year, meaning that land rents as a fraction of total output in a year was far less than 50%.

In contrast, on northern Chinese farms in the 1930's growing millet and wheat, labor earned only one-third of output according to Brandt (1987). This value for dry cereal production in China is similar to historical estimates for England from Clark (2002), who finds values between 0.36-0.40. Perhaps the most important aspect of Clark's estimates are that they are available for a period spanning 1650 to 1900. 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. An important aspect of these values is that they span the period in which England industrialized and mechanized its agricultural sector, and the labor share was relatively constant throughout. It can give us some assurance that the more recent observations for China and other tropical areas have relevance to periods farther into the past.

Most importantly, the overall labor shares are consistent with the technological differences between types of crops mentioned previously. That is, tropical rice production has higher labor shares in output, which matches the expectation given the earlier evidence on the inherent intensity of rice production compared to dry cereal crops.

3.2 Labor Elasticity Evidence

The other aspect of labor intensity is the elasticity of output with respect to labor, which captures the degree of diminishing returns in the agricultural sector. To get a handle on the values of this elasticity I turn to

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[19] Gollin (2002) provides evidence on labor's share in aggregate GDP. Assuming that labor's share of agricultural output differs across regions is not inconsistent with his results. Given the relatively small share of agricultural value added in GDP, even if labor's share in agricultural output is very small or very large this will not end up altering the aggregate share much. Additionally, Gollin does not establish that labor's share in output is *identical* across countries, only that it does not have a strong relationship to income levels.

cross-country evidence from contemporary periods in the absence of sufficiently detailed data from historical periods across geographic regions, although some comparisons will be possible.

The estimations are performed for various groups of countries, differentiated by primary agricultural products.[20] The FAO provides a breakdown of agricultural output data into different categories. The primary breakdown concerns 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. Three crops dominate production: maize, rice, and wheat.

[Table 1 Here]

Table 1 shows the share of total cereal production accounted for by these three crops across major regions of the world. The table reports averages from 98 countries using data from the year 2000 available from the FAO. 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 and other cereals.

This variation is consistent with differences in climate zones, as would be expected. The lower half of table 1 shows the breakdown of arable land within each region across various climates. 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).[21] 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.[22]

Those areas with heavy rice production also tend to be tropical and are far more likely to experience distinct dry seasons (as typified by the monsoon cycle in much of Asia). The temperate areas of the world, which tend to rely heavily on wheat, are also less likely to experience any distinct dry period over the typical

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

[21] 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.

[22] 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.

year. The information from Bray (1986), Grigg (1974), and Ruthenberg (1976) all link the labor intensity of rice production with the seasonal nature of rainfall and the requirement for precise water management compared to dry cereal crops, consistent with the correlations in table 1.

3.2.1 Estimation of Labor Intensity

Production is assumed to be described by a Cobb-Douglas function,

$$y_{it} = \gamma_0 + \beta l_{it} + \gamma_R r_{it} + \gamma_K k_{it} + \gamma_F f_{it} + \mu_i + v_t + \epsilon_{it} \tag{20}$$

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.[23]

Estimating (20) 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.

The problem is that in the short run as agricultural productivity goes up, more labor is released from the agricultural sector, creating a negative relationship of agricultural labor and total agricultural output *within* countries on a year-by-year comparison. This could provide information about the elasticity of agricultural output with respect to labor, but to tease this out would require additional statistical control for 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 cross-country but within-time comparisons, 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 agricultural types, eliminating one source of between-country variation. In addition, all the estimates will include log GDP per capita as an additional control which will pick up some of the between-country variation in general productivity as well. This control has the additional feature of

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[23] 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.

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 37 countries are used in the regressions, each with observations in the range 1961–1999, although not every country has the full 39 observations, so that the total number of observations is 1,364. While data on a larger number of countries is available, this set of 37 are used because their agricultural sector is particularly concentrated on either rice or wheat production and the estimates of β will be the most informative on differences in these kinds of agriculture.

3.2.2 Cross-country Results

The results of the various baseline estimates of $\hat{\beta}$ by primary crop can be found in table 2. The first three columns represent separate estimations, 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.

[Table 2 Here]

The first column of table 2 reports $\hat{\beta}$ for the 21 countries in which rice makes up over 50% of their cereal production. The value of β estimated is 0.577. This can be compared to column (2), which reports β equal to 0.227 for the 16 countries in which wheat is the dominant cereal crop. Clearly there is a distinct difference in the relationship between labor and output in agricultural production in these two samples. Consistent with the evidence on labor shares, and with the agronomic information on the labor-intensity of rice production, we see that the elasticity β is relatively large in rice-producing countries while being low for wheat producers.

The actual value of the elasticity for rice-producing countries, 0.577, is quite close to what the labor share evidence indicated would be the appropriate value of somewhere around 0.55.

The estimated elasticity for wheat countries, at 0.227, is relatively low compared to the labor share evidence from China and England, which indicated a value of around 0.35-0.40. Farm-level estimates on Chinese wheat farms, from Brandt (1987), indicate a labor elasticity of 0.32, which is also relatively lwo compared to the labor share evidence. Regardless, the evidence of columns (1) and (2) indicates, most importantly, the distinct difference in labor elasticity in production for the different types of crops.[24]

Returning to the comparison across crop types, one concern is that the wheat estimate in column (2) is biased down because the sample of 16 countries includes a number of relatively rich countries who may be operating a "modern" production technology that is not informative regarding wheat production over history. Column (3) excludes the eight developed countries from the sample (see the appendix for the full list) and re-estimates the elasticity with respect to labor. As can be seen, the value rises slightly to 0.250, but remains distinctly lower than the coefficient for rice-growing countries.

Consistent with the farm-level observations on marginal returns to labor, as well as the labor share evidence from various geographic areas, the cross-country evidence supports the idea that there are distinct differences in the shape of the production function in agriculture between crop types. Tropical areas that use rice as a primary crop have less severe diminishing returns to labor, while temperate areas focusing on wheat production feel tighter Malthusian constraints.

3.2.3 Population-based Estimates

An issue with the main results 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

$$\alpha + \phi n_{it} = y_{it} \tag{21}$$

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[24] For the other inputs to production, the estimated values are generally in line with the previous literature on agricultural production functions - see Mundlak (2000) for a summary. The livestock share is relatively large, and in particular is large in the wheat-producers, consistent with the observations regarding low livestock availability in tropical areas. The elasticity with respect to tractors is also relatively large in the wheat producers, and we will address the possibility below that this is because the wheat-producing countries are a sample of mainly rich countries with large capital stocks. Fertilizer and land coefficients are both close to zero, outcomes not unknown in the literature, as measurement is often imprecise. Fertilizer is also tightly correlated with GDP per capita, and therefore much of the variation is lost.

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 (21) with the production function in (20) suggests the following relationship

$$n_{it} = \frac{\gamma_0 - \alpha}{\phi} + \frac{\beta}{\phi} l_{it} + \frac{\gamma_R}{\phi} r_{it} + \frac{\gamma_K}{\phi} k_{it} + \frac{\gamma_F}{\phi} f_{it} + \frac{\mu_i}{\phi} + \frac{v_t}{\phi} + \frac{\epsilon_{it}}{\phi} \tag{22}$$

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, as the goal is to compare β across different crop types, 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.

Columns (4)-(6) perform these regressions with the log of total population as the dependent variable in place of agricultural value. In each case the estimated value has risen compared to the previous columns, indicating that $\phi < 1$. However, the pattern of results remains similar to before. For the 21 rice-producing countries the elasticity of population with respect to agricultural labor is 0.771, while for the 16 wheat-producers this value is only 0.365.

In column (6), once we exclude the relatively developed countries, the estimate for the wheat producers rises by a more significant amount than before, from 0.365 to 0.538, but this remains distinctly lower than the rice estimate. This comparison provides an assurance that the results in columns (1) through (3) are not simply capturing differences in the basket of food items purchased in the various countries, but reflect fundamental differences in the elasticity of population with respect to agricultural labor.

4 Implications for Comparative Development

How far can those empirical differences in labor intensity get us in explaining observed differences in Malthusian steady states? To answer this I begin with an economy that is given a realistic value of β for a temperate agricultural sector ("Europe") and calibrated to match historical evidence from the pre-Industrial Revolution era. Having set up this baseline, I then compare the outcomes for a tropical agricultural system ("Asia") that differs from the "European" baseline *only* in the value of β. We will be able to see that there are actually quite large differences in living standards driven by this simple change.

Given the empirical work of the previous section, the labor intensity of the European baseline is set to

$\beta = 0.4$, consistent with the labor shares observed in the U.K. and China historically for wheat producers. The labor intensity of the Asian comparison is set to $\beta = 0.5$, consistent with the labor share evidence from Asian economies producing mainly rice. These values are chosen to be relatively conservative. That is, there are reasons to suspect, given the empirical evidence, that β could be even higher in Asian regions, but $\beta = 0.5$ is chosen to show that even these small variations in labor intensity imply meaningful changes in outcomes.

To calibrate the European baseline case, I begin with the labor allocation to agricultural work. Le Roy Ladurie (1979) suggests that by 1300 nearly 15% of the population was being supported by the peasantry. Gregory King's estimate for England in 1688 is that between 60-80 percent of the population was engaged in agriculture, depending on how one allocates servants between sectors. France in 1700 has approximately 75 percent of population in agriculture (Toutain, 1963).[25] Wrigley (1985, p. 720) presents data that in 1700 only 55% of English population was in agriculture, and 63% in France. Given all this information, let us assume that for Europe, the value of L_A/L was equal to 75% in 1700. Using the steady state condition in (16) and the assumption for Europe that $\beta = 0.4$, this implies that $\gamma(1+\theta)/w_M\theta = 1.875$.

In terms of living standards, three different measures will be examined. The first is agricultural labor productivity (Y_A^*/L_A^*), which recall should be relatively high in areas with low labor-intensity. Manufactured goods per capita (Y_M^*/L^*) and output per capita (at constant prices) will both be examined as well. As we are interested in the comparison between regions, rather than the absolute levels of these variables, all three measures are set to equal one for the European baseline. These baseline values can be seen in column (1) of table 3.

Given this European baseline with $\beta = 0.4$, how does an economy that is identical in every respect save β compare? As noted above, the Asian economy is given $\beta = 0.5$. Given the value of $\gamma(1+\theta)/w_M\theta$ implied by the European example, the labor share in agriculture in Asia is $0.5 \times 1.875 = 0.94$, or 94%. This seems consistent with the historical evidence. Stover (1974, p. 16) suggests that of the 400 million Chinese in the late 1800's, approximately 2.5% did not work at agriculture, so it seems likely that in 1700 the percentage was not much different from this. The 7.5 million "non-producers" were of course not precisely equivalent to manufacturing workers, and among the rural areas of China there were certainly artisans that produced non-agricultural goods.[26] Table 3 reports this value, as well as the others for Asia, in column (2).

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[25] Urbanization rates are an imperfect indicator of labor force allocations. de Vries (1984, Table 3.7) reports that urbanization rates in 1700 were about 13% in England and below 10% in France, both well below the shares of labor reported.

[26] As noted, urbanization rates are an imperfect estimate of labor force allocation, but for what it is worth, Rozman (1973) reports that in the early 19th century only 3.8% of Chinese lived in cities of more than 10,000 persons, while 10% of Europeans did.

[Table 3 Here]

Agricultural labor productivity, Y_A^*/L_A^*, is compared in row two of table 3. Relative to Europe, the higher labor-intensity of agriculture in Asia reduces labor productivity in agriculture to only 80% of the European value. This difference is driven solely by the difference in β, as all measures of productivity (w_M and A) are identical between the regions in this calibration. The 80% comes from the simple construction of the model that assumes steady state agricultural consumption is identical across economies, exactly equal to the ratio of β values. Despite this simple set-up, labor productivity in agriculture of 80% of European values is a reasonable outcome. Boomgaard (2002) reports detailed calculations for Java in 1815. Each adult male agricultural worker produced 3.2 million calories per year. In comparison, Bairoch (1999, p.136) reports that in 1800 calories produced per adult male agricultural worker were 4.3 million in Spain and 4.2 million in Sweden, two countries that had not entered periods of sustained growth.[27] Thus the 80% value would appear to be consistent with observed range of preindustrial European countries.

In terms of living standards, two comparisons are made. First, consider manufactured goods per capita, row three of 3. Relative to Europe, the Asian individual would consume only one-fourth the industrial goods. Hajnal (1965) felt that ordinary Europeans had more household items and furniture, even adjusting for differences in climate. Contemporary travelers thought that average Europeans around 1700 had a standard of living unmatched by Asian peasants, even though the consumption of those at the top of Asian society was spectacular (Jones, 1987).

More concretely, Broadberry and Gupta (2006) present evidence on living standards that are broadly consistent with the variation calculated here. In the period 1700-49 wages (in grams of silver per day) in India were only about one-fifth of those in England. Similarly, wages in the Yangzi Delta of China were only 39% of English wages by the middle of the 17th century. Broadberry and Gupta show that silver wages were in fact an accurate depiction of relative development levels, even allowing for price level differences. Their work concludes that the difference in silver wages represents a real difference in consumption of tradable goods (e.g. textiles). Clark (2007) provides evidence that some of the advantage in incomes in Europe went towards greater food consumption, as evidenced by height differences, but a significant difference in non-agricultural goods consumed remains. Thus the difference in table 3 showing the Asian consumption of manufactured goods of only 24% of the European level is well within the range of historical evidence. Once again, these differences are the result only of differences in β.

One can also attempt to measure differences in output per capita across all goods, holding the relative

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[27] In comparison, the value for the United Kingdom at this point is 13.2 million calories per adult male agricultural worker.

prices of agricultural goods and non-agricultural goods constant. To do this requires some information about the expenditure share on food. Taking evidence from Clark (2007, Table 3.1) on English laborers prior to 1800, we have that 75% of income was spent on food and drink. In the steady state of the model presented, this implies that for Europe $p(1+\theta) = 3w_M(0.25)$. This ties down the value of $p(1+\theta)$, and knowing that we can calculate income at constant prices for Asia knowing their allocation of labor to manufacturing was 94%. Table 3 shows in the final row that output per capita for Asia is only 81% of the value for Europe.

For comparison, Broadberry and Gupta present "grain wages" for Europe, India, and China, which measure the quantity of grain (in wheat equivalents) wages could purchase per day. For the period 1650-99, Indian grain wages were 80% of the English wage. For China in the period 1550-1649 the grain wage was 87% of the English. While England may have been relatively developed in this period, the data for China comes from the Yangzi delta region, the most economically advanced area in the country at that time. Overall, their evidence suggests a wide variation in consumption of non-agricultural goods and a more muted comparison when income is valued at constant prices. The calibration in table 3 is capable of capturing such a difference solely through variation in labor-intensity in agriculture.

One thing to note at this point is that while theoretically it is true that population densities will be higher when $\beta = 0.5$, it is not possible to perform a simple comparison of outcomes as was done with living standards. The issue is that density, as will be seen by examining 19, is not unit-less when β varies. That is, the actual ratio of density in Asia ($\beta = 0.5$) to Europe ($\beta = 0.4$) depends on the precise number chosen to calibrate Europe. If European population density is set to 1, then density in Asia is approximately 1.4. If European density is set to 100, density in Asia is approximately 330. A similar problem holds for agricultural yields (Y_A^*/X), which is proportional to density.

While a strict calibration of density and yields is not possible, the remainder of the comparisons in table 3 demonstrate that a simple difference in labor intensity between the European and Asian regions can lead to significant differences in living standards in the Malthusian era, even if the actual technology levels are identical between them. This last point is important given the evidence presented by Pommeranz (2000) and others that suggests factor and goods markets in Asia were likely operating with a similar efficiency to the markets in Europe at the time. Similarly, techniques of manufacturing appear to be equal, if not better, in Asia prior to the Industrial Revolution. By allowing for differences in labor intensity in agriculture, we can account for the differences in average output per capita and industrialization in the Malthusian era without having to assume that Europe had an edge in efficiency or technology.

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, the type of crops available to individuals in these different regions had fundamentally different labor intensities. Rice production is labor intense, while wheat production is not, assertions that are shown to match well the evidence from agronomy and agricultural economics on the production of these crops.

With high labor intensity, the limitations of fixed factors of production in rice-growing areas 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 wheat 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. Importantly, these differences can exist even though available technologies and the efficiency of factor markets are identical between regions.

A simple calibration of the model is able to reproduce some stylized facts about Europe and Asia prior to the Industrial Revolution based on only a small difference in agricultural labor intensity. It shows a significantly smaller fraction of labor engaged in agriculture in Europe than in Asia. The calibrated advantages for Europe in average living standards given the labor intensity differences are shown to be sizable and similar to those found by the historical literature.

What this model and evidence suggest is that geographic differences in the shape of the agricultural production function were potentially crucial in the relatively early development of Europe versus Asia. Clearly, a full explanation for the differences between these areas, as well as an accounting for the experiences of Africa and the Americas, requires further information on institutional structures, culture, and levels of technology. However, these results point to the importance of geographic endowments in setting the stage upon which these other factors operate.

Appendices

A: 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.

B: Countries, by Region

The crop break-down is based on FAO production information from the year 2000.

Rice production $>$ 50% *of cereal production:* Bangladesh, Colombia, Costa Rica, Dominican Republic, Ecuador, Guinea, India, Indonesia, Japan, Korea, Madagascar, Malaysia, Panama, Peru, Philippines, Sierra Leone, Sri Lanka, Suriname, Thailand, Trinidad and Tobago, Uruguay

Wheat production $>$ 50% *of cereal production:* Algeria, Australia*, Bulgaria*, Canada*, Chile, France*, Iran, Israel*, Morocco, Netherlands*, Pakistan, Saudi Arabia, Syria, Tunisia, Turkey*, United Kingdom*

The asterisk indicates countries that are excluded from the wheat estimates in columns (3) and (6) of table 1.

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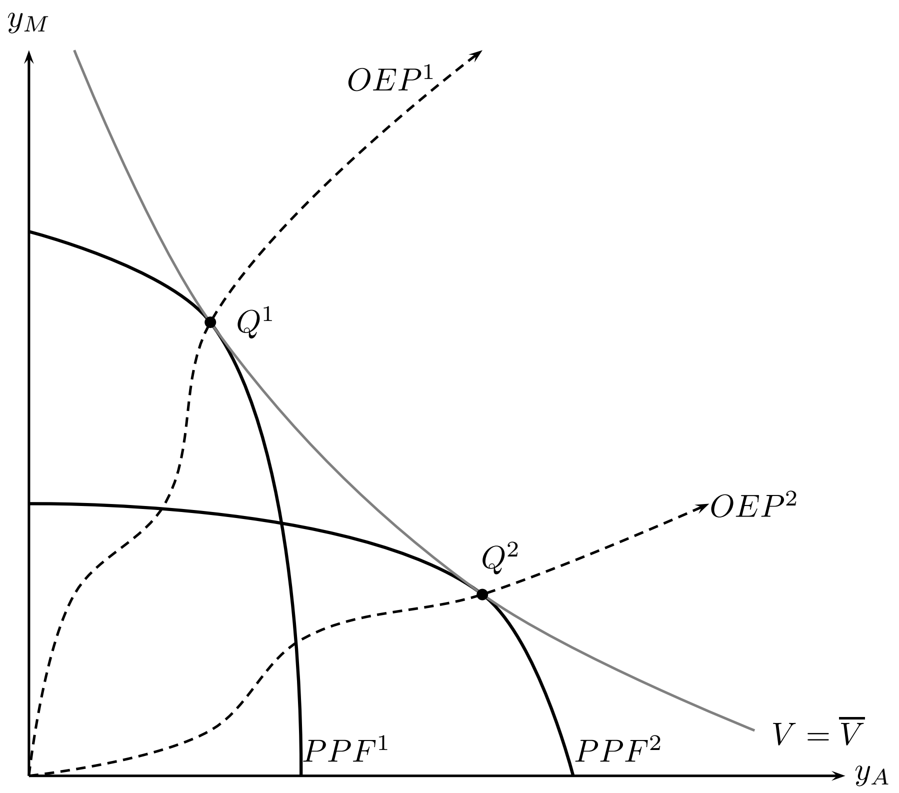

Figure 1: Equilibrium Outcomes at Different Labor Intensities

Note: At any given level of utility, $\overline{V}$, the equilibrium bundle of goods consumed depends on the labor intensity of the agricultural sector in the economy. Economy 1, with PPF^1, has a low-intensity agriculture, while economy 2, with PPF^2, has a high-intensity agriculture. Varying the level of $\overline{V}$ allows one to trace out the output expansion paths, denoted by OEP, for the two economies. The implication is that $OEP^1 > OEP^2$ at any level of y_A.

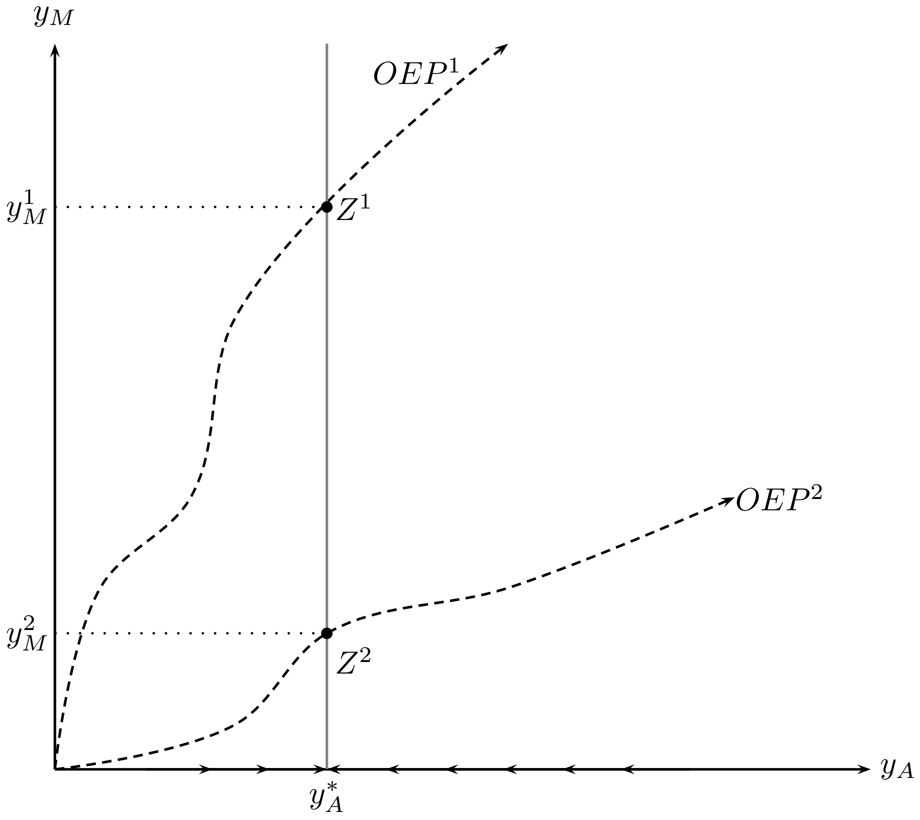

Figure 2: Steady-State Outcomes with Population Endogenous.

Note: As mentioned in the text, population size (and therefore output per capita) depends on y_A*. A steady state is reached at* $y_A = y_A^*$*, the level of agricultural output per capita at which* $n = 1$*, which is identical in the two economies. Given the output expansion paths, it must be that* $y_M^1 > y_M^2$ *in steady state. Given the assumption of a common labor productivity level in manufacturing in the economies, it must be the case that the fraction of workers allocated to manufacturing is higher in economy 1.*

Table 1: Country Level Summary Statistics, by Region

Region:	Sub-Sah. Africa	Mid-East N. Africa	Asia and Pacific	Central and S. America	Europe and Neo-Eur.
Crops as Share of Total Cereal Production, 2000					
Rice	0.174	0.060	0.786	0.366	0.011
Wheat	0.026	0.614	0.114	0.071	0.435
All others (incl. maize)	0.800	0.326	0.100	0.563	0.554
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

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: Agricultural Production Function, by Crop and by Sample

Dep Var:	Log Out. (y_{it}) (1)	Log Out. (y_{it}) (2)	Log Out. (y_{it}) (3)	Log Pop. (n_{it}) (4)	Log Pop. (n_{it}) (5)	Log Pop. (n_{it}) (6)
Log ag. pop (l_{it})	0.577	0.227	0.250	0.771	0.365	0.538
	(0.014)	(0.030)	(0.061)	(0.010)	(0.014)	(0.020)
Log livestock	0.219	0.429	0.573	0.055	0.085	0.226
	(0.015)	(0.030)	(0.054)	(0.008)	(0.010)	(0.017)
Log fert.	0.043	0.003	0.032	0.003	0.006	0.013
	(0.006)	(0.019)	(0.029)	(0.002)	(0.003)	(0.007)
Log land	0.029	-0.025	-0.111	0.002	0.004	0.087
	(0.011)	(0.014)	(0.038)	(0.003)	(0.004)	(0.010)
Log tractor	0.052	0.218	0.078	0.017	0.089	0.022
	(0.008)	(0.026)	(0.031)	(0.003)	(0.008)	0.011
Log GDP p.c.	0.302	0.234	0.150	0.088	0.046	0.034
	(0.014)	(0.035)	(0.059)	(0.010)	(0.011)	0.015
Main Cereal:	Rice	Wheat	Wheat	Rice	Wheat	Wheat
Obs.	783	581	299	783	581	299
Countries	21	16	8	21	16	8
Sample	All	All	Dev.	All	All	Dev.

Notes: Regressions vary in the countries included, which are determined by the main cereal produced. Rice countries have over 50% of their total production of cereals in rice, while wheat countries have over 50% of their total in wheat. “All” refers to the sample of all countries, including European and neo-European countries. “Dev.” excludes the European and Neo-Europes. See appendix for full list of countries. Each regression includes time dummies, and is estimated allowing for AR(1) correlation in the error terms as well as heteroscedasticity. See the text for a description of the explanatory variables.

Table 3: Comparing Steady States by Labor Intensity

	Labor Intensity	
	$\beta = 0.4$	$\beta = 0.5$
Variable	"Europe"	"Asia"
Labor Allocation: $\frac{L_A^*}{L^*}$	0.75	0.94
Agric. Labor Productivity: $\frac{Y_A^*}{L_A^*}$	1	0.80
Manuf. Good Consumption p.c.: $\frac{Y_M^*}{L^*}$	1	0.24
Output p.c. (at PPP): $\frac{Y^*}{L^*}$	1	0.81

Notes: The table demonstrates the different steady state outcomes under assumptions regarding labor intensity, β. The parameters of the model were selected to match the labor allocation and population density values for "Europe" in 1700 (see text for details). The remaining steady state values for "Europe" are normalized to one, and the "Asian" values are all calculated using the same parameters as "Europe", except for the change in β.