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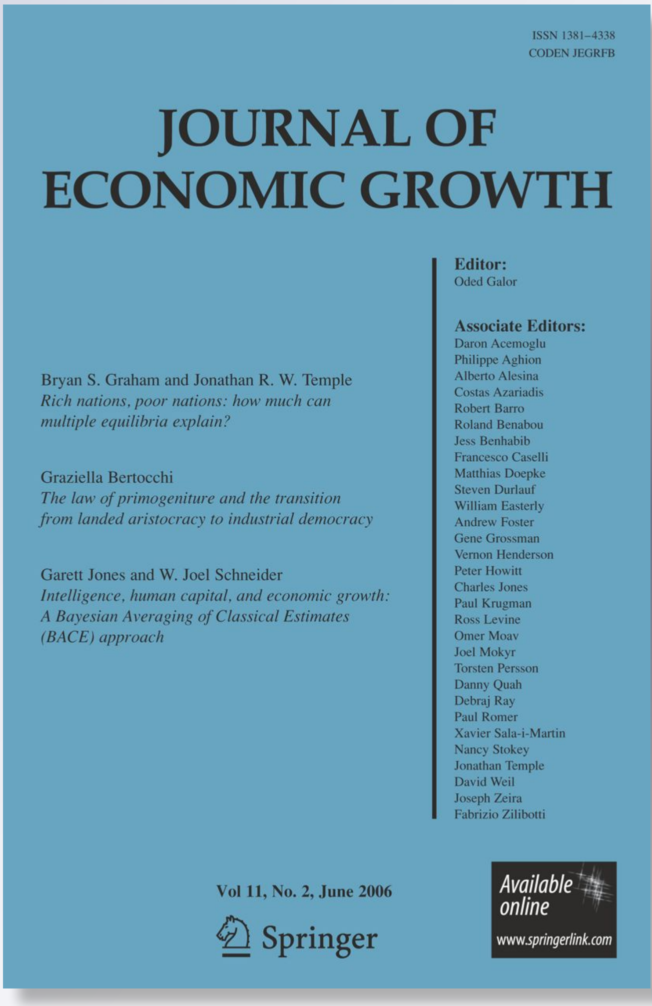

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Abstract This article shows, in a two-sector Malthusian model of endogenous population growth, that output per capita, population density, and industrialization depend upon the labor intensity of agricultural production. Because the diminishing returns 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 and historical evidence confirm that there are distinct, inherent 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 held constant in the two regions.

Keywords Agriculture · Production · Structural transformation · Endogenous population growth · Malthus · Growth

JEL Classification N10 · N50 · O41 · O11 · O13 · Q10

1 Introduction

In the Malthusian era describing much of human history, the positive relationship between population growth and income per capita led to stagnant living standards.[1] Stagnation, though, does not imply that output per capita must necessarily be at minimum subsistence levels. One

[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), and Doepke (2004). See Galor (2005) for a complete survey of the facts and theories involved in unified growth.

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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 as I document more fully below there is evidence of a European edge in living standards and urbanization for several centuries prior to that as well (see also 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 a gulf in agricultural technology levels, as the difference in labor productivity was not reflected in yields. Boomgaard (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 population growth 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 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.

In this article I explore the idea that differences in the labor intensity of agricultural production between Asia and Europe can provide a coherent explanation for variation in output per capita, population density, and industrialization levels in the Malthusian world, even while holding constant technology levels, preferences, institutions, and the extent of markets.[3] To be clear, I am concerned with labor intensity in the sense of the *shape* of the agricultural production function, as opposed to differences in the actual endowments of land and/or labor.

As evidence discussed below reveals, rice production is more labor-intense than wheat production. I take this difference in labor-intensity, and consider the effect on living standards within a Malthusian model where each child requires a fixed amount of food and labor is

[2] Allen (2005b) summarizes evidence regarding real wages in Europe, Japan, India, and China, finding instead ambiguous evidence for an advantage for Europeans in 1750. The important distinction will be in what reference prices are used, and Allen's work is focused mainly on purchasing power over food. As will be noted later, this is not inconsistent with a real advantage in living standards in Europe when measured in terms of non-food goods.

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

allocated between the production of food and manufactured goods.[4] The essential point is that the labor intensity in the agricultural sector determines the trade-off between consuming manufactured goods and having children, reflected in the relative price of food. Comparing the two crops, rice's high labor intensity means that the amount of food that must be sacrificed to acquire one unit of manufacturing goods is large when compared with low labor-intensity wheat. For that reason the relative price of food tends to be smaller in rice-producing economies.

The low price of food in rice-growing areas leads individuals, through the substitution effect, to choose higher fertility at any given level of income. The stable Malthusian equilibrium with zero population growth, however, requires that each individual desires only one offspring. With the substitution effect skewing their choices towards having children, individuals ultimately have to be comparatively poor in order for their optimal choice to be replacement fertility.

In contrast, in wheat-growing economies a higher relative price of food means that individuals have a comparatively low fertility rate at any given income level. In these places, the Malthusian equilibrium of replacement fertility can be reached at a relatively high living standard.[5] Combined with the Engel effect, the increased income of individuals leads towards a relatively greater demand for manufactured goods, so that the wheat-growing economy ends up with a larger fraction of individuals working in the manufacturing sector in the Malthusian equilibrium. When compared to the rice-growing regions, wheat-growing areas have a high relative price of food, but also higher consumption of manufactured goods per capita and overall living standards.[6]

Consistent with the Malthusian model (see Ashraf and Galor 2011), regional variations in the cost of raising children trigger differences in income across economies. However, in line with the Mathusian hypothesis, given these differences, an improvement in agricultural productivity will not generate a permanent effect on living standards but only on population size. It is important here to distinguish agricultural labor intensity from the level of agricultural productivity. The model presented here shows that agricultural labor intensity will have a significant effect on income per capita in equilibrium, while maintaining the Malthusian prediction that agricultural productivity has no effect on living standards. The reason for the distinction is that the influence of labor intensity on the relative price of food does not dissipate as population size increases, leading to a permanent effect on the cost of raising children. In contrast, an increase in agricultural productivity will temporarily lower food prices, but this will eventually be offset by a falling land/labor ratio, so that in the long run there is no change in the cost of children.

Observations by agronomists confirm that wheat (as well as other dry cereal crops) 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) support the idea

[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. Recent work by Voigtländer and Voth (2010b) 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 article's focus.

[5] Note that all individuals within an economy face the same prices. Specifically, there is no difference in the cost of children in the two sectors.

[6] Both Allen (2005b) and Broadberry and Gupta (2006) provide evidence that food prices were relatively high (compared with manufactured goods) in Europe, while in Asia food was relatively cheap. This difference is what drives their findings that while European and Asian "grain" wages were similar, Europe had higher real wages when valued using a basket including manufactured goods.

that the returns to labor diminish more slowly in rice production than in wheat production. 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 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. Both estimates are supported by data spanning several centuries. Evidence on the elasticity of output with respect to labor inputs also confirms the labor-intensity of rice production versus other cereals.

To address the quantitative relevance of these differences, I calibrate a simple two-sector model and compare steady state outcomes when varying the labor-intensity of agriculture. Using values consistent with the observed data, the model shows that a low-intensity "European" region will have agricultural labor productivity 25% larger than a stylized "Asia".[7] In addition, consumption of non-agricultural goods is up to four times higher and output per capita is approximately 30% higher in "Europe" when measured at manufactured good prices. Measuring relative to food prices shows similar levels of income between regions. The gaps are consistent with the variation identified in the historical literature regarding Malthusian-era output per capita in Asia and Europe, including the finding that living standards measured in food prices were comparable. These results arise solely from differences in the labor intensity of agriculture, holding constant sector-level productivity in the two regions. The results are shown to be robust to various assumptions regarding the strength of substitution and income effects of food prices on population growth, as well as to using a more generic production function.

One advantage of this approach is that it provides a way to reconcile the relative advantage of Europe in terms of industrialization and output per capita with the observations of Pomeranz (2000), Parthasarathi (1998), Keller and Shiue (2007) 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. Additionally, the work of Pomeranz and others indicates that the technological gaps between Europe and Asia were not drastic prior to the Industrial Revolution.[8] If Europe possessed only a mild productivity advantage, then agricultural labor-intensity differences provide an additional way of explaining Europe's early lead in living standards. This article thus shares with Voigtländer and Voth (2010a,b) a focus on how differences in population dynamics are an important factor in explaining differences in comparative development prior to the Industrial Revolution.

It is important to distinguish the approach of this article from others focusing on the structural transformation and improvements in agricultural productivity. Gollin et al. (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

7 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 0.55, both consistent with the historical data.

8 Mokyr (1990, p. 229) makes the point that one should not confuse the existence of modern science and its discoveries with a widespread technological advantage in Europe.

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 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.[9] This article suggests that the salient aspects of these endowments was the inherent intensity of labor in agricultural production, regardless of initial factor endowments.[10]

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 sustained growth. 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 et al. (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 et al. (1990), Galor and Weil (2000), and Galor et al. (2009) or the evolution of preferences for human capital as in Galor and Moav (2002) have also been proposed as reasons for the take-off to sustained growth. Regardless of the actual source, what the current article 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 children.[11]

More broadly, the relevance of the Malthusian mechanism for comparative development levels has been recently documented by Ashraf and Galor (2011). The current study offers a complementary approach to understanding variation across the Malthusian world. After introducing empirical evidence to support the idea that wheat production was associated with higher income per capita than rice production, I review data supporting the idea that the labor intensity of rice is much higher than that of wheat. Following that, the model is presented and a calibration is performed on the basis of the evidence showing that the model contains significant explanatory power for preindustrial development levels.

[9] Other recent research concerned with bio-geographical elements of long-run development include Ashraf and Galor (2009), Dalgaard and Strulik (2007), Galor and Michalopoulos (2011), Galor and Moav (2002), Lagerlöf (2003), Michalopolous (2008), and Olsson and Hibbs (2005).

[10] This article 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 article is about the comparison across regions of economies that have reached the point of using settled agricultural techniques.

[11] The ideas in this article 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.

Table 1 Summary statistics

Variable	Obs.	Mean	Std. dev.	Min.	Max.
Income per capita, 1500 C.E. (PPP $)	25	631	147	430	1100
Income per capita, 1820 C.E. (PPP $)	38	785	347	397	1838
Income per capita, 2000 C.E. (PPP $)	38	11,182	8,469	994	25,102
Wheat–rice difference	38	0.093	0.144	−0.079	0.498
Log land productivity	38	0.371	0.982	−2.708	1.424
Absolute latitude (°)	38	36.0	15.9	2.5	64.0
Years since Neolithic transition	38	6,497	2,122	3,500	10,500

Income per capita comes from Maddison (2003). The wheat–rice difference is from Fischer et al. (2002). The wheat–rice difference is the fraction of land classified as suitable for wheat minus the fraction of land classified as suitable for rice. Land is considered suitable for a crop if the yield of a crop is over 70% of the maximum possible yield under ideal conditions. Log land productivity, absolute latitude, and the years since the Neolithic transition are taken from Ashraf and Galor (2011)

2 Wheat, rice, and comparative development

The evidence in the introduction is suggestive of a difference in income per capita between Europe and Asia during the Malthusian era. Here, I show that these differences are closely related to the type of major crops grown in the two regions, and the effects persist from 1500 C.E. well into modern times.

I have constructed a measure for countries in Europe, North Africa, and Asia that captures their relative suitability for wheat production as opposed to rice production.[12] The Global Agro-Ecological Zones project (GAEZ hereafter) by Fischer et al. (2002) provides data on the fraction of land in a country that is suitable for the production of several different cereal crops, including rice and wheat. Suitability is determined by combining information on availability of sunlight, temperature, elevation, soil types, and the amount and pattern of rainfall with crop-specific biological requirements. The GAEZ reports land as suitable for a crop if its expected yield is more than 70% of the maximum attainable yield under optimum conditions. I calculate the suitability for a given crop in a country by dividing the total suitable land by total land area of that country.

To measure relative crop suitability within a country, I take the fraction of land suitable for wheat and subtract from that the fraction of land suitable for rice. A positive value thus indicates that a country that is more amenable to wheat production, while negative numbers indicate a country more amenable to producing rice. By differencing, I am able to focus on the relative suitability of wheat versus rice, while eliminating those characteristics that contribute to high productivity across both crops.[13] Summary statistics of the wheat–rice difference, as well as all other variables, are available in Table 1.

This wheat/rice difference is closely correlated with living standards across a long span of time. Table 2, in column 1, shows the results of a simple regression of log income per

[12] I focus in this article on differentials in living standards across these three regions as they all made the transition to settled agriculture relatively early, and were the three most developed regions by 1500 C.E. Additionally, both wheat and rice were only introduced to the Americas and Sub-Saharan Africa after the European discoveries. Regardless, if one includes countries from all regions of the world in the regressions, the results still hold. Those results are available from the author upon request.

[13] Alternative methods of measuring the relative suitability, such as using one plus wheat suitability divided by one plus rice suitability, provide similar results.

Table 2 Relative suitability for wheat versus rice and income per capita

	Dependent variable: log income per capita in								
	1500 C.E.			1820 C.E.			2000 C.E.		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Wheat–rice suitability difference	0.819***	0.649***	0.604*	2.019***	1.710***	1.246***	4.481***	3.846***	2.763**
	(0.197)	(0.211)	(0.343)	(0.283)	(0.326)	(0.425)	(0.730)	(1.120)	(1.168)
Log land productivity		0.026	0.003		0.029	−0.012		−0.049	−0.150
		(0.031)	(0.044)		(0.039)	(0.046)		(0.144)	(0.133)
Log absolute latitude		0.034	0.016		0.103	0.079		0.433	0.379
		(0.069)	(0.080)		(0.068)	(0.062)		(0.276)	(0.299)
Log years since transition		0.118	0.191		−0.071	0.197		−0.853**	−0.222
		(0.122)	(0.188)		(0.132)	(0.163)		(0.404)	(0.474)
Asia			−0.001			−0.130			−0.300
			(0.169)			(0.156)			(0.466)
Mideast and N. Africa			−0.150**			−0.342***			−0.815**
			(0.062)			(0.095)			(0.303)
Constant	6.303***	5.157***	4.630***	6.399***	6.681***	4.636***	8.496***	14.540***	9.709**
	(0.037)	(1.112)	(1.367)	(0.041)	(1.120)	(1.263)	(0.169)	(3.518)	(3.645)
R-squared	0.316	0.360	0.414	0.548	0.572	0.680	0.401	0.525	0.616
Observations	25	25	25	38	38	38	38	38	38

The table shows that having land appropriate for wheat production as opposed to rice production (the wheat–rice difference), is positively associated with income per capita in three different time periods. The sample is limited to 25 countries in 1500 C.E. due to a lack of income per capita data. All regressions are OLS, with robust standard errors reported in parentheses. Overall crop suitability, log land productivity, log absolute latitude, and log years since the Neolithic transition are included to control for overall agricultural productivity. The Mideast and N. Africa dummy captures countries in that region, and overlaps with the Asia dummy for those countries located on that continent. The sources for all variables can be found in the table of summary statistics, Table 1

* Denotes significance at 10%, ** at 5%, and *** at 1%

capita (from Maddison 2003) in 1500 C.E. on the wheat/rice difference. As can be seen, for the sample of 25 countries there is a highly significant positive relationship, indicating that as a country becomes more suitable for wheat relative to rice, income per capita was higher. One additional note is that the R-squared indicates that the wheat–rice difference, by itself, can account for 31% of the variation in income per capita in this period.

This simple correlation is suggestive, but may be biased if land suitable for wheat also tends to be more productive than land suitable for rice. To control for this, I incorporate a set of controls for overall agricultural productivity. These come from the work of Ashraf and Galor (2011), who study the relationship of agricultural productivity and living standards in the Malthusian era. They provide a measure of land productivity, which is composed of information on the amount of arable land and inherent land fertility. They also provide the log of years since the Neolithic transition, which measures the length of time that a country has had experience with settled agriculture, presumably influencing their built-up stock of knowledge in agricultural production. Finally, the log of absolute latitude is included to capture any differences due purely to location near the tropics and the effect of this on productivity.

In column 2, these controls are included in the regression for log income per capita in 1500. As can be seen, the estimated effect of the wheat/rice difference falls in size, but significance remains at the 1% level. One additional thing to note is that all the productivity variables in column 2 are generally unrelated to income per capita, consistent with what Ashraf and Galor (2011) find. We thus retain the typical Malthusian result regarding agricultural productivity, but even so there is clearly a relationship of income per capita with the *type* of crops that are typically grown. The model presented below is able to replicate this particular pattern found in the data.

A final area of concern is that the wheat/rice difference is simply capturing broad cultural or institutional differences between Asian and European economies. Without meaningful measures of these at the country level, I incorporate dummies to control for these broad regional differences. The Asia dummy captures those countries on that continent. I also include a Middle-east and North African dummy, allowing a differentiation between the east Asian countries that were primarily rice producers from the west Asian nations that were not.[14]

Column 3 of Table 2 shows the result for income per capita in 1500 when these regional dummies are included. As can be seen, the estimated effect of the wheat/rice difference falls only slightly compared to column 2 and remains significant at 10%.[15] This holds despite the high correlation of the wheat/rice difference and the Asian dummy, and shows that the variation in crop type is significant in explaining variation in living standards even *within* the different regions. The Asian dummy itself is essentially zero, and not even remotely significant, while the Middle-east and North Africa dummy picks up distinctly lower living standards in that region.

A one standard deviation increase in the wheat–rice difference of 0.15 can be notionally thought of as switching 7.5% of the land area of a country from being suitable for rice to being suitable for wheat. This 0.15 increase in the difference is associated with a roughly 9% increase in income per capita, given the estimates in column 3.

There is a significant difference in living standards associated with the wheat/rice difference in 1500, but the effects persist even beyond this period. Columns 4 through 6 replicate the specifications, but instead use log income per capita in 1820 as the dependent variable. At this later date, even though Great Britain (and to some extent, the Netherlands) had begun the transition towards sustained growth, the majority of the world remained in the Malthusian regime. In 1820, broader information on income per capita is available, and the sample size is increased to 38 countries, which includes a number of additional Asian nations.

Similar to the prior results, living standards in 1820 were significantly related to the wheat/rice difference in crop production. The simple correlation in column 4 is highly significant, and this survives the inclusion of productivity controls in column 5 and the regional dummies in column 6. One thing to note is that the estimated effect of producing wheat as opposed to rice is much larger in 1820, with coefficients close to double those seen in columns 1 through 3. From these estimates, a one standard deviation increase in the wheat/rice difference is associated with a 19% increase in income per capita in 1820. Combined with

[14] There are 18 Asian countries in the sample (7 in 1500), nine Middle-east and North African ones (5 in 1500), and 16 European countries (16 in 1500). The Middle-east and North African and Asian dummies overlap for several countries, so those totals add up to more than the 38 nations represented in the 1820 and 2000 samples, and more than the 25 in the 1500 sample.

[15] A one-sided test that the coefficient on wheat/rice difference is positive (as opposed to simply non-zero) has a p-value of 4.76%.

the results from 1500, this evidence indicates that crop type had an effect on the Malthusian outcomes, while perhaps also influencing the timing of the take-off to sustained growth.

This increased advantage is even more prominent as time passes, which is shown in columns 7 through 9. Here, income per capita in 2000 is strongly and significantly related to the wheat/rice difference in all specifications. The sample in these regressions is limited to the same 38 countries that were used in the 1820 regressions for consistency. Now, a one standard deviation increase in the wheat/rice difference is associated with 51% higher income per capita. This would again appear to represent the advantage of an early lead in the take-off to sustained growth, as opposed to a direct effect of crop types on developed nations today. While these results suggest that crop type may have had persistent effects on living standards (through any number of possible channels), I focus in this article on the effect on Malthusian outcomes.

Overall, it can be seen that there is a strong relationship between the type of crops grown within a country and its level of development, even holding constant overall agricultural productivity. This link exists during the Malthusian era in 1500, at the onset of the Industrial Revolution in 1820, and well into contemporary times. The important feature of these results are that, while absolute measures of productivity fit the standard Malthusian prediction of no effect, countries that are more amenable to wheat production as opposed to rice had significantly higher living standards.

3 Labor intensity in agricultural production

The other important fact to establish is the actual difference in labor intensity between the two types of crops, as this will be what drives the theoretical results. 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.[16]

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 to a much greater extent than the availability of land *per se*.

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 pro-

[16] It is important to note that by rice production, I am referring to evidence regarding paddy rice production. Upland types of rice are grown as dry cereals, and have production properties similar to other dry cereal crops such as wheat.

duction 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 1950s (p. 141). Allen (2009) shows that in 1800 the days of labor applied per acre were nearly ten 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 twentieth-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*.

While this evidence is all consistent with higher labor intensities in rice production versus wheat (or other dry crop) production, additional verification of the differences can be presented in terms of a specific production function.

Let agricultural production be described by a Cobb–Douglas function over land and labor, as in

$$Y_A = AX^{1-\beta}L_A^{\beta} \tag{1}$$

where A is a total factor productivity term, X is the total amount of land used, and L_A is labor employed in agriculture. The value of β captures the elasticity of production with respect to labor, which indicates directly the labor-intensity of agricultural production.[17]

The next two section provide two different approaches to getting at the value of β, 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

David and Baker (1979) report a labor share in agriculture for the Philippines of 0.53, where rice makes up roughly 2/3 of total agricultural output, by value, over the period 1948–1971. For China, Brandt et al. (2008) suggest that the labor share, as a whole, is approximately 0.50 when estimated using household surveys from the period after the agricultural reforms of the late 1970s. Note that the values for China span a range of agricultural zones, including the predominantly rice-growing southern areas and the wheat and millet zones of the north, so the share of 0.50 is a weighted average across these areas. Provincial data from Hsueh

[17] Inferring the labor intensity directly from labor shares works only in the case where the Cobb–Douglas is the true production function. With a more flexible constant elasticity of substitution function, labor's share doesn't necessarily imply anything about labor intensity, or how fast the marginal product of labor changes in response to using more labor. The data below, however, show that labor's share in agricultural output is very persistent over time, lending weight to using the Cobb–Douglas.

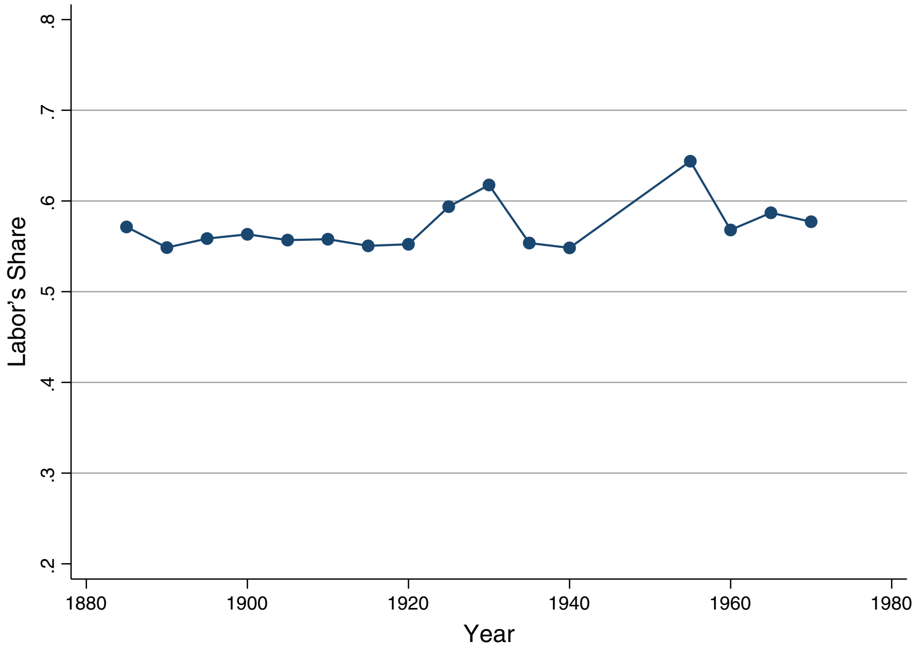

Fig. 1 Labor's share of agricultural output, Japan. *Note* Information is from Yamada and Hayami (1979), Table J-5, adjusted to share of value added. Figures are 5-year averages centered on years shown. Values for 1945 and 1950 are excluded due to the effects of World War II and reconstruction on agricultural production, see Yamada and Hayami (1979) for details

and Li (1999) yields a labor share of 0.76, focused more heavily on rice-producing regions. Farm level data reported in Barker et al. (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%.[18]

Longer run estimates are available from several Asian countries. Yamada and Hayami (1979) present data on the long-run share of labor in agriculture for Japan. Figure 1 presents their estimates of labor's share. As can be seen, for Japan the series is relatively constant at a value of around 0.55 until the 1930s, after which some variations occur, but always in the upward direction. Across the whole series from 1880–1970, labor's share in agriculture in Japan is approximately 0.57. One feature of these data to note is that these shares are not changing radically across this period despite the increasing use of fertilizers and machinery, indicating that the Cobb–Douglas specification for production is a suitable assumption.

[18] 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.

For Taiwan, Lee and Chen (1979) provide a shorter time-series on factor shares. For the pre-World War II era, 1911–1935 they find shares of approximately 0.54, while for the period from 1951–1970 the average share is approximately 0.53. Combined with the Japanese data, these values appear consistent with the individual observations mentioned previously from other rice-growing areas, and suggest the labor's share is roughly 55% across these regions.

If we turn attention instead to wheat production, we find distinctly lower shares of output going to agricultural labor. With respect to English agriculture, Clark (2002) and Allen (2005a) have both calculated labor's share over relatively long time periods prior to the Industrial Revolution.

Figure 2 plots the labor share in agriculture from both sources. Clark's data covers the period from 1600 to 1850, and shows quite clearly that labor's share is roughly constant at around the value of 0.40, with only slight variations above and below this value. Allen's data is available for only four specific periods, but matches closely with Clark's estimates, the only deviation being in 1850 when Allen estimates a share of about 0.35 compared to Clark's 0.42. Regardless, the overall impression from Fig. 2 is that labor's share in agricultural output in England over the period prior to and including the early Industrial Revolution is constant at about 40%.

This share is matched in other regions of the world based around dry cereal production. On northern Chinese farms in the 1930s growing millet and wheat, labor earned only one-third of output, according to Brandt (1987). This provides some evidence that labor share vary not solely due to institutional differences between Asia and Europe, but based on the type of agriculture practiced.

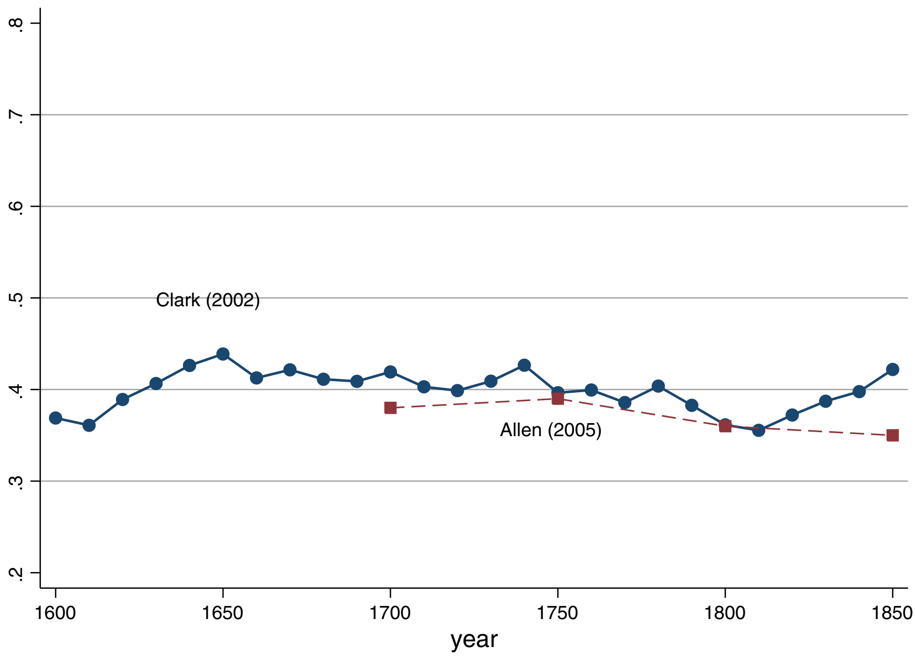

Fig. 2 Labor's share of agricultural output, England. *Note* Clark (2002) share is calculated using his preferred measure of labor income, his Table 3, divided by net agricultural output from his Table 4. Allen (2005a,b) data is from his Table 14

Providing more confirmation of the low labor share in dry cereal production, Hoffman (1996) study of French agriculture in the 17th and eighteenth centuries uses farm-level accounts to establish that labor was earning approximately 35–40% of output. The farm accounts used to calculate these shares come from widely separate regions of France, yet show a consistent share for labor below 40%.

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 than dry cereal production, 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

Compared to labor share evidence, there is less direct evidence on the elasticity of agricultural output with respect to labor. The main issue is that one can directly measure labor's share of output, but the elasticity has to be estimated using farm-level regressions.

Brandt (1987) does estimate a labor elasticity for Chinese wheat farms, finding a value of 0.32, which is slightly lower than the labor shares found for wheat, but certainly consistent with that data. In contrast, Barker et al. (1985) estimate an elasticity of 0.49 for rice production across thirteen Asian countries using data covering the 1950s, 1960s, and 1970s. These countries were relatively underdeveloped and were primarily using traditional techniques. The value of 0.49 is slightly lower than the labor share evidence for rice. However, it does show a value distinctly higher than that for the wheat elasticity, consistent with a higher labor intensity in rice production.

4 Labor intensity and Malthusian outcomes

Given the evidence that labor-intensity varies by crop type, the question that arises is whether these differences are sizable enough to produce meaningful quantitative variation in living standards in that theoretical steady state. To answer that, this section develops a fully-specified two-sector model of production and consumption with endogenous population growth. After establishing the Malthusian steady state conditions in this model, I calibrate it to European outcomes, and then consider how a single change to a higher labor-intensity in agriculture alters the Malthusian outcomes. As will be seen, even small changes in labor-intensity will lead to large differences in labor's share in agriculture and various measures of living standards.[19]

4.1 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).[20] Each adult has a fixed subsistence consumption of food that produce no utility, while having children also requires an input of food.

[19] The model is strictly Malthusian in that it generates a positive relationship between income and population growth 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 child-bearing 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 population growth, but do not consider relative development levels.

[20] One should think of n_t as representing the net number of surviving children. I will not model explicitly the mortality process, so that n_t could be thought to capture the number of children that are raised to adulthood.

The specific utility function employed is

$$U_t = \frac{c_{Mt}^{1-\sigma}}{1-\sigma} + \gamma \frac{n_t^{1-\phi}}{1-\phi} \tag{2}$$

which nests several popular forms of utility in long-run growth models. Setting $\sigma = \phi = 1$ yields log utility over both consumption and children, a common assumption. Alternately, setting $\sigma = 0$ and $\phi = 1$ gives a quasi-linear specification, as explored by Weisdorf (2008) and shown by Strulik and Weisdorf (2008) to be useful in creating a simple unified growth model. What will be seen is that the relative sizes of σ and ϕ will determine how important differences in labor intensity will be for steady state outcomes. The point to note is that the influence of labor-intensity arises regardless of what the exact specification of σ and ϕ are.[21]

The budget constraint depends on income, I_t, given 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 $\theta > 0$. Income not spent on food is consumed, so that the overall constraint is

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

The first-order condition for individuals can be written as

$$n_t = c_{Mt}^{\sigma/\phi} \left(\frac{\gamma}{p_t\overline{a}\theta} \right)^{1/\phi} \tag{4}$$

which shows how the relative size of σ and ϕ will influence the optimal population growth rate. If σ/ϕ goes towards zero, population growth depends solely on the price of feeding children. As σ/ϕ goes to one we have the case that children and manufacturing consumption will be proportional, as in the typical Cobb–Douglas utility case.

4.2 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 the production function is identical to the one used previously in Eq. 1 interpreting the evidence on labor shares: $Y_{At} = AX^{1-\beta}L_{At}^{\beta}$. As noted in the previous section, β indexes the labor-intensity of agricultural production. This is the crucial parameter that we will examine in the calibration, and see how variation in this value influences the steady state outcomes.

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

$$\begin{aligned} w_{At} &= p_t\beta\frac{Y_{At}}{L_{At}} \\ r_{At} &= p_t(1-\beta)\frac{Y_{At}}{X} \end{aligned} \tag{5}$$

where w_{At} is the agricultural wage rate and r_{At} is the rental rate for land, both in terms of manufactured goods.[22]

[21] One could use a more general utility function that included parent's consumption of food. In this case, so long as parent's food consumption and fertility are not gross substitutes, all the conclusions will follow. The additive nature of the utility function is sufficient to ensure this holds.

[22] 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

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

$$\begin{aligned} w_{At} &= w_M \\ p_t \beta \frac{Y_{At}}{L_{At}} &= w_M. \end{aligned} \tag{6}$$

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

$$I_t = p_t \beta \frac{Y_{At}}{L_{At}} + p_t(1-\beta)\frac{Y_{At}}{L_t}. \tag{7}$$

4.2.1 Equilibrium and dynamics

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

$$Y_{At} = \overline{a}(1+\theta n_t)L_t \tag{8}$$

which tells us implicitly what level of population growth 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 population growth is possible. Hence there is a positive relationship between L_{At} and n_t.[24]

An equilibrium at period t in this model consists of an allocation of labor, L_{At}, to agriculture, a population growth rate, n_t, a consumption level of manufactured goods, c_{Mt}, and a relative price of agricultural goods, p_t that meet the following conditions

- Optimal population growth: $n_t = c_{Mt}^{\sigma/\phi}\left(\frac{\gamma}{p_t \overline{a}\theta}\right)^{1/\phi}$
- Budget constraint: $p_t \beta \frac{Y_{At}}{L_{At}} + p_t(1-\beta)\frac{Y_{At}}{L_t} = c_{Mt} + p_t \overline{a}(1+\theta n_t)$
- Labor mobility: $p_t \beta \frac{Y_{At}}{L_{At}} = w_M$

Footnote 22 continued
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 (2002) and Allen (2005a) 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 thirteenth 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. Alternatively, one can conceive of L_A/L as measuring the share of a peasants time spent on agricultural production within the household, and that this choice of allocation is made to equate the marginal return from the two activities.

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

[24] I am assuming that initial density and agricultural productivity are such that $L_0/X < A^{1/(1-\beta)}/\overline{a}$, which ensures that the agricultural sector is capable of providing at least the subsistence constraint for each adult. Given this assumption, adults will have at least some income over subsistence to allocate over manufactured goods and children.

- Market clearing: $Y_{At} = \overline{a}(1 + \theta n_t)L_t$ and $Y_{Mt} = c_{Mt}L_t$

The optimal population growth condition is the first-order condition relating number of children and consumption from the individual in Eq. 4. The budget constraint simply replaces income, I_t, in the individual's constraint from (3) with factor income from (7). Finally, the market clearing condition is the requirement that the agricultural sector produce enough food to feed all adults and their children, while the manufacturing sector produces an amount equal to the amount demanded. The values of L_t, w_{Mt}, X, and A_t are taken as given.

Given the non-linear nature of the optimal population growth condition, there is not a simple analytical solution to the equilibrium in any given period t. However, we can gain some insight into the steady state outcomes in which population is stable, and therefore $n_t = 1$.

At the Malthusian steady state, the following condition will define L_A^*/L^* implicitly

$$\frac{L_A^*}{L^*} = \beta \left(1 - \frac{L_A^*}{L^*}\right)^{\sigma/\phi} w_M^{\sigma/\phi - 1} \frac{\gamma(1+\theta)}{\theta}. \tag{9}$$

This expression shows the role of labor-intensity on long-run outcomes. As β increases, L_A^*/L^* will rise to keep this equation balanced.

To gain some intuition for why this result holds, consider two economies, one with a low β value (economy 1) and one with a high β value (economy 2). Let us compare those economies out of steady state, with identical technology levels, A and w_M. The endowment of land per capita, X/L_t, is also assumed to be identical to begin with in both economies. Importantly, land per capita is presumed to be less than one, which can be achieved by a proper choice of units.[25]

Given these assumptions and the production function in Eq. 1, for any given share of labor allocated to agriculture, economy 2 will have a higher level of agricultural output per capita, due to the larger β. Thus, for any given y_M, agricultural output per capita will be higher, and as fertility depends upon this agricultural output per capita, fertility will be higher in economy 2 as well.

The implication is that the production possibility frontier of economy 2 is, holding X/L_t constant, larger than in economy 1. This is shown visually in Fig. 3. Economy 2 can support higher levels of agricultural output per capita (and hence higher fertility) at each level of y_M. Given preferences, the equilibrium bundles chosen in the two economies are denoted by Q^1 and Q^2, respectively. Note that, consistent with the higher population growth rate in economy 2, the relative price of food (i.e. the slope of the implicit budget line that is tangent to both the PPF and indifference curve) is lower in economy 2.

This comparison of bundles Q^1 and Q^2 was made, recall, holding the endowment of land per capita constant. As drawn, each economy has $y_A > \overline{a}(1 + \theta)$, which given Eq. 8, means that $n_t > 1$. In each, then, land per capita will fall, and hence output per capita will fall. The income expansion paths, denoted by IEP^1 and IEP^2, show how the equilibrium bundles chosen in both economies vary with the level of land per capita. Note that for any given level of land per capita, economy 2 will continue to choose a relatively higher population growth rate given that the price of food will remain relatively cheap due to the high β.

Dynamically, both economies thus travel "down" the income expansion paths toward the point at which $n_t = 1$, the Malthusian steady state, which is reached when $y_A = \overline{a}(1 + \theta)$.

[25] The fact that the choice of units matters for the outcomes is a result of comparing economies with different elasticities in the production function. As the "right" way of measuring land per capita is not known, the mechanism in Fig. 3 need not necessarily follow. However, the ability of the model to capture relevant distinctions in outcomes given the differences in labor-intensity hopefully makes the arbitrary assumption that $X/L_t < 1$ more palatable.

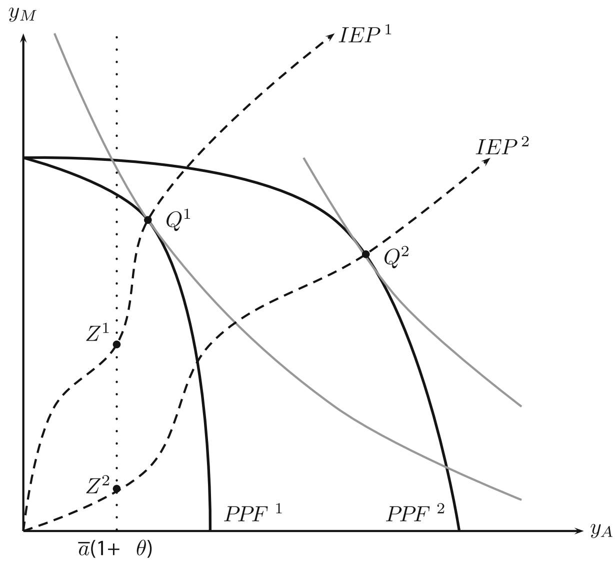

Fig. 3 Equilibrium outcomes at different labor intensities. *Note* The PPF's for both economy 1 and 2 are shown, each with the same endowment of land per capita, x. PPF^2 is larger due to the higher labor-intensity of agricultural production. The equilibrium points Q^1 and Q^2 show the equilibrium bundles given the utility function. The income expansion paths shown denote how the equilibrium bundles change as the value of x varies. Economy 2's income expansion path lies everywhere below the income expansion path of economy 1. The Malthusian steady state is where $n = 1$, which results when $y_A = \overline{a}(1 + \theta)$, and this is reached at the points Z^1 and Z^2, respectively. Economy 2 will have lower steady state consumption of manufactured goods

The steady state bundles are denoted by Z^1 and Z^2. Here we see the long-run implications of the high labor-intensity in economy 2. Because β is large in economy 2, food is relatively cheap at any given level of land per capita. The substitution effect thus incents individuals in economy 2 towards higher population growth. Thus to reach the steady state population growth rate of $n_t = 1$ the income effect must overcome that, which requires a lower level of land per capita (i.e. higher population density). Economy 2, therefore, ends up with a lower steady state consumption of manufactured goods per capita than in economy 1, which implies a larger fraction of labor in agriculture in economy 2, as seen in Eq. 9.

One additional note is that the labor allocation to agriculture in steady state depends upon the term σ/ϕ. This is capturing the curvature of utility with respect to consumption versus children. In practice, it provides information about the relative strength of substitution versus income effects of the price of food on the number of children. As σ/ϕ goes to zero, substitution effects dominate, and a higher β will induce a more severe increase in population growth, and hence the steady state allocation of labor to agriculture will have to be larger. As σ/ϕ goes to one, income effects are larger, and an increase in β induces a smaller response in population growth. Hence the steady state differences in labor allocation will be smaller as σ/ϕ goes to one.

4.3 Calibration and comparison

Using Eq. 9 as a starting point, we can consider how the Malthusian steady states compare when labor intensity in agriculture (β) varies. To do this I calibrate the model to match a "European" steady state on the eve of the Industrial Revolution, using a low labor-intensity value, and then compare this to an "Asian" equilibrium in which all parameters except labor-intensity are identical. 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.

To calibrate the European baseline case, I require a value for L_A^*/L^*, the steady state labor allocation to agricultural work. Le Roy Ladurie (1979) suggests that by 1300 nearly 15% of the population was being supported by the peasantry in Europe. Gregory King's estimate for England in 1688 is that between 60–80% of the population was engaged in agriculture, depending on how one allocates servants between sectors. France in 1700 has approximately 75% of population in agriculture (Toutain 1963).[26] 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 in general, the value of L_A/L was equal to 75%. Note that I am not trying to match specifically data from England, but rather a rough average of the European situation prior to the Industrial Revolution.

The next piece of information required is the relative size of σ and ϕ. As noted previously, prior research has used values of $\sigma/\phi = 0$ or $\sigma/\phi = 1$. To address the sensitivity of these results, I calibrate the model under several different assumptions regarding this ratio, ranging from $\sigma/\phi = 0.05$ to $\sigma/\phi = 1$. I do not use $\sigma/\phi = 0$, as this allows for the possibility that the optimal allocation of labor to agriculture is greater than one (with utility linear in consumption of the manufactured good, individuals would be willing to consume negative amounts if utility from children were high enough). I also do not consider values of $\sigma/\phi > 1$, as this implies, given Eq. 9, that increases in manufacturing productivity (w_M) would increase the steady state share of labor engaged in agriculture. In addition, $\sigma/\phi > 1$ would potentially imply that food expenditures have an elasticity with respect to income of greater than one, at odds with Engel's Law and historical experience. Finally, note that I am only varying the ratio σ/ϕ, and the absolute size of both can be greater than one to be consistent with general assumptions regarding consumption smoothing and risk aversion.

Starting with $L_A^*/L^* = 0.75$ and $\beta = 0.4$ for Europe, one can back out of (9) a value of $w_M^{\sigma/\phi-1}\gamma(1+\theta)/\theta$. This collection of parameters is then held constant while the value of β is set to an "Asian" value of 0.55 and Eq. 9 is solved numerically for the new value of L_A^*/L^*. We are thus holding manufacturing technology (w_M), the preferences for children (γ), and children's cost in terms of food (θ), constant across the two regions. The value of $\beta = 0.55$ appears consistent with the previously presented evidence regarding labor's share of output in predominantly rice-growing regions of Asia. Note that that fact that w_M is assumed to be identical across regions is done only to highlight the role of β in the calibration, and doesn't imply that technology levels were necessarily identical in Europe and Asia in this period.

Table 3 shows the results of this calibration under the different assumptions regarding the value of σ/ϕ. Panel A displays the comparison for the labor allocation L_A^*/L^*. As can be seen, in each column the value of Europe is set to 0.75. The value for Asia is that found numerically once β has been increased to 0.55.

With a relatively small value of $\sigma/\phi = 0.05$, the increase in labor-intensity of agriculture results in 95% of labor working in agriculture, versus only 75% for Europe, despite having access to the identical manufacturing technology and similar preferences for children. The high labor intensity in agriculture lowers the relative cost of children, raising population growth and driving down land per capita. Despite this Malthusian response, the high

[26] 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.

Table 3 Comparing steady states by labor intensity

	Assumed value of σ/ϕ:				
	0.05	0.25	0.50	0.75	1.00
A: *Labor allocation* (L_A/L)					
Europe	0.75	0.75	0.75	0.75	0.75
Asia	0.95	0.87	0.84	0.82	0.80
B: *Agricultural labor productivity* (Y_A/L_A)					
Europe	1.00	1.00	1.00	1.00	1.00
Asia	0.79	0.86	0.89	0.91	0.94
C: *Manufacturing output per capita* (Y_M/L)					
Europe	1.00	1.00	1.00	1.00	1.00
Asia	0.20	0.52	0.64	0.72	0.80
D: *purchasing power in manuf. terms* (y^M)					
Europe	1.00	1.00	1.00	1.00	1.00
Asia	0.77	0.74	0.73	0.73	0.72
E: *Purchasing power in agric. terms* (y^A)					
Europe	1.00	1.00	1.00	1.00	1.00
Asia	0.91	0.96	0.98	1.00	1.01

The table demonstrates the different steady state outcomes under assumptions regarding labor intensity, for Europe $\beta = 0.4$ and for Asia $\beta = 0.55$. The values of σ/ϕ refer to the relative size of the preference parameters in the utility function. See text for a complete description of the calculations

labor-intensity in agriculture allows for continued high food production and high population growth. The Asian economy only reaches a Malthusian steady state with $n_t = 1$ if incomes are driven low enough, which coincides with a larger fraction of labor engaged in agriculture.

Reading across panel A in Table 3, one can see that as σ/ϕ increases, the difference in outcomes diminishes. What is happening is that even though the higher β in Asia lowers the relative price of food, and encourages higher population growth, it also lowers incomes, which drives down population growth. As σ/ϕ increases, this income effect becomes stronger and more people can engage in non-agriculture while keeping incomes such that $n_t = 1$. Note, though, that Asia remains behind Europe in all cases.

The higher labor allocation in agriculture seems consistent with the historical evidence. Stover (1974, p. 16) suggests that of the 400 million Chinese in the late 1800s, approximately 2.5% did not work at agriculture, so it seems likely that in the 1700s 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.[27] Nevertheless, the model shows, at least at sufficiently low levels of the σ/ϕ ratio, that high labor-intensity in Asian agriculture can well describe the very small fraction of labor engaged in industry.

Beyond labor allocations, we can compare the steady state outcomes for several other measures of productivity and living standards. First, consider agricultural labor productivity, Y_A^*/L_A^*. Given that, in steady state with $n = 1$, agricultural output per adult is equal to

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

$\overline{a}(1+\theta)$, then

$$\frac{Y_A^*}{L_A^*} = \frac{\overline{a}(1+\theta)}{L_A^*/L^*}. \tag{10}$$

which depends negatively on the share of labor in agriculture.

Standardizing the European value of $Y_A^*/L_A^* = 1$ allows one to back out a value of $\overline{a}(1+\theta)$ and then calculate Y_A^*/L_A^* for Asia based on the Asian share of labor in agriculture. Panel B of Table 3 presents this comparison, which shows Asian agricultural labor productivity relative to the European standard. As can be seen, regardless of the value of σ/ϕ, labor productivity is relatively low. For low levels of σ/ϕ, it is only 80% of that in Europe.

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.[28] Thus the 80% value for Asia is consistent with observed range of preindustrial European countries outside of the leading country of England.

A second set of comparisons concerns living standards or purchasing power. To see how the different labor-intensities influence these, consider first the simple measure of manufacturing output *per capita*, Y_M^*/L^*.[29] This is simply

$$\frac{Y_M^*}{L^*} = w_M\left(1 - \frac{L_A^*}{L^*}\right). \tag{11}$$

Again normalizing the European value to one, Table 3 compares the Asian level of manufacturing output per capita in panel C. Here some dramatic differences in consumption can be seen. For low levels of σ/ϕ Asian individuals would only consume one-fifth the amount of non-agricultural goods as Europeans. Even for higher levels of the σ/ϕ term, consumption is only 60–80% of European values.

These stark differences match the historical perception of a prosperous Europe and a relatively poor Asia. 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). This model is able to generate stark differences in consumption of non-agricultural goods without having to appeal to any distinct technological differences in non-agricultural technology. Note, however, that this does not imply that manufacturing technologies *were* precisely identical, only that one can go a long ways towards explaining relative living standards without being forced to make such an assumption.

If we instead try to measure purchasing power, we will see that this depends on the reference prices used, and that the resulting pattern matches historical evidence. Take first the purchasing power, per capita, in terms of manufactured goods. This is

$$y^M = p^*\overline{a}(1+\theta) + w_M\left(1 - \frac{L_A^*}{L^*}\right) \tag{12}$$

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

[29] Note that manufacturing output *per worker* (Y_M^*/L_M^*) is identical in both economies, given that technology w_M is presumed to be identical.

which sums the per-capita consumption of food, $\overline{a}(1+\theta)$, measured in terms of manufactured goods, p^*, and the per-capita consumption of manufactured goods. The relative price in steady state can be backed out from the labor mobility condition given the level of Y_A^*/L_A^*.

Panel D of Table 3 presents the comparison of purchasing power in Asia relative to that of Europe, where again the European value has been normalized to one. As can be seen, regardless of what our assumptions are regarding the value of σ/ϕ, Asian purchasing power is always about three-quarters the value in Europe. It actually declines as σ/ϕ increases, due to the fact that while manufacturing output per capita is rising, the relative price of food remains relatively low, and so the overall purchasing power of the Asian economies actually falls. Regardless, the overall story is clear, with higher labor-intensity in agriculture, the steady state outcome in Asia is to have relatively low purchasing power in manufactured goods despite the equivalent non-agricultural technology.

The results of panel D, as well as those in panel C regarding the consumption of manufacturing goods per capita, are in line with the historical evidence. Broadberry and Gupta (2006) present evidence on living standards that are broadly consistent with the variation calculated here. In the period 1700–1749 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 seventeenth century. As those authors suggest, this represented real differences in purchasing power over manufactured goods, as opposed to simply a monetary phenomenon.[30] 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 low Asian consumption of manufactured goods and their relatively low purchasing power in terms of manufactured goods appear consistent with the evidence.

If we instead were to look at purchasing power in terms of food, we find a somewhat different picture. Valued in terms of agricultural goods, purchasing power is now

$$y^A = \overline{a}(1+\theta) + \frac{w_M}{p^*}\left(1 - \frac{L_A^*}{L^*}\right). \tag{13}$$

The lower are relative agricultural prices, the greater this value will be. Hence the high labor-intensity Asian economy will have an advantage. After computing this value, and again setting the European value to one for comparison, panel E of Table 3 shows the results. It is immediately apparent that the Asian economies were very close to parity with Europe when we measure income in terms of its ability to purchase food rather than purchase manufactured goods. In fact, in some situations the measured purchasing power is greater than Europe's, as the relative price of agricultural goods is relatively low in Asia.

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 1650–1699, Indian grain wages were 80% of the English wage. For China in the period 1550–1649 the grain wage was 87% of the English. Recalling that England was

[30] Broadberry and Gupta (2006) further conclude that the European advantage arises solely from higher productivity, but that is not the only possible explanation given their data. They have data on the wages of non-tradable (building sector) workers, so their observation that nominal (silver) wages are higher in Europe could either be because the price of non-tradables (food) is larger, or because productivity is higher. Their additional finding that grain wages are close to equivalent between Europe and Asia suggests that much of the difference is due to higher non-tradable prices as opposed to productivity.

already the most advanced area of Europe at this time, then it seems likely that average European purchasing power over food was unlikely to be much greater than the Asian values. Allen (2005b) finds that while London and Amsterdam had wages relatively large compared to India, Valencia, Vienna, and northern Italy, all these cities had similar levels of wages in 1750 when deflated by a consumption basket made up almost entirely of food. Similarly, Allen finds that "calorie wages" were similar in Asia and Europe, indicating equivalent purchasing power over food. Overall, this evidence suggests a wide variation in consumption of non-agricultural goods and a more muted comparison when purchasing power is compared with respect to food. The calibration in Table 3 is capable of capturing such a difference solely through variation in labor-intensity in agriculture.

What of actual differences in manufacturing productivity? I have presumed that w_M was identical across regions, but this was to highlight the effect that differences in β have for standards of living. An alternative explanation, given Eq. 9, is that Europe had a higher level of w_M than Asia, which would give rise to a similar pattern of results. There is nothing about the results in Table 3 that necessarily imply the differences are driven by β.

One of the reasons, though, that differences in agricultural labor intensity are useful is that it does not appear that an equally large gap in manufacturing technology existed at this point in time. Mokyr (1990) discusses that Europe and China were operating with similar technologies in the year 1400, so for there to be a large gap in manufacturing productivity, it would have to have arisen in Europe from 1400 to about 1750. However, there does not appear to be evidence that average productivity levels rose dramatically in this period. Clark (2007, chapter 12) offers an estimate of aggregate productivity in England from 1250–2000. His series shows no growth in productivity from 1400 to 1750, so it is not clear that, despite numerous innovations in this period, these were large enough or widespread enough to create a large advantage in average manufacturing productivity in Europe in this period.[31] Further, Clark's estimates are for England, which was the leader within Europe, and so it seems even less likely that Europe as a whole saw any significant growth in average manufacturing productivity in this period. There may have been places in Europe using more advanced manufacturing technology than any place in Asia, but it seems that the average technology in use across Europe was not distinctly better than in Asia, as Pomeranz (2000) concludes.

One caveat to the overall results is that if the model allowed for parental food consumption and fertility to be gross substitutes, this would reduce the size of the effects found. As gross substitutes, the lower price of food under rice production would translate into higher parental food consumption, and not necessarily into higher fertility. Within this setting, the difference in labor intensity would result in better nutritional outcomes in Asia, but not necessarily in higher population densities or lower living standards. My findings are conditional on not having this gross substitution present.

Finally, a question regarding these results is whether they are driven by the inherent difference in labor intensity, or simply by a difference in labor's share of output. With the Cobb–Douglas production function, these two concepts are not necessarily distinct. We can divorce them by using a more flexible constant elasticity of substitution production function, and this is discussed in detail in the appendix. The important outcome of that analysis is

[31] Broadberry and Gupta (2006) conclude on the basis of their evidence that Europe had a productivity advantage by the late 1700s. This advantage, though, is confined to the tradable goods sector, namely textiles, and these form only a portion of total output. As mentioned previously, their evidence of higher silver wages in non-tradable sectors is likely due to higher prices, not higher productivity.

that so long as Europe has a less labor-intense agricultural system (i.e. has a lower elasticity of substitution between land and labor), it will end up with higher living standards than Asia, regardless of the actual labor share in either region. The results in Table 3 reflect a difference driven by the labor intensity of agriculture, and are not peculiar to the Cobb–Douglas case.

4.4 Density and yields

One of the most striking differences between Asia and Europe in the Malthusian era was the much higher population density in the former. The higher density of Asian economies was also reflected in much higher yields per hectare, as noted in the introduction.

One can compute the steady state population density for the model presented, and by extension, the agricultural yield. Density will be

$$\frac{L^*}{X} = \left(\frac{L_A^*}{L^*}\right)^{\beta/(1-\beta)} \left(\frac{A}{\overline{a}(1+\theta)}\right)^{1/(1-\beta)} \quad (14)$$

which shows that as the share of labor in agriculture increases, so does population density. In addition, the labor-intensity of agriculture, measured by β influences density due to the fact that it governs the diminishing returns to labor.

Because of this additional effect, comparing Europe to Asia (by varying β) becomes problematic as the actual choice of units matters. That is, the actual ratio of density in Asia to Europe 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 no strict comparison is possible, the relative effects are consistent with the historical record. That is, a higher β in Asia is associated with higher densities and higher agricultural yields compared to Europe, while at the same time leading to lower living standards.

5 Conclusion

This article has argued that the correlation of geography and living standards prior to the Industrial Revolution is more than a coincidence. The origin of the difference lies in the inherent labor-intensity of crop production in tropical versus temperate regions. 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 relative price of food in rice-growing areas is low, and this incents individuals to increase fertility. To reach the Malthusian equilibrium with replacement fertility, then, requires a relatively low level of income. For low-intensity wheat producing areas, the high relative price of food keeps fertility low, and allows for a comparatively high level of income per capita in the Malthusian steady state. Importantly, these differences can exist even though available manufacturing 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. In particular, the calibration matches the idea that Europe had a much larger purchasing power over manufactured goods, but similar purchasing power to Asia when measured over food.

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 human capital, institutional structures, culture, and levels of technology. However, these results point to the importance of agricultural endowments in setting the stage upon which these other factors operate.

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Appendix: constant elasticity of substitution

The empirical evidence reviewed suggests that labor's share of agricultural output was relatively constant over very long periods of time in both Europe and Asia. This would indicate that a Cobb–Douglas production function, with an elasticity of substitution between land and labor of one, is a useful approximation. In this case, the difference in labor intensity between Asia and Europe shows up directly in labor's share.

However, one can alternatively make the case that the distinction between the regions was in their elasticity of substitution between the two factors in agriculture. Wilde (2009) makes a study of England, and estimates that the elasticity of substitution was on the order of 0.5–0.6 over the very long term. This low elasticity, implying that land and labor in agriculture were complements, is consistent with the descriptions of dry crop farming where the marginal product of labor falls very quickly upon the application of additional labor. As complements, additional labor is useless without additional land.

While there is no direct estimate of the elasticity for an Asian country, the idea that the marginal product of labor remained high even as additional labor was applied is suggestive that the elasticity of substitution between land and labor in Asia was relatively high. In this appendix I examine how this difference in elasticities between the regions will produce a similar result to differences in labor's share. This provides confirmation that the results are not simply driven by labor's share of output, but rather by the way in which the marginal product of labor responds to the addition of more labor.

Specifically, let agricultural production now be

$$Y_{At} = A\left[(1-\beta)X^{p} + \beta L_{At}^{p}\right]^{1/p} \tag{15}$$

so that the elasticity of substitution between land and labor is $EOS = 1/(1-p)$. Manufacturing production is identical to as before, as our preferences. Labor mobility implies that

$$p_t S_t \frac{Y_{At}}{L_{At}} = w_M \tag{16}$$

which is similar to the Cobb–Douglas case, except that now S_t represents the share of output that goes to an agricultural worker. This share is

$$S_t = \frac{\beta L_{At}^p}{(1-\beta)X^p + \beta L_{At}^p} \tag{17}$$

and as is typical, this nests the Cobb–Douglas result. With an $EOS = 1$, the value of $p = 0$, and labor's share is equal to β.

Looking at the steady state outcome in this model, we have a similar condition to the original one determining the fraction of labor employed in agriculture

$$\frac{L_A^*}{L^*} = S_t \left(1 - \frac{L_A^*}{L^*}\right)^{\sigma/\phi} w_M^{\sigma/\phi - 1} \frac{\gamma(1+\theta)}{\theta}. \tag{18}$$

The only difference from the earlier form is that we have S_t in place of β. In steady state, knowing that $Y_{At} = \overline{a}(1+\theta)L_t$, one can use the production function in (15) to solve for the denominator of S_t. This allows the steady state value of S_t to be written as

$$S^* = \beta \left(\frac{L_A^*}{L^*} \frac{A}{(1+\theta)\overline{a}}\right)^p \tag{19}$$

which can be combined with (18) to solve for L_A^*/L^*, similar to before.

Using these results, I perform a similar calibration exercise to before. Here, though, I set the European elasticity of substitution to 0.5, consistent with Wilde (2009) estimate. I

Table 4 Comparing steady states by elasticity of substitution

	Assumed value of σ/ϕ:				
	0.05	0.25	0.50	0.75	1.00
A: *Labor Allocation* (L_A/L)					
Europe	0.75	0.75	0.75	0.75	0.75
Asia	0.98	0.90	0.86	0.83	0.82
B: *Agricultural labor productivity* (Y_A/L_A)					
Europe	1.00	1.00	1.00	1.00	1.00
Asia	0.77	0.83	0.87	0.90	0.91
C: *Manufacturing output per capita* (Y_M/L)					
Europe	1.00	1.00	1.00	1.00	1.00
Asia	0.08	0.40	0.56	0.68	0.72
D: *purchasing power in manuf. terms* (y^M)					
Europe	1.00	1.00	1.00	1.00	1.00
Asia	0.47	0.45	0.44	0.43	0.42
E: *Purchasing power in agric. terms* (y^A)					
Europe	1.00	1.00	1.00	1.00	1.00
Asia	0.96	0.99	1.01	1.03	1.04

The table demonstrates the different steady state outcomes under assumptions regarding elasticity of substitution, with Europe having $EOS = 0.5$ while Asia has an $EOS = 1$. The underlying relative weight on labor in the CES production function is set to $\beta = 0.4$ for both countries. The value of $A/(1+\theta)\overline{a}$ is set to 2 for the calibration. The values of σ/ϕ refer to the relative size of the preference parameters in the utility function. See text for a complete description of the calculations set Asia's elasticity of substitution equal to 1, capturing the concept that labor was more substitutable for land in rice production, and that the marginal product of labor declined more slowly with additional workers. The value of β is set to 0.4 for both regions, and the share of agricultural output going to labor is not forced to match the evidence presented in Sect. 2.

Table 4 shows the similar comparisons to the main paper, only now distinguishing Asia and Europe by their elasticity of substitution. As can be seen, the results are similar in the direction of the effect. That is, compared to Europe, Asia has a larger fraction of individuals employed in the agricultural sector, which leads to lower agricultural labor productivity, lower manufacturing output per capita, lower purchasing power in manufactured goods terms, and relatively equal purchasing power in agricultural terms. The results in the table appear stronger than the original results, in the sense that living standards are more depressed in Asia in Table 4. However, one cannot make too much of this difference, as the values for the elasticities of substitution are not as well-grounded in evidence, and the need to make an arbitrary choice for the size of the $A/(1+\theta)\overline{a}$ term. The table shows that the effects documented in this article are not simply an artefact of labor shares in agricultural output, but rather reflect differences in the speed at which the marginal product of labor changes in different types of agricultural production.

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