A Western Reversal Since the Neolithic? The Long-Run Impact of Early Agriculture*

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Abstract

In this paper, we document a reversal of fortune within the Western core area, showing that regions that made an early transition to Neolithic agriculture are now poorer than regions that made the transition later. The finding contrasts some recent influential work emphasizing the beneficial role of an early transition. Using data from a large number of carbon-dated Neolithic sites throughout the Western agricultural core area, we determine an approximate date of transition for about 60 countries and 1400 regions. Our empirical analysis shows that there is a robust negative correlation between years since transition to agriculture and contemporary levels of income on the national level whereas the regional result depends on the inclusion of country fixed effects. Our results further indicate that the reversal had become manifest already before the era of European colonization.

Keywords: Neolithic agriculture, comparative development, Western reversal
JEL Codes: N50, O43

1 Introduction

A striking feature of contemporary comparative development is that regions that made an early transition to agriculture and to civilization, like current Iraq, Egypt and Syria, are now relatively poor and have recently experienced numerous symptoms of state collapse. In the northern periphery of the Western cultural zone, regions that made a very late transition to civilization, like current Sweden and the Netherlands, now host prosperous and stable democracies. In comparison, these observations stand in stark contrast to some of the seminal works in the literature suggesting a strong and positive relationship between an early agricultural transition in history and high income levels today.

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In this paper, we document a strong pattern of a Western reversal of fortune from the Neolithic Revolution to the current day. The Neolithic Revolution was a momentous event which introduced agriculture to humans around the year 10,000 BCE. It marked for the first time humans' departure from their hunter-gatherer lifestyle for agriculture and sedentary living. We argue that although industrialization in particular contributed critically to the massive divergence between countries that emerged during the last 200 years, our analysis suggests that the relative prosperity of North European regions followed a longer trajectory with roots in the Neolithic.

By creating a new data set on the Neolithic transition for all Western areas, we confirm that regions that made an early transition to agriculture do tend to be relatively poor today in terms of GDP per capita, whereas regions that made a late transition are now relatively rich. On the country level, this basic finding is robust to controlling for an extensive set of geographical and historical controls. In addition, we also show that this reversal started to manifest itself in the centuries preceding 1500 CE and then grew stronger over time. On a finer regional level, using data on 1,371 European NUTS3-regions, there is also a very strong overall negative relationship although the result largely goes away when we control for country fixed effects.

Our paper is related to vast literature on Western economic and social history.[1] In his classic work on the long-run impact of plant and animal domestication, Jared Diamond (1997) argues that the region making up the Fertile Crescent in the Middle East (roughly Israel, Lebanon, Syria, Southeastern Turkey, Iraq, and Western Iran) was the first to make the transition to agriculture by about 10,000 BCE because of its superior access to plants and animals suitable for domestication. Even though other regions such as China also developed agriculture independently, the highly favorable biogeography in the Fertile Crescent and in large parts of the rest of the Western agricultural core (encompassing Europe, South Asia including western India, and North Africa) implied that this part of the world could develop civilization, statehood, science, military technology, and political strategy much earlier. By 1500 CE, these advantages of an early start allowed European countries to colonize and dominate much of the rest of the World.[2]

In subsequent research, Diamond's hypothesis has been tested: That current income levels across the world should have a positive relationship with biogeographical suitability for agriculture in prehistory and/or with the timing of the agricultural transition (Hibbs and Olsson, 2004; Olsson and Hibbs, 2005; Putterman, 2008; Ashraf et al, 2010, Putterman and Weil, 2010; Bleaney and Dimico, 2011). Most of these studies have confirmed a positive relationship on a worldwide basis, suggesting that countries that made the transition early

[1] An incomplete listing of the most important works includes Wittfogel (1957), Jones (1981), Kennedy (1988), Mokyr (1990), North (1990), Landes (1998), Pomeranz (2000), Clark (2008), Morris (2010), Acemoglu et al (2002), Acemoglu and Robinson (2012) and Ashraf and Galor (2013). Please see the extended version of this paper for a more thorough review of this literature.

[2] Other important contributions to our understanding of the Neolithic transition include Harlan (1995), Smith (1998), and Bellwood (2005). In the economics literature, see Ashraf and Michalopoulos (2011) for an account of the spread of agriculture in Europe using the data from Pinhasi et al (2005). Weisdorf (2005) reviews the arguments on the transition to agriculture.

had a long-term advantage that is still detectable in current levels of prosperity.[3]

In this paper, we refrain from suggesting one particular intermediate channel to explain the negative effect of early agricultural transition on the future income level.[4] Instead we focus on showing that this positive relationship in a worldwide sample, a la Diamond, is mainly driven by differences between agricultural core region averages, whereas the relationship *within* the Western core (the region that made the transition first) is actually negative. Figure 1 illustrates this point and also summarizes one of the key insights of the paper. The graph shows the bivariate relationship between log GDP per capita in 2005 and the time (in years) since agricultural transition for 158 countries. The relationship in the figure is positive when all 158 countries are included in the regression. However, when the relationships within three agricultural core areas (Western, Sub-Saharan Africa, and East Asia) are investigated separately, we see in the graph that the relationships turn negative. The negative relationship for the Western core region in the upper right corner, is the main finding of this paper that we document in various ways.[5]

Figure 1

In line with this evidence, we suggest the following revised interpretation: Average income levels per capita are higher in the Western core than in all other parts of the world due to the advantages of an early transition to agriculture and civilization, but in comparisons *within* agricultural core areas, early adoptions of agriculture led to a relatively low level of current economic development. In the original Diamond model, Neolithic biogeography played an important role for Eurasia *as a whole* by introducing agriculture to the hunter-gatherers in the continent earlier than in any other core areas in the world. In this paper, we analyze variations within the Western core, and argue that it was the timing of the agricultural transition which determined the type of economic performance that was experienced in the long run.

We believe the paper makes the following important contributions to the literature. Firstly, we create new data for the emergence of agriculture among all Western countries as well as among 1,371 regions. Second, we provide strong evidence of a distinctive reversal of income and development levels since the Neolithic within the Western core area. Third, we demonstrate how previous results of a positive association between time since agriculture and current income can be reconciled with our evidence of a negative relationship within the Western agricultural core.

[3] For a recent overview of this research, see Spolaore and Wazciarg (2013).

[4] In an extended version of this paper (Olsson and Paik, 2012), we argue that the key intermediate link is institutions: Countries that made an early transition to agriculture tended to develop autocratic institutions and societies characterized by inequality and rent seeking. Due to the relative prosperity of the early empires, people there lived in the constant threat of military intervention from the outside. The situation was quite the reverse in the peripheral north, which favored the emergence of democratic institutions and social equality. See also Olsson and Paik (2013) for an analysis of the impact of early agriculture on informal norms.

[5] Please see Figures 1-2 in the Appendix that document in more detail the negative and significant relationships within East Asia and Sub-Saharan Africa.

The paper proceeds in the following order: Section 2 introduces the data and Section 3 presents the empirical strategy. Section 4 then proceeds with the results. Finally, Section 5 concludes by summarizing the main findings and offering avenues for future research.

2 Data

The key explanatory variable in the empirical analysis is the time since the Neolithic transition.[6] We develop a new variable *Average time since agricultural transition* for regions as well as for countries in the Western zone. In doing so, we use a sample of calibrated C14-dates from Neolithic sites in the Near East and Europe available from Pinhasi et al (2005). The data contains a full list of excavation sites (765 in total) that spans from the Fertile Crescent to Northwest Europe; the list includes the location coordinates as well as calibrated C14-dates estimated for each site.[7] The oldest site in the sample is M'lefaat, near Mosul in Northern Iraq, dating back 12,811 years.

We use the location and dating of the individual sites to create a comprehensive map of the date of transition for each grid cell in the Western core. The method that we employ is Inverse Distance Weighted Interpolation (IDW) in ArcGIS. The first step of calculating the average adoption date for a given region is interpolating observed points of archaeological sites. For each cell S_0 on the map, the formula used in interpolation is as follows (Johnston 2003):

$$\hat{Y}(S_0) = \sum_{i=1}^{N} \lambda_i Y(S_i)$$

In this expression, $\hat{Y}(S_0)$ is the predicted adoption date for location S_0, N is the number of measured sample points surrounding the prediction location that will be used in the prediction,[8] λ_i are the weights assigned to each measured point, and $Y(S_i)$ is the observed value at the location S_i, one of the known archaeological sites.

The formula to determine the weights is:

$$\lambda_i = d_{i0}^{-p} / \sum_{i=1}^{N} d_{i0}^{-p} \text{ where } \sum_{i=1}^{N} \lambda_i = 1$$

The variable d_{i0} is the distance between location S_0 and archaeological sites, S_i. The power parameter p is determined by minimizing the root-mean-square prediction error (RMSPE) in the Geostatistical Analyst tool of ArcGIS.[9] In determining the adoption

[6] Appendix tables A1 and A2 show the descriptive statistics for the variables used in the cross-country and cross-regional analyses.

[7] Pinhasi et al (2005) only include observations with standard errors of the mean that are less than 200 radiocarbon years. Other outlier dates were also omitted. Relatively few of the observations were obtained through the highest standard of radiocarbon age determination (accelerator mass spectrometry). The material used was most often charcoal.

[8] In our study, N is set to 15.

[9] As explained in Johnston (2003), each observed point is removed and compared to the predicted value for that location. The RMSPE is the summary statistic of the error of the prediction surface. The

date of a given area, the IDW methodology implicitly assumes that the archaeological site closest to the area gives best information on the approximate date of agricultural adoption. Given that the IDW method calculates the interpolated adoption date for every cell, the average adoption date for each subnational unit of analysis is simply calculated as the average of all the estimated adoption date of location cells within that subnational unit.[10][11]

Taking the year 2000 as the benchmark year, the mean in the cross-country sample is 7,611 years, the minimum is 5,608 (Denmark) and the maximum 9,743 (Syria). The mean time since agricultural transition in our cross-regional sample is 7,055 years with a range from 5,243 to 11,320. This translates into a mean adoption date of 5,055 BCE and a first adoption date of 9,320 BCE.

Most cross-country studies that include the time since Neolithic transition as a variable have so far used the cross-country data set in Putterman (2006). For each country, Putterman (2006) determines a date of transition by using the first attested date of Neolithic agriculture within the country's borders as stated by various specialized sources. We believe that our new methodology offers several advantages as compared to Putterman (2006). As far as we know, the data in Pinhasi et al (2005) offer the most recent and most comprehensive compilation of transition dates for the Western region. Furthermore, our methodology provides the *average* date of transition for a country rather than the *first* date of transition, as in Putterman (2006).[12] We believe that this practice will more accurately reflect the transition for the whole country since there may be large discrepancies in dates of transition between regions within countries, as also acknowledged by Putterman (2006). With our methodology, it is further possible to determine transition dates on a much finer geographical level.

We further introduce a novel set of data measuring Neolithic vegetation variation at the advent of the Neolithic Revolution, based on maps from Adams-Faure (1997) and Oak Ridge National Laboratory's Environmental Sciences Division (www.esd.ornl.gov/projects/qen).[13]

Geostatistical Analyst in ArcGIS tries several different powers for IDW to identify the power that produces the minimum RMSPE.

[10] Another class of interpolation techniques, often known as *kriging*, uses geostatistical properties. Kriging relies on autocorrelation as a function of distance and assumes that the data comes from a stationary stochastic process. Given the terrain variation and boundaries, however, the spread of agricultural adoption does not appear to satisfy this assumption. Pinhasi et al (2005) finds that for Eurasia the agricultural adoption date in an area can be well approximated as a linear function of the distance from the origin in the Fertile Crescent. The correlation between IDW and kriging estimates nevertheless remain very high (0.9729) and have little impact on the final result.

[11] Figure A3 in the Appendix shows an example of this methodology applied to the 78 Neolithic sites within Italy.

[12] We average over the calculated scores for all the cells within each country to get the country score.

[13] The vegetation types are defined as follows. 1. Desert: very sparsely vegetated. 2. Dry Steppe: similar to Steppe-Tundra, with a more temperate climate, open woody vegetation types and low shrubs. 3. Ice. 4. Lake. 5. Polar Desert: very sparsely vegetated with only low herbaceous plants. 6. Semi-Desert: open scrub/grassland. 7. Steppe-Tundra: sparse ground cover, herbaceous with a few low shrubs. 8. (Warm) Temperate Forest: fairly tall, many broad-leaved evergreen/semi-deciduous angiosperm trees but moisture-requiring conifers also tend to be abundant. 9. Wooded Steppe (Cool Temperate Forest): closed forest, including mixed conifer-broad-leaved forest. 10 Forest Steppe: mainly herbaceous steppe, but with scattered clumps of trees or bushes in favourable pockets. 11. Montane Desert (Polar and Alpine Desert/

Each observation records the fraction of different vegetation types occupying the unit of land, summing up to one.

The historical roots of European growth is commonly seen in the Roman Empire (Landes, 1998, Jones, 1981), while the presence of Ottoman rule may have eradicated some nations' Roman traditions (Kuran, 2011) and the access to the Atlantic Ocean may have opened up trade opportunities and subsequent rise to economic powers among European nations (Acemoglu et al, 2005). The Ottoman empire during its greatest expansion in the 17th Century also coincides with the spread of Islam.

To investigate whether these heritage and geographical factors are important, we obtain indicator variables for whether a region was part of these empires by using the Euratlas (2012) historical georeferenced vectorial data. The variables used in the cross-country analysis give the fraction of the country's territory that was part of the empires in question at the time when the empires reached their peak (Rome in 200 CE, Byzantine Empire in 500 CE and the Ottoman Empire in 1600 CE). A variable capturing the Atlantic coastline to area-ratio is taken from Acemoglu et al (2005) and provides a measure of a country's exposure to the Atlantic and hence its potential for Atlantic trade. We also include indicators for whether the country was invaded by Mongols during the 13th century and whether it was recently part of the Soviet union or a Warsaw pact country (details on these variables are provided in the Appendix).

The dependent variable in the cross-country section is GDP per capita in 2005 from World Development Indicators. Long-run income data for the Western core are taken from Maddison (2013). The dependent variable in our regional analyses is the mean intrastate GDP per capita 1997-2008 from Eurostat (2012). The level of disaggregation is NUTS3, which gives a total number of 1,371 available observations from 30 countries.

3 Empirical strategy

In the cross-country analysis, we will most often run reduced-form equations of the very simple form

$$Y_j = \alpha_0 + \alpha_1 T_j + \alpha_2 X_j + \epsilon_j \tag{1}$$

where Y_j is income per capita in country j in our Western sample, T_j is the time since agricultural transition, X_j is a vector of control variables, and ϵ_j is a normally distributed error term. The parameter of interest in this setting is α_1, showing the reduced-form impact of agricultural history on economic performance. Our key hypothesis is that α_1 is negative, i.e. an adverse long-run impact of agricultural experience on economic prosperity.

A key identifying assumption in this setup is of course that Y_j did not in any way influence T_j. Once agriculture was invented in the Fertile Crescent, it gradually spread towards the northwest in a fairly regular pattern. Even regions with a similar biogeography

Dry Sparse Tundra): very sparsely vegetated with only low herbaceous plants/ mainly herbaceous or with low shrubs. See the working paper version of this paper for a more detailed description of this data.

such as Turkey and Spain experienced very different dates of adoption on the basis of their distance to the Fertile Crescent. Although local geographical and climatic conditions no doubt played a role in this diffusion (see for instance Ashraf and Michalopoulos, 2011), we think there are no good reasons to believe that current or historical levels of income per capita should have affected the date of agricultural transition.

There is further widespread archaeological and genetic support for the "Neolithic demic diffusion model", arguing that agriculture mainly spread through physical migration by people from the original farming areas in the Fertile Crescent to areas further and further away.[14] Agriculture thus typically appeared in a region as an exogenous intervention and did not arise indigenously.[15]

We also recognize that T_j is typically strongly related to subsequent attributes of civilization such as the emergence of states, laws, cities, and military organization. In this sense, one might interpret T_j more broadly as an indicator of the date of adoption of a modern lifestyle.

In the cross-regional analysis, the estimated equation is

$$Y_{ij} = \beta_0 + \beta_1 T_{ij} + \alpha_2 X_{ij} + f_j + \varepsilon_{ij}$$

where Y_{ij} is income per capita in region i in country j, T_{ij} is the time since agricultural transition for the region, X_{ij} is a vector of region-specific control variables, and ε_{ij} is an error term. The key difference from the cross-country analysis is the inclusion of the country fixed effect f_j. As will be shown below, the choice whether to include this fixed effect or not in the regional analysis will have important consequences for the results. The key parameter of interest is also here β_1, which we expect to be negative.

4 Results

4.1 Cross-country analysis

The main results for the cross-country analysis are shown in Table 1. The base sample includes 64 Western countries in Europe, Middle East, North Africa, and Southwestern Asia that belonged to the Western core of agricultural diffusion.

Table 1

As is clear from the table, *Average time since agricultural transition* in the Western core has consistently a negative and significant impact on log income per capita in 2005. We use three sets of control variables. The *Geographical controls* include country area,

[14] See Ammerman and Cavalli-Sforza (1984) and Bellwood (2005) for thorough accounts of this theory. Demic diffusion of agriculture is often discussed in relation to "cultural diffusion" whereby agriculture proposedly spreads through the diffusion of technology rather than through migration.

[15] A reviewer suggested that there seems to have been pre-existing institutional differences that sometimes influenced T_j. Although we recognize this possibility, we find no reason to believe that such variations were systematically related to either X_j or Y_j and should not bias the results.

the percentage of arable land in 2005, and the average altitude of the country. The *Historical controls* include variables proxying for the influence of Atlantic trade, Mongol invasions, the impact of being part of the Roman, Byzantine, and Ottoman empires, and whether the country was a previous communist country or former Soviet republic. The *Biogeography controls* contain the fraction of a country's territory covered by nine different types of vegetation prevailing in the Western region 10,000 BCE.[16] We also calculate Conley (1999) standard errors that correct for possible spatial autocorrelation, and find that the significance of the main results remain unchanged under the alternative standard errors.

The control variables are successively introduced in Columns 2-4 in Table 1. The estimate for *Average time since agricultural transition* changes (and levels of R-squared increase), but the level of significance remains below the 0.10-level even in Column 4 where the full set of 19 control variables are included. When the geographical and historical controls are employed as in Column 3, the point estimate (-0.653) indicates that a 1,000-year earlier transition to agriculture would have implied a 65 percent lower GDP per capita. The numbers imply that if a country close to the mean time since transition such as Italy had experienced the transition to agriculture in 6,300 BCE instead of in the actual year 5,300 BCE, their GDP per capita in 2005 would have been 6,727 $US instead of 19,386 $US. The economic significance is thus also quite strong. The conditional scatter plot for this regression is shown in Figure 2.

Figure 2

In Column 5, we check whether the key tendency is robust to using *Earliest date of transition* from the Pinhasi et al (2005) data rather than the *Average time since agricultural transition.* It could be argued that the earliest date is more in line with the method used in Putterman (2006) whose data provide the basis for the empirical results in several papers. Although the estimate in (5) is lower, the negative slope coefficient is significant.

In Column 6, we exclude all countries in the sample that do not have at least one of the 765 site observations from Pinhasi et al (2005) within their borders. In this way, we restrict the sample to country observations with a greater precision in the measurement of the date of agricultural transition. Reassuringly, in this smaller sample of 44 countries, the t-values for the negative estimates of *Average time since agricultural transition* are very high.

A potential objection to using the full Western sample is that it includes a quite heterogenous group of countries, mixing European states with North African and Middle Eastern countries. In Columns 7-8, we therefore restrict our sample to 40 European countries and the 31 countries that had more than 50 percent of its territory within the Roman empire in year 200 CE. The latter countries arguably shared a similar institutional and cultural context during a very formative period of Western history. Even in these limited

[16] Please see the working paper version for information about the estimated coefficients of the control variables.

samples and when controlling for the standard geographical and historical variables, time since agricultural transition is still significant.[17]

4.2 Timing of the reversal

When did this reversal happen in the Western world? There are at least two strands in the literature arguing for a great divergence happening in the Western world after 1500 CE. Acemoglu et al (2005) demonstrate that Atlantic trading nations, benefitting from the newly opened colonial trade, surged ahead of other countries and regions in Europe after 1500. The second and very significant shift was the Industrial Revolution, starting around 1750, which even further contributed to the economic and technological dominance of Britain and other north European countries (Mokyr, 1990; Acemoglu and Robinson, 2012). A key question in our analysis is thus if the reversal since the Neolithic was visible already by 1500?

For the Malthusian era, it is widely accepted that population density is a good indicator for the level of economic development in a country (Ashraf and Galor, 2011). In Table 2, Columns 1-3, we use population density in years 1, 1000 and 1500 CE as dependent variables. In year 1, the reversal does not seem to be in place since the estimate for *Average time since agricultural transition* is positive. In 1000 CE, the estimate is negative but insignificant. However, by 1500, the reversal is evident since time since agricultural transition in that year is both negative and significant.

Table 2

In Columns 4-7, we instead use *Log GDP per capita* from 1, 1000, 1500, and 1820 CE as the dependent variables. The sample is now limited to only 20-28 countries but a quite similar pattern emerges in these regressions. The time since agricultural transition even has a positive and significant influence on income in year 1000 CE, whereas the reversal becomes evident by 1500 CE and then is very strong in 1820.

When we use income per capita data also for 1600, 1700, 1913, 1980, and 2005 and run the same bivariate regressions as in Table 2, we can track more in detail how the regression coefficient of *Average time since agricultural transition* develops over time. Figure 3 shows the pattern, suggesting a stronger and stronger tendency for a reversal after 1000.

Figure 3

We do not interpret these results as evidence against the critical roles played by Atlantic trade, the Reformation, and the Industrial Revolution. Undoubtedly, these fundamental processes contributed very importantly to the great divergence that made Britain and its northern followers so much richer than the Mediterranean and Middle Eastern countries. What we do suggest, however, is that the process of reversing fortunes in the Western world

[17] Please see the working paper version of this article for further robustness checks, using for instance the same set of controls as in the recent paper by Ashraf and Galor (2013).

seems to have followed an older trajectory rooted in the Neolithic which has previously not been recognized and which seems to have become manifest already during the Medieval period. We leave it for future research to investigate further why the reversal emerged when it did.

4.3 Cross-regional and within-country analysis

Table 3 shows the results for the cross-regional analysis among 1,371 Western NUTS3-regions in 30 European countries.[18] As in Table 1, more and more control variables are gradually included in the analysis. The geographical controls now feature the area, latitude, and altitude of the region, whereas the historical controls include the indicators for the region under Roman, Ottoman, Byzantine, Mongol, and communist rule. Seven biogeographical variables specify the fraction of the region covered by different Neolithic vegetation types.

Columns 1-3 show the OLS regressions where we do not control for country fixed effects. The estimate for *Average time since agricultural transition* is then negative and significant, as before, even when we control for latitude. However, when we include fixed effects in Column 4, the sign remains negative but the estimate is no longer significant.

In order to analyze these contrasting results further, we show the unconditional bivariate scatter plot for all 1,371 regions in Figure 4. As the figure indicates, there is a very strong negative relationship overall. However, when we introduce the separate regression lines for five of the largest countries in the sample with many Pinhasi sites within their borders (Germany, France, Italy, Spain, and Turkey), the picture is somewhat modified. The individual estimates for these countries, without and with controls, are shown in Table 4. The relationships within Turkey, Spain, and Italy remain negative and significant even when adding geographical controls. The unconditional regression coefficient for Germany is positive and significant but changes sign and becomes negative and significant at the 0.1-level when we add controls.[19] For most countries in the sample, there is no significant within-country relationship in either direction.

Figure 4
Table 4

Our interpretation of these results is that most of the action in the relationship between current income levels and time since agricultural transition comes from the cross-country level rather than from the cross-regional level, although the strong negative correlations within countries like Turkey, Spain and Italy are interesting in themselves. One potential interpretation of the general tendency is that whereas the average time since transition

[18] Please see Table A2 in the Appendix for further details about the variables included in the regional analysis.

[19] For Germany, the situation is complicated by the recent merge of East and West Germany. When we also include a former communist dummy to the controls in Table 4, there is neither a positive nor a negative relationship within Germany.

within a country has had a strong influence on that country's comparative average level of development (as proxied by GDP), the governments in those countries managed to even out the initial differences from different dates of agricultural transition, perhaps by installing common institutions throughout the country.

5 Conclusions

In this paper, we document that there is a reversal of fortune within the Western agricultural core region in the sense that countries that adopted agriculture and complex civilizations early in history tend to be poorer today than countries in the periphery of the core that adopted agriculture late. Preliminary results suggest that this stylized pattern also seems to be in place in East Asia and Sub-Saharan Africa. We further demonstrate that there is a strong negative association between time since agricultural transition and current income levels among European regions, although this result is not robust to introducing country fixed effects. Importantly, the economic reversal appears to have been in place already in 1500 CE, i.e. before Western colonization and industrialization. Hence, the very large income differences that emerged during the last 500 years seem to be partly rooted in development trajectories dating back to the Neolithic.

This paper does not analyze the mechanisms whereby an early transition to agriculture eventually led to poor economic outcomes. We believe there are several potential intermediate channels. For instance, it could be the case that early adopters of agriculture eventually suffered from technological inertia. Another plausible channel is that the early civilizations overexploited fragile agricultural lands and thereby had a long-term environmental disadvantage. A third potential mechanism, developed at some length in an extended version of this article, suggests that the early agricultural regions developed autocratic institutions with persistent inquality and rent seeking that eventually became a major hindrance to economic development in Medieval times. We leave it for future research to probe deeper into the mechanisms behind this long-run reversal.

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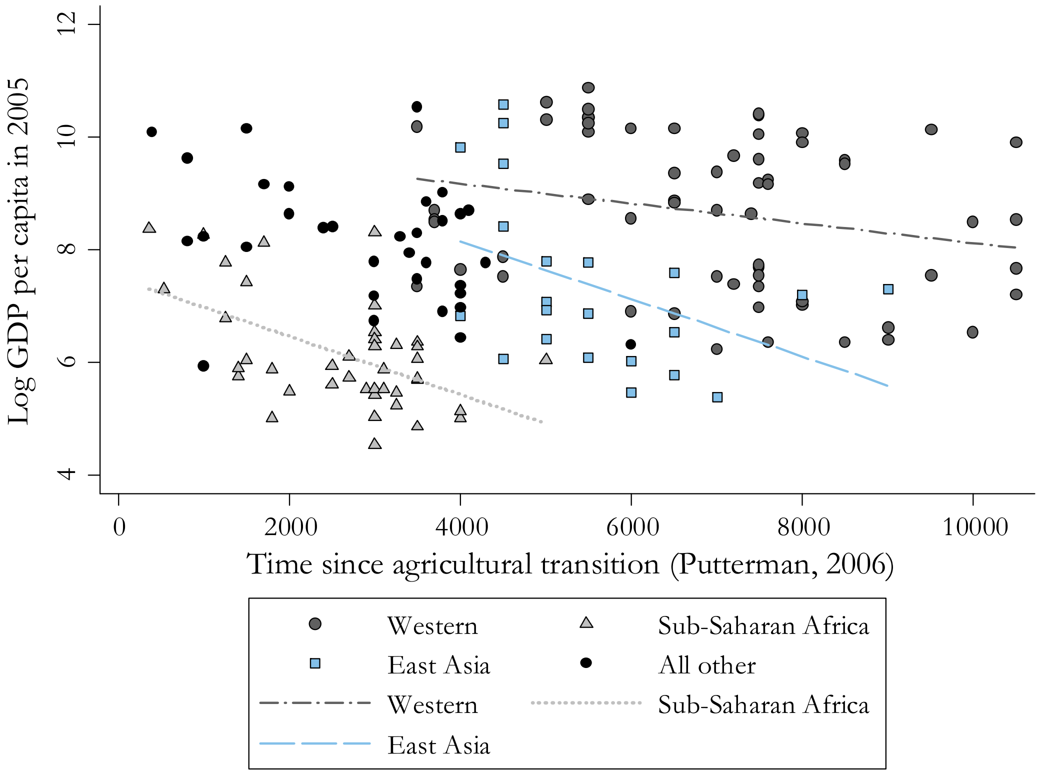
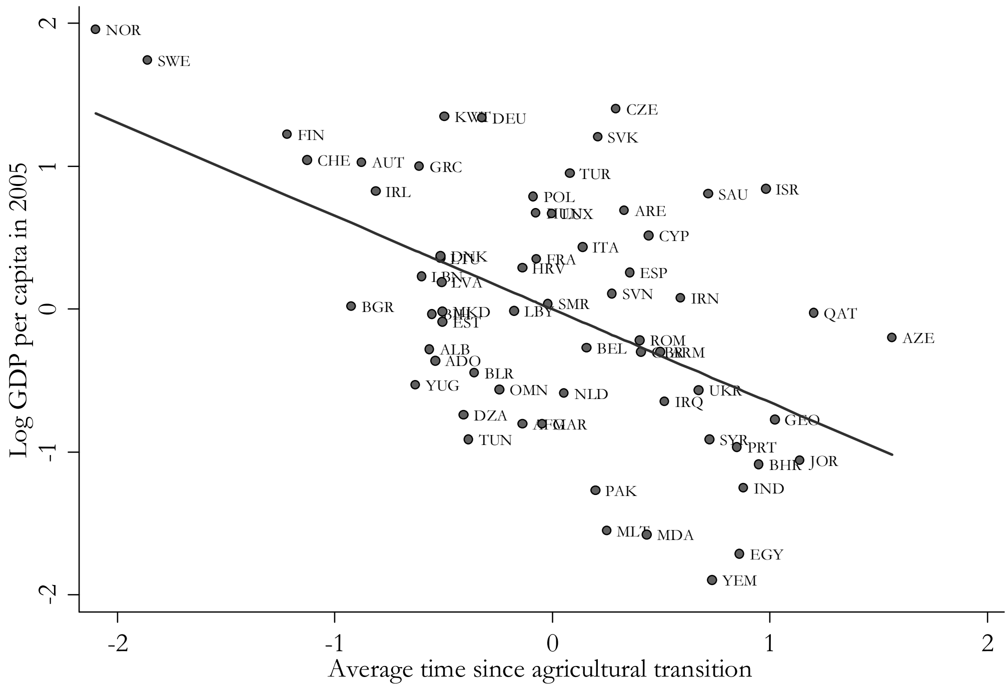
Figure 1: Relationship between log GDP per capita in 2005 and time since agricultural transition within the Western, Sub-Saharan African, and East Asian core areas.



Note: The figure combines three fitted lines for separate OLS regressions using the Western sample (N=62), the East Asian sample (N=22), and the Sub-Saharan African sample (N=41). Included in the graph are also 33 other country observations. The color and shape of each country indicates whether it belongs to the Western, East Asian, Sub-Saharan African, or All other category. *Time since agricultural transition* is taken from Putterman (2006). In the total sample of 158 observations, the fitted equation is *Log GDP per capita in 2005 = 6.99*** +0.000147**** $\times$ *Time since agricultural transition*. *** indicates significance at the .01 level.

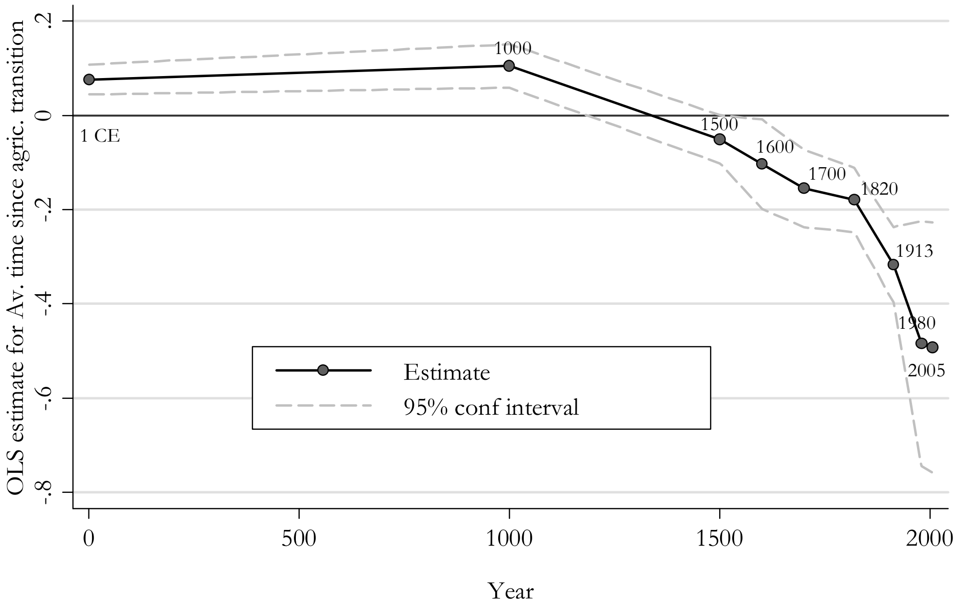
Figure 2: Conditional relationship between log GDP per capita in 2005 and average time since agricultural transition among 64 Western countries



coef = -.65315267, (robust) se = .13298409, t = -4.91

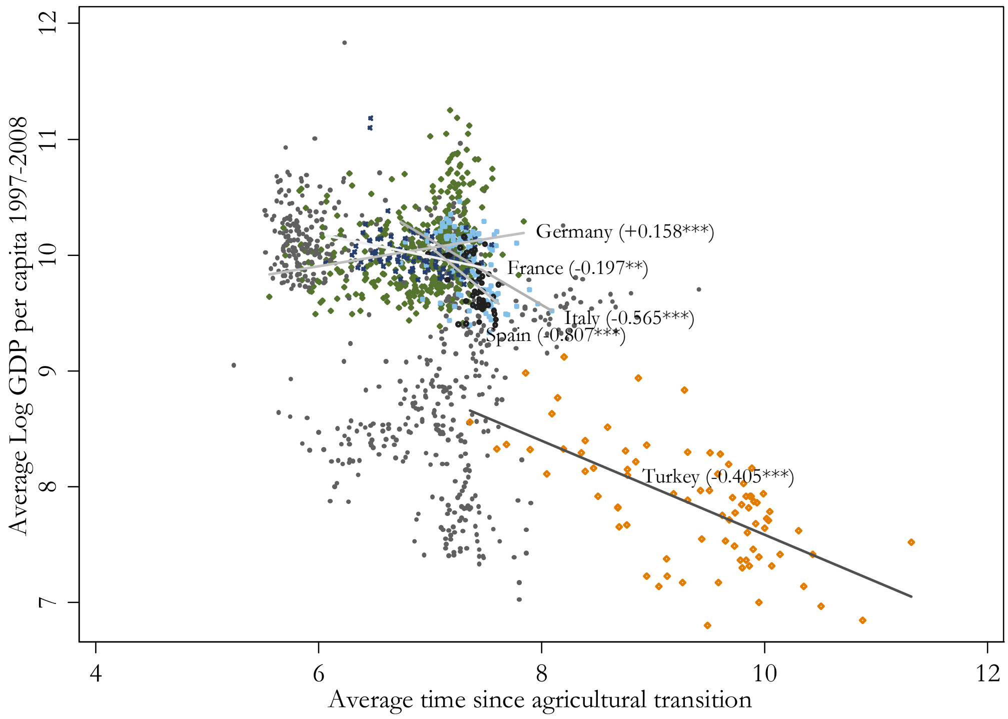
Note: The figure shows the added-variable plot for the conditional relationship between *Log GDP per capita in 2005* and *Average time since agricultural transition* from the regression specification in Table 1, Column 3.

Figure 3: Historical evolution of relationship between log GDP per capita and average time since agricultural transition among Western countries



Note: The figure shows the regression coefficients from nine separate regressions for different time periods, using the specification *Log GDP per capita (in year t)* = $\beta_0 + \beta_1$**Average time since agricultural transition (in year t)* + ε *(in year t)* where β_0 is a constant, β_1 is the regression coefficient of interest, and ε is a random error term. The dashed lines show the 95% confidence interval. The included years *t* (in the CE period with number of Western country observations in parenthesis) are 1 (23), 1000 (20), 1500 (21), 1600 (19), 1700 (21), 1820 (28), 1913 (34), 1980 (43), and 2005 (64). The data on GDP per capita for all periods except 1980 and 2005 are from Maddison (2013). Results from the regressions for 1, 1000, 1500, and 1820 are shown in Table 2 and for 2005 in Table 1. Results from the regressions for 1600, 1700, 1913, and 1980 are available upon request.

Figure 4: Scatter plot and unconditional relationships within five countries between average log GDP per capita in 1997-2008 and average time since agricultural transition among 1,371 European NUTS3-regions.



Note: The figure shows the scatter plot for the relationship between *Average Log GDP per capita 1997-2008* and *Average time since agricultural transition* for 1,371 Western NUTS3-regions. It also shows the separate unconditional regression lines for Germany, France, Italy, Spain and Turkey with slope coefficients and levels of significance in parenthesis. German observations are green, French observations dark blue, Italian observations light blue, Spanish observations black and Turkish observations dark orange. All other region observations are grey. More details for the within-country regressions are shown in Table 4. The regression coefficient for the whole sample is shown in Table 3, Column 1.

Table 1: Relationship between GDP per capita in 2005 and time since agricultural transition among Western, European, and former Roman countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Dependent variable: Log GDP per capita in 2005							
Sample	Western					Sites>0	Europe	Roman
Average time since agricultural transition	-0.492*** (0.133)	-0.573*** (0.131)	-0.653*** (0.133)	-0.386** (0.187)		-0.599*** (0.144)	-0.439* (0.228)	-0.602*** (0.202)
Earliest date of transition					-0.228** (0.104)			
Conley SE	[0.189]	[0.161]	[0.111]	[0.140]	[0.076]	[0.096]	[0.217]	[0.154]
Geographical controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Historical controls	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Biogeographical controls	No	No	No	Yes	Yes	No	No	No
Observations	64	64	64	59	56	44	40	31
R-squared	0.16	0.44	0.62	0.80	0.80	0.71	0.81	0.72

Note: The estimator is OLS in all specifications. Robust standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. The sample of Western countries includes all countries specified as Western in the text. The sample of countries in column 6 includes all countries with at least one site from Pinhasi et al (2005) within their borders. The sample of countries from the Roman Empire includes all countries in which more than 50 percent of its territory was within the Roman Empire in 200 AD. Geographical controls include log total area, log arable land area, and log mean elevation. Historical controls include the ratio of Atlantic coastline to area, fraction of country area within the Roman Empire by 200 AD, fraction of country area within Byzantine Empire by 500 AD, fraction of country area within the Ottoman Empire by 1600 AD, an indicator for whether the country was dominated or invaded by Mongols in 13th century, and whether the country was part of the Eastern Block (former communist countries in Eastern Europe or within the Soviet Union). Biographical controls include a set of fractions of country area covered by each of the Neolithic vegetation types: Desert, Tropical Extreme, Steppe-Tundra, Polar Desert, Ice, Semi-Desert, Wooded Steppe, Dry Steppe, and Mediterranean Scrubs. In calculating Conley standard errors (in square brackets), we assume that spatial autocorrelation exists among observations which are within fifteen degrees of each other.

Table 2: Historical evolution of relationships between population density and GDP per capita and average time since agricultural transition among Western countries.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Dependent variable:						
	Log Population density in:			Log GDP per capita in:			
Average time since agricultural transition in:	1 CE	1000 CE	1500 CE	1 CE	1000 CE	1500 CE	1820 CE
- 1 CE	0.215			0.076***			
	(0.142)			(0.015)			
- 1000 CE		-0.001			0.105***		
		(0.125)			(0.022)		
- 1500 CE			-0.231*			-0.050*	
			(0.137)			(0.024)	
- 1820 CE							-0.180***
							(0.033)
Constant	-0.164	1.328	3.375***	5.748***	5.448***	6.778***	8.013***
Observations	54	60	61	23	20	21	28
R-squared	0.04	0.00	0.04	0.30	0.69	0.07	0.36

Note: The estimator is OLS in all specifications. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. The sample is all Western countries with available data.

Table 3: Relationship between average GDP per capita 1997-2008 and time since agricultural transition among 1,371 European NUTS3-regions

	(1)	(2)	(3)	(4)	(5)
	Dependent variable: Average log GDP per capita 1997-2008				
	OLS	OLS	OLS	FE	FE
Average time since agricultural transition	-0.484***	-0.473***	-0.117***	-0.063	-0.066
	(0.021)	(0.032)	(0.025)	(0.136)	(0.058)
Conley SE	[0.092]	[0.129]	[0.050]	[0.092]	[0.040]
Geographical controls	No	Yes	Yes	No	Yes
Historical controls	No	No	Yes	No	Yes
Biogeographical controls	No	No	Yes	No	Yes
Observations	1,371	1,371	1,370	1,371	1,370
Countries	29	29	29	29	29
R-squared	0.234	0.408	0.8241	0.234	0.441
- Within				0.006	0.250
- Between				0.078	0.229

Note: The estimator is OLS in columns 1-3 and fixed effects (FE) with countries as the group variable in columns 4-5. The sample is all Western regions with available data n NUTS3-level. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In calculating Conley standard errors (in square brackets), we assume that spatial autocorrelation exists among observations which are within ten degrees of each other.

Table 4: Within-country relationships between average GDP per capita and time since agricultural transition for NUTS3-regions in five large countries

Country	Estimated coefficient for *Average time since agricultural transition 1997-2008*			
	Without controls	Adding controls	Obser-vations	Pinhasi sites
France	-0.197**	-0.084	96	108
	(0.075)	(0.063)		
	{0.098}	{0.444}		
Germany	0.158***	-0.079*	429	57
	(0.037)	(0.040)		
	{0.040}	{0.396}		
Italy	-0.565***	-0.251***	107	78
	(0.106)	(0.062)		
	{0.208}	{0.802}		
Spain	-0.807***	-0.508***	51	8
	(0.175)	(0.251)		
	{0.234}	{0.439}		
Turkey	-0.405***	-0.241***	81	30
	(0.047)	(0.053)		
	{0.407}	{0.531}		

Note: The table shows estimated coefficients for the the within-country relationships between *Average time since agricultural transition* and *Log Average GDP per capita 1997-2008* for the five largest countries with significant regression coefficients. The estimator is OLS in all specifications and each observation is a NUTS3-region. A constant with unreported coefficients has been included in all regressions. The set of geographical control variables includes *Log Area, Latitude, and Altitude* with unreported coefficients. Robust standard errors are in ()-parentheses, R2-values for the regression are in {}-parentheses. *Pinhasi sites* refers to the number of archaeological sites in Pinhasi et al (2005) within each country's borders. *** p<0.01, ** p<0.05, * p<0.1.

Appendix (online)

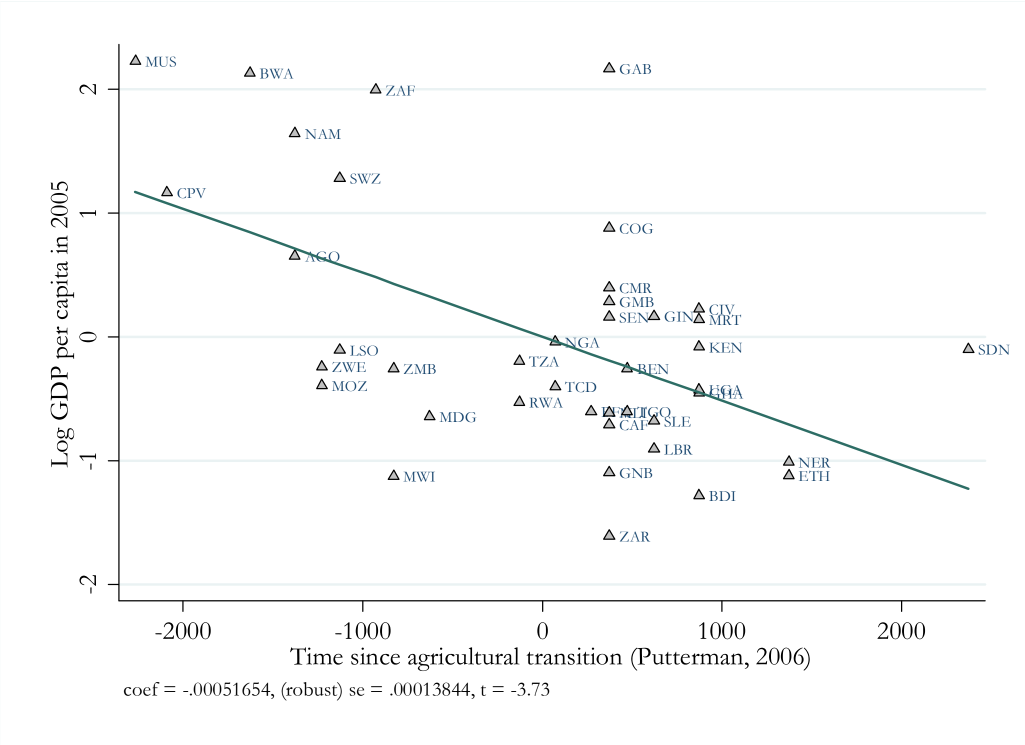
Table A1: Summary statistics and sources of variables for the cross-country analysis in tables 1-2

Variables	N	Mean	SD	Min	Max	Source
Dependent variables						
Log GDP per capita in 2005 (constant 2000 USD)	64	8.688	1.369	6.224	10.859	World Development Indicators (WDI)
Log Population density in 1 CE	54	1.024	1.266	-1.481	3.170	Ashraf and Galor (2013)
Log Population density in 1000 CE	60	1.318	1.136	-1.258	3.442	Ashraf and Galor (2013)
Log Population density in 1500 CE	61	1.733	1.296	-1.258	4.135	Ashraf and Galor (2013)
Log GDP per capita in 1 CE	24	6.144	0.164	5.991	6.696	Maddison (2013)
Log GDP per capita in 1000 CE	21	6.097	0.156	5.991	6.477	Maddison (2013)
Log GDP per capita in 1500 CE	22	6.432	0.231	6.064	7.003	Maddison (2013)
Log GDP per capita in 1820 CE	29	6.693	0.396	6.064	7.516	Maddison (2013)
Independent variables						
Average time since agricultural transition (in 1000 yrs from 2000 CE)	64	7.611	1.100	5.608	9.743	Own assessment based on Pinhasi et al (2005)
Earliest date of transition (for any region country, in 1000 yrs from 2000 CE)	60	8.446	1.593	5.673	12.408	Own assessment based on Pinhasi et al (2005)
Geographical controls						
Log Country area (km 2)	64	4.501	2.131	-2.797	8.098	WDI (2013)
Log Arable land (percent)	64	2.575	1.250	-2.106	4.028	WDI (2013)
Log Altitude (m)	64	-1.117	1.032	-4.198	0.588	WDI (2013)
Historical controls						
Roman Empire (fraction of country part of empire in 200 CE)	64	0.469	0.455	0	1	Own assessment based on Euratlas (2012)
Byzantine Empire (fraction of country part of empire in 500 CE)	64	0.174	0.357	0	1	Own assessment based on Euratlas (2012)
Mongol Empire (dummy=1 if country was overrun by Mongols in 13-14th centuries CE)	64	0.196	0.398	0	1	Own assessment based on Euratlas (2012) and other sources
Ottoman Empire (fraction of country part of empire in 1600 CE)	64	0.267	0.383	0	1	Own assessment based on Euratlas (2012)
Atlantic coastline to area-ratio	64	0.0023	0.0079	0	0.051	Acemoglu et al (2005)
Warsaw pact or Former Soviet republic (dummy=1 if country part of the above before 1989)	64	0.328	0.473.	0	1	Own assessment
Biogeographical controls						
Steppe tundra, 10000 ysrs ago (fraction of area)	59	0.266	0.400	0	1	Own assessment
Polar desert, 10000 yrs ago (fraction of area)	59	0.032	0.110	0	0.497	Own assessment
Ice, 10000 Yrs Ago (fraction of area)	59	0.035	0.131	0	0.663	Own assessment
Wooded Steppe, 10000 yrs ago (fraction of area)	59	0.151	0.297	0	1	Own assessment
Desert, 10000 yrs ago (fraction of area)	59	0.101	0.275	0	1	Own assessment
Tropical extreme, 10000 yrs ago (fraction of area)	59	0.059	0.213	0	1	Own assessment
Semi-desert, 10000 yrs ago (fraction of area)	59	0.053	0.162	0	0.764	Own assessment
Dry steppe, 10000 yrs ago (fraction of area)	59	0.211	0.342	0	1	Own assessment
Mediterranean, 10000 yrs ago (fraction of area)	59	0.023	0.115	0	0.742	Own assessment

Table A2: Summary statistics and sources of variables used in the cross-regional study

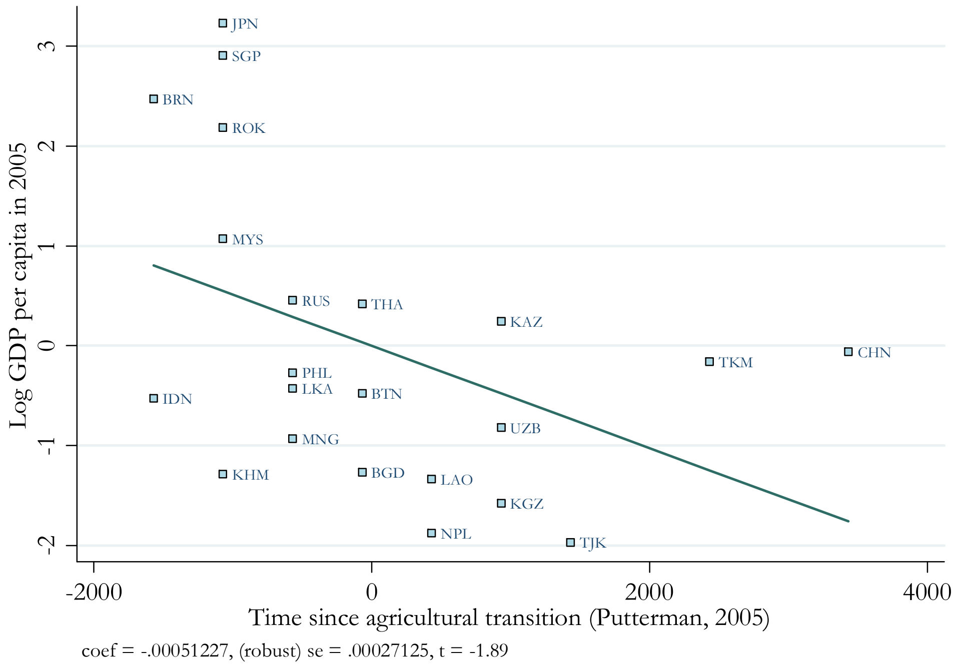
Variables	N	Mean	SD	Min	Max	Source
Dependent variable						
Log Average GDP per capita 1997-2008 (in €)	1,371	9.580	0.846	6.802	11.83	Eurostat (2012)
Independent variables						
Average time since agricultural transition (in 1000 yrs from 2000 CE)	1,371	7.055	0.847	5.243	11.32	Own assessment based on Pinhasi et al (2005)
Geographical controls						
Log Region area	1,371	7.382	1.384	2.962	10.58	Own assessment
Altitude (m)	1,371	347.9	362.7	-2.639	2328	Own assessment
Latitude	1,371	47.97	5.169	35.05	59.77	Own assessment
Biogeographical controls						
Steppe Tundra, 10000 yrs ago (percent of area)	1,370	59.92	48.11	0	100	Own assessment
Ice, 10000 Yrs Ago (percent of area)	1,370	2.049	13.28	0	100	Own assessment
Polar Desert, 10000 yrs ago (percent of area)	1,370	2.779	14.61	0	100	Own assessment
Semi Desert, 10000 yrs ago (percent of area)	1,370	0.559	6.648	0	100	Own assessment
Dry Steppe, 10000 yrs ago (percent of area)	1,370	17.39	36.20	0	100	Own assessment
Wooded Steppe, 10000 yrs ago (percent of area)	1,370	16.20	35.43	0	100	Own assessment
Temperate Forest, 10000 yrs ago (percent of area)	1,370	0.437	5.683	0	100	Own assessment
Historical controls						
Ottoman Empire (dummy=1 if region part of empire in 1600 CE)	1,371	0.155	0.362	0	1	Own assessment based on Euratlas (2012)
Roman Empire (dummy=1 if region part of empire in 200 CE)	1,371	0.670	0.471	0	1	Own assessment based on Euratlas (2012)
Byzantine Empire (dummy=1 if region part of empire in 500 CE)	1,371	0.129	0.335	0	1	Own assessment based on Euratlas (2012)
Mongol Empire (dummy=1 if region was overrun by Mongols in 13-14th centuries CE)	1,371	0.229	0.420	0	1	Own assessment based on Euratlas and other sources
Atlantic Ocean (dummy=1 if region located by Atlantic ocean)	1,371	0.116	0.320	0	1	Own assessment
Warsaw pact or Former Soviet republic (dummy=1 if region part of the above before 1989)	1,371	0.175	0.380	0	1	Own assessment

Figure A1: Relationship between log GDP per capita in 2005 and time since agricultural transition among 41 Sub-Saharan African countries.



Note: The figure shows the unconditional bivariate relationship between *Time since agricultural transition* and *Log GDP per capita in 2005*. N=41, R^2=0.281, p-value < 0.001. OLS estimate using robust standard errors. Each country is identified by a three-letter isocode. *Time since agricultural transition* is taken from Putterman (2006).

Figure A2: Relationship between log GDP per capita in 2005 and time since agricultural transition among 22 Central and East Asian countries.



Note: The figure shows the unconditional bivariate relationship between *Time since agricultural transition* and *Log GDP per capita in 2005*. N=22, R^2=0.186, p-value = 0.074. OLS estimates using robust standard errors. Each country is identified by a three-letter isocode. *Time since agricultural transition* is taken from Putterman (2006).

Figure A3: Neolithic sites and the spread of agriculture in Italy