

Columbus's Contribution to World Population and Urbanization: A Natural Experiment Examining the Introduction of Potatoes

Nathan Nunn^{*‡}

Harvard University and NBER

Nancy Qian^{*§}

Brown University, Harvard Academy and CEPR

August 2008

ABSTRACT: This study exploits the changes in agricultural productivity brought about by the introduction of potatoes to the Old World from the New World, and provides an estimate of the impact of agricultural productivity on population growth and economic development. Using a difference-in-differences estimation strategy, we examine whether countries with a greater geographic suitability for the adoption of potatoes witness a larger increase in population and urbanization growth after potatoes were introduced to the Old World. According to our most conservative estimates, the adoption of potatoes explains 18% of the observed post-1700 increase in population growth and 37% of the increase in urbanization growth. We show that our results are robust to a wide range of alternative determinants of population growth and economic development during this period, including globalization, colonial rule, and the slave trade.

Key words: Demography; Agriculture; Economic Development; Industrialization

JEL classification: J1, N1, N5, O14

^{*}We thank Azim Essaji, Oded Galor, Claudia Goldin, David Weil and seminar participants at Harvard University, BREAD, and the CEA Annual Meetings for their helpful comments.

[‡]Department of Economics, Harvard University, 1805 Cambridge Street, Cambridge, MA 02138, U.S.A. (e-mail: nnunn@fas.harvard.edu; website: <http://www.economics.harvard.edu/faculty/nunn>).

[§]Department of Economics, Harvard University, 1805 Cambridge Street, Cambridge, MA 02138, U.S.A.

“It provides more calories, more quickly, using less land and in a wider range of climate than any other plant. It is, of course, the potato.” - “Spud We Like”, *The Economist*, March 1st, 2008.

1. Introduction

The relationship between agriculture and economic development is one of the oldest and most fundamental topics in the study of development economics (see e.g., Johnston and Mellor, 1961). Despite its long history, we still do not have a complete and clear understanding of the role that agriculture plays in economic development. From a theoretical point of view, the effect of agricultural productivity on economic development is not obvious. On the one hand, an increase in agricultural productivity may increase surplus labor in the countryside which can then be released to the industrial sector in the cities. This is possible, for example, in the world described in the Lewis (1954) model.¹ Alternatively, an increase in agricultural productivity may increase the returns to agriculture relative to industry and delay a switch to a modern economy. This occurs, for example, in the two sector growth model of Ngai (2003). Other models, such as that developed in Matsuyama (1992), predict that the relationship between agricultural productivity and economic growth is more nuanced; in Matsuyama’s model the relationship depends on how open the economy is to international trade. Finally, arguments along the line of Malthus (1798), suggest that an increase in agricultural productivity may raise income in the short-term, but in the long-run, the productivity increase results in increased population and income remains stagnant.

Overall, theory does not provide a clear prediction about the relationship between agriculture and economic development. The question then becomes an empirical issue. However, empirical evidence suffers from an important identification problem: both agricultural productivity and the outcomes of interest are influenced by omitted factors. An example of one of these factors is political stability, which may increase investment and productivity in all parts of the economy, including agriculture. Not accounting for this factor will bias upwards the relationship between agricultural productivity and economic development.

The existing empirical literature has generally attempted to infer evidence of the role of agriculture in economic development from correlations in the data (Hwa, 1988). Most recently, a

¹See also Ranis and Fei (1961) who generalized and provide a more formal version of the Lewis’s original model. More recently, also see the models of Kögel and Prskawetz (2001) and Gollin, Parente, and Rogerson (2002).

study by Tiffin and Irz (2006) attempts to address the issue of causality by examining panel data and employing lags and Granger causality tests. Their empirical results provide evidence that agricultural growth ‘causes’ aggregate GDP growth.

Our analysis addresses this identification problem by focusing on an agricultural productivity shock that was caused by the introduction of potatoes to the Old World from the New World after the discovery of the Americas by Christopher Columbus. This ‘experiment’ allows us to estimate the causal effect of this agricultural technology shock on historic population growth and economic development, measured by urbanization rates. Because potatoes are nutritionally superior relative to grain crops, both in terms of caloric yield per acre of land and in terms of the important vitamins and nutrients provided by the crop, the parts of the Old World that were able to adopt potatoes experienced a dramatic increase in their agricultural productivity. Our empirical analysis estimates the effect of this positive productivity shock by implementing a differences-in-differences (DD) estimation strategy that compares the relative difference in the growth of population and urbanization, before and after the introduction of potatoes, between countries that were able to adopt potatoes and countries that were not. That is, we investigate whether we see the largest increase in the growth rates of population and urbanization after potatoes were introduced to the Old World occur in the countries that most suitable for potato cultivation.

Rather than using the actual date of a country’s adoption and its actual extent of adoption, we use the median date of the adoption and each country’s suitability for potato cultivation. Based on the historic evidence we take the median date of the adoption of potatoes as a field crop to be 1700 and we measure a country’s suitability for potato cultivation using data from the FAO that is based on whether an area’s weather, climate, and land satisfy the requirements necessary to grow potatoes. The advantage of this strategy is that a country’s ability to adopt potatoes (unlike its actual adoption) and the date of introduction (rather than the date of actual adoption) are less likely to be correlated with omitted factors that also affect population growth and economic development. However, our estimates will still be biased if our country level measure of potato suitability is correlated with other country level characteristics that affect population and urbanization differently, and systematically, before or after 1700.

One concern is that the suitability of potato production may be correlated with overall agricultural productivity, which may have become more important after 1700. Therefore, in our baseline estimates we also control for a measure of a country’s overall suitability for agriculture, and allow

this effect to vary after 1700. We also control for the suitability for growing other New World crops like maize and allow their effects to vary after 1700. Another concern arises from the fact that there were a number of other changes in the world around 1700, the most important being the industrial revolution in Western Europe and increased global integration. We include a number of country characteristics which through these large historic events may also have affected population growth and urbanization around 1700.

Our most conservative estimates indicate that the introduction of potatoes accounts for up to 18% of the increase in Old World population growth after 1700, and 37% of the increase in the growth of urbanization. Interestingly, our results show that the effect of potatoes on urbanization lags the effect on population by 100 years. These results are consistent with the research of many historians. Based on descriptive evidence, it has been argued that in Europe, “the spread of the potato culture everywhere corresponded with the rapid increase of population” (Langer, 1963, p. 14). Even more boldly, McNeill (1999) argues that “potatoes, by feeding rapidly growing populations, permitted a handful of European nations to assert domination over most of the world between 1750 and 1950”. While our results cannot prove McNeill’s assertion that the potato is responsible for Europe’s global domination, they do provide empirical validation for the common view that the potato is responsible for part of Europe’s increased population and economic development during this period.

There has been only one previous study that empirically examines the effect of the introduction of the potato. This is a study by Joel Mokyr (1981) that looks at a cross-section of counties within Ireland in 1845 and tests for a relationship between potato cultivation and population growth. To address the problem of endogenous adoption, Mokyr estimates a system of two equations using 2SLS. He finds that potato cultivation resulted in a statistically significant increase in population growth. He also finds no evidence that the potato was adopted in response to rapid population growth. Our study differs from Mokyr’s (1981) in two ways. First, our difference-in-differences estimation strategy is very different from Mokyr’s IV strategy. Second, our data allow us to examine the impact of potatoes beyond the Irish context, as well as the impact of potatoes on long-term economic development.

The paper is organized as follows. The following section provides a description of the potato, discussing its nutritional benefits and its diffusion from the New World to the Old World. Section 3 describes the data used in our analysis and section 4 reports our estimating equations and our

empirical results. Section 5 concludes.

2. The Potato: Background and History

A. Nutrition

From a nutritional point of view the potato is a truly remarkable food for two reasons. First, it is the single food that can best support life when fed as the sole article of diet (Davidson, Passmore, Brock, and Truswell, 1975, p. 213, Reader, 2008). Potatoes contain nearly all of the important vitamins and minerals. For example, humans can subsist healthily on a diet of only potatoes and milk, which provides vitamins A and D. Based on data from the (U.S. Department of Agriculture, 2007), a medium potato (150g/5.3 oz.) with the skin provides 29.55 mg. vitamin C (45% of the daily value (DV)), the necessary deterrent for scurvy. This important since the other staple crops, wheat, oats, barley, rice, and maize, do not contain any vitamin C. In contrast, the average Irish diet of 4.5 to 6.5 kilograms of potatoes per day provided 40 to 60 times the quantity of Vitamin C required to prevent scurvy (Hughes, 2000). For much of Northern Europe the potato provided the only source of vitamin C and protection against scurvy. A medium potato also contains 632 mg. of potassium (18% of DV), 0.44 mg. vitamin B6 (20% of DV), as well as significant amounts of thiamin, riboflavin, folate, niacin, magnesium, phosphorus, iron, and zinc. Moreover, the fiber content of a potato with skin (3.5 grams) is similar to that of many other cereals such as wheat.

The second remarkable fact about the potato is that it yields more energy per acre than any Old World cereal crop and requires less labor input. Direct evidence of the historic superiority of the potato over all pre-existing Old World crops is shown in Table 1. The table reports data collected by Arthur Young (1771) in a survey of farming communities throughout England in 1770. The first two columns compares the average yields, measured in either bushels or kilograms per acre, of oats, wheat, barley, and potatoes. As shown, yields measured in bushels or kilograms are well over 10 times higher for potatoes relative to any of the other Old World crops. However, part of this reflects the fact that potatoes are 75–80% water and therefore naturally more bulky than the other crops. Column 3 compares the energy value of the yields in columns 1 and 2. As shown, an acre of potatoes yields approximately three times more energy than the other crops. The final column reports this fact in a slightly more intuitive manner. It shows the number of acres required to provide the total energy needs of a family of two adults (a man and a woman) and three young

Table 1. Average crop yields of English farms in the 18th century.

	Average Yield per Acre		Energy Value of Crop	Acres of land needed to provide 42 MJ per day for one year
	Bushels	Kilograms	Megajoules	
Wheat	23	650	8,900	1.70
Barley	32	820	11,400	1.40
Oats	38	690	9,300	1.60
Potatoes	427	10,900	31,900	0.50

Notes: Data are from 18th century England, recorded in Young's (1771, p. 20) *The Farmer's Tour through the East of England Volume 4* and reproduced in Davidson *et al.* (1975).

children, which is estimated to be 42 mega joules (or approximately 10,000 calories) per day. While this family could subsist cultivating a plot of only 1/2 acre of potatoes, it would need to cultivate 1.5 acres if it was to grow wheat, oats, or barley.

The data from Table 1 are consistent with the historic fact that a single acre of land cultivated with potatoes and one milk cow was nutritionally sufficient to feed a large family of six to eight (McNeill, 1999, Langer, 1963). This typical Irish diet of potatoes and milk, although monotonous, was able to provide one with sufficient amounts of protein, calcium, iron, and all vitamins (Connell, 1962).

Potatoes also had two additional benefits that further increased the amount of calories available. First, due to easy storage during the winter, potatoes provided excellent fodder to livestock. This meant that potatoes increased both meat available for consumption and manure which was used as an input in agriculture. Second, potatoes increased the efficiency of land in producing indigenous grain crops. It was often planted before grain crops during crop rotations. Typically, on land under grain cultivation between 1/3 and 1/2 of the land was left fallow each year. Fallowing was a strategy that was undertaken to control weeds. One benefit of potatoes was that they could be planted on the fallow land between periods of grain cultivation (Mokyr, 1981, McNeill, 1999). Thus, even if land was not converted from the cultivation of grains to the cultivation of potatoes, the introduction of the potato still increased the supply of food from a given plot of land.

B. Diffusion from the New World to the Old World

Archeological evidence suggests that the potato was first cultivated in the Andes between 7,000 and 10,000 years ago (Messer, 2000b). After the discovery of the Americas by Christopher Columbus in 1492, the potato was soon introduced to Europe by the Spanish in the late sixteenth century, around 1570. From here the plant spread to northern Italy, where the cultivation of the crop is dated back to 1601 when Carolus Clusius reported in his *Rariorum Plantarum Historia* that potatoes were common in Northern Italy (McNeill, 1999, p. 73). In England by the 1690s, the potato begun to be cultivated and was used as a supplement to bread. A few decades later, by the 1730s, the Scottish had also adopted potatoes as a staple food crop (Langer, 1963, McNeill, 1999).

Although there are examples of early adoption of the potato, by and large the adoption of the potato as a field crop was slow at first. This is because the potato was generally viewed either as an strange exotic gift and botanical curiosity, or as a poisonous and dirty plant that caused leprosy (Langer, 1975). It was not until the 18th century, when starvation forced large populations to adopt the new plant, that the potato become an important crop in Europe. In 1744, Prussia's Frederick the Great ordered his subjects to grow potatoes as insurance against cereal crop failure and distributed free seed potatoes with instruction on how to plant them. The French scientist, Antoine Parmentier, influenced by his observation of the benefit of potatoes in Prussia during the Seven Years war (1756–1763), devoted his research to investigating and extolling the virtues of the potato. In the late 18th and early 19th centuries a number of countries, like France, Austria and Russia, used government policy to encourage domestic cultivation of potatoes (Langer, 1963, McNeill, 1999). Once persuaded to plant potatoes, European farmers quickly recognized their advantages over other crops, and soon potatoes became the staple field crop that they are today.

The potato was spread to the other parts of the New World by European mariners who carried potato plants to ports across Asia and Africa. Although we do not have historical evidence on the exact date of its first introduction, the existing evidence suggests that the potato was probably brought to the Philippines in the late 16th century and later brought to Java in the 17th century by the Dutch (Burkill, 1935). The potato's introduction to China probably occurred several times during the seventeenth century. The potato was cultivated as early as 1603 by Dutch settlers of the Penghu Islands, and later in Taiwan after the Dutch occupied the island from 1624 to 1662. Given the Dutch initiated trade links between Taiwan and the coastal province of Fujian, it was likely that the potato was also introduced to mainland China during this time. There is evidence from

a document dating back to 1700 of potato cultivation in a mountainous area of northern Fujian. According to (Lee, 1982, p. 738), by 1800 the populations in Southwest China had replaced the traditional lower yields crops of barley, oats, and buckwheat with either potatoes or another New World crop, maize.²

Historic evidence suggest that the potato first reached India not much later than Europe, taken there by either the British or the Portuguese. The earliest known reference to the potato in India is from an account by Edward Terry, who was chaplain to Sir Thomas Roe, British ambassador to the court of the Mughal Emperor Jahanagir from 1615 to 1619, in Northern India. British colonial governor Warren Hastings promoted potato cultivation during his term (1772 to 1785) and by the late eighteenth to early nineteenth century, potatoes were well established in the hills and plains of India (Pandey and Kaushik, 2003).

In Africa, the potato arrived slightly later, around the end of the 19th century. In Ethiopia, the potato was introduced in 1858 by a German immigrant named Wilhelm Schimper. The subsequent adoption by native farmers occurred gradually over several decades. According to Laufer (1938), by the 1930s the potato had become naturalized in southern Ethiopia and southeastern Sudan.

As the historical evidence illustrates, the actual date of the adoption of potatoes as a field crop varied significantly across the Old World. This was due in large part to idiosyncratic factors, such as the views of individuals and the ability and desire of governments to promote the adoption of the crop. Because the date of adoption in each region is potentially endogenous to factors that may also be correlated with subsequent population growth and economic development, in our difference-in-differences estimates we use one date of adoption for all countries of the Old World. As our year of adoption we take the median adoption dates and consider 1700 to be the date that countries began to first adopt potatoes as a field crop.

3. Data

A. *FAO Data on Crop Suitability*

Data on the suitability of soil for growing crops are from the FAO's *Global Agro-Ecological Zones* (GAEZ), 2000 database. The construction of the GAEZ occurs in two stages. The FAO first collects

²We discuss in detail below and examine empirically the effect of maize and other New World food crops on Old World population growth and economic development. As we show, other maize and other New World crops did not have the same impact as the potato.

information on the soil and climatic conditions required to grow 28 core crop types. Each crop requires specific amounts of heat, light, and water to survive. The specific constraints that prevent each crop from being grown are identified.

Next, the FAO compiles data on the physical environment across 2.2 million grid cells that are 5 arc minutes long by 5 arc minutes wide. Five arc minutes is equal to 1/12th of a degree, or 9.3 kilometers (measured at the equator). The primary characteristics used are climatic, and are taken from a global climatic database that has been compiled by the Climate Research Unit (CRU) at the University of East Anglia. The global climatic database includes nine variables (measured monthly) that are used by the FAO in the GAEZ study: precipitation, frequency of wet days, mean temperature, diurnal temperature range, vapor pressure, cloud cover, sunshine, ground-frost frequency and wind speed. The second set of characteristics are land characteristics taken from the FAO's Digit Soil Map of the World (DSMW). Information on the slope of soils is taken from the GTOPO30 database, which was developed at the U.S. Geological Survey (USGS) EROS Data Center.

Combining the information on the constraints for crop cultivation with the data on the actual environment of the different grid cells of the world, the FAO calculates an estimate of the potential yield of each crop in each grid cell for an assumed level of intensity of cultivation and input use. For each grid cell and crop, it is first determined when the temperature and moisture conditions of the crop are met. The FAO then calculates the length of the growing period (LGP), which is defined as the number of days when both water availability and prevailing temperatures permit growth. Depending on its length, the LGP may allow for no crops to be grown per year, for only one growth of the crop, or for multiple growth in a year. Soil and terrain constraint are also identified for each crop. The following constraints are examined: terrain-slope constraints, soil depth constraints, soil fertility constraints, soil drainage constraints, soil texture constraints, and soil chemical constraints.

For each crop, the FAO constructs a raster file that records a classification of the suitability of the environment for growing that particular crop. The FAO has also constructed a country level version of the database, which reports for each country and crop, the proportion of the country's land that is classified under five mutually exclusive categories describing how suitable the environment is for growing the crop in question. The categories are based on the calculated percentage of the maximum yield that can be attained in each grid-cell. The five mutually exclusive categories, and their corresponding yields, are: (i) very suitable land (80–100%), (ii) suitable land

(60–80%), (iii) moderately suitable land (40–60%), (iv) marginally suitable land (20–40%), and (v) not suitable land (0–20%). The measures are provided for three different assumptions about the intensity of cultivation and input use. The categories for input intensity are: (i) high intensity, (ii) intermediate intensity, (iii) low intensity. For all constructed measures, the FAO assumes that cultivation occurs under rain-fed conditions.

Using the FAO's *Global Agro-Ecological Zones* (GAEZ) 2000 database, we calculate for each Old World country the fraction of the country that is suitable for potato cultivation. We define land that is suitable for cultivation as land that is classified in the database as being either "very suitable", "suitable", or "moderately suitable", assuming an "intermediate intensity" of cultivation and input use. Put differently, our measure defines land to be suitable if it yields at least 40% of the maximum possible yield. Our baseline measure of a country's suitability for growing potatoes is the fraction of each country's land area that is defined as suitable based on our definition.

The FAO database also provides the same calculations for land that can grow any crop for human consumption (e.g., excluding fodder crops). We use this information to calculate a measure of a country's overall agricultural suitability. We use this as a control variable in our empirical analysis. Like the potato suitability measure, this variable measures the proportion of a country's land area that classified as being either "very suitable", "suitable", or "moderately suitable" for growing any crop assuming an "intermediate intensity" of cultivation use.

Figure 1 shows the underlying grid cell data that the FAO's country level database is based on. The map shows grid-cells which are defined as being either suitable or not suitable based on our 40% yield cut-off. The suitable areas are shaded in dark green and the areas that are not suitable are in light green. Figure 1 shows a map of the same underlying data aggregated to the country level. The map shows the fraction of each country's land area that is suitable by our definition. A darker shade indicates a greater proportion of land that is suitable. The ranges corresponding to each shade are reported in the map's legend. Both maps show only the countries of our sample (i.e., only Old World countries).

From the two maps a number of facts are immediately apparent. The first is that most of the world is not suitable for growing potatoes. As a result of this, 51 of the 129 Old World countries in our sample have no land that is suitable for cultivating potatoes. The large number of countries with zero suitability is shown in figure 3, which shows a histogram of our potato suitability variable. In our empirical analysis we pay particular attention to this fact. As we show, our

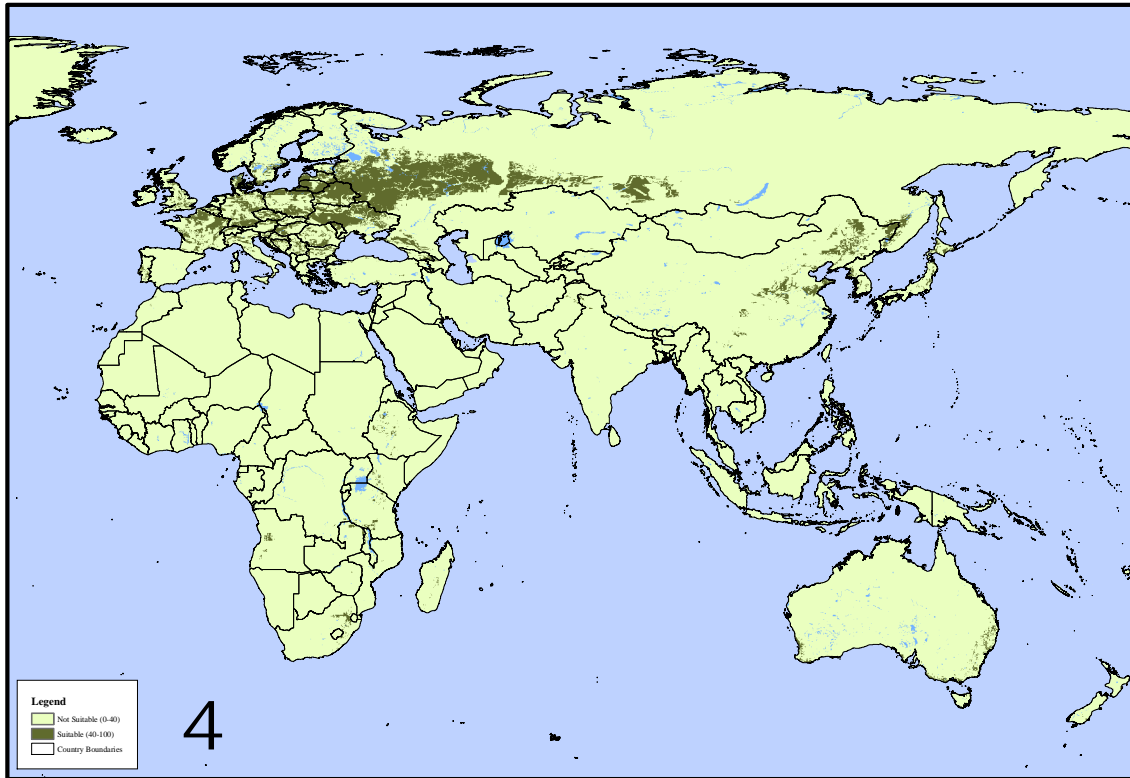


Figure 1. Average potato suitability among Old World countries, measured at the grid-cell level.

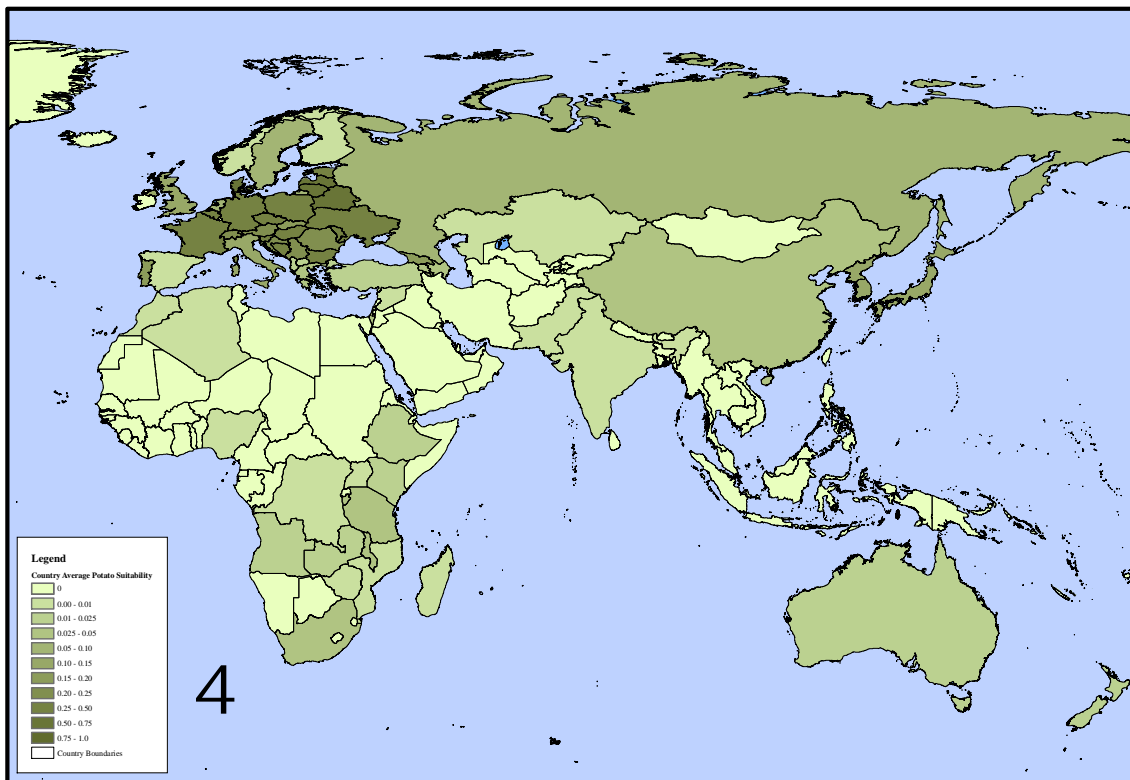


Figure 2. Average potato suitability among Old World countries, measured at the country level.

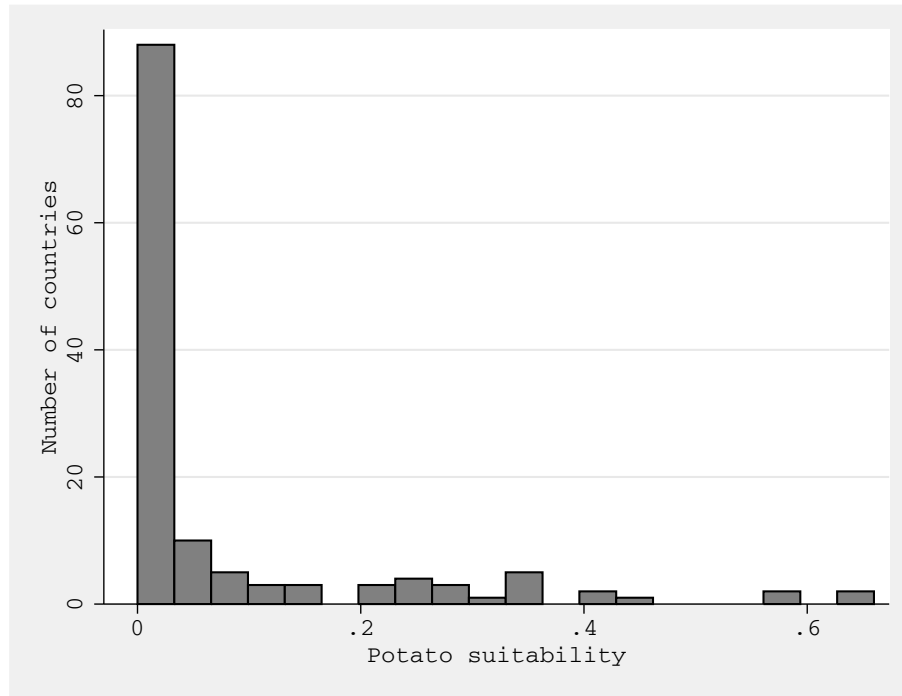


Figure 3. Histogram of average country level potato suitability among Old World countries.

results are not being driven by zero suitability countries. Our results are unchanged if we omit zero suitability countries from our sample.

The second fact that is apparent from the maps in figures 1 and 2 is that areas that have the most land area suitable for potato cultivation appear to be concentrated in Europe. This fact is a potential cause of concern, since we know that after 1700, Western Europe diverged from the rest of the world. The underlying cause of this divergence may bias our estimated impact of the introduction of potatoes on population and economic development. We address this concern explicitly in a number of ways. We show that our estimates do not change if we omit Western European countries or even all European countries, or if we control for underlying determinants of Western Europe's divergent growth after during and after the 18th century.

A final concern with our potato suitability measure is whether the suitability measure calculated in 2000 by the FAO is an accurate indicator of suitability two hundred years ago. However, the nature of the suitability measures suggest that they are. The suitability measures are based primarily on geographic characteristics that do not change over the time span considered by our study. Characteristics, such as temperature, humidity, length of days, sunlight, and rainfall have not changed in any significant way since 1700. In constructing our measure, the FAO intentionally

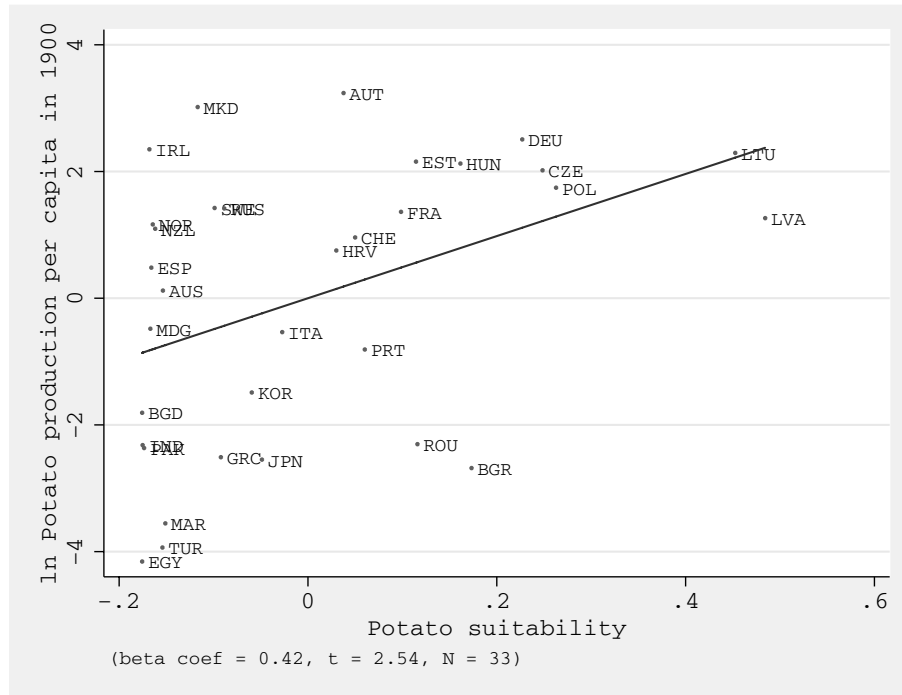


Figure 4. Bivariate relationship between the natural log of tons of potato production per capita and potato suitability among 33 Old World countries.

assumes rain fed conditions, avoiding measurement error caused by changes over time in irrigation technology and intensity of irrigation use.

As a check of the validity of our potato suitability measure, we examine whether our measure is correlated with historic potato production. The earliest period for which data are available for a cross-section of countries is 1900. These data are from Mitchell (1998, 2003). We construct the natural log of tons of potato production per capita and examine its relationship with our potato suitability measure. The bivariate relationship between the two measures is shown in figure 4. The correlation between the two variables is 0.42, which is statistically significant at the 1% level. Figure 4 only shows Old World countries. If we also include the 11 additional New World countries for which data are available the results are left essentially unchanged.

B. Outcome Variables: Population and Urbanization

The historic populations of land area that today comprise countries are from McEvedy and Jones (1978). In our analysis, we examine the level of population in the following years: 1000, 1400, 1500, 1600, 1700, 1800 and 1900. We also examine the average annual population growth rate between

each time period. This is calculated in the standard manner:

$$\text{Population growth}_{it} = \frac{\ln(\text{Population}_{it}) - \ln(\text{Population}_{it-n})}{n}$$

where n is typically 100 years, except when $t = 1400$. Then $n = 400$.

We also examine the effect of potatoes on economic development. Because per capita income data are unavailable prior to 1500, and even in 1500 they are only available for 22 Old World countries,³ we use the urbanization rate as an alternative measure of economic development. Data on the populations of urban centers are from Chandler (1987), Bairoch (1988), and Modelski (2003). We measure a country's total urban population to be the number of people living in cities with more than 20,000 inhabitants. We construct each country's urbanization rate by dividing its total urban population by its total population taken from McEvedy and Jones (1978). We measure the urbanization rate in percent; it therefore ranges from 0 to 100.

In our analysis we also examine the average annual change in the urbanization rate, which we calculate as follows:

$$\text{Change in urbanization}_{it} = \frac{\text{Urbanization rate}_{it} - \text{Urbanization rate}_{it-n}}{n}$$

Our use of the urbanization rate as a measure of historic economic development follows a number of previous studies that also use either historic urbanization or historic city size as a measure of economic development (e.g., DeLong and Shleifer, 1993, Acemoglu, Johnson, and Robinson, 2002, 2005).

The validity of urbanization as a measure of economic development is shown by Acemoglu *et al.* (2002), who document a very strong relationship between urbanization rates and per capita income levels across former colonies in 1995. However, there are reasons why one may argue that this relationship does not provide sufficient evidence for the use of urbanization in our context. First, the relationship documented in Acemoglu *et al.* is among former colonies only. Acemoglu *et al.*'s sample is different from the sample in this study since their sample also includes New World countries and does not include Old World countries that are not former colonies. Second, the evidence from Acemoglu *et al.* only shows that there is a relationship in the cross section in 1995. It does not show that there is a relationship in the cross-section in earlier periods and it does not show that there is a relationship in the time series. In other words, it does not show that urbanization rates are a valid measure in a historic panel setting.

³The most extensive and complete historic income data available are from Maddison (2003).

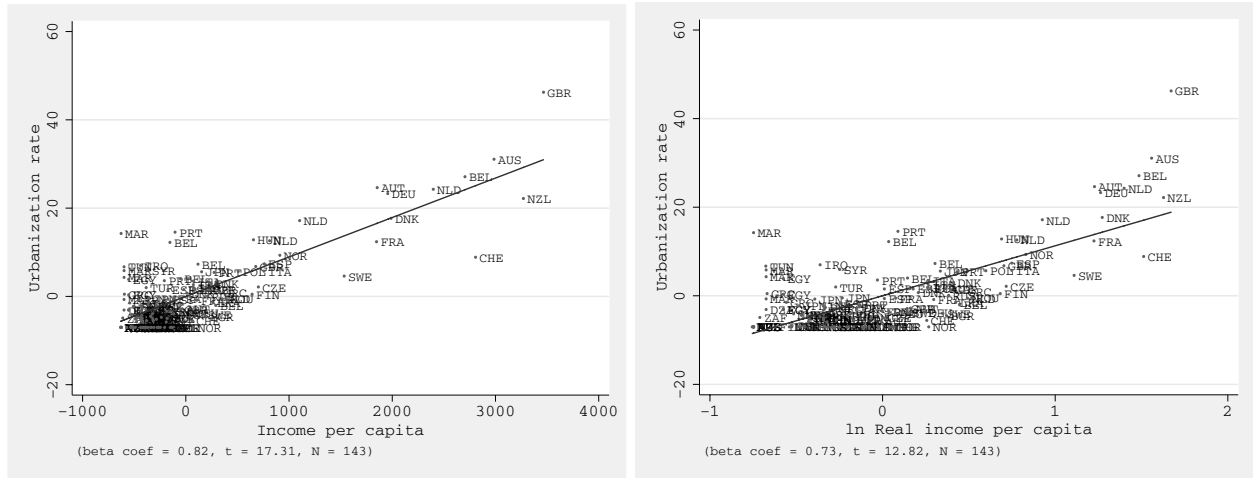


Figure 5. Bivariate relationship between (i) urbanization and per capita income, and (ii) urbanization and log per capita income.

Using the available historic income data from Maddison (2003), we are able to examine the relationship between urbanization and income back to 1500, looking both in the cross section and in the time series. The strength of the relationship between the two measures is illustrated in the two graphs shown in figure 5. In the graphs a unit of observation is an Old World country in either 1500, 1600, 1700, 1800, or 1900. The left graph in the figure shows the relationship between income and urbanization. The correlation between the two variables is 0.83. The right graph shows the relationship between the natural log of income and urbanization; the correlation is 0.73. The figures provide a visual illustration of a fact that is apparent if one examines the data more formally: there is a very strong relationship between urbanization and per capita income in both the cross-section and the time-series. As shown in table 5 in the appendix, if one estimates the relationship between urbanization and income in the cross section in different centuries (with time period fixed effects) or overtime for each country (with country fixed effects), one still finds a very strong relationship between urbanization and income. Similarly, if one estimates the relationship between the two variables in an estimating equation that includes both country fixed effects and century fixed effects, then one still finds a very strong positive relationship between the two measures. The t -statistics are 12.3 and 9.8 when urbanization is regressed on income and log income, respectively.

Overall, the evidence from the available data suggests that in both the cross section and the time series urbanization is a very good proxy for real per capita income. Based on this, we use historic urbanization rates as our measure of historic economic development, and use urbanization and economic development interchangeably in our discussion.

4. Estimating Equations and Empirical Results

A. Flexible Estimating Equation

Our first estimating equation imposes very little structure on the data and simply examines how the relationship between population growth or economic development and a country's suitability for growing potatoes changes over the time periods in our sample. Our estimating equation is:

$$Y_{it} = \sum_{j=1400}^{1900} \beta_j Potato_i \times I_t^j + \sum_{j=1400}^{1900} \delta_j AllCrops_i \times I_t^j + \sum_c \gamma_c I_i^c + \sum_{j=1400}^{1900} \rho_t I_t^j + \varepsilon_{it} \quad (1)$$

where i indexes countries and t indexes time periods, which are for the years 1000, 1400, 1500, 1600, 1700, 1800 and 1900. Y_{it} denotes our outcome of interest, either population, average annual population growth, the urbanization rate, or the average annual change in the urbanization rate. The equation includes country fixed effects $\sum_c I_i^c$, which capture average time invariant differences in country characteristics that affect the outcome variable. Similarly, the time period fixed effects $\sum_j I_t^j$ capture time specific shocks that affect all countries.

The variable $Potato_i$ measures the fraction of total land in country i that is suitable for the cultivation of potatoes. By interacting the variable with the time period indicator variables, we are able to estimate a period specific relationship between potato suitability and the outcome variable. These β_j 's are our coefficients of interest. If population growth or economic development increased due to the adoption of potato cultivation after 1700, then we expect to find that after 1700, countries with great potato suitability experience disproportionately faster growth. Therefore we expect to find that: $\hat{\beta}_{t>1700} > \hat{\beta}_{t \leq 1700} \approx 0$. Because $Potato_i$ is time invariant, the estimated β_t 's must be relative to a baseline time period, which we take to be 1000.

We control for the share of land suitable for agriculture overall interacted with the time period dummy variables $\sum_j \delta_j AllCrops_i \times I_t^j$ to ensure that the effect of introducing potatoes is not confounded by other changes in the importance of agricultural productivity over time. $AllCrops_i$ is measured as the fraction land that is suitable for growing any crop.

The estimated β_j 's and δ_j 's from (1) are reported in table 2. Each column reports estimates from an estimating equation with one of our four dependent variables. For the estimates where the dependent variable is measured in levels, the number of observations is 900. When the dependent variable is measured in levels, we no longer have observations for $t = 1000$ and the sample size

Table 2. OLS estimates from the flexible estimating equation.

	Dependent variable			
	ln Population _{it}	Population growth _{it}	Urbanization rate _{it}	Change in urbanization _{it}
	(1)	(2)	(3)	(4)
$Potato_i \times I_t^{1400}$	0.305*		5.32*	
	(0.171)		(3.41)	
$Potato_i \times I_t^{1500}$	0.495**	0.127	4.96	-0.016
	(0.250)	(0.074)	(3.31)	(0.019)
$Potato_i \times I_t^{1600}$	0.614**	0.046	0.536	-0.058
	(0.262)	(0.086)	(5.48)	(0.037)
$Potato_i \times I_t^{1700}$	0.549*	-0.136	4.25	0.024
	(0.295)	(0.081)	(3.62)	(0.039)
$Potato_i \times I_t^{1800}$	1.345***	0.725***	6.34*	0.008
	(0.374)	(0.124)	(3.30)	(0.042)
$Potato_i \times I_t^{1900}$	2.494***	1.079***	34.19***	0.266***
	(0.455)	(0.118)	(6.59)	(0.056)
$AllCrops_i \times I_t^{1400}$	0.499***		0.417	
	(0.128)		(1.69)	
$AllCrops_i \times I_t^{1500}$	0.609***	0.037	0.289	-0.001
	(0.149)	(0.030)	(1.85)	(0.005)
$AllCrops_i \times I_t^{1600}$	0.658***	-0.057	4.42	-0.007
	(0.146)	(0.064)	(3.08)	(0.005)
$AllCrops_i \times I_t^{1700}$	0.856***	0.100	1.81	0.002
	(0.176)	(0.059)	(2.01)	(0.004)
$AllCrops_i \times I_t^{1800}$	0.828***	-0.126*	0.518	0.001
	(0.216)	(0.064)	(1.76)	(0.005)
$AllCrops_i \times I_t^{1900}$	0.549*	-0.377***	-3.86	0.033***
	(0.280)	(0.132)	(2.74)	(0.010)
Country fixed effects	Y	Y	Y	Y
Time period fixed effects	Y	Y	Y	Y
Observations	900	770	900	770
Clusters	129	129	129	129
R-squared	0.98	0.64	0.51	0.27

Notes: The table reports estimates of equation (1). The unit of observation is an Old World country i in time period t . All regressions include country fixed effects and time period fixed effects. Standard errors are clustered at the country level. ***, **, and * indicate significance at the 1, 5, and 10% levels.

is reduced to 770. In all estimates the number of countries in the sample is 129, and all reported standard errors are clustered at the country level.

To help provide a visual sense of the results, the coefficient estimates and their 95% confidence intervals are also plotted in figures 6 to 9. The estimates are from columns (1) and (3) of table 2. The figures for the average annual growth in population and urbanization (columns (2) and (4) of table 2) are similar. Figure 6 shows that prior to 1700 there is no significant change in the estimated effect of having an environment more suitable for potato cultivation and population levels. This is reassuring because this is the period before the mass diffusion of potatoes to the Old World. However, after 1700 there is a significant positive and monotonically increasing estimated effect (relative to the effect in 1000AD). After the potato was introduced to the Old World, we observe that Old World countries with better suitability for potato cultivation subsequently experienced a disproportionately faster growth in their populations.

Looking at urbanization, which is shown in figure 7, one finds that it is not until after 1800 that there is a significant increase in the relationship between potato suitability and urbanization. Prior to 1800, the estimated relationship is close to zero and generally insignificant. This suggests that 100 years after the adoption of the potato and its effect on population, there is a positive effect on economic development. This is consistent with the argument that a positive shock to agriculture increases agricultural populations, which can then be released into the industrial sectors, and this in turn spurs economic development (Lewis, 1954, Gollin *et al.*, 2002). The results are also consistent with arguments that the introduction of potatoes provided cheap labor that fueled the industrial revolution (McNeill, 1999).

Figures 8 and 9 show the estimated coefficients for the interaction between overall agricultural suitability and the time period fixed effects. As the figures show, there is no systematic pattern of the coefficients for overall agricultural suitability. That is, we do not find that the relationship between agricultural suitability and either population or urbanization changes in any systematic way. Again, this is reassuring since there are no obvious historic events that should strengthen or weaken the relationship between the variables.

B. Difference-in-Differences Estimating Equation

Our second estimating equation estimates examines the impact of the introduction of potatoes in a more structured manner, using a difference-in-differences estimation strategy. This strategy

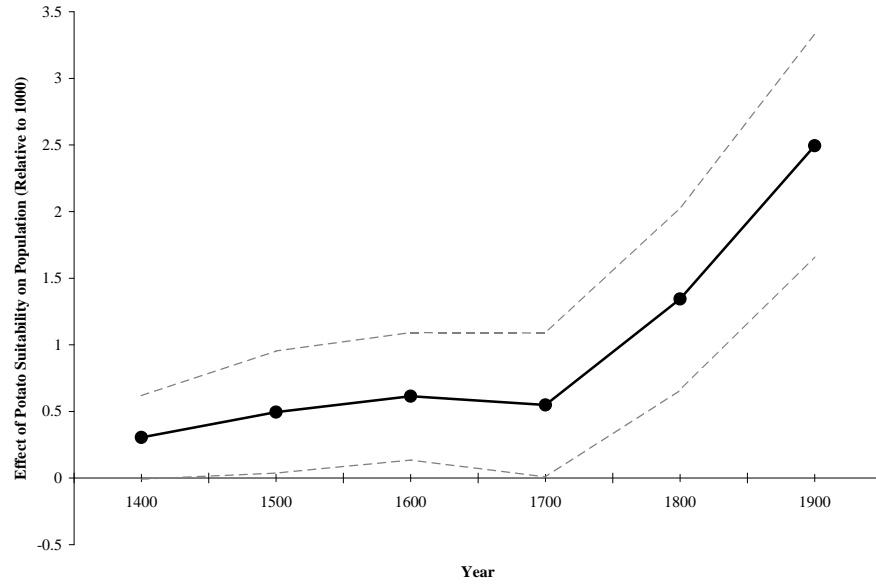


Figure 6. Estimated coefficients of the interaction of potato suitability with the time period fixed effects, $Potato_i \times I_t^j$. The dependent variable is log population.

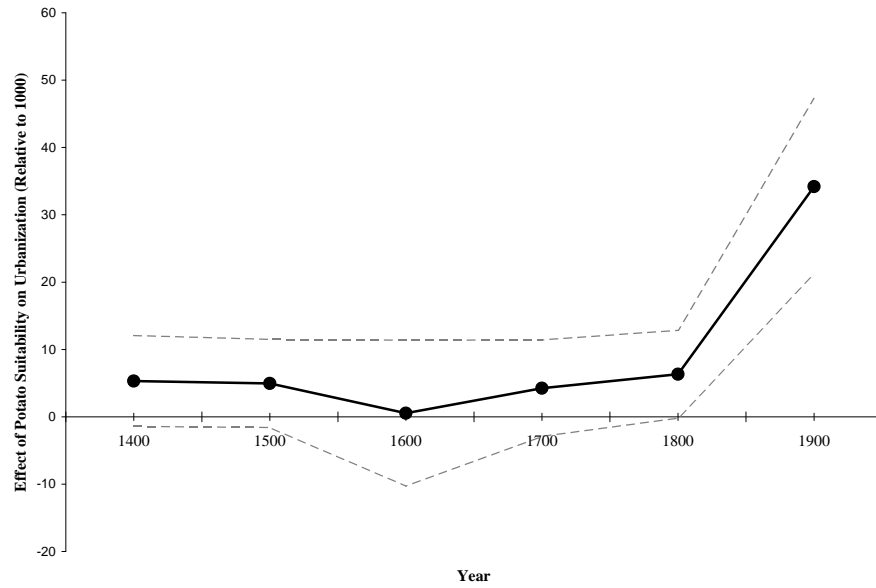


Figure 7. Estimated coefficients of the interaction of potato suitability with the time period fixed effects, $Potato_i \times I_t^j$. The dependent variable is urbanization.

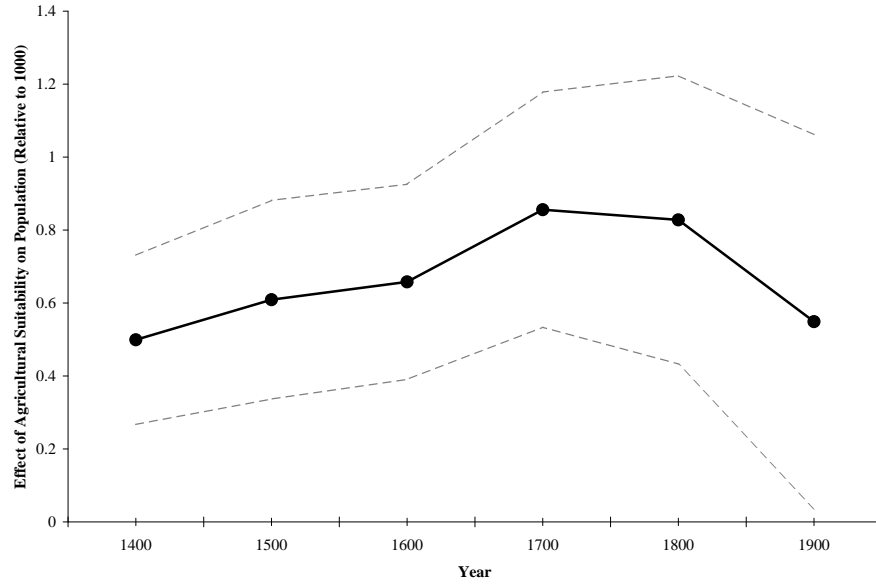


Figure 8. Estimated coefficients of the interaction of the suitability for planting any crops with the time period fixed effects, $AllCrops_i \times I_t^j$. The dependent variable is log population.

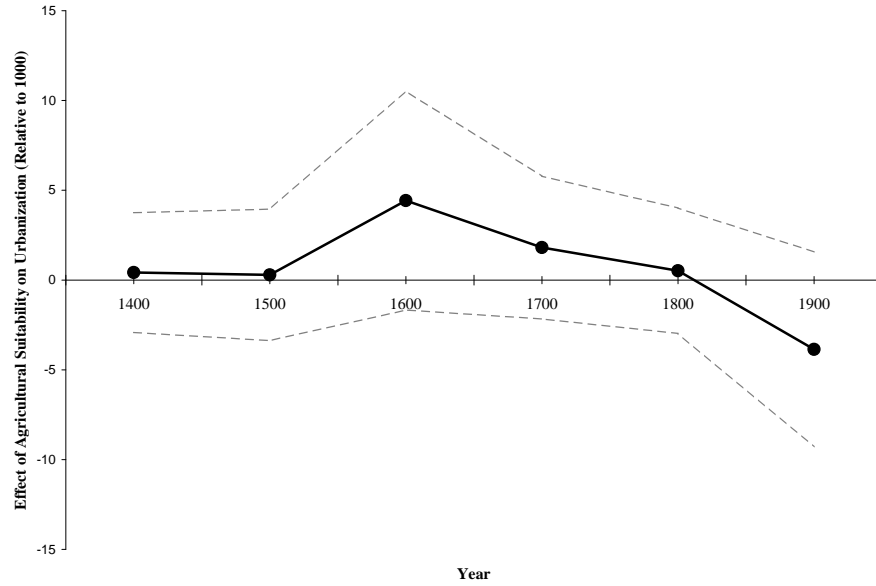


Figure 9. Estimated coefficients of the interaction of the suitability for planting any crops with the time period fixed effects, $AllCrops_i \times I_t^j$. The dependent variable is urbanization.

compares the relative difference in population growth and economic development, before and after the introduction of potatoes, between countries that were able to adopt potatoes and countries that were not.

Our strategy, rather than using the actual date of a country's adoption and its actual extent of adoption, uses the median data of the adoption (1700) and each country's suitability for potato cultivation. From the history of the diffusion of the potato reviewed in section 2, it is clear that a country's date of adoption was influenced by government policy and by the presence of war and conflict. Because of the endogeneity of each country's specific date, we instead use the median date of adoption among all countries.

Like the timing of adoption, the extent of adoption is also potentially endogenous. For example, Cullen (1968) argues that in Ireland population expansion led to the adoption of the potato, and not the other way around as many others have argued.⁴ Because of the potential endogeneity of actual historic potato adoption, we instead use our measure of the suitability of a country's environment for the production of potatoes, which is not endogenous to other country characteristics.

Conceptually then, our DD analysis does not compare countries with high potato adoption rates to those with low adoption rates before and after their periods of adoption. Although, this would be a natural approach to take, the endogeneity of the extent and timing of adoption make this an unattractive estimation strategy. Instead, our DD estimation strategy compares countries endowed with an environment conducive to potato cultivation to those less endowed before and after potatoes were adopted in the Old World.

Our difference-in-differences estimating equation is given by:

$$Y_{it} = \beta Potato_i \times I_t^{Post} + \delta AllCrops_i \times I_t^{Post} + X'_{it}\eta + \sum_c \gamma_c I_i^c + \sum_{j=1400}^{1900} \rho_j I_t^j + \varepsilon_{it} \quad (2)$$

where, as before Y_{it} denotes our outcome of interest, $\sum_c I_i^c$ and $\sum_j I_t^j$ are country and time period fixed effects. Our measure of potato suitability $Potato_i$ is now interacted with an indicator variable that equals one after 1700, I_t^{Post} . We will describe these control variables when we report our estimates.

We also include in our baseline estimates a control for the suitability for growing any crop interacted with our post-1700 indicator variable, $AllCrops_i \times I_t^{Post}$. As in equation (1), this is to control for the possibility that potato suitability may be correlated with overall agricultural

⁴For views arguing the reverse causality see Salaman (1949) and Connell (1962). Also, see the empirical evidence from Mokyr (1981).

suitability and that the importance of agricultural suitability may have changed over time. Finally, we also include a number of additional control variables which we denote \mathbf{X}'_{it} . These covariates will be discussed in detail as they are introduced.

Our coefficient of interest is β , which is the estimated impact of potato suitability on the difference in the outcome variable before and after 1700. Consider population growth as the dependent variable. The estimated coefficient, $\hat{\beta}$, measures how the difference in average population growth after 1700 related to the prior period differs for countries with different levels of potato suitability. If the coefficient is positive, then this indicates that countries with an geographic environment more suitable for growing potatoes witness a greater increase in population growth after 1700 relative to prior 1700.

Our estimation strategy has all of the advantages and potential hazards of standard DD estimators. If countries suitable for potato production are different from countries that are not in ways that do not change over time (and whose effect on the dependent variable does not change over time), then this difference is controlled for by the country fixed effects. Similarly, if there are secular trends in population or urbanization that are similar across countries, then this difference is controlled for by the time period fixed effects. Our identification relies on there not being any systematic changes correlated with suitability for potatoes that occurred around 1700 when potatoes were introduced. Below we will consider, and control for, alternative country characteristics along with historic events that may potentially bias our results.

Our baseline estimates are reported in the top panel of table 3. The estimates of (2) are reported in the odd numbered columns. In all specifications, the estimated coefficients for the potato-post 1700 interaction term, $\hat{\beta}$, are positive and statistically significant. The estimating equations also include an interaction between overall agricultural suitability and the post 1700 indicator variable. These estimated coefficients, $\hat{\delta}$, are generally insignificant. These results are reassuring since there is no obvious reason why agricultural suitability should have a differential impact after 1700.

In the even numbered columns we also control for each country's suitability for cultivating other New World crops. This is important since New World crops, other than potatoes, were also introduced to the Old World. These other New World crops include maize, tomatoes, chilli peppers, cacao, and the sweet potato. From the FAO, suitability data are also available for sweet potatoes and for two types of maize (silage maize and grain maize). Using this additional data, we calculate the proportion of each country's land that can grow any New World food crop. We do

this by calculating for our four New World crops (potatoes, silage maize, grain maize, and sweet potatoes) the proportion of land that yields at least 40% of the potential yield. We then calculate, for each country, the maximum of the four different New World crop variables. The resulting measure is the maximum amount of land in each country that can grow one of the four New World food crops. We denote this variable $NWCrops_i$, where NW denotes ‘New World’.⁵

As shown the estimated effect of potatoes are robust to adding this control. As well, including the control tends to increase the magnitude of the coefficient of the potato interaction. This suggests that the estimated potato coefficients do not simply capture the benefits to population and urbanization of other New World Crops. The estimated coefficients for $NWCrops_i \times I_t^{Post}$ are negative and only significant when the dependent variable is log population. These estimates do not provide evidence that the other New World Food crops, sweet potatoes or maize, had a positive impact on population or urbanization. This fact is not surprising once one examines the history and nutritional characteristics of these two foods.

Maize is unable to rival potatoes in terms of nutrients or calories. Further, while one can subsist on a diet of potatoes and little else, this is not true of maize. Significant consumption of maize is associated with Pellagra, which is a disease caused by niacin deficiency. It was first observed among poor populations throughout Europe, the Middle East, and the United States whose diet relied heavily on corn. The effects of Pellagra include skin disorders, digestion disorders, mental disorders, and death. The disease was first observed in the 1730s in Italy and even today continues to affect poor populations with diets that rely too heavily on corn. An additional adverse effect of a primarily corn diet is protein deficiency (Messer, 2000a). Given the negative effects associated with diets too heavily dependent on corn, it is not surprising that the data indicate that corn did not have the same positive effects as potatoes.

Although sweet potatoes are very nutritious, there are two reasons why they may have not have had a large impact on population growth and economic development. First, the archaeological evidence suggests that sweet potatoes reached Oceania long before European contact with the New World. Therefore, their impact on the increase in population and urbanization growth after 1700 will be diminished by this fact. For many of the countries in our sample, their impact would have been felt as early as 1000 AD (Hather and Kirch, 1991). As well, a close substitute to the sweet

⁵The results are similar if one calculates this variable as the average of the four New World food crop variables, rather than the maximum. As well, the results are similar if one constructs these variables excluding potatoes, so that the variables reflect the suitability for growing the ‘other’ New World food crops.

Table 3. Baseline difference-in-differences estimates.

	Dependent variable							
	In Population _{it}		Population growth _{it}		Urbanization rate _{it}		Change in urbanization _{it}	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Baseline difference-in-differences estimates								
<i>Potato</i> _{<i>i</i>} × <i>I</i> _{<i>t</i>} ^{Post}	1.527***	1.674***	0.893***	0.966***	17.25***	18.83***	0.149***	0.159***
	(0.244)	(0.227)	(0.093)	(0.094)	(4.88)	(4.68)	(0.037)	(0.036)
<i>AllCrops</i> _{<i>i</i>} × <i>I</i> _{<i>t</i>} ^{Post}	0.163	0.883**	-0.271***	0.088	-3.06**	4.63	-0.031**	0.014
	(0.151)	(0.420)	(0.077)	(0.167)	(1.44)	(7.38)	(0.014)	(0.049)
<i>NWCrops</i> _{<i>i</i>} × <i>I</i> _{<i>t</i>} ^{Post}		-1.13**		-0.561***		-12.03		-0.070
		(0.556)		(0.216)		(10.59)		(0.068)
Country fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Time period fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.97	0.98	0.64	0.64	0.48	0.48	0.25	0.25
Clusters	129	129	129	129	129	129	129	129
Observations	900	900	770	770	900	900	770	770
Panel B. Difference-in-differences estimates with country-specific time trends								
<i>Potato</i> _{<i>i</i>} × <i>I</i> _{<i>t</i>} ^{Post}	1.145***	1.228***	0.971***	1.032***	12.62**	14.00**	0.092***	0.094***
	(0.224)	(0.223)	(0.149)	(0.150)	(5.93)	(5.54)	(0.028)	(0.027)
<i>AllCrops</i> _{<i>i</i>} × <i>I</i> _{<i>t</i>} ^{Post}	-0.103	0.340	-0.254	0.131	-4.06**	3.38	-0.025*	-0.012
	(0.139)	(0.338)	(0.103)	(0.212)	(1.87)	(6.49)	(0.015)	(0.063)
<i>NWCrops</i> _{<i>i</i>} × <i>I</i> _{<i>t</i>} ^{Post}		-0.688		-0.589**		-11.52		-0.019
		(0.338)		(0.300)		(9.39)		(0.091)
Country fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Time period fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Country-specific time trends	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.99	0.99	0.74	0.75	0.49	0.63	0.40	0.40
Clusters	129	129	129	129	129	129	129	129
Observations	900	900	770	770	900	900	770	770

Notes: The table reports estimates of equation (2). The unit of observation is an Old World country *i* in time period *t*. All regressions include time period fixed effects and country fixed effects. In panel B, 129 country-specific time trends are included. Standard errors are clustered at the country level. ***, **, and * indicate significance at the 1, 5 and 10% levels.

potato, the yam, had already spread throughout the Old World long before 1700 (O'Brien, 2000). This also serves to dampen the impact of the diffusion of sweet potato after the discovery of the Americas.

C. Robustness Checks and Sensitivity Analysis

The first robustness check that we perform is to include country specific time-trends to our estimating equation (2). More precisely, we include $\sum_c \alpha_c I_i^c \times Year_t$, where $Year_t$ is a continuous measure of time that takes on the values 1000, 1400, 1500, 1600, 1700, 1800, and 1900; and I_i^c denotes 129 indicator variables that takes on the value of one when an observation is for a particular country. Including these 129 additional control variables provides a demanding test of the robustness of our

results. Our estimate of interest $\hat{\beta}$ captures the effect that a country's ability to cultivate potatoes has on the increased population growth and economic development after 1700, relative to the period before 1700. If potato suitability affects the change after 1700, then it will also mechanically affect the average trend in the outcome variable between 1000 and 1900. Therefore, by controlling for country-specific time trends we are potentially capturing part of the effect of potato suitability.

The estimates with 129 country-specific time trends are included in our estimating equation are reported in panel B of table 3. The estimated magnitudes of the estimated effects of potatoes $\hat{\beta}$ tend to decrease slightly. This is consistent with the time trends capturing part of the effect of potatoes on the dependent variables. Despite the slight decrease in magnitudes, the coefficients remain highly significant.

We next check that our results are not driven by outliers in the data by examining the partial correlation plots for the potato interaction, $Potato_i \times I_t^{Post}$. The partial correlation plots for columns (2) and (6) of panel A are shown in figures 10 and 11. The partial correlation plots for the other specifications reported in table 3 are similar. A fact that is immediately apparent from the partial correlation plots is that the countries most affected by the introduction of the potato were not only the early industrializing Western European countries, but many were the Eastern European countries, such as Belarus, Latvia, Lithuania, and Poland. This is important because a concern is that the results may be driven by Western European countries, which may have experienced an increase in population growth and economic development after 1700 for reasons unrelated to their adoption of potatoes.

The partial correlation plots also highlight two groups of countries that are potentially influential outliers. The first group are the observations in the most eastern portion of figure 11. These are observations for Belarus (BLR), Denmark (DNK), Latvia (LVA), and Lithuania (LTU). As a check that our estimates are not being driven by this small group of countries, we re-estimate equation (2) with these countries omitted from the sample. The results are reported in panel A of table 4.⁶ As shown, omitting these countries tends to increase the magnitude of the estimated coefficients. A second group of potential outliers are countries that have very large residuals. These include Australia, New Zealand, Great Britain and Thailand. We re-estimate (2) after omitting these countries. These results are also reported in panel A of table 4. The results remain robust.

⁶We report estimates with the control for other New World crops included in the estimating equation. The results are similar whether we include this control or not.

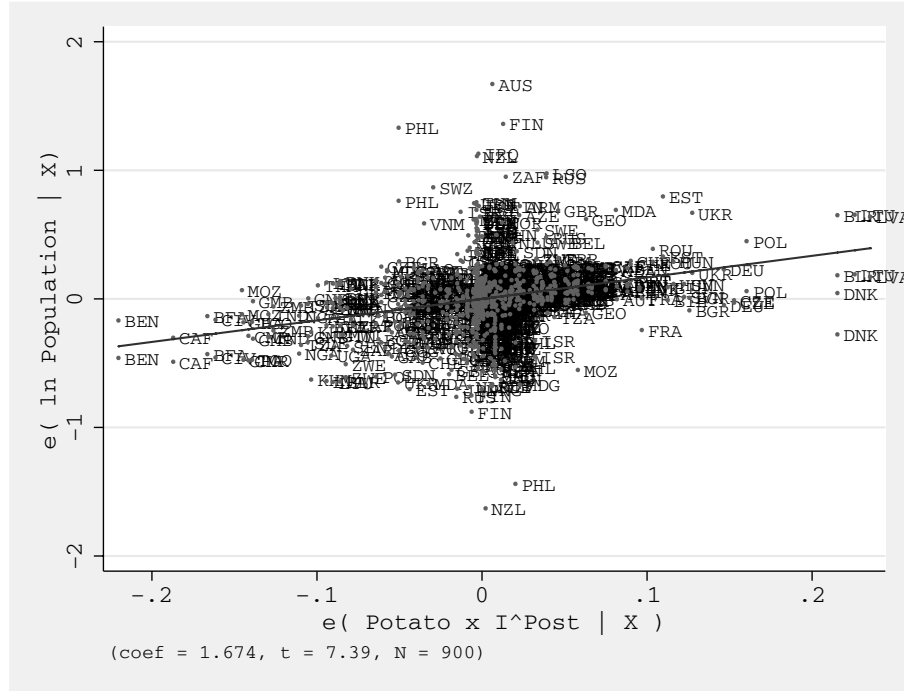


Figure 10. Partial correlation plot for $Potato_i \times I_t^{Post}$ from column (2) of table 3 panel A.

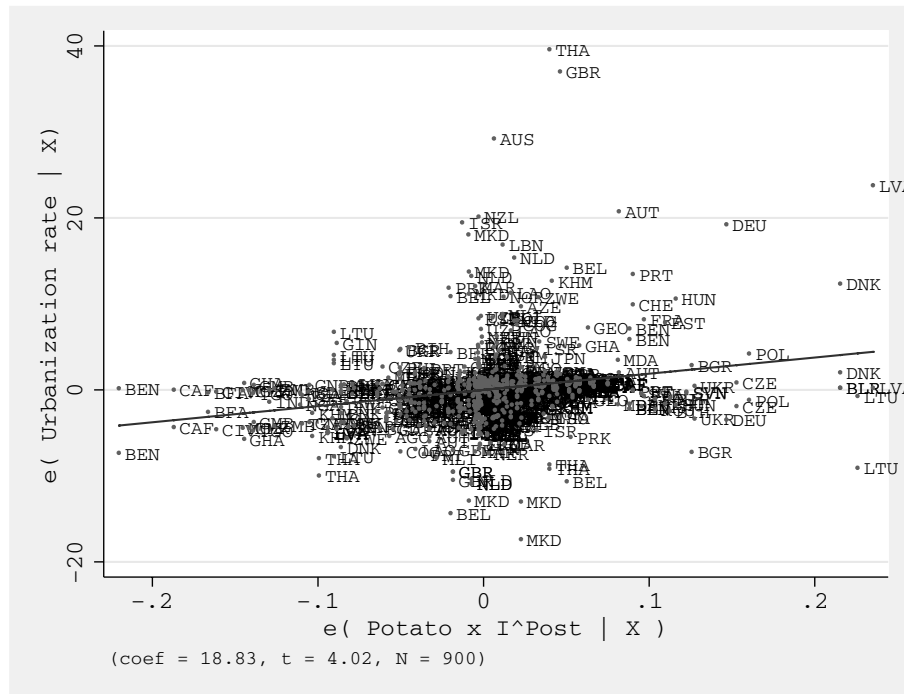


Figure 11. Partial correlation plot for $Potato_i \times I_t^{Post}$ from column (6) of table 3 panel A.

Finally, we simultaneously omit both groups of countries. Again, the results remain robust.

As we have noted, a potential concern with our potato suitability measure is the large number of countries that take on a value of zero. We re-estimate (2) using only countries for which the variable *Potato_i* takes on a positive value. The results are reported in panel B of table 4. As shown, the estimates are essentially identical to the estimates when the full sample is used. Therefore, the results are not being driven by the zero suitability countries.

An additional concern with our baseline estimates is that they may be biased by the inclusion of Western European countries which experienced the industrial revolution at approximately this same time period. Below, we attempt to control for alternative country characteristics that may make Western European countries different from other countries. However, as shown in panel B of table 4, even if we take a much more brut-force approach and omit all Western European countries from our sample, we obtain estimates similar to our baseline estimates.⁷ Similarly, if one goes a step further to omit all European countries from the sample, the results also remain robust. The coefficient for the potato interaction variable remains positive and statistically significant. The magnitude of the estimated coefficients actually increase significantly for all four of our dependent variables.

⁷The Western European countries that are dropped from the sample are: Belgium, Switzerland, Germany, Denmark, Spain, Finland, France, Great Britain, Ireland, Italy, Liechtenstein, Luxembourg, Netherlands, Norway, Portugal, and Sweden.

Table 4. Robustness of the results to the removal of outliers and to various subsamples.

	In Population _{<i>t</i>}			Population growth _{<i>t</i>}			Urbanization Rate _{<i>t</i>}			Change in urbanization _{<i>t</i>}		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A. Omitting potentially influential observations												
Omitted observations:	BLR, DNK, LVA, LTU	AUS, GBR, NZL, THA	Both groups	BLR, DNK, LVA, LTU	AUS, GBR, NZL, THA	Both groups	BLR, DNK, LVA, LTU	AUS, GBR, NZL, THA	Both groups	BLR, DNK, LVA, LTU	AUS, GBR, NZL, THA	Both groups
$Potato_i \times I_t^{Post}$	1.848*** (0.252)	1.667*** (0.226)	1.853*** (0.249)	1.023*** (0.122)	0.976*** (0.092)	1.023*** (0.120)	18.03*** (4.08)	16.88*** (4.42)	16.34*** (3.82)	0.156*** (0.036)	0.149*** (0.036)	0.148*** (0.036)
$AllCrops_i \times I_t^{Post}$	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
$NWCrops_i \times I_t^{Post}$	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
All fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.98	0.98	0.98	0.63	0.69	0.68	0.47	0.54	0.54	0.23	0.28	0.25
Clusters	126	125	122	126	125	122	126	125	122	126	125	122
Observations	879	874	853	752	749	731	879	874	853	752	749	731
Panel B. Robustness of results to various subsamples												
Omitted observations:	Zero suitability	Western Europe	All of Europe	Zero suitability	Western Europe	All of Europe	Zero suitability	Western Europe	All of Europe	Zero suitability	Western Europe	All of Europe
$Potato_i \times I_t^{Post}$	1.734*** (0.294)	1.775*** (0.194)	4.174*** (1.120)	0.939*** (0.118)	1.057*** (0.093)	2.027*** (0.830)	18.77*** (4.58)	13.38*** (4.82)	23.33*** (9.38)	0.148*** (0.034)	0.134*** (0.037)	0.199*** (0.094)
$AllCrops_i \times I_t^{Post}$	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
$NWCrops_i \times I_t^{Post}$	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
All fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.97	0.98	0.98	0.67	0.63	0.56	0.51	0.44	0.44	0.35	0.20	0.14
Clusters	78	115	96	78	115	96	78	115	96	78	115	96
Observations	543	803	670	464	687	573	543	803	670	464	687	573

Notes: The table reports estimates of equation (2). The unit of observation is an Old World country i in time period t . All regressions include, $AllCrops_i \times I_t^{Post}$, $NWCrops_i \times I_t^{Post}$, time period fixed effects, and country fixed effects. Standard errors are clustered at the country level. ***, **, and * indicate significance at the 1, 5 and 10% levels.

A general concern with our estimates is that a country's soil suitability for potato crops may be correlated with other country characteristics. The effect of these characteristics on population growth and economic development will be captured by the country fixed effects unless these characteristics affect our outcomes of interest differently in the post-1700 period relative to the pre-1700 period. We control for other likely country characteristics that may affect either population growth or economic development differently after 1700. This is done by including country specific variables interacted with our post-1700 indicator variable I_t^{Post} in equation (2) .

We begin by including a proxy variable that may capture country characteristics that affect population growth and economic development. In our population regressions, we include each country's average annual population growth between 1000 and 1400 interacted with the post 1700 indicator variable I_t^{Post} . In our urbanization regressions, we include the average annual change in urbanization between 1000 and 1400 interacted with the post 1700 indicator variable. The estimation results are reported in columns (1) and (6) of table 5. The estimated effect of potato suitability remains robust to the inclusion of this additional control variable. The coefficient remains positive and statistically significant.

Our next strategy is to include control variables that capture other potential determinants of the increasing gap between the population and incomes of Europe after 1700 relative to the period prior to 1700. It is well known that the income gap between Europe and the rest of the world increased significantly after 1700. If the cause of this great divergence is correlated with soil suitability for potatoes, then our estimates will be biased.

A recent study by Acemoglu *et al.* (2005) examines the determinants of Europe's divergent growth. The authors show that the rise of Europe is primarily a rise of Atlantic traders with access to the lucrative three corner trade between the Americas, Africa and Europe. We control for this determinant by including an interaction between an indicator variable that equals one if a country was a European Atlantic trader (as defined by Acemoglu *et al.* (2005)) and I_t^{Post} . The estimates are reported in columns (2) and (7) of table 5. The results remain robust to the inclusion of this control variable.

In their study, Acemoglu *et al.* (2005) also use an alternative measure of an Atlantic trader, which is a country's European Atlantic coastline divided by land area. The results using this alternative measure, which we do not report to conserve space, are qualitatively identical. Other determinants for Europe's divergence have also been put forth. One explanation is that many

Table 5. Difference-in-differences estimates, controlling for additional determinants.

	Dependent variable									
	ln Population _{it}					Population growth _{it}				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$Potato_i \times I_t^{Post}$	1.422*** (0.188)	1.676*** (0.211)	1.430*** (0.394)	1.497*** (0.235)	0.807*** (0.335)	0.946*** (0.096)	0.999*** (0.084)	0.779*** (0.163)	0.883*** (0.098)	0.672*** (0.178)
Pop Growth (1000-1400) _i $\times I_t^{Post}$	3.12*** (0.539)				3.27 (0.452)	0.210 -0.335				0.291 (3.42)
Atlantic Trader _i $\times I_t^{Post}$		-0.011 (0.136)			-0.059 (0.109)		-0.185*** (0.069)			-0.203*** (0.076)
Tropics _i $\times I_t^{Post}$			-0.106 (0.163)		-0.199 (0.125)			-0.081 (0.067)		-0.097 (0.070)
Slaves Exports _{it}				-0.008* (0.005)	-0.007 (0.005)				-0.004** (0.002)	-0.004* (0.002)
$AllCrops_i \times I_t^{Post}$	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
$NWCrops_i \times I_t^{Post}$	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
All fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.98	0.98	0.98	0.98	0.98	0.63	0.65	0.64	0.64	0.64
Clusters	127	129	129	129	127	127	129	129	129	127
Observations	889	900	900	900	889	762	770	770	770	762
	Urbanization rate _{it}					Change in urbanization _{it}				
$Potato_i \times I_t^{Post}$	18.44*** (4.82)	17.58*** (4.37)	13.61** (5.36)	18.24*** (4.45)	13.32** (6.06)	0.158*** (0.036)	0.161*** (0.033)	0.110*** (0.040)	0.147*** (0.033)	0.103** (0.045)
Change in urban. (1000-1400) _i $\times I_t^{Post}$	37.09 (59.29)				37.70 (59.28)	0.018 (0.39)				0.017 (0.370)
Atlantic Trader _i $\times I_t^{Post}$		7.04** (3.15)			6.90** (3.30)		-0.015 (0.019)			(0.019) (0.022)
Tropics _i $\times I_t^{Post}$			-2.26* (1.33)		-1.49 (1.42)			-0.021** (0.009)		-0.021** (0.010)
Slaves Exports _{it}				-0.027 (0.049)	-0.021 (0.051)				-0.0006* (0.0003)	-0.0006 (0.0003)
$AllCrops_i \times I_t^{Post}$	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
$NWCrops_i \times I_t^{Post}$	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
All fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.48	0.49	0.48	0.48	0.50	0.24	0.25	0.25	0.25	0.24
Clusters	127	129	129	129	127	127	129	129	129	127
Observations	889	900	900	900	889	762	770	770	770	762

Notes: The table reports estimates of equation (2). The unit of observation is an Old World country i in time period t . All regressions include, $AllCrops_i \times I_t^{Post}$, $NWCrops_i \times I_t^{Post}$, time period fixed effects, and country fixed effects. Standard errors are clustered at the country level. ***, **, and * indicate significance at the 1, 5 and 10% levels.

European countries benefited from a history of Roman rule. Acemoglu *et al.* (2005) construct two measures for these determinants of Europe's divergent growth: an indicator variable that equals one if a country was part of the Roman Empire and an indicator variable that equals one if a country's dominant religion was Protestant (in 1600). We control for the interaction terms of these variables with an indicator variable for post 1700. The results remain robust to controlling for either of these alternative determinants of Europe's success. Again, to conserve space these results are not reported in table 5.

Overall, these results, combined with our previous results showing that our baseline estimates are completely robust to the exclusion of Western European countries, provide strong evidence that our results are not being driven by the rise of Europe after 1700.

We also consider potential determinants of population growth and economic development in parts of the Old World outside of Europe. The most obvious candidate determinant is colonial rule. It is clear that some former colonies, such as Canada, the United States, Australia and New Zealand, have prospered, while most of the rest remain less developed. The timing of our estimates may therefore be biased by country characteristics that affected the impact of colonial rule on population growth and economic development.

Acemoglu, Johnson, and Robinson (2001) have shown that an important determinant of the effect of colonial rule on subsequent development was the initial disease environment. In areas with less disease, better institutions were implemented by the European colonizers, and therefore post-1700 population growth and economic development may be disproportionately higher relative to their pre-1700 levels. To capture this potentially omitted factor we control for an important determinant of the disease environment, the proportion of a country's land that is defined as being tropical. This measure is taken from Nunn and Puga (2007). As before, we interact the measure with I_t^{Post} and include it as an additional control in equation (2). The results are reported in columns (3) and (8) of table 5. Again, our potato estimates are robust to the inclusion of this control variable.⁸

The final factor that we consider is the trade in slaves in Africa. The slave trades reached their height in the 1700s, which is approximately the same time that potatoes were being adopted globally. If countries that were least able to adopt potatoes were also African countries from which the

⁸The results are also robust to controlling for the strength and pervasiveness of malaria vectors, using a measure constructed by Kiszewski, Mellinger, Spielman, Malaney, Sachs, and Sachs (2004). The country level measure is constructed by Nunn and Puga (2007).

most slaves were taken, then this may explain part of the effect of potatoes on increased population growth and economic development after 1700. To capture the potential effects of Africa's slave trades, we include a country-specific measure of the number of slaves taken during the 100 years prior to period t . The data are taken from Nunn (2008). The results are reported in columns (4) and (9) of table 5. As shown, including this control changes our estimated potato coefficients very little.

In columns (5) and (10) we include all four measures together. Although, the potato coefficients are reduced slightly, they remain statistically significant. Overall, the results of table 5 show that our results are robust to including the most likely alternative determinants of countries increased growth in population and economic development after 1700, relative to the pre-1700 period. Around 1700 there were many other important changes occurring in the world: the industrial revolution, colonial rule, and the slave trade. We include controls to account for these events and find that our results remain robust.

D. Additional Estimation Concerns

One concern with our estimates that we have not yet addressed is the potential effect of international trade. If potatoes were freely tradable then countries could benefit from the introduction of potatoes even if that country could not cultivate potatoes. This could occur, for example, if a country's trading partners began to produce and export potatoes. In this case, countries located close to countries that were able to adopt potatoes would also benefit, even if potatoes could not be cultivated within their own country. In this environment, the true benefit of potatoes will tend to be underestimated. This is because our estimates are obtained by comparing the difference between the evolution of population and economic development after 1700 between countries that could adopt potatoes to those that could not. If the countries that could not adopt potatoes also benefited from the introduction of potatoes because of international trade in potatoes, then the observed difference between this group and those that could adopt potatoes will be smaller and therefore the estimated impact of potatoes will be lower.

In reality, however, it is unlikely that this bias is qualitatively important. This is because potatoes are heavy and bulky with a very low value to weight ratio. This is primarily a result of the fact that 75–80% of potatoes are water. The result of this is that historically, and even today, potatoes are not a highly traded commodity.

Although we do not have data on the historic trade of potatoes, we do have data beginning in 1962. Although the amount of trade in potatoes would have been much lower prior to 1900 than in 1962, even in 1962 we find that there was very little international trade in potatoes. In 1962, the total world production of potatoes was 271 million tonnes. Of this production, only 2.8 million tonnes, or 1.02% were exported internationally. Despite improvements in transportation over time, potatoes continued to be consumed domestically. In 2005, just under 2.8% of potato production was exported internationally.⁹

E. Quantifying the Impact of Potatoes

It is well known that after 1700 the world experience an unprecedented increase in the growth of population and in economic development. This well established fact can be seen in figure 12, which shows the evolution of total Old World population between 1000 and 1900. It is clear from the figure that relative to the period prior to 1700, after 1700 there is a clear increase in both the level and the growth rate of population. This is also shown in the first three rows of table 6. The first two rows report the averages of each of our four outcome variables across countries during the two time periods. The first row reports averages for the pre-1700 period and the second row reports the averages for the post-1700 period. The third row reports the difference between these two averages. The table confirms that for all four of our outcome variables during the period after 1700 (relative to the period before 1700), countries witnessed a significant increase in average population, population growth, the urbanization rate, and the rate of change of urbanization.

To illustrate the magnitude of our estimates we calculate how much of these pre- and post-1700 differences can be attributed to the introduction of the potato. According to our definition of potato suitability, the average country has approximately 7.7% of its land suitable for cultivating potatoes.¹⁰ We take this as our measure of the average fraction of land that could be used to grow potatoes after 1700. Prior to 1700, since potatoes were not yet introduced, no country was able to grow potatoes and therefore this number was effectively 0%. The introduction of potatoes, therefore, increased this figure from 0 to 7.7%.

Our DD estimates provide a measure of the benefit of being able to cultivate potatoes on increased population growth and economic development after 1700. To be as conservative as

⁹Data are from the FAO's ProdSTAT and TradeSTAT databases.

¹⁰This figure is reported in the summary statistics table 8.

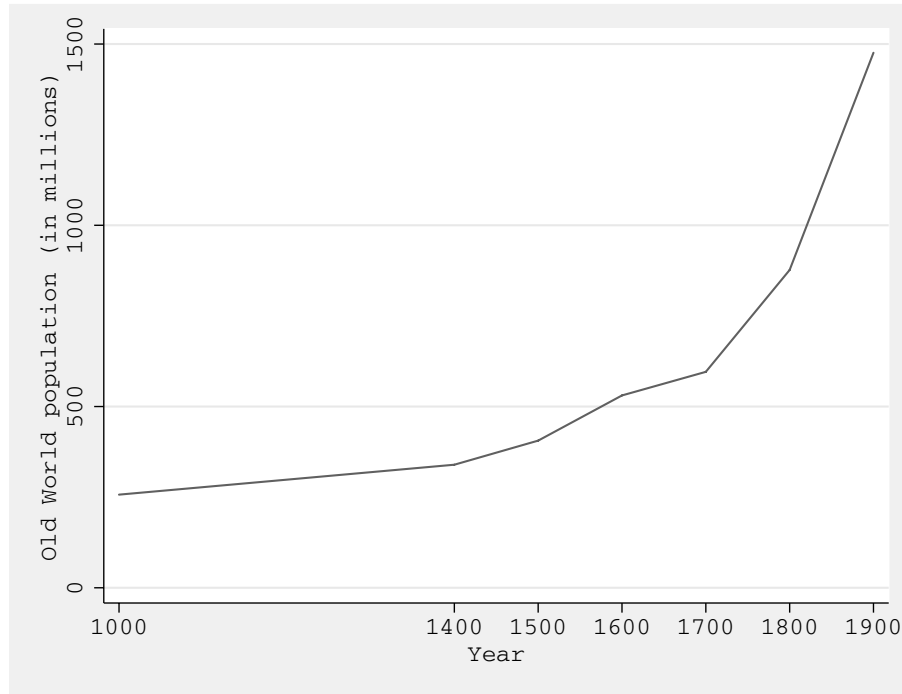


Figure 12. Total Old World population from 1000–1900.

Table 6. Calculating the percentage of the post-1700 increase in population growth and economic development explained by the introduction of potatoes.

	Outcome variable			
	$\ln \text{Population}_{it}$	Population growth _{it}	Urbanization rate _{it}	Change in urbanization _{it}
	(1)	(2)	(3)	(4)
(1) Pre-1700 average	-0.434	0.131	2.062	0.0004
(2) Post-1700 average	0.435	0.419	4.325	0.0217
(3) Difference: (2) - (1)	0.869	0.288	2.263	0.021
(4) Difference from Potatoes	0.062	0.052	1.026	0.008
Percent explained by potatoes: (4) ÷ (3)	7.2%	18.0%	45.3%	37.4%

Notes : The first row of the table reports the average outcome for all countries in each time period between 1000 and 1700. The second row reports the same averages for the time periods after 1700 (i.e., 1800 and 1900). The difference between the two averages is reported in row 3. The fourth row reports the estimated impact from the introduction of the potato. Details of these calculations are reported in the text. The final row reports the percentage of the total difference between the pre- and post-1700 periods that is explained by the introduction of potatoes. This is equal to row 4 divided by row 3.

possible, we use our lowest estimates, which are the estimates with our full set of control variables included in our estimating equation (2). These estimates are reported in columns (5) and (10) of table 5.

Using these estimates it is straight-forward to calculate the gains from the introduction of potatoes to the Old World. The introduction of potatoes: (i) increased the average population across Old World countries by 6.2% (i.e., $0.81 \times 0.077 = 0.062$), (ii) increased the average annual growth rate across Old World countries by 0.07 percentage points, (iii) increased the average urbanization rate across Old World countries by 1.03 percentage points, (iv) increased the average annual growth in the urbanization rate across Old World countries by 0.008 percentage points. These estimated effects are reported in the fourth row of table 6.

To help put these figures into perspective we calculate how much of the increase in our four outcome variables is explained by the introduction of potatoes. These numbers are reported in the final row of the table. Take as an example population growth. The average annual population growth was 0.13% per year between 1000 and 1700 and 0.42% per year between 1700 and 1900 and the difference was 0.29%. Our estimates imply that the introduction of potatoes accounts for 18.0% ($0.052/0.29 = 0.18$) of this increase. Similarly, for the change in urbanization, according to our estimates the introduction of potatoes account for 37.4% ($0.008/0.021 = 0.374$) of the post-1700 increase in the average annual change in the urbanization.

Because these figures may seem large to some, we want to be clear about what they mean. Take for example our figure of 18% for population growth. This does not mean that 18% of the total increase in population growth between 1000 and 1900 is explained by potatoes. Nor does it mean that 18% of the increase in population growth after 1700 is explained by potatoes. The statement is that after 1700, relative to the period before 1700, there is an increase in the average rate of population growth. Conceptually, this can be thought of as the kink in figure 12 at the year 1700. It is this kink, or difference in the average growth between the two periods, that is being explained.

5. Conclusions

We have examined one of the oldest and most fundamental issues in economic development: the interplay between the agricultural sector and economy wide economic growth and development. Relying on the unique shock to agricultural productivity brought about by the introduction of the potato to the Old World after the discovery of the Americas by Christopher Columbus, we

have estimated the impact of this agricultural productivity shock on population growth and long-term economic development. By exploiting this unique historic event, our difference-in-differences estimation strategy is able to provide a well identified estimate of the effects of a large positive shock to agricultural productivity.

According to our most conservative estimates, the introduction of the potato explains 18% of the observed post-1700 increase in population growth and 37% of the increase in the growth of urbanization. These results provide evidence for the notion that a positive agricultural productivity shock can spur economic development.

Appendix A. Data Appendix

Population data are taken from McEvedy and Jones (1978). Data on urban populations, defined as the number of people living in cities larger than 20,000 people, are from Chandler (1987), Bairoch (1988), and Modelski (2003). Dividing a country's total population by its land area we are able to calculate population density. Urbanization rates are calculated by dividing the total number of people living in a country's cities from Chandler (1987), Bairoch (1988), and Modelski (2003) by the total population of the country from McEvedy and Jones (1978). The resulting measure is the fraction of a country's population living in cities larger than 20,000.

Data on the suitability of soil for growing crops are from the FAO's *Global Agro-Ecological Zones* (GAEZ), 2000 database. The country-level data have been made publicly available and can be downloaded from: <http://www.fao.org/ag/AGL/agll/gaez/index.htm>. Data on crop suitability are available for 158 countries. For each country information is available on the total amount of land of different suitabilities for cultivating the crop in question. Land is classified into each of the following mutually exclusive categories: (i) very suitable land (80–100% of the maximum yield), (ii) suitable land (60–80%), (iii) moderately suitable land (40–60%), (iv) marginally suitable land (20–40%), and (v) not suitable land (0–20%). The measures constructed assuming rain fed conditions and are constructed for three different assumptions about the intensity of cultivation and intensity of input use. The three categories are: (i) high intensity, (ii) intermediate intensity, (iii) low intensity.

To construct our country-level measure of the suitability for the adoption of potatoes, we measure land that can grow white potatoes as land that is classified as “very suitable”, “suitable”, or “moderately suitable” under “intermediate intensity” of input use. In other words, we define land that can yield over 40% of the maximum yield under an intermediate intensity of input use as being suitable for potato cultivation. Our baseline measure of potato suitability is the percentage of a country's land that falls into this category.

Table 7. Documenting the strong relationship between urbanization and per capita income.

	Dependent variable: Urbanization rate _{it}							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
income _{it}	0.825*** (0.048)		0.880*** (0.042)		0.863*** (0.066)		0.936*** (0.073)	
ln (income _{it})		0.734*** (0.057)		0.953*** (0.059)		0.688*** (0.079)		1.07*** (0.114)
Country fixed effects	N	N	Y	Y	N	N	Y	Y
Time period fixed effects	N	N	N	N	Y	Y	Y	Y
R-squared	0.68	0.54	0.88	0.82	0.68	0.55	0.89	0.84
Observations	143	143	143	143	143	143	143	143

Notes: The unit of observation is an Old World country i in time period t . The dependent variable is the urbanization rate. Standardized beta coefficients are reported with standard errors in brackets. *** indicates significance at the 1% level.

Table 8. Summary Statistics.

Variable	Obs	Mean	Std. Dev.	Minimum	Maximum
ln Population _{it}	900	-0.185	1.729	-5.22	6.16
Population growth _{it}	770	0.228	0.270	-0.533	2.93
Urbanization rate _{it}	900	2.71	5.73	0.000	53.3
Change in urbanization _{it}	770	0.008	0.049	-0.429	0.404
Fraction of land suitable for potatoes: <i>Potatoes</i> _{it}	900	0.077	0.144	0.000	0.660
Fraction of land suitable for agriculture: <i>AllCrops</i> _{it}	900	0.289	0.237	0.000	0.807
Fraction of land suitable for New World crops: <i>NWCrops</i> _{it}	900	0.169	0.175	0.000	0.690

Notes: A unit of observations is an Old World country i in time period t . Population is measured in millions of people. Population growth is the average annual percentage change in population. The Urbanization rate is the percentage of the population living in cities with more than 20,000 inhabitants. Change in urbanization is the average annual change in the urbanization rate.

References

- Acemoglu, Daron, Simon Johnson, and James A. Robinson, "The Colonial Origins of Comparative Development: An Empirical Investigation," *American Economic Review*, 91 (2001), 1369–1401.
- , "Reversal of Fortune: Geography and Institutions in the Making of the Modern World Income Distribution," *Quarterly Journal of Economics*, 117 (2002), 1231–1294.
- , "The Rise of Europe: Atlantic Trade, Institutional Change and Economic Growth," *American Economic Review*, 95 (2005), 546–579.
- Bairoch, Paul, *Cities and Economic Development: From the Dawn of History to the Present* (University of Chicago Press, Chicago, 1988).
- Burkill, I.H., *A Dictionary of the Economic Products of the Malay Peninsula* (Crown Agents for the Colonies, London, 1935).
- Chandler, Tertius, *Four Thousand Years of Urban Growth: An Historical Census* (The Edwin Meller Press, Lewiston, U.S.A., 1987).
- Connell, K.H., "The Potato in Ireland," *Past and Present*, 23 (1962), 57–71.
- Cullen, L.M., "Irish History Without the Potato," *Past and Present*, 40 (1968), 72–83.
- Davidson, Stanley, R. Passmore, J.F. Brock, and A.S. Truswell, *Human Nutrition and Dietetics* (Churchill Livingstone, New York, 1975).
- DeLong, J. Bradford, and Andrei Shleifer, "Princes and Merchants: City Growth Before the Industrial Revolution," *Journal of Law and Economics*, 36 (1993), 671–702.
- Gollin, Douglas, Stephen Parente, and Richard Rogerson, "The Role of Agriculture in Development," *American Economic Review Papers and Proceedings*, 92 (2002), 160–164.
- Hather, Jon, and Patrick V. Kirch, "Prehistoric Sweet Potato (*Ipomoea Batatas*) from Mangaia Island, Central Polynesia," *Antiquity*, 65 (1991), 887–893.
- Hughes, R.E., "Scurvy," in Kenneth F. Kiple, ed., *The Cambridge World History of Food, Volume II* (Cambridge University Press, New York, 2000), 988–1000.
- Hwa, Erh-Cheng, "The Contribution of Agriculture to Economic Growth: Some Empirical Evidence," *World Development*, 16 (1988), 1329–1339.
- Johnston, Bruce F., and John W. Mellor, "The Role of Agriculture in Economic Development," *American Economic Review*, 51 (1961), 566–593.
- Kiszewski, Anthony, Andrew Mellinger, Andrew Spielman, Pia Malaney, Sonia Ehrlich Sachs, and Jeffrey Sachs, "A Global Index of the Stability of Malaria Transmission," *American Journal of Tropical Medicine and Hygiene*, 70 (2004), 486–498.
- Kögel, Tomas, and Alexia Prskawetz, "Agricultural Productivity Growth and Escape from the Malthusian Trap," *Journal of Economic Growth*, 6 (2001), 337–357.
- Langer, William L., "Europe's Initial Population Explosion," *American Historical Review*, 69 (1963), 1–17.
- , "American Foods and Europe's Population Growth," *Journal of Social History*, 8 (1975), 51–66.

- Laufer, B., *The American Plant Migration. Part I: The Potato Archeology Series*. (Field Museum of National History, Chicago, 1938).
- Lee, James, "Food Supply and Population Growth in Southwest China, 1250–1850," *Journal of Asian Studies*, 41 (1982), 711–746.
- Lewis, Arthur, "Economic Development with Unlimited Supplies of Labor," *Machester School of Economic and Social Studies*, 22 (1954), 139–191.
- Maddison, Angus, *The World Economy: Historical Statistics* (Organisation for Economic Co-operation and Development, Paris, 2003).
- Malthus, Thomas R., *An Essay on the Principle of Population* (Norton (1st Edition Reprint 1976), New York, 1798).
- Matsuyama, Kiminori, "Agricultural Productivity, Comparative Advantage, and Economic Growth," *Journal of Economic Theory*, 58 (1992), 317–334.
- McEvedy, Colin, and Richard Jones, *Atlas of World Population History* (Penguin Books, Harmondsworth, 1978).
- McNeill, Wiliam H., "How the Potato Changed the World's History," *Social Research*, 66 (1999), 67–83.
- Messer, Ellen, "Maize," in Kenneth F. Kiple and Kriemhild Coneè Ornelas, eds., *The Cambridge History of World Food, Volume I* (Cambridge University Press, New York, 2000a), 97–112.
- , "Potatoes," in Kenneth F. Kiple and Kriemhild Coneè Ornelas, eds., *The Cambridge History of World Food, Volume I* (Cambridge University Press, New York, 2000b), 187–201.
- Mitchell, B.R., *International Historical Statistics: Africa, Asia and Oceania, 1750-1993* (Palgrave MacMillan, London, 1998).
- , *International Historical Statistics: Europe* (Palgrave MacMillan, London, 2003).
- Modelski, George, *World Cities: -3000 to 2000* (Faros, Washington, D.C., 2003).
- Mokyr, Joel, "Irish History with the Potato," *Irish Economic and Social History*, 8 (1981), 8–29.
- Ngai, Rachel, "Barriers and the Transition to Modern Growth," *Journal of Monetary Economics*, 51 (2003), 1353–1383.
- Nunn, Nathan, "The Long-Term Effects of Africa's Slave Trades," *Quarterly Journal of Economics*, 123 (2008), 139–176.
- Nunn, Nathan, and Diego Puga, "Ruggedness: The Blessing of Bad Geography in Africa," (2007), mimeo.
- O'Brien, Patricia J., "Sweet Potatoes and Yams," in Kenneth F. Kiple and Kriemhild Coneè Ornelas, eds., *The Cambridge History of World Food, Volume I* (Cambridge University Press, New York, 2000), 207–218.
- Pandey, S.K., and S.K. Kaushik, "Origin, Evolution, History and Spread of Potato," in S.M. Paul Khurana, J.S. Minhas, and S.K. Pandey, eds., *The Potato : Production and Utilization in Sub-Tropics* (Mehta, New Delhi, 2003).

Ranis, Gustav, and John C.H. Fei, "A Theory of Economic Development," *American Economic Review*, 51 (1961), 533–565.

Reader, John, *Propitious Esculent: The Potato in World History* (William Heinemann, London, 2008).

Salaman, Radcliffe, *The History and Social Influence of the Potato* (Cambridge University Press, Cambridge, 1949).

Tiffin, Richard, and Xavier Irz, "Is Agriculture the Engine of Growth?" *Agricultural Economics*, 35 (2006), 79–89.

U.S. Department of Agriculture, *USDA National Nutrient Database for Standard Reference, Release 20* (U.S. Department of Agriculture, Agricultural Research Service, Washington, D.C., 2007).

Young, Arthur, *The Farmer's Tour through the East of England, Volume 4* (W. Strahan, London, 1771).