THE POTATO'S CONTRIBUTION TO POPULATION AND URBANIZATION: EVIDENCE FROM A HISTORICAL EXPERIMENT*

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We exploit regional variation in suitability for cultivating potatoes, together with time variation arising from their introduction to the Old World from the Americas, to estimate the impact of potatoes on Old World population and urbanization. Our results show that the introduction of the potato was responsible for a significant portion of the increase in population and urbanization observed during the eighteenth and nineteenth centuries. According to our most conservative estimates, the introduction of the potato accounts for approximately one-quarter of the growth in Old World population and urbanization between 1700 and 1900. Additional evidence from within-country comparisons of city populations and adult heights also confirms the cross-country findings. *JEL* Codes: J1, N1N5, O14.

I. INTRODUCTION

Between 1000 and 1900, world population grew from under 300 million to 1.6 billion, and the share of population living in urban areas more than quadrupled, increasing from two to over nine percent. As shown in Figure I, the increase accelerated dramatically over time and occurred almost entirely towards the end of the period. The determinants of these phenomena have been of much interest to economists, demographers, and historians alike.[1] This study uses country-level historical data on population and urbanization to empirically investigate the extent to which this historical

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1. For studies in the growth literature that have focused on the link between population increase and factors such as per capita incomes, see Galor and Weil (2000), Jones (2003), and Voigtländer and Voth (2006). For micro-level studies of the determinants of increased life expectancy, see the literature review provided by Cutler, Deaton, and Lleras-Muney (2006).

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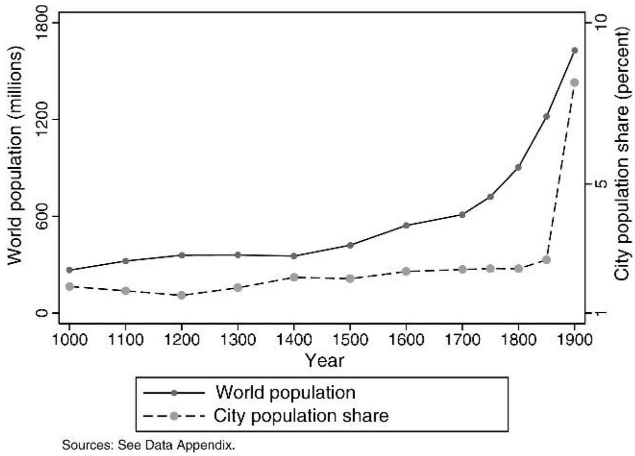

FIGURE I
Growth in World Population and Urbanization, 1000–1900

increase is due to the introduction of potatoes from the New World to the Old World, by which we mean the entire Eastern Hemisphere.

Potatoes provide more calories, vitamins, and nutrients per area of land sown than other staple crops. The potato's role in increasing population and promoting economic development has been a subject of much discussion amongst scholars across a variety of disciplines (e.g., Langer 1963; McNeill 1948, 1999; Salaman 1949). For example, historian William Langer (1963, p. 14) argues that within Europe, "the spread of the potato culture everywhere corresponded with the rapid increase of population." Potatoes dramatically improved agricultural productivity and provided more calories and nutrients relative to preexisting Old World staples. In *The Wealth of Nations*, Adam Smith extols the advantages of potatoes over preexisting staples in Europe, writing that "the food produced by a field of potatoes is ... much superior to what is produced by a field of wheat. ... No food can afford a more decisive proof of its nourishing quality, or of its being peculiarly suitable to the health of the human constitution" (Smith 1776, pp. 67–68).[2]

2. Other historians have attributed even greater significance to the potato. McNeill (1999, p. 67), in an article titled "How the Potato Changed World History," 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

Similar observations have been made outside of Europe. A particularly interesting example comes from anthropologist Christoph von Fürer-Haimendorf (1964), who argues that the introduction of the potato into Nepal significantly increased food production and agricultural surplus. He writes that "the population of Khumbu was a fraction of its present size until the middle of the nineteenth century and there can be no doubt that the great increase of the last hundred years coincided with the introduction and spread of the potato" (pp. 9–10).[3] Another example is from the famous Japanese scholar Takano Chôei, who wrote of the benefits of the potato in his 1836 treatise *Ni butsu kô*. He argued that extensive cultivation of potatoes would cure many social ills of the empire by alleviating food demands from a growing population (Laufer 1938, p. 83).

Despite qualitative accounts of the benefits of the potato to the Old World, empirical evidence quantifying the overall impact of the potato is scarce. This is no doubt partly due to the estimation difficulties caused by the endogeneity of potato adoption. First, there is an issue of reverse causality. The adoption of potatoes might have caused population growth, but alternatively, latent population pressure and the associated demand for food might have caused the adoption of potatoes. A number of historians have argued for the latter relationship (e.g., Salaman 1949; Connell 1962; Cullen 1968). The second problem is joint determination. Both population growth and the adoption of new agricultural technologies can be the outcome of a third unobserved factor.

To the best of our knowledge, the only existing empirical study attempting to estimate the causal effect of potatoes is a study by Joel Mokyr (1981), in which he examines the relationship between potato adoption and population growth across Irish counties in 1845. He addresses endogeneity issues by estimating a system of two equations using 2SLS, instrumenting for potato cultivation

1950." He continues, writing that "an essential—but by no means the only—factor explaining the surprising rise of the west . . . was the extra food that potato fields made available to the peoples of northern Europe. It is certain that without potatoes, Germany could not have become the leading industrial and military power of Europe after 1848, and no less certain that Russia could not have loomed so threateningly on Germany's eastern border after 1891" (p. 82).

3. Von Fürer-Haimendorf also argues that the increase in agricultural surplus from the potato was responsible for the sophisticated Buddhist civilization that developed in the Sherpa Khumbu region of Eastern Nepal (von Fürer-Haimendorf 1964, pp. 10–11).

with per capita income (intended to capture the demand for potatoes), the capital to labor ratio (intended to capture the supply of manure), the standard deviation of altitude, and the proportion of land classified as "improvable" for tillage but not currently under cultivation (both of which are intended to capture geographic features that increased potato adoption). Mokyr finds that potato cultivation resulted in a statistically significant increase in population growth. He finds no evidence of the reverse causal relationship—that the potato was adopted in response to rapid population growth.[4]

The principal contribution of our study is to provide a rigorous quantitative analysis of the historical role of potatoes in increasing population and urbanization. We expand the scope of Mokyr's analysis by examining the effect of potatoes on the entire Old World during the eighteenth and nineteenth centuries and by examining urbanization, city growth, and adult height in addition to population. Our estimation strategy exploits two sources of variation. The first is time variation arising from the introduction of potatoes as a field crop in the Old World. Potatoes did not exist in the Old World for most of history. They are native to South America and were first discovered by Europeans during the voyages of Columbus. Potatoes were widely adopted as a field crop in Europe towards the end of the seventeenth and beginning of the eighteenth centuries. Their cultivation then spread to the rest of the Old World, mainly through European sailors and missionaries. The second source of variation is cross-sectional and arises from differences in countries' suitability for cultivating potatoes, as determined by time-invariant geoclimatic conditions. Conditional on access to potatoes, regions that are more suitable for potato cultivation will be able to increase food production more. Our identification strategy relies on the interaction of the two sources of variation, and only the interaction can be interpreted as plausibly exogenous. Our strategy, similar in spirit to a differences-in-differences (DD) strategy, compares population and urbanization levels between Old World countries that were more suitable for potato cultivation to regions that were less suitable, before and after potatoes were adopted in the Old World.

4. Additional evidence about the effects of the potato, although not causally identified, comes from Baten and Murray (2000). The study examines the determinants of the heights of 4,100 male and female prisoners from Bavaria between 1856 and 1908. One of their findings is that prisoners from regions with greater potato production were taller.

Our strategy shares most of the advantages and disadvantages of a standard DD strategy. On the one hand, it allows us to control for both country and time-period fixed effects so that all time-invariant differences across countries—such as geography, food preferences, or institutions (to the extent that they change slowly over time)—and secular changes over time—such as global improvements in health, sanitation, and technological advancements—are controlled for. On the other hand, the strategy relies on there being no other shocks occurring around the same time that potatoes were adopted that are correlated with countries' suitability for potato cultivation. We address this identification concern by directly controlling for time- and country-varying factors that might bias our estimates. In the baseline estimates, we control for potentially important characteristics, each interacted with the full set of time-period indicator variables. This allows the effect of each factor to vary flexibly over time. The characteristics include a country's suitability for cultivating the Old World staple crops wheat and rice, as well as three geographic characteristics that are correlated with potato suitability: terrain ruggedness, elevation, and the presence of a tropical climate. We also control for a number of characteristics that have been identified as being important for historical growth and development.

We find that Old World regions that were suitable for potato cultivation experienced larger increases in population and urbanization after the introduction of potatoes. The estimates are robust to a number of sensitivity checks, which include controlling for a large number of alternative determinants of population and economic growth. These include legal origin, identity of the colonizer, the prevalence of disease (measured as distance from the equator and potential prevalence of malaria), distance from the coast, a history of Roman rule, the prevalence of Protestantism, being an Atlantic trader, and the historical volume of the slave exports. In addition, we show that we obtain similar results when we examine variation across countries within continents. Together, the results suggest that it is unlikely that our findings are simply capturing other historical determinants of economic development, including those factors that led to the divergence of Europe from the rest of the world.

To assess the magnitudes of our estimated effects, we calculate how much of the increase from 1700 to 1900 in Old World population and urbanization can be explained by the introduction of the potato. Our baseline estimates suggest that the potato accounts for approximately 25–26 percent of the increase in total population and 27–34 percent of the increase in urbanization.

To verify our cross-country estimates, we use our estimation strategy to examine within-country variation in city population growth and adult heights (a conventional measure of the nutritional investments made during an individual's years of growth). Looking within countries, we find that the adoption of potatoes spurred city growth: more suitable locations experienced faster relative population growth after the diffusion of the potato. Using information from military records of French soldiers born in the seventeenth and eighteenth centuries, we show that potatoes also increased adult height. Our estimates suggest that for villages that were fully suitable for potato cultivation, the introduction of the potato increased average adult heights by approximately one-half inch.

These findings contribute to several existing literatures. First, our findings add to the debate about the importance of improvements in nutrition in explaining the historical decline in mortality and increase in life expectancy (e.g., Fogel 1984, 1994, 2004; McKeown 1976; Livi-Bacci 1991). Our results provide evidence of a causal effect of access to improved nutrition on population growth. Second, our findings also contribute to the understanding of the relationship between agricultural productivity and aggregate economic growth. Because of reverse causality and omitted variables bias, identifying the causal link between agricultural productivity and economic growth is difficult.[5] Our findings provide evidence that increased agricultural productivity can lead to increased economic growth, as measured by urbanization rates.

Finally, our findings contribute to the historical debate about the importance of the Columbian Exchange for Old World living standards. The traditional view has been that the period of globalization following the discovery of the New World did not have significant effects on Old World living standards until the early nineteenth century (e.g., O'Rourke and Williamson 2002). This has been challenged by recent studies which, for example, have found that the growth of Atlantic traders such as Great Britain accelerated relative to the rest of Europe starting in the sixteenth century (Acemoglu, Johnson, and Robinson 2005), or that the increased availability of certain commodities such as sugar, tea,

5. Existing empirical studies, such as Tiffin and Irz (2006), have attempted to infer the effect of agriculture on economic development by examining panel data and employing lags and conducting Granger causality tests.

coffee, and tobacco increased the welfare of the English population prior to the nineteenth century (Hersh and Voth 2009). Our finding that potatoes positively affected population starting in the eighteenth century is consistent with the more recent view.

The paper is organized as follows. Section II provides a discussion of the nutritional and historical background of potatoes, while Section III outlines the conceptual framework. Section IV describes the data used in the analysis. Section V presents the empirical strategy and baseline results. Section VI reports additional robustness checks, including our within-country estimates examining city populations and adult heights. Section VII offers concluding remarks.

II. Background

II.A. Virtues of the Potato

From a nutritional standpoint, potatoes were superior to preexisting staple crops because they provided more vitamins and nutrients and they provided a greater supply of calories. Because potatoes contain nearly all important vitamins and nutrients, they support life better than any other crop when eaten as the sole article of diet (Davidson et al. 1975; Reader 2008). Humans can have healthy diets from consuming potatoes, supplemented with only dairy, which contain the two vitamins not provided for by potatoes, vitamins A and D (Connell 1962; Davidson et al. 1975).[6] Historically, this was the typical Irish diet, which although monotonous, was able to provide sufficient calories, vitamins, and nutrients (Connell 1962; Burton 1948, p. 189).

According to the U.S. Department of Agriculture (2007), a medium potato (150 grams/5.3 ounces) with the skin provides 29.55 milligrams of vitamin C (45 percent of the daily value [DV]). This is important since other staple crops such as wheat, oats, barley, rice, and maize do not contain any vitamin C, a necessary deterrent for scurvy. For much of the Old World, the potato provided the only source of vitamin C and protection against scurvy.[7]

6. Dairy is not actually necessary for vitamin D because humans produce it after absorbing sunlight.

7. As an example, the average Irish diet of 4.5 to 6.5 kilograms of potatoes per day provided forty to sixty times the quantity of vitamin C required to prevent scurvy (Hughes 2000). An alternative source of vitamin C in the Old World was turnips (although potatoes provide more vitamin C than turnips). Turnips were also relatively hardy in cold weather. Some have argued that they played an important

TABLE I
AVERAGE CROP YIELDS OF ENGLISH FARMS IN THE EIGHTEENTH CENTURY

	Average yield per acre		Energy value of crop	Acres of land needed to provide 42 megajoules 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 eighteenth-century England, recorded in Young's (1771, p. 20) *The Farmer's Tour through the East of England*, Volume 4; reproduced in Davidson et al. (1975).

A medium potato also contains 632 milligrams of potassium (18 percent of DV), 0.44 milligrams of vitamin B6 (20 percent 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 benefit of potatoes is that relative to Old World staples, they require less land to produce the same amount of calories (Connell 1951, p. 391; Langer 1963, pp. 11–12). Historical evidence of the caloric superiority of the potato over preexisting Old World crops is shown in Table I, which reports data collected in Arthur Young's (1771) survey of farming communities throughout England in the 1760s. The first two columns compare the average yields of oats, wheat, barley (three Old World staple crops), and potatoes. It shows that yields (measured in either bushels or kilograms) are well over ten times higher for potatoes relative to the other crops. To adjust for the fact that potatoes are 75–80 percent water and therefore naturally heavier and more bulky than the other crops, the third column compares the energy value of the yields reported in the first two columns. It shows that an acre of potatoes yields approximately three times more energy than an acre of each of the other crops. The final column shows the number of acres required to provide the total energy needs for a family of two adults and three young children, which is estimated to be 42 megajoules (or approximately 10,000 calories) per day.

role in providing nutrition for places such as England (Timmer 1969). However, relative to a potato, the turnip provides fewer nutrients, and more importantly, it provides less than one-quarter the calories (U.S. Department of Agriculture 2007).

While this family could subsist by cultivating a plot of only half an acre of potatoes, it would need to cultivate about 1.5 acres—three times as much land—if it were to grow wheat, oats, or barley. The data from Table I confirm historical reports that a single acre of land cultivated with potatoes and one milk cow was nutritionally sufficient for feeding a large family of six to eight (Langer 1963; McNeill 1999).

Although there is a consensus among historians that potatoes required less land to produce the same amount of calories, it is less clear whether potatoes required more or less labor than Old World cereals. Turner (1996, Ch. 6) reports historical labor requirements data from an Irish tenant farm collected between 1837 and 1885. In the sample, potatoes required approximately 2.5 times more labor input per acre cultivated than wheat, oats, or barley. However, the figure does not account for the fact that potatoes yield three times more calories per acre (recall the figures from Table I). Therefore, in terms of labor per calorie harvested, potatoes appear to be comparable or even better than cereals.

An additional benefit of potatoes was that their cultivation did not require a complete switch away from the cultivation of Old World staples; it was possible to plant potatoes between the growing seasons of other crops. Potatoes could be planted on the land that was otherwise left fallow between the periods of grain cultivation (Mokyr 1981; McNeill 1999). McNeill (1999, p. 79) describes this benefit of potatoes, writing that "by planting potatoes on the fallow, and using hoes to eliminate weeds, there was absolutely no need to decrease the grain supply! What a bonanza!" One shortcoming of the potato was that unlike rotation crops such as clover and legumes, it did not increase the supply of nitrogen in the system, which was a constraining factor for agricultural productivity at the time (Allen 2008; Chorley 1981).

Potatoes also provided indirect benefits. Being relatively easy to store, potatoes provided excellent fodder for livestock (primarily pigs and cattle), especially through the winter. Often, a significant proportion of the potato crop would be used as fodder.[8] This meant that potatoes also increased meat consumption, as well as manure, which was a valuable input for crop production.[9] Finally, potatoes, as well as other crops introduced over time, provided

8. See Ó Gráda (2006, p. 8) for evidence from nineteenth-century Ireland.

9. For example, according to nineteenth-century data presented in Burton (1948, pp. 84–85), manuring increased the yield of potatoes per acre by over 150 percent.

additional means of crop diversification, which reduced vulnerability to famine (Ó Gráda 2009, p. 35).

II.B. The Potato's Diffusion from the New World to the Old World

Archeological evidence suggests that the potato was first cultivated in the Andes between seven thousand and ten thousand years ago (Messer 2000b). Pre-Columbian cultivation occurred within modern-day Colombia, Ecuador, Peru, Bolivia, Chile, and Northern Argentina (Glendinning 1983, pp. 79–80). Although parts of Mexico and the Eastern portion of North America are suitable for potato cultivation, the historical evidence suggests that the potato never migrated to these areas until after European contact (Ugent 1968).

For the Old World, the potato was discovered along with the discovery of the Americas. The first evidence of potatoes being consumed in Europe is from Seville, Spain, where there are records of potatoes being purchased by a hospital in 1573 (Salaman 1949, pp. 68–69). After Spain, the potato next appeared in Italy in 1586, then England in 1596 and Germany in 1601 (Brown 1993, pp. 363–364).

Despite the benefits of potatoes, their widespread adoption did not follow immediately after their first appearance at the end of the sixteenth century. For most of the seventeenth century, potatoes remained a botanical curiosity in Europe. Several characteristics of the potato prevented its immediate adoption. First, because the potato belongs to the poisonous nightshade family, it was initially presumed to be poisonous. Second, the similarity between the appearance of the potato—discolored and lumpy—and the flesh of those afflicted with leprosy led many to believe that potatoes caused the disease (Brown 1993; Langer 1975).[10] Finally, because many characteristics of the potato were unique and previously unobserved prior to its arrival, these also caused suspicion and apprehension. Salaman (1949, p. 112) describes these, writing that "the potato was the first edible plant in Europe to be grown from tubers and not from seed, and till then, no similar plant ... was grown which bore on underground stems numerous white or flesh coloured nodules; both the cultivation, behaviour and the habits of the plant were unusual."

10. The tendency to link plants to diseases based on their outward appearance was a common form of reasoning, called the "Doctrine of Signatures," at the time (Salaman 1949, pp. 109–121).

The eventual diffusion of potato cultivation was gradual and uneven. Adoption first began in the late seventeenth century by Irish peasants. Also in the late seventeenth century, potatoes began to be cultivated on the European mainland in East and West Flanders and in Alsace (Vandenbroeke 1971, pp. 17, 20–21). By the early eighteenth century, potato cultivation had also spread to the Scottish Highlands, as well as to parts of England and France (Langer 1963, pp. 12–13; Laufer 1938, pp. 60–61).[11] In Scandinavia, the cultivation of the potato lagged behind the rest of Europe. Cultivation in Sweden and Norway did not begin until the mid-eighteenth century (Laufer 1938, pp. 67–68).

From Europe, the potato was spread across the rest of the Old World by mariners who carried potatoes to ports in Asia, Africa, and Oceania. The potato was probably introduced to China on several different occasions during the seventeenth century. It 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 initiation of trade links between Taiwan and the coastal province of Fujian, it is likely that the potato was also introduced to mainland China during this time. According to Lee (1982, p. 738), by 1800 the farmers in Southwest China had replaced the traditional lower yield crops of barley, oats, and buckwheat with either potatoes or maize, another New World crop.[12]

The potato first reached India not long after it arrived in Europe, introduced by either the British or the Portuguese. The earliest known reference to potato cultivation in India is a written account from the 1670s by John Fryer (Laufer, 1938, p. 91). By the late eighteenth century there are various accounts of widespread cultivation in many parts of India (Pandey and Kaushik 2003; Stuart 1923, p. 381). The introduction of potatoes to Africa is not particularly well documented. Existing accounts suggest that potatoes arrived later than in other parts of the world, around the end of the nineteenth century. In Ethiopia, the potato was introduced in 1858 by a German immigrant named Wilhelm

11. We are unable to provide an exhaustive summary of the historical adoption in different parts of the Old World here. We have summarized the existing evidence in an unpublished Online Appendix that accompanies the paper. This is available from the authors' web pages. Solar (1997, pp. 114–117) also provides a comprehensive overview of the pattern of adoption within Europe by the mid-nineteenth century.

12. In our analysis, we explicitly control for the effects of maize and other New World food crops.

Schimper. Subsequent adoption by native farmers occurred gradually over a period of several decades.

The historical evidence suggests that other than the consumption of the potato in Seville, Spain in 1573, widespread cultivation did not begin until the late seventeenth and early eighteenth centuries. Over the next 150 years, cultivation gradually increased, both in geographic coverage and in intensity. Our analysis uses the beginning of the widespread cultivation of potatoes as our postadoption cutoff period. Based on this, we take our post-treatment periods to be observations after 1700, which include 1750, 1800, 1850, and 1900. We do not take this cutoff for granted. In the empirical analysis, we check for patterns in the data directly. We find that consistent with the historical record, potato suitable regions begin to experience systematic increases in population and urbanization after 1700. We also find that consistent with the gradual diffusion of cultivation, the strength of the relationship monotonically increases between 1750 and 1900.[13]

II.C. Other New World Staple Crops

After the discovery of the Americas, other New World crops were also introduced along with potatoes. These include maize, cassava, tomatoes, chili and bell peppers, cacao, sunflowers, and the sweet potato (Grennes 2007; Nunn and Qian 2010). Of these, the three crops that became high-caloric staples in the Old World are maize, cassava, and the sweet potato.

Maize is unable to rival potatoes in terms of nutrients or calories. It produces significantly fewer calories per acre of land. Moreover, humans are unable to subsist on a diet that is too concentrated in maize. Significant consumption of maize is associated with pellagra, a disease caused by niacin deficiency. The effects of pellagra include skin, digestion, mental disorders, and, if untreated, eventual 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 maize. A second adverse effect of a corn-heavy diet is protein deficiency (Messer 2000a).

Sweet potatoes are also nutritious and produce similar amounts of calories per acre of land as potatoes, but they differ from potatoes in two important ways. First, the archaeological

13. For urbanization, the monotonic increase is delayed by fifty years, and the increase is weaker in the early periods. See Section V.B. for a full discussion.

evidence suggests that sweet potatoes, transported by Polynesians, reached the Old World long before the European discovery of the New World. For many countries in our sample, their impact would have been felt as early as 1000 (Hather and Kirch 1991). Second, a close substitute to the sweet potato, the yam, already existed in the Old World (O'Brien 2000). Yams are broadly similar to sweet potatoes in terms of both nutritional content and the requirements for cultivation. Many regions that were suitable for cultivating sweet potatoes had already cultivated yams when the former were introduced.

The New World staple, cassava, which is also called manioc or yuca, also provides abundant calories. But its deficiency in protein and other important nutrients causes it to be a less "complete" food than potatoes (Cock 1982). In addition, because cassava contains toxic cyanogenic glycosides (e.g., cyanide), failure to properly prepare cassava causes konzo, a neurological disease that causes paralysis.

In Section V.D., we show that the estimates are robust to controlling for the potential effects of these other New World staple crops on population and urbanization.

III. Conceptual Framework

Our analysis examines the effect of the positive agricultural productivity shock from the introduction of the potato on population and urbanization levels. The way an increase in agricultural productivity can affect a population is straightforward: an increase in food productivity increases living standards, causing fertility and life expectancy to increase, both of which result in increased population.

The effect of potatoes on urbanization might occur through a number of different channels. The first potential channel arises because a shock to agricultural productivity changes the relative returns to agriculture and industry, affecting the number of people that work in the agricultural sector and live outside cities. To illustrate the conditions under which a shock to agricultural productivity can increase urbanization, we develop a simple model where the introduction of potatoes is interpreted as an increase in the productivity of agricultural production.

Individuals choose to work in one of two sectors: agriculture, which takes place in the countryside, and manufacturing, which occurs in cities. Let L^F and L^W denote the number of farmers employed in agriculture and the number of workers employed in manufacturing. Total labor is normalized to 1. Each worker in the manufacturing sector produces one unit of the manufacturing good, and each agricultural farmer produces e units of the agricultural good. Preferences over the two commodities are the same for both types of workers and are given by $U_i = \frac{1}{1-\sigma}\left(c_A^i\right)^{1-\sigma} + c_M^i$, where i denotes farmers or workers and c_A^i and c_M^i denote consumption of agricultural and manufactured goods. The price of the agricultural good relative to the manufacturing good is given by p.

Farmers maximize utility subject to their budget constraint:

$$\max \frac{1}{1-\sigma}\left(c_A^F\right)^{1-\sigma} + c_M^F \quad \text{subject to} \quad pc_A^F + c_M^F = pe.$$

Similarly, the worker's problem is

$$\max \frac{1}{1-\sigma}\left(c_A^W\right)^{1-\sigma} + c_M^W \quad \text{subject to} \quad pc_A^W + c_M^W = 1.$$

The first-order conditions from the farmer and worker's problems yield

$$c_A^F = c_A^W = p^{-1/\sigma}. \tag{1}$$

Free mobility and labor market clearing require agents to be indifferent between working in either sector, and therefore, $pe = 1$. Market clearing for the agricultural product requires

$$c_A^F + c_A^W = eL^F. \tag{2}$$

Substituting (1) into (2) and using the fact that $pe = 1$ gives the equilibrium labor force (and labor share) employed in the agricultural sector:

$$L^F = 2e^{1/\sigma-1}.$$

Therefore, the share of labor employed in agriculture is decreasing in the productivity of agricultural production e iff $\sigma > 1$, where σ measures the inverse of the price elasticity of demand for the agricultural good: $1/\sigma = -\frac{\partial c_A/c_A}{\partial p/p}$.[14] A value of $\sigma > 1$ means that a

14. To see this, note that total consumption of the agricultural good is $c_A = 2p^{-1/\sigma}$ (where $c_A \equiv c_A^F + c_A^W$). Therefore, the price elasticity of demand is $\frac{\partial c_A/c_A}{\partial p/p} = -1/\sigma$.

1 percent decrease in the price of the agricultural good increases demand for that good by less than 1 percent (i.e., the demand for agricultural good is price inelastic).

Therefore, as long as the demand for agricultural goods is inelastic, an increase in agricultural productivity decreases the share of the population that are farmers living in rural areas. This occurs because an increase in agricultural productivity e decreases the price of agricultural goods p (since $p = 1/e$). When the demand for the agricultural good is inelastic ($\sigma > 1$), its increased consumption does not fully offset the price decrease, and this decreases the relative returns to agriculture and causes a movement of labor from the countryside into cities. The existing empirical evidence suggests that the demand for agricultural goods is indeed price inelastic. Studies typically estimate the price elasticity of food demand to be between -0.80 and -0.20 (e.g., Tobin 1950; Tolley et al. 1969; Van Driel et al. 1997).

The second channel through which potatoes might affect urbanization arises from the close relationship between urbanization and per capita income.[15] The positive productivity shock from the adoption of potatoes can also increase per capita income. Galor and Weil (2000) provide a unified framework that illustrates the conditions under which this might occur. Their analysis models three periods of economic growth: a Malthusian period, a post-Malthusian regime, and a modern regime. In the Malthusian regime, a positive productivity shock is fully offset by fertility increases. Although living standards might increase temporarily, in the long run this is fully offset by increased fertility, which leaves per capita income constant and population levels higher. In this regime, which is dated to have been in effect until the nineteenth century, potatoes are predicted to affect the level of population but to have no effect on steady-state per capita income.[16]

In the post-Malthusian regime, which is dated to have begun in the nineteenth and early twentieth centuries, a positive productivity shock is not fully offset by a fertility increase, and therefore it will have a positive effect on economic growth, increasing

15. See DeLong and Shleifer (1993); Acemoglu, Johnson, and Robinson (2002); and Acemoglu, Johnson, and Robinson (2005); as well as our discussion in Section IV.B. for details.

16. Interestingly, Malthus (1798, pp. 451–457) wrote of the relationship between potatoes, population, and income. He was concerned that the adoption of the potato would simply increase population, leaving the population similarly impoverished in the long run.

living standards even in the long run.[17] Therefore, in this regime, the introduction of the potato might affect long-term per capita income (and therefore urbanization). This mechanism is featured more generally in growth models in which income growth is increasing in population size (i.e., there are scale effects) and standard Malthusian mechanisms—that cause population increases to fully erode income gains—are weak or absent.[18]

The final regime of their analysis is the modern regime, which is dated to have begun at the end of the nineteenth century in Europe, and the late twentieth century for Latin America and Asia (Galor 2005, pp. 195–198).[19] The regime is characterized by a complete absence of Malthusian mechanisms. Increased productivity has a negative effect on fertility and population, not a positive one as in the first two regimes. Therefore, once one begins to mix observations from the modern regime with those from the earlier Malthusian and post-Malthusian regimes, there is no longer a clear theoretical prediction about the effect of a positive productivity shock on population. For this reason, we end our analysis in 1900.

Our baseline regressions estimate the impact of the introduction of the potato on either total population or urbanization. As we show in Section V.B., we find evidence that the potato caused sustained increases in population and urbanization levels over time. These findings are consistent with potatoes having an effect on the growth rate of population and urbanization. This could occur in a world where the rate of innovation is increasing in population size (i.e., there are scale effects), and therefore a one-time shock to population levels causes an increase in the growth rate. However, the finding is also consistent with potatoes only having long-term level effects (and no growth effects) if convergence to the new steady-state levels of population and urbanization occurred gradually. The slow convergence could occur in part because the adoption of the potato was gradual. Because we do not have a sense for precisely how long it takes to transition from one steady state to another or data on the adoption process in

17. The beginning of the post-Malthusian regime is believed to have varied across regions. It is typically dated as beginning in the early nineteenth century in Europe and the late nineteenth century for most of Asia, Latin America, and Africa (e.g., Galor 2005, pp. 180–195).

18. See Jones (2005) for a comprehensive review of growth models that feature scale effects.

19. Africa is identified as not yet having entered the modern regime.

different parts of the world, our empirical results are silent about whether potatoes only affected steady state levels or whether they also affected steady state growth rates.

IV. Data

IV.A. Crop Suitability

Our empirical analysis relies on measures of a region's suitability for growing potatoes, as well as suitability measures for other staple crops. To construct these variables, we use data from the Food and Agriculture Organization (FAO)'s Global Agro-Ecological Zones (GAEZ) 2002 database. These data measure the suitability for cultivating individual crops at a very disaggregated geographic level.

The construction of the FAO's GAEZ database occurred in two stages. The FAO first collected information on the characteristics of 154 different crops. These data were used to determine what environmental conditions are required for the cultivation of each crop. The FAO then compiled data on the physical environment of 2.2 million grid cells, spanning the entire globe. Each cell is 0.5 degrees by 0.5 degrees, which is approximately fifty-six kilometers by fifty-six 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 at the University of East Anglia. In total, nine variables from the global climatic database are used by the FAO: precipitation, frequency of wet days, mean temperature, diurnal (i.e., daily) temperature range, vapor pressure, cloud cover, sunshine, ground-frost frequency, and wind speed. The second set of characteristics are land characteristics and are taken from the FAO's Digital Soil Map of the World. The final characteristic is the slope of soils, which is from the GTOPO30 Database, developed at the U.S. Geological Survey (USGS) EROS Data Center.

Combining the information on the constraints for the cultivation of each crop with the data on the physical environment of each grid-cell, the FAO calculated an estimate of the potential yield of each crop in each grid cell, given an assumed level of crop management and input use. This process involved a number of detailed steps, which we briefly summarize here.

First, for each grid cell and crop, the FAO identified the days of the year when the moisture and thermal (i.e., temperature) requirements of the crop are met. With this information, the FAO determined the exact starting and ending dates of the length of growing period (LGP) for each crop and grid cell.[20] An initial classification of each grid-cell and crop pair was then performed. If the minimum requirements for cultivation were not satisfied, then the cell was determined to be unsuitable for cultivation of the crop.[21] If the minimum requirements were met, then a second stage was performed where potential yields are determined. For each crop, constraint-free crop yields were determined, and the yield in each grid-cell was measured as a percentage of this benchmark. Next, the FAO identified additional constraints that exist in each cell for each crop. The procedure quantified the agroclimatic constraints (i.e., variability in water supply and existence of pests and weeds) as well as the agroedaphic suitability (i.e., soil erosion) of each grid cell.

The end product of the procedure is, for each crop, a GIS raster file with global coverage that contains information on the suitability of each grid cell for the cultivation of each crop in question. The FAO also constructed a country-level version of the database that reports the proportion of each country's land that is classified under five mutually exclusive categories describing how suitable the environment is for growing each crop. The categories are based on the calculated percentage of the maximum yield that can be attained in each grid cell. The five categories and their corresponding yields are: (*i*) very suitable land (80–100 percent), (*ii*) suitable land (60–80 percent), (*iii*) moderately suitable land (40–60 percent), (*iv*) marginally suitable land (20–40 percent), and (*v*) unsuitable land (0–20 percent). To approximate historical conditions as closely as possible, we use variables constructed under the assumption that cultivation occurs under rain-fed conditions and under medium input intensity.

We define land to be suitable for cultivation if it is classified in the database as being either "very suitable," "suitable," or "moderately suitable." Put differently, our measure defines land to be suitable if it yields at least 40 percent of the maximum possible yield.[22]

20. The growing period is defined as the period of time for which the minimum temperature and moisture requirements of the crop are satisfied.

21. This is done by comparing each crop's requirements with the grid cell's calculated (*i*) length of the growing period (LGP), (*ii*) temperature profile, (*iii*) and the accumulated temperature.

22. As we discuss in Section VI, the results are very similar when we use 20 percent or 60 percent of the maximum yield as alternative cutoffs.

Figure II illustrates the FAO's suitability measures at the grid cell level for the Old World countries of our sample. The map reports an FAO-created suitability index, which is a summary measure of suitability based on the underlying categories. The suitability index is constructed by assigning the value of 0.90 to "very suitable" land, 0.70 to "suitable" land, 0.50 to "moderately suitable" land, and 0.30 to "marginally suitable" land. The suitability index then reports the average value of each grid cell, weighted by the proportion of land in each category. A higher index value and a darker shade corresponds to greater suitability.

Figure II shows that much of the land area suitable for potato cultivation is concentrated in Europe. This fact is a potential cause of concern because it is well known that Western Europe diverged from the rest of the world after 1700 for reasons beyond the fact that it was more suitable for potato cultivation. The other underlying causes of the divergence could bias our estimated impact of the introduction of potatoes on population and urbanization if they are positively correlated with cultivation for spurious reasons. We view this as the greatest potential threat to our estimation strategy and take a number of measures to address it. We include controls for potential underlying determinants of Western Europe's divergence. We also check the robustness of our results to the inclusion of continent-year fixed effects, which capture any time-varying differences between Europe and the rest of the world. We also examine the effect of the potato on city populations using only within-continent, and even within-country, variation.

An additional concern is whether the measure calculated in the 1990s by the FAO is an accurate indicator of suitability two hundred years earlier. The construction of the suitability measures do not give any obvious cause for concern. In fact, the construction suggests that the suitability measures should be good proxies for historical conditions because they are primarily based on climatic characteristics such as temperature, humidity, length of days, sunlight, and rainfall that have not changed significantly over the period of our study. Land characteristics, such as soil pH or slope, which can be affected by human intervention, only affect the yield calculations after a grid cell has been classified as suitable or not based on the climatic characteristics. Moreover, in constructing our measure, we also deliberately used the FAO measures that assume rain-fed conditions to avoid measurement error from changes over time in irrigation intensity and technologies.

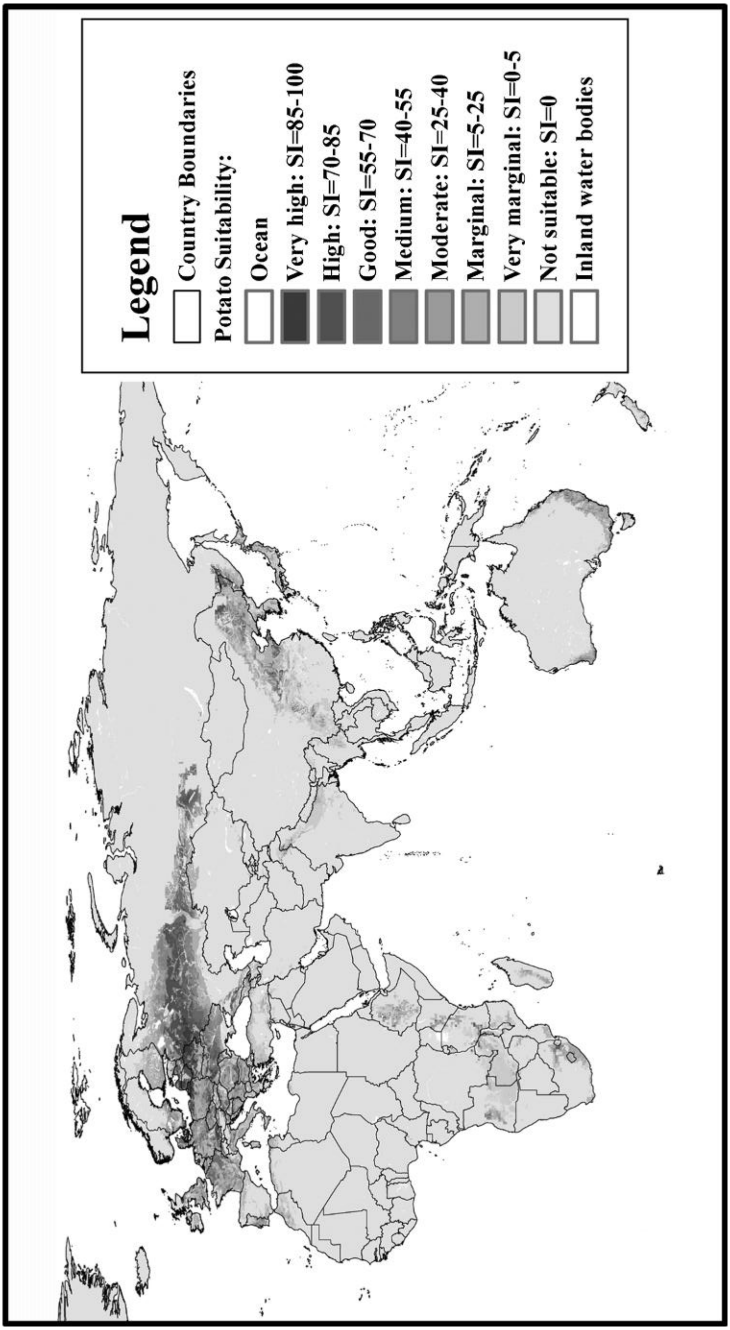

FIGURE II
Average Potato Suitability in the Old World

An additional potential source of concern arises from the fact that potato varieties evolved over time. In particular, the concern is that potatoes might have been bred to be cultivated in locations experiencing fast population growth. If this were the case, then our estimates would reflect the effect of historical population growth on potato suitability. The historical evidence suggests that while new varieties were developed, the focus was not on developing varieties that could be grown in locations with high population growth. There are two well-documented epochs in the development of potato varieties. In the nineteenth century, after the potato blights of 1845 and 1846, there was, for the first time, a concerted effort to develop new varieties with increased resistance to the disease (Salaman 1949, pp. 159–166). Redcliffe Salaman (1949, p. 165) writes that "no spectacular development took place in variety raising until after the crisis caused by the pandemic Blight (*Phytophthora infestans*)." To the best of our knowledge, the focus was not on developing varieties that could be grown in climates with rapid population growth. In the twentieth century, commercial cultivars focused on developing varieties that were visually appealing to consumers. To this end, varieties were developed that were oval or kidney-shaped, had a uniform skin color, and were without sprouts in their pits. In addition, there have been attempts to develop varieties that are resistant to dry rot, which can occur during transit (Salaman 1949, pp. 169–171). We have not found evidence of deliberate breeding of new varieties that could be grown in new locations with high population growth.

It is also important to recognize that the FAO's potato suitability measures are not based on the most commonly produced variety today or on varieties only grown in specific climates. Suitability is calculated using four varieties that intentionally span a wide range of geographic environments. The varieties chosen can be cultivated in a range of climates including boreal, temperate, subtropical, and tropical climate zones. See Tables 4.1, 5.10, and 5.11 of Fischer et al. (2002) for further details.

Although we have found no evidence that modern varieties were developed to be grown in locations with fast-growing populations, we cannot rule out this possibility. Therefore, in our analysis we perform a number of checks to ensure that our estimates are not being driven by the selective breeding of potato varieties. These are reported in Section V.D.

We are also able to conduct a direct check of how well our ex post suitability measure captures historical conditions by

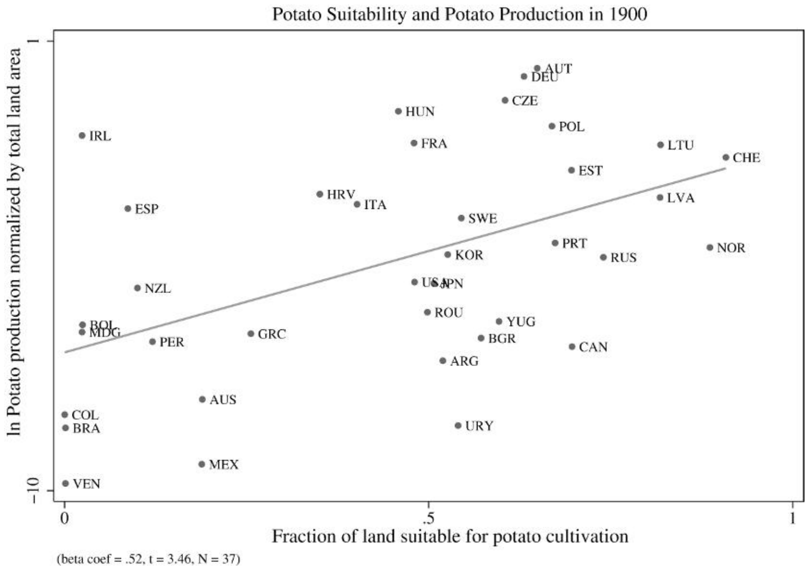

FIGURE III
Bivariate Relationship between Potato Suitability and Potato Production in 1900

examining the correlation between a country's suitability for potato cultivation and historical potato production. The earliest period for which production data are available for a cross-section of countries is 1900. These data are from Mitchell (1998, 2003). We normalize both the land suitable for potato cultivation and the total production of potatoes (measured in tons) in 1900 by the total land area of a country (measured in thousands of hectares).[23] The bivariate relationship between the share of land suitable for potatoes and the natural log of potato production per hectare is shown in Figure III. There is a strong positive correlation between the two variables. The standardized beta coefficient is 0.52 and is statistically significant at the 1 percent level.[24] The strong positive

23. We take the natural log of production per hectare because the distribution is highly skewed otherwise.

24. The strong positive relationship between suitability and production is similar if alternative specifications are used. For example, taking the natural log of share of land suitable for potatoes yields a beta coefficient of 0.52. Alternatively, examining the relationship between the natural log of the total production of potatoes and the natural log of land suitable for potatoes, while controlling for either the natural log of land suitable for any crop, land suitable for Old World crops, or

relationship provides reassurance that the ex post suitability measure provides a reasonable proxy for historical conditions.

In our analysis, we also control for the suitability of other New World staple crops (grain maize, silage maize, sweet potatoes, and cassava) and for Old World staple crops (wetland rice, dryland rice, and wheat). In addition, some specifications control for a measure of overall agricultural suitability, which is a composite measure of the suitability of an area for growing any agricultural crop for human consumption (i.e., not including crops for fodder). These additional suitability measures are also constructed using data from the FAO's GAEZ database and using the same 40 percent suitability threshold as for potatoes.

IV.B. Population and Urbanization Data

Our analysis examines two outcomes at the country level: total population and urbanization. Total population, which is measured as the number of individuals living on land that is a modern country today, are taken from McEvedy and Jones (1978). Urbanization is measured as a country's total urban population, defined as people living in locations with forty thousand or more inhabitants, divided by the total population. Data on the populations and locations of cities used to construct the numerator are from Chandler (1987), Bairoch (1988), and Modelski (2003). Finer details of the procedure are reported in the Data Appendix.[25]

Since historical measures of income per capita are unavailable prior to 1500, and even in 1500 they are only available for twenty-two Old World countries, studies examining historical income, such as DeLong and Shleifer (1993); Acemoglu, Johnson, and Robinson (2002); and Acemoglu, Johnson, and Robinson (2005); use urbanization as a measure of historical per capita GDP. The strong correlation between urbanization and per capita income is documented in Acemoglu, Johnson, and Robinson (2002).[26]

total land yields a beta coefficient of 0.46, 0.47, or 0.45 (respectively), all of which are statistically significant.

25. Our decision to measure population and urbanization at the country level is driven by the fact that the historical population estimates from McEvedy and Jones (1978) are only available at the country level. As we describe below, we also examine the effect of the potato on city populations.

26. Using the most extensive historical income data available, which are from Maddison (2003), we have also examined the relationship between urbanization and income back to 1500. In a panel setting with either country fixed effects or year fixed effects, we find that the correlation between urbanization and income is extremely strong and highly significant.

Following previous studies, we interpret urbanization as a proxy for income.

Our study includes twelve time periods between 1000 and 1900: eight time periods spaced at one hundred-year intervals (1000, 1100, 1200, 1300, 1400, 1500, 1600, and 1700) and four time periods spaced at fifty-year intervals (1750, 1800, 1850, and 1900).

In auxiliary regressions, we examine variation across European cities with populations of one thousand or more. These data are taken from Bairoch, Batou, and Chèvre (1988) and DeVries (1984). We also examine variation in adult heights within France. These data are from Komlos (2005).

Accuracy is an obvious concern for historical data that span such a long time horizon and broad cross-section. However, classical measurement error in our outcome variables will not bias our regression estimates. Similarly, any systematic measurement error that varies by time-period or by country is captured by the country and year fixed effects, which are included in all specifications.

V. Empirical Strategy and Main Results

V.A. *Empirical Strategy*

Our main estimation strategy follows the same logic as a standard differences-in-differences (DD) strategy. We compare the relative change in population and urbanization in the postadoption period relative to the preadoption period between locations that were able to adopt the potato and those that were not. The difference between our estimates and a standard DD strategy is that we use a continuous measure of the intensity of treatment (i.e., potato suitability) and thereby capture more variation in the data. Because the date of actual adoption in a country could be partly driven by endogenous factors such as latent population demand, we use the same date of initial adoption for all countries. The historical evidence summarized in Section II.B. suggests that extensive adoption as a field crop began in the late seventeenth century, and by the early eighteenth century, adoption was well underway throughout much of Europe. This is also the period of initial contact and early adoption in many parts of the world like India, Indonesia, and Japan. Therefore, in our estimates, we use this as the cutoff period and define the periods prior to and including 1700 as the preadoption periods, and the periods after 1700 (i.e., 1750, 1800, 1850, and 1900) as the postadoption periods. Note that we do not take this cutoff date for granted. In the next section, we use a number of procedures to check that our chosen cutoff is consistent with the data. We also show that our results are very robust to alternative cutoffs close to the chosen one (see Section VI).

Our main estimating equation assumes that a country's total population is proportional to the total amount of land suitable for potato cultivation. Therefore, the natural log of total population is proportional to the natural log of the amount of suitable land.[27] This is written as

$$y_{it} = \beta \ \ln Potato\,Area_i \cdot I_t^{Post} + \sum_{j=1100}^{1900} \mathbf{X}'_i \mathbf{I}_t^j \Phi_j + \sum_c \gamma_c I_i^c + \sum_{j=1100}^{1900} \rho_j I_t^j + \varepsilon_{it}, \tag{3}$$

where i indexes countries and t indexes time periods, which are 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1750, 1800, 1850, and 1900. The variable $\ln Potato\ Area_i$ is the natural log of the total amount of land that is suitable for potatoes, and I_t^{Post} is an indicator variable that equals one for the periods after 1700 (i.e., 1750, 1800, 1850, and 1900). The outcome of interest, denoted y_{it}, is either the natural log of total population or the urbanization rate. The equation also includes country and year fixed effects, $\sum_c I_i^c$ and $\sum_j I_t^j$, and country-specific characteristics interacted with time-period fixed effects, $\sum_{j=1100}^{1900} \mathbf{X}'_i \mathbf{I}_t^j \Phi_j$. The country controls include a large set of geographic and historical variables. They are described when introduced in the analysis.

The coefficient of interest in equation (3) is β, which is the estimated impact of potato suitable land on either population or urbanization. For concreteness, consider the case with total population as the dependent variable. The estimated coefficient $\hat{\beta}$ measures the additional growth in population levels experienced by countries that are suitable for potatoes (relative to those that are not) after potatoes were introduced in 1700 (relative to before). A positive coefficient indicates that countries with a geographic environment more suitable for growing potatoes witnessed a greater increase in population growth after 1700 relative to before 1700.

27. We take the natural log of the variables to remove the skewness that exists in their distributions otherwise.

The estimation strategy has all of the advantages and potential pitfalls of standard DD estimators. Country fixed effects control for all time invariant factors that differ between countries. Time period fixed effects control for any secular patterns of population growth or urbanization that affect all regions similarly. Our identification relies on the assumption that there are no other events beyond those we have controlled for that also occurred around 1700 and affected population or urbanization. This assumption should not be taken for granted because the Old World experienced many changes during the eighteenth and nineteenth centuries. We address this in detail below.

V.B. Flexible Estimates

Equation (3) examines the average effect of the potato on population and urbanization after its introduction. Estimation requires that we choose a date in which the potato was adopted in the Old World. The historical evidence suggests that the adoption of the potato began in a few locations in the late seventeenth century and spread significantly by the early eighteenth century. Given the evidence, reasonable cutoff dates range between 1700 and 1750, and therefore 1750 is the first postadoption time period. Before taking this cutoff as given, we use a number of different strategies to examine whether the patterns in the data are consistent with this assumption. The first strategy is to estimate a fully flexible estimating equation that takes the following form:

$$(4) \qquad y_{it} = \sum_{j=1100}^{1900} \beta_j \ln Potato\ Area_i \cdot I_t^j + \sum_{j=1100}^{1900} \mathbf{X}'_i \mathbf{I}_t^j \Phi_j + \sum_c \gamma_c I_i^c + \sum_{j=1100}^{1900} \rho_j I_t^j + \varepsilon_{it},$$

where all variables are defined as in equation (3). The only difference from equation (3) is that in equation (4), rather than interacting $\ln Potato\ Area_i$ with a postadoption indicator variable, we interact the suitability measure with each of the time-period fixed effects. The estimated vectors of β_js reveal the correlation between potato suitability and the outcomes of interest in each time-period. If, for example, the introduction of potatoes increased population, then we would expect the estimated β_js to be constant over time for the years before potatoes were adopted (e.g.,

$\hat{\beta}_{1100} \approx \hat{\beta}_{1200} \approx \hat{\beta}_{1300} \approx \ldots$). We also expect the coefficients to be larger in magnitude for the years after adoption, and because diffusion occurred gradually, the effects might be increasing over time (e.g., $\ldots \approx \hat{\beta}_{1600} \approx \hat{\beta}_{1700} \leq \hat{\beta}_{1750} \leq \hat{\beta}_{1800} \leq \ldots$).

It is important to note that we are not particularly interested in the individual magnitudes of the point estimates. Because $\ln$ *Potato Area*$_i$ is time invariant and equation (4) includes country and time-period fixed effects, the estimated β_js must be measured relative to a baseline time-period, which we take to be 1000. Therefore, the absolute level simply tells us the difference in the relationship relative to an arbitrarily chosen baseline. Choosing an alternative baseline period changes the point estimates and standard errors of all coefficients. Instead, we are interested in the pattern over time; specifically, whether we observe a discontinuity in the pattern around the time potatoes were adopted in the Eastern Hemisphere.

Estimates of equation (4) are reported in Table II. Columns (1)–(3) report estimates for total population and columns (4)–(6) report estimates for urbanization. The first specification, reported in columns (1) and (4), includes time-period fixed effects and country fixed effects only, without additional controls. In columns (2) and (5), we include a control for natural log of the amount of land suitable for Old World crops interacted with the time-period fixed effects.[28] This is done to ensure that the effect of introducing potatoes is not confounded by other changes in the importance of Old World staple crops over the same time-period. The final estimates, in columns (3) and (6), report estimates for our baseline specification. In addition to the control for land suitable for Old World crops (interacted with the time-period fixed effects), we also control for three geographic characteristics, which we expect *a priori* might be correlated with potato suitability. Because one of the attributes of potatoes is that they can be successfully cultivated on rugged terrain at high altitudes, we control for the natural log of a country's average elevation and the natural log

28. We define Old World staple crops to be wet-land rice, dry-land rice, and wheat. As with our potato suitability measure, we define land to be suitable for cultivation if it is classified as either "very suitable," "suitable," or "moderately suitable." The measure is the natural log of the amount of land that can grow the most suitable Old World crop. An alternative strategy is to measure the union of the land that is suitable for each Old World crop (i.e., the fraction of land that can grow any Old World crop). This alternative measure yields very similar estimates, which is unsurprising since the two measures are highly correlated.

TABLE II
FLEXIBLE ESTIMATES: THE RELATIONSHIP BETWEEN POTATO-SUITABLE LAND AREA AND POPULATION OR CITY POPULATION SHARE BY TIME PERIOD

	Dependent Variable					
	ln total population			City population share		
	(1)	(2)	(3)	(4)	(5)	(6)
ln *Potato-Suitable Area* × 1100	0.013	0.011	0.012	–0.0018	–0.0013	–0.0006
	(0.003)	(0.003)	(0.004)	(0.0014)	(0.0009)	(0.0013)
ln *Potato-Suitable Area* × 1200	0.029	0.024	0.024	–0.0011	–0.0013	–0.0012
	(0.005)	(0.005)	(0.007)	(0.0009)	(0.0009)	(0.0012)
ln *Potato-Suitable Area* × 1300	0.039	0.031	0.030	0.0002	–0.0005	0.0014
	(0.007)	(0.007)	(0.010)	(0.0008)	(0.0011)	(0.0014)
ln *Potato-Suitable Area* × 1400	0.019	0.004	0.021	0.0008	0.0002	0.0010
	(0.008)	(0.008)	(0.012)	(0.0012)	(0.0015)	(0.0014)
ln *Potato-Suitable Area* × 1500	0.034	0.014	0.027	0.0003	–0.0002	0.0008
	(0.009)	(0.010)	(0.014)	(0.0009)	(0.0012)	(0.0013)
ln *Potato-Suitable Area* × 1600	0.041	0.021	0.026	0.0002	–0.0010	–0.0000
	(0.009)	(0.011)	(0.015)	(0.0014)	(0.0025)	(0.0029)
ln *Potato-Suitable Area* × 1700	0.043	0.018	0.024	0.0020	0.0017	0.0022
	(0.012)	(0.013)	(0.018)	(0.0010)	(0.0013)	(0.0015)
ln *Potato-Suitable Area* × *1750*	*0.055*	*0.030*	*0.031*	*0.0015*	*0.0011*	*0.0013*
	(0.012)	*(0.014)*	*(0.020)*	*(0.0009)*	*(0.0013)*	*(0.0018)*
ln *Potato-Suitable Area* × *1800*	*0.073*	*0.048*	*0.041*	*0.0020*	*0.0016*	*0.0018*
	(0.014)	*(0.015)*	*(0.022)*	*(0.0009)*	*(0.0013)*	*(0.0017)*

TABLE II
(CONTINUED)

	Dependent Variable					
	ln total population			City population share		
	(1)	(2)	(3)	(4)	(5)	(6)
ln *Potato-Suitable Area* × *1850*	*0.095*	*0.069*	*0.060*	*0.0024*	*0.0022*	*0.0031*
	(0.015)	*(0.017)*	*(0.020)*	*(0.0011)*	*(0.0014)*	*(0.0017)*
ln *Potato-Suitable Area* × *1900*	*0.121*	*0.092*	*0.080*	*0.0118*	*0.0123*	*0.0100*
	(0.017)	*(0.021)*	*(0.024)*	*(0.0023)*	*(0.0024)*	*(0.0032)*
Baseline Controls (× Year fixed effects):						
ln *Old World Crops Area*	N	Y	Y	N	Y	Y
ln *Elevation*	N	N	Y	N	N	Y
ln *Ruggedness*	N	N	Y	N	N	Y
ln *Tropical Area*	N	N	Y	N	N	Y
Observations	1552	1552	1552	1552	1552	1552
R-squared	0.99	0.99	0.99	0.42	0.42	0.46
F Stat for Joint Signficance 1750–1900	17.88	13.60	4.20	8.02	8.82	4.89

Notes. Observations are at the country-year level. All regressions use a baseline sample of 130 Old World countries. Countries in North and South America are excluded. The periods are 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1750, 1800, 1850, and 1900. The dependent variable is either the natural log of the total population of the country measured in persons (ln total population) or the share of the population living in cities with forty thousand inhabitants or more (City population share). ln *Potato-Suitable Area* is the natural log of land that is defined as suitable for the cultivation of potatoes. This is interacted with an indicator for each period of the sample. All regressions include year fixed effects and country fixed effects. Each control variable listed is interacted with a full set of time-period fixed effects. Full details of each control variable are provided in the text and Data Appendix. The inclusion of a control of a variable interacted with the full set of time-period fixed effects is indicated by a Y; N indicates that the control is not included in the specification. Coefficients are reported with standard errors, clustered at the country level, in parentheses.

of its ruggedness, both interacted with the time-period fixed effects.[29] Furthermore, since potatoes are relatively less suitable for cultivation in humid tropical climates, we also control for the natural log of a country's land that is defined as being tropical.[30] The tropical climate control also accounts for the fact that during our sample period, locations with temperate climates prospered relative to locations with more tropical climates. We address this issue in more detail in Section VI.

A clear pattern emerges from the table. The relationship between potato-suitable land and population is constant over time and small in magnitude during 1000 to 1700 and then steadily increases in magnitude from 1750 to 1900. The patterns in the data can be seen most clearly by plotting the coefficients of the interaction terms over time. Figures IVa and IVb plot the point estimates from columns (3) and (6) in Table II and their 95 percent confidence intervals.

We learn several important facts from the fully flexible estimates. First, we do not observe any clear trends of the estimated interaction effects during the time periods immediately prior to the adoption of potatoes. We confirm this impression with a more formal analysis in the next section. The second insight we gain is that after 1700, the population and urbanization of potato-suitable locations begin to increase relative to locations that are not suitable. The effect on population appears to begin immediately after 1700, while the effect on urbanization appears to lag behind the effect on population by approximately fifty to one hundred years. The coefficients for the interaction between $\ln \textit{Potato Area}_i$ and the time-period fixed effects do not begin to increase until after 1750, and even then the increase is moderate until after 1850. There are many possible explanations for this. One stems from the long-run growth theories discussed in Section III—in particular the unified growth framework of Galor and Weil (2000). The delayed effect of potatoes on urbanization could reflect the fact that a weakening of Malthusian links did not occur until the post-Malthusian regime, which is dated by Galor (2005) to have begun in the nineteenth century. Prior to this regime, the benefits from potatoes might have manifested themselves as population increases, rather than increase in per capita income

29. Similarly, Mokyr (1981) uses the standard deviation of ruggedness as one of the instruments for potato cultivation in his empirical analysis.

30. Details of the data sources and construction of the measures are provided in the Data Appendix.

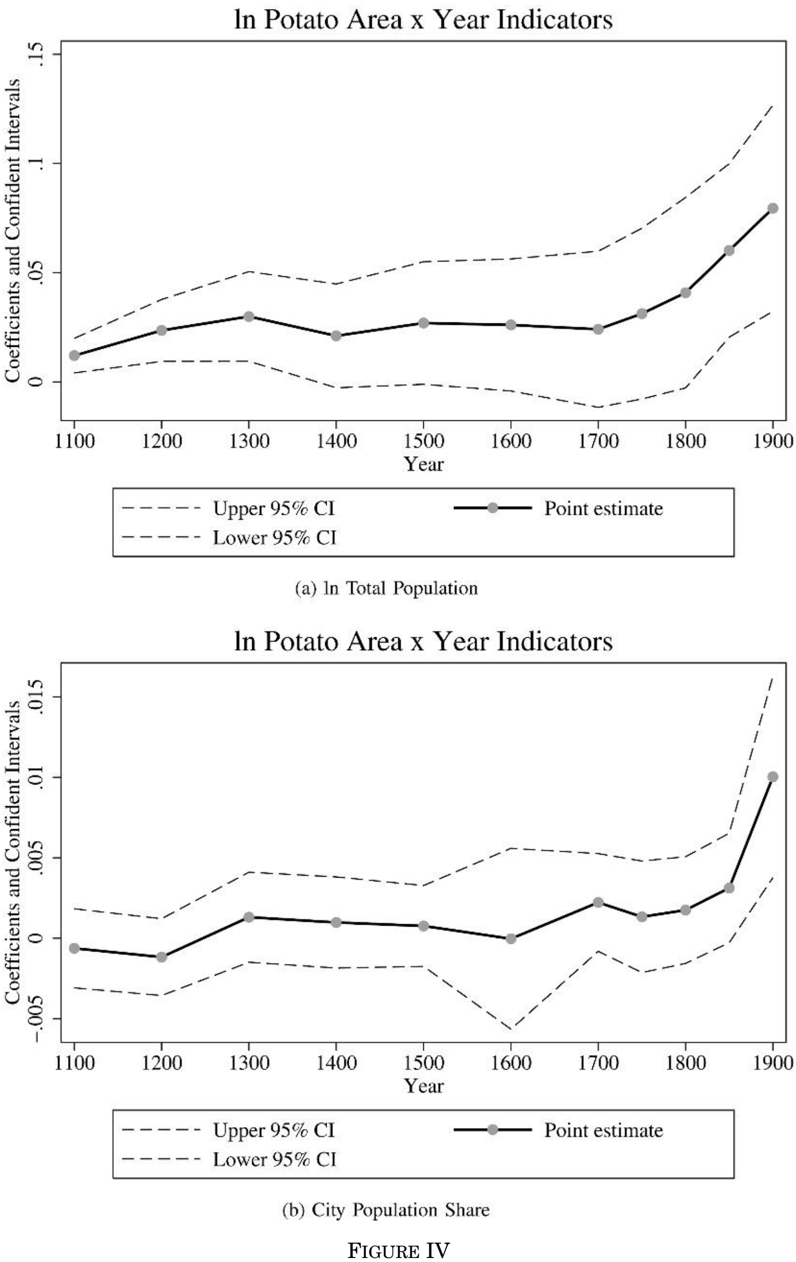

FIGURE IV

Flexible Estimates of the Relationship between Potato-Suitable Land and Either Total Population or City Population Share and urbanization. Throughout our analysis, we conservatively use 1700 as the cutoff data for both population and urbanization. Using a later date for urbanization would strengthen the results.

The final insight we gain from the flexible estimates is that the positive correlation between potato suitability and the outcomes of interest persistently increase in magnitude during the years after 1700. As we discussed in Section III, this is consistent with potatoes having effects on growth, but it is also consistent with potatoes only having effects on levels, and with the gradual adoption of potato cultivation over the period.

V.C. Rolling Estimates

The second strategy we employ as a check for our chosen cutoff date is similar in spirit to tests for structural breaks.[31] We systematically examine four-hundred-year segments of our full panel.[32] For each window, we estimate the baseline specification from equation (3), defining the later two centuries as the post-adoption period. The estimated coefficient for the interaction between potato suitability and the postadoption indicator variable reveals the average increase in population and urbanization between the pre and post periods for suitable countries relative to unsuitable countries. We expect the estimates to be close to zero until the cutoff begins to coincide with the historical description of the approximate date of potato adoption.[33] Prior to the adoption date, there is no reason to expect potato-suitable countries to have differential growth in population or urbanization.

The estimates are reported in Table III. Columns (1) and (2) report estimated effects for population and urbanization using a sample that includes four hundred-year periods, ranging from 1200 to 1500 (i.e., 1200, 1300, 1400, and 1500). For these regressions, the post indicator variable I_t^{Post} takes on the value of zero in 1200 and 1300 and the value of one in 1400 and 1500. Since the Old World adoption of potatoes as a staple crop did not begin until

31. Because of the limited number of time periods in our sample, we are not able to conduct the standard statistical tests for detecting structural breaks. See Hansen (2001) for a review of the literature on testing for structural breaks.

32. The results are robust to the choice of different window lengths.

33. An alternative strategy is to choose alternative cutoffs including all time periods and conduct a Chow test. The difficulty with this exercise is that for all specifications, a significant portion of the post period coincides with the "true" post-potato adoption period. The results are qualitatively similar if this alternative strategy is employed. They are not reported in the paper for brevity but are available upon request.

TABLE III

THE IMPACT OF THE POTATO WITH ALTERNATIVE CUT-OFFS

	Placebo Treatment Periods											
	1200–1500; Post = 1400, 1500		1300–1600; Post = 1500, 1600		1400–1700; Post = 1600, 1700		1500–1800; Post = 1700, 1800		1600–1900; Post = 1800, 1850, 1900		1600–1900; Post = 1750, 1800, 1850, 1900	
	ln pop.	City share	ln pop.	City share	ln pop.	City share	ln pop.	City share	ln pop.	City share	ln pop.	City share
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
ln *Potato Area* × Post	–0.002	0.0008	0.001	–0.0008	0.001	0.0002	0.006	0.0014	0.033	0.0038	0.028	0.0030
	(0.006)	(0.0012)	(0.005)	(0.0017)	(0.006)	(0.0016)	(0.007)	(0.0017)	(0.011)	(0.0015)	(0.009)	(0.0017)
Observations	516	516	518	518	520	520	650	650	780	780	780	780
R-squared	0.99	0.56	0.99	0.56	0.99	0.59	0.99	0.59	0.99	0.62	0.99	0.62

Notes. Observations are at the country-year level. All regressions use a baseline sample of 130 Old World countries. Countries in North and South America are excluded. The periods vary by specification and are reported in the column headings. The dependent variable is either the natural log of the total population of the country measured in persons (ln pop.) or the share of the population living in cities with forty thousand inhabitants or more (City share). ln *Potato Area* is the natural log of land that is defined as suitable for the cultivation of potatoes. The Post indicator variable varies by specification. Its definition is reported in the column headings. All regressions include year fixed effects, country fixed effects, and each of the following baseline controls interacted with the full set of time-period fixed effects: ln *Old World Crop Suitable Area*, ln *Elevation*, ln *Ruggedness*, ln *Tropical Area*. Full details of each control variable are provided in the text and Data Appendix. Coefficients are reported with standard errors, clustered at the country level, in parentheses.

the end of the seventeenth century, the results from this specification can be interpreted as a placebo experiment. The same is true for the estimates reported in columns (3)–(6). Columns (3) and (4) examine the 1300–1600 periods and use a post indicator variable that equals one in 1500 and 1600, while columns (5) and (6) examines 1400–1700 and use an indicator variable that equals one in 1600 and 1700. The coefficient estimates for $\ln Potato\,Area_i \cdot I_t^{Post}$ in all six specifications are close to zero and insignificant. We find no evidence of a differential relationship between potato suitability on population and urbanization in these early preadoption time periods.

Columns (7) and (8) report estimates for the window from 1500 to 1800, with a post indicator variable that equals one in 1700, 1750, and 1800. In this specification, two of the three years in the post period coincide with the postadoption period (1750 and 1800). Therefore, we expect the estimates to capture some of the effects of the introduction of potatoes. Consistent with this, we find a positive but small and statistically insignificant coefficient for $\ln Potato\,Area_i \cdot I_t^{Post}$.

Columns (9) and (10) report estimates for 1600–1900, with a post indicator variable that equals one in 1800, 1850, and 1900. Here all three of the post years coincide with the postadoption period (1800, 1850, and 1900), although one of our postadoption periods (1750) is classified as a preadoption year. We now expect the coefficients to more fully capture the introduction of potatoes. Indeed, we find much larger positive coefficients that are highly significant.

As a final check, in columns (11) and (12) we use the 1600–1900 window and alter the indicator variable to take on the value of one in 1750, 1800, 1850, and 1900. The post indicator variable now coincides exactly with the postadoption period. Again, the results yield positive and statistically significant coefficient estimates.

Taken together, the results confirm the finding from the flexible estimates: the relationship between suitability for potato cultivation and population or urbanization changes after 1700. Therefore, we use 1700 as the last preadoption period and 1750 as the first postadoption period in the DD estimations.[34]

34. The results do not depend on the exact time period chosen. For example, qualitatively similar results are obtained if 1750 is included in the preadoption period.

V.D. Baseline Estimates

We now turn to the estimates from our main estimating equation (3), which are reported in Table IV. The table reports results from five specifications for each outcome of interest. The first three specifications, reported in columns (1)–(3) and (6)–(8), include the same control variables as the specifications for the flexible estimates reported in Table II. The first specification includes country and time-period fixed effects only; the second includes the additional controls for land suitable for Old World staple crops interacted with time-period fixed effects; and the third, which is our baseline specification, further adds controls for ruggedness, elevation, and tropics, each interacted with the time-period fixed effects.

The estimates of equation (3) confirm the earlier findings that suggest that the introduction of potatoes increased total population and urbanization. The estimated coefficient of the potato suitability interaction term, $\ln Potato\,Area_i \cdot I_t^{Post}$, reveals the average increase in our outcomes of interest arising from increased access to the potato after 1700.[35] According to the estimate in column (3), increasing the amount of land suitable for potatoes by 1 percent increases population by 0.032 percent on average. The estimated coefficient for the city population share from column (8) suggests that a 1 percent increase in land that is suitable for cultivating potatoes increases the urban population share by 0.36 percentage points.

To illustrate the magnitudes of our estimates, we perform a simple calculation that measures how much of the observed increase in log population and urbanization (of the Old World) between 1700 and 1900 can be explained by the introduction of the potato. Based on our data, the natural logarithm of Old World population increased by 0.90, from 20.21 in 1700 to 21.11 in 1900. Using the baseline estimate reported in column (3) of Table IV, we can calculate the counterfactual population in 1900 for each country if potatoes had not been introduced. This is equal to the observed log population in 1900 minus the estimated impact of potatoes, $\hat{\beta}$, multiplied by the natural log of the country's land area suitable for potato cultivation, i.e., $\ln Total\,Population_{i,1900} - \hat{\beta} \cdot \ln Potato\,Area_i$. We then aggregate all countries' counterfactual

35. We report standard errors clustered at the country level. We have also calculated Conley (1999) standard errors that correct for possible spatial autocorrelation. These are virtually identical to the clustered standard errors reported here.

TABLE IV
THE IMPACT OF THE POTATO: BASELINE ESTIMATES

	Dependent Variable									
	ln total population					City population share				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ln *Potato Area* × Post	0.059	0.044	0.032	0.034	0.043	0.0044	0.0046	0.0036	0.0039	0.0039
	(0.009)	(0.011)	(0.012)	(0.011)	(0.014)	(0.0009)	(0.0009)	(0.0012)	(0.0011)	(0.0011)
Baseline Controls (× Year fixed effects):										
ln *Old World Crops Area*	N	Y	Y	N	Y	N	Y	Y	N	Y
ln *Elevation*	N	N	Y	Y	Y	N	N	Y	Y	Y
ln *Ruggedness*	N	N	Y	Y	Y	N	N	Y	Y	Y
ln *Tropical Area*	N	N	Y	Y	Y	N	N	Y	Y	Y
Other Controls (× Year fixed effects):										
ln *All Crops Area*	N	N	N	Y	N	N	N	N	Y	N
ln *Maize Area*	N	N	N	N	Y	N	N	N	N	Y
ln *Silage Maize Area*	N	N	N	N	Y	N	N	N	N	Y
ln *Sweet Potatoes Area*	N	N	N	N	Y	N	N	N	N	Y
ln *Cassava Area*	N	N	N	N	Y	N	N	N	N	Y
Observations	1552	1552	1552	1552	1552	1552	1552	1552	1552	1552
R-squared	0.99	0.99	0.99	0.99	0.99	0.38	0.39	0.44	0.44	0.48

Notes. Observations are at the country-year level. All regressions use a baseline sample of 130 Old World countries. Countries in North and South America are excluded. The periods are 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1750, 1800, 1850, and 1900. The dependent variable is either the natural log of the total population of the country measured in persons (ln total population), or the share of the population living in cities with forty thousand inhabitants or more (City population share). ln *Potato Area* is the natural log of land that is defined as suitable for the cultivation of potatoes. The Post indicator variable equals zero for the periods 1000–1700 and one for the periods 1750–1900. All regressions include year fixed effects and country fixed effects. Each control variable listed is interacted with a full set of time-period fixed effects. Full details of each control variable are provided in the text and Data Appendix. The inclusion of a control variable interacted with the full set of time-period fixed effects is indicated by a Y; N indicates that the control is not included in the specification. Coefficients are reported with standard errors, clustered at the country level, in parentheses.

populations and calculate a counterfactual measure of Old World log population. According to the calculations, the counterfactual log population in 1900 would have been 20.87 (rather than 21.11), and the increase would have been 0.66 (rather than 0.90). Therefore, the increase would have only been 74 percent (0.66/0.90) of the observed increase if potatoes had not been introduced. In other words, according to the estimates, the introduction of the potato explains 26 percent of the observed increase in Old World population between 1700 and 1900.

The average urbanization rate across Old World countries increased by 0.0402 (4.02 percent), from 0.0179 (i.e., 1.79 percent) in 1700 to 0.0581 (5.81 percent) in 1900.[36] Based on our baseline estimates (from column [8] of Table IV), the increase would have been 0.0265 without potatoes. Hence, the increase would have only been 66 percent (0.0265/0.0402) of the observed increase if potatoes had not been introduced. Therefore, the potato explains 34 percent of the observed increase in Old World urbanization between 1700 and 1900.

Columns (4), (5), (9), and (10) of the Table IV report the robustness of our results to the use of other baseline control variables. An alternative to controlling for Old World crop suitability is to control for the existence of land suitable for producing any crop, rather than just Old World staple crops. These estimates, which are reported in columns (4) and (10), are nearly identical to the baseline estimates reported in columns (3) and (8). The estimates in columns (5) and (12) show that results are unaffected by controlling for other New World crops. The specifications include the natural log of land suitable for cultivating grain maize, silage maize, sweet potatoes, and cassava, each interacted with the time-period fixed effects. The results are robust to controlling for these other New World crops.[37]

Sensitivity to Variable Definitions. The first sensitivity check that we perform tests the robustness of our estimates to the use of alternative postadoption dates and suitability measures. Estimates of equation (3) using alternative cutoff dates and suitability thresholds are reported in Table V. Each cell of the table reports the coefficient and standard error for β (the coefficient

36. The average is an unweighted country average. The results are similar if we calculate country averages weighted by city populations or total populations.

37. The results are similar if we instead control for the crops one at a time or if we control for a composite measure of New World crop suitability.

for $\ln Potato\ Area_i \cdot I_t^{Post}$) from one regression. Each row reports results using an alternative definition of the postadoption period. The first row uses the baseline definition of the postadoption period, which is 1750 and later. The other two rows use 1700 and later, and 1800 and later, as similar but alternative definitions. Each column uses a different suitability measure. Columns (1) and (5) use our baseline threshold of 40 percent assuming medium input intensity. Columns (2) and (6) use a lower threshold of 20 percent.

The estimates show that the results remain robust to the choice of slightly different adoption dates and different suitability thresholds. All combinations of the alternative measures produce estimates that are positive, similar in magnitude, and highly significant.

The remaining columns of Table V report results using alternative suitability measures that address the potential endogeneity of our measure of potato suitability due to selective breeding. As we discussed in Section IV.A., one potential concern is that potato varieties in locations with higher historical population growth might have been more intensively bred to develop high yielding varieties. In other locations, without fast population growth, varieties were not as intensively bred and therefore they provide lower yields today. To address this possibility, we construct an alternative measure of suitability that measures the amount of land in each country that can grow any amount of potatoes, even if the land is only able to yield a small fraction of the maximum obtainable yield. In other words, we create a measure that does not include the intensity of yield, which might have been affected by the evolution of varieties. In practice, this is the amount of land that can yield 20 percent or more under low input intensity, which is the lowest threshold one can choose. The results reported in columns (3) and (7) show that the estimates remain robust to the use of this alternative measure.

A second related concern is that areas with historically high population growth bred varieties to not only yield more, but to be grown more extensively on the land within the country. Therefore, breeding might have not only affected the intensive margin of cultivation, but also the extensive margin as well. To address this potential endogeneity, we construct an alternative suitability measure that equals the total amount of arable land if any amount of land within the country can be used to cultivate potatoes (no matter what the yield or how small the amount of land that can

TABLE V

ROBUSTNESS TO THE USE OF ALTERNATIVE DEFINITIONS FOR POTATO SUITABILITY AND FOR THE POSTADOPTION TIME PERIOD

	Dependent Variable							
	ln total population				City population share			
	Moderate input intensity & 40% suitability cutoff	Moderate input intensity & 20% suitability cutoff	Low input intensity & 20% suitability cutoff	Complete suitability if any amount of land yields >20% at low input intensity	Moderate input intensity & 40% suitability cutoff	Moderate input intensity & 20% suitability cutoff	Low input intensity & 20% suitability cutoff	Complete suitability if any amount of land yields >20% at low input intensity
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post = 1750, 1800, 1850, 1900 (Baseline)	0.032 (0.012)	0.039 (0.012)	0.038 (0.011)	0.026 (0.009)	0.0036 (0.0012)	0.0035 (0.0011)	0.0035 (0.0011)	0.0020 (0.0009)
Post = 1800, 1850, 1900	0.039 (0.012)	0.045 (0.013)	0.045 (0.012)	0.029 (0.010)	0.0044 (0.0012)	0.0040 (0.0013)	0.0040 (0.0013)	0.0020 (0.0010)
Post = 1700, 1750, 1800, 1850, 1900	0.027 (0.012)	0.033 (0.012)	0.033 (0.011)	0.025 (0.009)	0.0035 (0.0011)	0.0035 (0.0010)	0.0036 (0.0010)	0.0021 (0.0009)

Notes. Each cell of the table reports the coefficient for ln *Potato Area* × Post from one regression. The regressions use different postadoption cutoffs and different potato suitability measures. The periods for which the Post indicator variable equals one are reported in the leftmost column of the table. The potato suitability measure used is reported in the column headings. In all regressions, observations are at the country-year level for a sample that includes all Old World countries and the following time periods: 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1750, 1800, 1850, and 1900. All regressions include year fixed effects, country fixed effects, and the following baseline controls, each interacted with the full set of time-period fixed effects: ln *Old World Crop Suitable Area*, ln *Elevation*, ln *Ruggedness*, ln *Tropical Area*. Coefficients are reported with standard errors, clustered at the country level, in parentheses.

deliver this yield). Intuitively, the variable assumes full (and equal) treatment to all countries for which there is any evidence that potatoes can be cultivated on the land.[38] Variation in yield or the expanse of land that can cultivate potatoes, both of which might have been impacted by historical breeding, does not enter into the measure. The results reported in columns (4) and (8) show that the estimates are robust to this alternative variable as well.

VI. Robustness

VI.A. *Controlling for Additional Determinants of Population and Urbanization*

The results thus far show that after the introduction of potatoes, locations with greater suitability for potato cultivation experienced faster increases in population and urbanization. In our analysis, we control for a baseline set of country characteristics, each interacted with the full set of time-period fixed effects. We now consider a host of additional factors (each interacted with time-period fixed effects) that might have affected historical population and urbanization. Our choice of controls is guided by the determinants of long-term economic development that have been emphasized in the literature.

Our first set of controls captures differences in geography that might not be captured by the geography controls in our baseline specification. The first is motivated by studies that have identified a strong relationship between a country's distance from the equator and its economic development (e.g., Hall and Jones 1999). We therefore control for the natural logarithm of the distance from the equator (measured in degrees). We also control for the country-average of Kiszewski et al.'s (2004) malaria stability index. This is included to capture the historical impact that malaria (and the disease environment more generally) had on domestic institutions because of colonial rule (Acemoglu, Johnson, and Robinson 2001).

We also include additional covariates that capture differences in the evolution of countries' legal institutions. We control for indicator variables that identify each country's legal origin, as defined by La Porta et al. (1998): British, French, German, and

38. An alternative, but similar strategy, is to construct a "treatment" indicator variable that equals one if any amount of land in the country can yield any amount of potatoes. Using this measure also produces robust estimates.

Socialist (the omitted category is Scandinavian). We also control for the identity of the colonizer among former colonies. The colonizer identities, which are taken from Nunn and Puga (forthcoming), are: British, Portuguese, French, Spanish, and other European (the omitted category is for countries that were never colonized).

Our next set of controls captures factors that have been cited as causing the rise of Western Europe over the past three centuries. If European geoclimatic conditions are on average more suitable for potatoes, then other factors that led to the rise of Europe could cause our estimates to overstate the true effect of potatoes. We capture these determinants with indicator variables that identify countries that were Atlantic traders, part of the Roman Empire, and majority Protestant in 1600. All three factors have been argued to have been the key determinant of the rise of Europe: Acemoglu, Johnson, and Robinson (2005) argue for the importance of being an Atlantic trader; Jones (1981) and Landes (1998) argue for the importance of a history of Roman rule; while Weber (1993) identifies the importance of the Protestant religion.

Our final two variables account for the fact that the spread of potatoes occurred during a period of increased globalization and overseas trade. We account for differential impacts of globalization by controlling for countries' natural openness to overseas trade measured by a country's average distance from an ice-free coast. We also explicitly control for the trade in slaves from the African continent. The slave trade peaked during the eighteenth century, at approximately the same time that potatoes were being adopted. If the countries that were least able to adopt potatoes—e.g., parts of sub-Saharan Africa—were also countries that were depopulated because of the slave trade, then this might account for part of the estimated impact of potatoes. To account for this, we control for the number of slaves taken between periods $t-1$ and t.

The estimates are reported in Table VI. In Panel A, the dependent variable is total population, and in Panel B it is urbanization. Column (1) shows our baseline estimates of equation (3) as a benchmark for comparison. Columns (2)–(10) report estimates that separately control for each alternative determinant interacted with time-period fixed effects. Column (11) controls for all alternative determinants simultaneously.

In all specifications, the point estimates for $\ln Potato\ Area_i \cdot I_t^{Post}$ remain stable, suggesting that estimated impacts of potatoes

TABLE VI
ROBUSTNESS TO CONTROLLING FOR ADDITIONAL TIME- AND COUNTRY-VARYING FACTORS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Panel A. Dependent Variable: ln total population										
ln *Potato Area* × Post	0.032	0.030	0.025	0.029	0.033	0.033	0.032	0.028	0.034	0.034	0.031
	(0.012)	(0.012)	(0.016)	(0.011)	(0.011)	(0.012)	(0.012)	(0.012)	(0.012)	(0.011)	(0.016)
Controls (× Year fixed effects):											
Baseline controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
ln *Distance from Equator*	N	Y	N	N	N	N	N	N	N	N	Y
Malaria Index	N	N	Y	N	N	N	N	N	N	N	Y
Legal Origin Indicators	N	N	N	Y	N	N	N	N	N	N	Y
Colonial Origin Indicators	N	N	N	N	Y	N	N	N	N	N	Y
Atlantic Trader Indicator	N	N	N	N	N	Y	N	N	N	N	Y
Roman Heritage Indicator	N	N	N	N	N	N	Y	N	N	N	Y
Protestant Indicator	N	N	N	N	N	N	N	Y	N	N	Y
ln *Distance from Coast*	N	N	N	N	N	N	N	N	Y	N	Y
ln *Slave Exports*	N	N	N	N	N	N	N	N	N	Y	Y
Observations	1552	1552	1552	1552	1552	1552	1552	1552	1552	1552	1552
R-squared	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

TABLE VI
(CONTINUED)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Panel B. Dependent Variable: city population share										
ln *Potato Area* × Post	0.0036	0.0037	0.0034	0.0035	0.0036	0.0035	0.0033	0.0029	0.0030	0.0037	0.0029
	(0.0012)	(0.0012)	(0.0014)	(0.0011)	(0.0013)	(0.0012)	(0.0011)	(0.0012)	(0.0011)	(0.0011)	(0.0013)
Controls (× Year fixed effects):											
Baseline controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
ln *Distance from Equator*	N	Y	N	N	N	N	N	N	N	N	Y
Malaria Index	N	N	Y	N	N	N	N	N	N	N	Y
Legal Origin Indicators	N	N	N	Y	N	N	N	N	N	N	Y
Colonial Origin Indicators	N	N	N	N	Y	N	N	N	N	N	Y
Atlantic Trader Indicator	N	N	N	N	N	Y	N	N	N	N	Y
Roman Heritage Indicator	N	N	N	N	N	N	Y	N	N	N	Y
Protestant Indicator	N	N	N	N	N	N	N	Y	N	N	Y
ln *Distance from Coast*	N	N	N	N	N	N	N	N	Y	N	Y
ln *Slave Exports*	N	N	N	N	N	N	N	N	N	Y	Y
Observations	1552	1552	1552	1552	1552	1552	1552	1552	1552	1552	1552
R-squared	0.44	0.45	0.45	0.49	0.46	0.45	0.47	0.46	0.47	0.45	0.55

Notes. Observations are at the country-year level. All regressions use a baseline sample of 130 Old World countries. Countries in North and South America are excluded. The periods are 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1750, 1800, 1850, and 1900. The dependent variable is either the natural log of the total population of the country measured in persons (ln total population) or the share of the population living in cities with forty thousand or more inhabitants (City population share). ln *Potato Area* is the natural log of land that is defined as suitable for the cultivation of potatoes. The Post indicator variable equals zero for the periods 1000–1700 and one for the periods 1750–1900. All regressions include year fixed effects, country fixed effects, and the following baseline controls, each interacted with the full set of time-period fixed effects: ln *Old World Crop Suitable Area*, ln *Elevation*, ln *Ruggedness*, ln *Tropical Area*. Full details of each additional control variable are provided in the text and Data Appendix. The inclusion of a control variable interacted with the full set of time-period fixed effects is indicated by a Y; N indicates that the control is not included in the specification. Coefficients are reported with standard errors, clustered at the country level, in parentheses.

are robust to controlling for other determinants of long-term growth and development. Using the point estimates from Table VI, we can again calculate how much of the increase in Old World population and urbanization can be attributed to the introduction of the potato. Performing the same calculations as in Section V.D. and using the estimates from column (11), we find that the potato accounts for 25 percent of the increase population and 27 percent of the increase in urbanization. These effects, although slightly lower than those from our baseline estimates, are still sizeable.

Motivated by the concern that there still remain omitted geographic characteristics, we perform a number of additional sensitivity tests in which we control for geographic characteristics used by the FAO as inputs in the construction of their GAEZ crop suitability variables. As we have explained, the FAO's constructed crop suitability measures are created using three underlying geographic characteristics that constrain crop growth: climate constraints, soil constraints, and terrain slope constraints. Climate constraints are determined by a host of geographic factors including daily precipitation, evapotranspiration, average daily temperatures, accumulated daily temperatures, number of frost-free days, and so on. Soil constraints are a function of depth, fertility, drainage, texture and chemical constraints. Terrain slope constraints are a function of the slope of the land.

We have tested the robustness of our results to controlling for the three geographic components, each interacted with the full set of time-period fixed effects. The estimates, which we report in the Online Appendix, show that the estimated impact of potatoes remains robust to controlling for these underlying geographic constraints. The point estimates remain positive and highly significant and are almost exactly the same magnitudes as the baseline estimates.

VI.B. Examining within Continent Variation

We now return to the concern that our results might be simply capturing the fact that Europe is, on average, more suitable for potatoes and that European population and urbanization diverged from the rest of the world for reasons other than the adoption of potatoes. Our previous strategy was to control for factors that might have caused Europe divergence. Here we pursue an alternative strategy and estimate the effect of potatoes using within-continent variation only. We do this by adding continent fixed effects interacted with time-period fixed effects to our baseline specification, equation (3). With the continent-year fixed effects, our coefficient of interest, β, is identified from within-continent variation only. Therefore, the estimates are not identified from differences between Europe and the rest of the world. An additional benefit of the continent-year fixed effects is that they capture any historical continent-wide shocks that affected countries within a continent similarly.[39]

Estimates are reported in Table VII. Columns (1) and (3) report baseline estimates for comparison, while the remaining columns of the table report estimates with the continent-year fixed effects, with and without the set of baseline control variables. The estimates show that although the point estimates are reduced slightly, they remain positive and significant. The slightly smaller point estimates might reflect a loss of precision arising from the fact that there are relatively few countries within each continent.

TABLE VII
ROBUSTNESS TO USING WITHIN-CONTINENT VARIATION ONLY

	Dependent Variable					
	ln total population			City population share		
	(1)	(2)	(3)	(4)	(5)	(6)
ln *Potato Area* × Post	0.032	0.031	0.020	0.0036	0.0018	0.0022
	(0.012)	(0.013)	(0.013)	(0.0012)	(0.0011)	(0.0013)
Controls (× Year fixed effects):						
Baseline Controls	Y	N	Y	Y	N	Y
Continent Fixed Effects	N	Y	Y	N	Y	Y
Observations	1552	1552	1552	1552	1552	1552
R-squared	0.99	0.99	0.99	0.44	0.45	0.48

Notes. Observations are at the country-year level. All regressions use a sample of Old World countries that does not include countries in North and South America. The periods are 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1750, 1800, 1850, and 1900. The dependent variable is either the natural log of the total population of the country measured in persons (ln total population), or the share of the population living in cities with forty thousand inhabitants or more (City population share). ln *Potato Area* is the natural log of land that is defined as suitable for the cultivation of potatoes. The Post indicator variable equals zero for the periods 1000–1700 and one for the periods 1750–1900. All regressions include year fixed effects, country fixed effects, and the following baseline controls, each interacted with the full set of time-period fixed effects: ln *Old World Crop Suitable Area*, ln *Elevation*, ln *Ruggedness*, ln *Tropical Area*. The continent fixed effects are for Europe, Asia, Africa, and Oceania. The inclusion of a control variable interacted with the full set of time-period fixed effects is indicated by a Y; N indicates that the control is not included in the specification. Coefficients are reported with standard errors, clustered at the country level, in parentheses.

39. The continents in the sample are Europe, Asia, Africa, and Oceania. The continents of North America and South America are not in the sample.

VI.C. City Populations

As an alternative to examining variation across countries within a continent, we also examine variation in city populations. This has several benefits. The first is that this provides a richer source of variation for the within-continent estimations. The second benefit is that historical population data are generally believed to be more reliable for cities (Bairoch 1988, pp. 524–525).

The conceptual link between a city's suitability for potato cultivation and its population is made possible because, unlike Old World grain crops, potatoes were predominantly a subsistence crop, grown by those who consumed them. Trade in potatoes was very difficult because of their low value to weight and because of their tendency to spoil during transport. Therefore, historically there was almost no long-distance trade in potatoes (Mokyr 1983, p. 122). However, short-distance transport did occur and was more common. For example, Hoffman and Mokyr (1981, p. 42) note that urban residents in Ireland often rented plots of land just outside the city to grow potatoes for their own consumption.

Our analysis requires a measure of a city's suitability for cultivating potatoes. In choosing the land to examine when constructing this measure, we face a tradeoff. We want to include land that was just outside of the city center because this land might have grown potatoes consumed by those in the city. However, given the lack of longer-distance trade in potatoes, we do not want to include land that is too far from the city center. Therefore, we consider all land that is within one-hundred-kilometers of the centroid of the city and calculate the natural log of the land within this area that is suitable for potato cultivation.[40]

The city-level estimates are reported in Table VIII. All specifications control for time-period and city fixed effects. We conservatively cluster the standard errors at the country level and report Conley (1999) standard errors in square brackets (just below the clustered standard errors).[41] All regressions control for the baseline controls—Old World crop suitability, elevation, ruggedness, and prevalence of a tropical climate—but measured at the city level (and each interacted with time-period fixed effects).

40. We have also used fifty- or two-hundred-kilometer distances from a city's center and find that the results are robust.

41. Conley (1999) standard errors adjust for potential spatial interdependence of observations. It is assumed that independence is decreasing in the distance between observations and there is complete independence for cities that are more than five degrees apart.

TABLE VIII
THE EFFECTS OF THE POTATO ON CITY POPULATIONS

	Dependent Variable: ln city population						
	Cities with 40,000+ Population (Baseline Sample)					Cities with 1000+ Population	
	All Old World Cities		Omitting Europe		Europe Only	Europe Only	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ln Potato Area × Post	0.050	0.047	0.035	0.039	0.034	0.042	0.029
Clustered s.e.	(0.023)	(0.021)	(0.022)	(0.019)	(0.075)	(0.025)	(0.015)
Conley s.e.	[0.020]	[0.020]	[0.024]	[0.021]	[0.045]	[0.023]	[0.019]
Controls (× time-period fixed effects):							
Baseline controls	Y	Y	Y	Y	Y	Y	Y
Continent fixed effects	N	Y	N	Y	Y	N	N
Country fixed effects	N	N	N	N	N	N	Y
Observations	1607	1607	933	933	674	9319	9319
R-squared	0.77	0.79	0.75	0.75	0.87	0.74	0.79

Notes. Observations are at the city-year level. Columns (1)–(5) use a sample of cities with forty thousand or more inhabitants and the following time periods: 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1750, 1800, 1850, and 1900. Columns (6) and (7) use a sample of European cities with one thousand or more inhabitants and the following time periods: 1000, 1200, 1300, 1400, 1500, 1600, 1700, 1750, 1800, and 1850. For all specifications, the Post indicator variable equals zero for the periods 1000–1700 and one for periods 1750 and later. All regressions include year fixed effects, city fixed effects, and the following baseline controls, each interacted with the full set of time-period fixed effects: ln *Old World Crop Suitable Area*, ln *Elevation*, ln *Ruggedness*, ln *Tropical Area*. The inclusion of a control variable interacted with the full set of time-period fixed effects is indicated by a Y; N indicates that the control is not included in the specification. In all specifications, coefficients are reported with clustered standard errors, clustered at the country level, in parentheses. Conley standard errors are reported in square brackets. Spatial autocorrelation is assumed to exist among observations that are within ten degrees of each other.

Column (1) of Table VIII reports estimates of the baseline specification for all Old World cities. The estimate shows that increasing suitability by 1 percent increases city population by 0.050 percent. This estimate is not very different from our baseline country-level population effect of 0.032 percent (see column [3] of Table IV). In column (2), we add continent-year fixed effects. The estimated coefficient of 0.047 is very similar in magnitude and remains highly significant.

Next, we probe the robustness of our results to the omission of Europe from the sample. Columns (3) and (4) report estimates for non-European cities, with and without continent-year fixed effects. The point estimates are slightly lower but similar to the full sample estimates from columns (1) and (2). In column (5), we report estimates for a sample that includes only European cities. The coefficient for the European sample remains robust, with a point estimate that is similar to the estimates for the full sample, although the estimate is much less precise. We investigate this further by examining finer city-level data that are available for Europe only. Recall that our baseline measure of city populations only includes cities that have a population of forty thousand or more. When we restrict our sample to European cities, then we are able to use finer data from Bairoch, Batou, and Chèvre (1988) and DeVries (1984) on cities with one thousand or more inhabitants.

Estimates using the sample of European cities above the lower population threshold are reported in columns (6) and (7) of Table VIII. Column (6) reports a point estimate that is similar to the Europe-only estimate using the higher forty thousand-person threshold. However, the point estimate is now much more precisely estimated and is statistically significant. Column (7) reports estimates from a more demanding specification that includes country-year fixed effects. The estimates, therefore, are identified from variation across cities within countries. The estimate decreases slightly but remains positive and significant.

VI.D. Adult Soldier Heights within France

In our final exercise, we move to an even finer level of variation and examine the adult heights of soldiers that were born in France between 1658 and 1770. Height provides a summary measure of the stock of nutritional investments made during an individual's growing years of life and is associated with increased living standards, increased life expectancy, and decreased mortality (Waaler 1984; Fogel et al. 1982; Micklewright and

Ismail 2001; Meng and Qian 2009). Our sample includes 13,646 soldiers that were born in France between 1658 and 1770. These are all soldiers from the database constructed by Komlos (2005) for which we could determine the location of their town or village of birth.

We use the same estimation structure as in our baseline equation (3) to test whether the potato had an effect on adult height:

$$(5) \qquad Height_{ivt} = \eta \ln Potato\,Area_v \cdot I_t^{Post} + \mathbf{X}'_i \Gamma + \sum_d \mathbf{X}'_v \mathbf{I}_t^d \Phi_d + \sum_v \gamma_v I_i^v + \sum_{j=1658}^{1770} \rho_j I_t^j + \varepsilon_{ivt}.$$

The outcome of interest, adult height, $Height_{ivt}$, is measured in inches. It varies across individuals, indexed by i, that were born in village v in year t. The specification includes town-of-birth fixed effects, $\sum_v \gamma_v I_i^v$, as well as year-of-birth fixed effects, $\sum_j \rho_j I_t^j$. $\mathbf{X}'_i$ denotes controls for the age and age-squared of individual i when the height was measured, and $\sum_d \mathbf{X}'_v \mathbf{I}_t^d \Phi_d$ denotes a vector of village-level control variables interacted with decade (indexed by d) fixed effects.

We continue to define years after 1700 (i.e., 1701–1770) as the postadoption period. Like much of Europe, adoption in France began in the late seventeenth century and early eighteenth century, during which time potato cultivation spread in Franche-Comté, Lorraine, Burgundy, Lyonnais, and Alsace (Laufer, 1938, pp. 60–61).[42] To measure potato suitability across French villages, we use a more localized twenty-five-kilometer radius, rather than the one-hundred-kilometer radius we used to examine variation across cities globally.

Estimates of equation (5) are reported in Table IX. The estimates in column (1) control for town-of-birth fixed effects, year-of-birth fixed effects, the age and age-squared of the soldier when the height measurement was taken, and our set of baseline control variables, measured at the village-of-birth level, each interacted with decade-of-birth fixed effects. In column (2) we also include region-of-birth fixed effects, also interacted with the decade-of-birth fixed effects. In columns (3) and (4), we also include the

42. The estimates are robust to the choice of alternative but similar cutoff dates. Specifically, choosing any cutoff date between 1680 and 1730 yields similar results.

TABLE IX
THE EFFECTS OF THE POTATO ON SOLDIER HEIGHTS WITHIN FRANCE

	Dependent Variable: Adult height (inches)			
	(1)	(2)	(3)	(4)
ln *Potato Area* × Post	0.102	0.062	0.103	0.054
Clustered s.e.	(0.025)	(0.018)	(0.025)	(0.018)
Conley s.e.	[0.014]	[0.013]	[0.017]	[0.015]
Controls (× decade fixed effects):				
Baseline controls	Y	Y	Y	Y
French region fixed effects	N	Y	N	Y
Additional controls	N	N	Y	Y
Observations	13646	13646	13646	13646
R-squared	0.23	0.23	0.23	0.24

Notes. The dependent variable is the height of a French soldier (measured in inches), born in France between 1658 and 1770. Observations are at the town-of-birth and year-of-birth levels. The sample includes 1467 French towns and all years from 1658 to 1770. The Post indicator variable equals zero for years-of-birth from 1658–1700 and one for years 1701–1770. All regressions include year-of-birth fixed effects, town-of-birth fixed effects, the soldier's age and age squared at the time of height measurement, and our set of baseline controls, each interacted with decade fixed effects (ln *Old World Crop Suitable Area*, ln *Elevation*, ln *Ruggedness*, ln *Tropical Area*). The additional controls include: ln *Distance from Equator*, malaria index, and ln *Distance from the Coast*. For all specifications, the inclusion of a control variable interacted with decade fixed effects is indicated by a Y; N indicates that the control is not included in the specification. In all specifications, coefficients are reported with standard errors, clustered at the province level, in parentheses. Conley standard errors are reported in square brackets. Spatial autocorrelation is assumed to exist among observations that are within five degrees of each other.

additional controls from Table VI, each interacted with the decade-of-birth fixed effects. Because many of the controls from Table VI do not vary within France (e.g., legal origin), the set of additional controls is reduced to: ln *Distance from the Equator*, the malaria index, and ln *Distance from the Coast*. The table reports standard errors clustered at the province level as well as Conley standard errors.

The estimates provide evidence of a positive effect of potatoes on adult height. All estimates of η are positive and significant. The coefficients suggest that for towns that were fully suitable for potato cultivation, the introduction of the potato increased average adult height by 0.41–0.78 inches.[43]

In addition to providing estimates based on variation within finely defined French villages where much is held constant, the results also provide evidence for the mechanisms underlying our population estimates. They suggest that potatoes had a positive

43. For towns with full suitability, the introduction of the potato increased the potato interaction, $\ln Potato Area_v \cdot I_t^{Post}$, from 0 to 7.58. Therefore, the calculated effects range from 7.58 × 0.054 = 0.41 to 7.58 × 0.103 = 0.78.

impact on long-term health. And because previous studies find that within France during this time-period, height correlates with wealth, education, and literacy (Komlos 2003, pp. 159–160), the estimates also complement our urbanization findings and suggest that potatoes also increased living standards and income.

Overall, the estimates presented in Tables VII–IX provide reassurance that our baseline estimates of the effect of potatoes are not biased by other factors responsible for the rise of Europe during the period. Table VII shows that the country-level estimates are still positive and similar in magnitude when we control for continent-year fixed effects. The estimates from Tables VIII and IX show that the same is true when we examine variation in city populations within continents and countries and when we examine variation in heights across individuals within France.

VII. Conclusions

This study examines the effect of the introduction of potatoes on population and urbanization in the Old World during the eighteenth and nineteenth centuries. The nutritional and caloric superiority of potatoes relative to existing Old World staple crops, together with their introduction from the New World to the Old World, allows us to use a strategy similar to difference-in-differences to estimate the causal effect of the availability of potatoes on population and urbanization. According to our estimates, the introduction of the potato explains 25–26 percent of the increase in Old World population between 1700 and 1900 and 27–34 percent of the increase in urbanization.

Additional evidence from within-country comparisons of city populations and adult heights confirmed our cross-country findings. We found that the adoption of potatoes spurred city growth. Within a country, more suitable locations experienced faster relative population growth after the diffusion of the potato. Using anthropometric measurements of French soldiers born in the seventeenth and eighteenth centuries, we also found that potatoes increased adult height. According to our estimates, for villages that were completely suitable for potato cultivation, the introduction of the potato increased average adult heights by about half an inch.

Our findings contribute to the historical debate about the importance of nutritional improvements in explaining part of the rapid population increase over the past three centuries. They provide evidence that nutrition matters. Furthermore, because urbanization rates and adult heights provide reasonable proxies for economic development and overall standards of living, our results suggest that the availability of potatoes also played an important role in spurring economic growth in the eighteenth and nineteenth centuries.

Data Appendix

A. Crop Suitability Measures

Data on the suitability of climates for growing different crops are from the FAO's Global Agro-Ecological Zones (GAEZ) 2002 database (http://fao.org/Ag/AGL/agll/gaez/index.htm). We use the country-level measures constructed by the FAO in our regressions at the country level.

The FAO's measure of overall agricultural suitability is a composite measure of the suitability of an area for growing any agricultural crop for human consumption (not including crops for fodder).

The suitability variables are constructed as the natural log of one plus the amount of suitable land. In the country-level regressions, land is measured in thousands of hectares. For the city or village level regressions, land is measured in square kilometers.

B. Population and Urbanization

Country-level population data are from McEvedy and Jones (1978). Data on the populations of cities with more than forty thousand inhabitants are from Chandler (1987), Bairoch (1988), and Modelski (2003). Among the three sources, Chandler (1987) is the most complete, followed by Bairoch (1988) and then Modelski (2003). We therefore use the city measures from Chandler (1987), supplemented by Bairoch (1988) and Modelski (2003) if a city's population is missing from Chandler (1987) but exists in either Bairoch (1988) or Modelski (2003).

C. Baseline Geographic Control Variables

The variables measuring each country's average elevation, average ruggedness, and amount of land in a tropical climate are all from Nunn and Puga (forthcoming). Average elevation is measured in meters; ruggedness is the terrain ruggedness index measured in hundreds of meters. A country's total tropical land area, measured in thousands of hectares, is calculated by multiplying the fraction of a country's land that is tropical from Nunn and Puga (forthcoming) by a country's total land area from the FAO's GAEZ database. Each variable enters the regression equation log-linearly.

D. All Other Control Variables

A country's average distance from the equator (measured in degrees) and its average distance from an ice-free coast (measured in thousands of kilometers) are both taken from Nunn and Puga (forthcoming). Indicator variables for a country's legal origin and for the identity of the colonizer are also from Nunn and Puga (forthcoming). The indicator variable for a country's history of Roman rule equals one if a country was a part of the Roman Empire and not subsequently part of the Ottoman empire. The variable was defined and constructed by Acemoglu, Johnson, and Robinson (2005), who rely on information from Langer (1972). The Atlantic trader and Protestant religion indicator variables are also taken from Acemoglu, Johnson, and Robinson (2005). The Protestant indicator variable equals one if a country had a majority Protestant religion in 1600. The index of the stability of malaria transmission is taken from Nunn and Puga (forthcoming), who calculate country-level averages using underlying data from Kiszewski et al. (2004). The number of slaves taken from a country during the Indian Ocean, Red Sea, trans-Saharan, and trans-Atlantic slave trades in the years between each time-period (i.e., from $t-1$ to t) is taken from Nunn (2008). Because of data limitations, estimates are only available from 1400. We assumed that no slaves were taken prior to 1400. Although this is true for the trans-Atlantic trade, it is not true, strictly speaking, for the other three slave trades, in which a modest number of slaves were exported.

E. City-Level Variables

Data on the populations of cities with more than forty thousand inhabitants are from Chandler (1987), Bairoch (1988), and Modelski (2003). For the Europe-only analysis of cities with more than one thousand inhabitants data on city sizes are from Bairoch, Batou, and Chèvre (1988) and DeVries (1984); because the former source has wider geographic coverage and a longer time series, these figures are used with missing observations filled in with data from DeVries (1984) where possible. Because of limited temporal coverage in both sources, the analysis using this data only includes the following time periods: 1000, 1200, 1300, 1400, 1500, 1600, 1700, 1750, 1800, and 1850. The geographic locations of cities were identified using the global gazetteer Geonames, which is accessible at www.geonames.org.

Data on the suitability of the climate of a city for growing various crops are from the FAO's Global Agro-Ecological Zones (GAEZ) 2002 database. The data are publicly available and can be downloaded from www.iiasa.ac.at/Research/LUC/SAEZ/index.html. We use the underlying grid cell data, which are available as GIS raster files. The data on tropical climates are from the same source (plate 3). We define the tropics and subtropics as having a tropical climate. City level suitability is measured by the suitability of land within a one-hundred-kilometer radius of the city.

The underlying data used to construct city-level measures of ruggedness are from the FAO's Terrastat 2002 data compilation. The data are originally from the USGS GPOTO 30 elevation grid, which is the same source used by Nunn and Puga (forthcoming) to construct a country-level measure of terrain ruggedness. Ruggedness is measured as the average uphill slope of land within a one-hundred-kilometer radius of the city. Data used to construct each city's average elevation (measured in meters) is from Global Mapping International's Seamless Digital Chart of the World Base Map (DCW), version 3.2.

F. Soldier Heights Variables

Data on the heights of French soldiers and their dates and towns of birth are from Komlos (2005). Soldier heights are measured in inches. Village-level potato suitability is measured by the amount of suitable land within a twenty-five-kilometer radius of the soldier's village of birth. The construction of the village-level controls also uses a twenty-five-kilometer radius.

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