Potatoes, Milk, and the Old World Population Boom*

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Abstract

This paper explores the role of two foods, potatoes and milk, in explaining the increase in economic development experienced throughout the Old World in the 18th and 19th centuries. Nunn and Qian (2011) show the introduction of the potato from the New World has a significant explanatory role for within country population and urbanization growth over this period. I expand on this by considering the role of milk consumption, which is hypothesized to be a complement in diet to potatoes due to a differential composition of essential nutrients. Using a country-level measure for the suitability of milk consumption, the frequency of lactase persistence, I show that the marginal effect of potatoes on post-1700 population and urbanization growth is positively related to milk consumption. As the frequency of milk consumption approaches unity, the marginal effect of potatoes more than doubles in magnitude compared to the baseline estimate of Nunn and Qian.

JEL Classification: J1, N1, N5, O13.

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1 Introduction

A large literature links nutrition to a number of economic and health outcomes. Improvements in nutrition, particularly early in life, are associated with increased cognitive performance, improvements in later-life health, and a lessened burden of infectious disease, resulting in significant improvements to economic productivity.[1] Given this strong association, the historical lessening of malnutrition through country-level improvements to agricultural practices is shown to have led to large gains in economic growth (Fogel 1994). An important factor of the historical improvement in agricultural productivity within the Old World is the addition of the nutrient-dense potato from the Americas.

In a recent work, Nunn and Qian (2011; hereafter NQ) show an exogenous determinant of potato usage, land suitability, has a significant, positive effect on population and urbanization growth after the introduction of the potato from the New to the Old World. This positive effect is due to the nutritional superiority of potatoes compared to Old World staple crops. The increased nutrition from the introduction of South American potatoes to Old World farmers led to an increase in caloric output for a given acre of land, which in turn, led to an increase in both the carrying capacity of a country and the fraction of the labor force working in urban manufacturing centers.[2]

The main hypothesis of the current work is that milk complements the potato in diet by providing necessary vitamins, minerals, proteins, and fatty acids that are absent in potatoes. In other words, holding constant agricultural suitability, those countries that consume milk at a greater frequency are hypothesized to benefit more from the introduction of the potato. This idea is supported by the following statement in Nunn and Qian (2011, P. 601; McNeil 1999): "[A] single acre of land cultivated with *potatoes* and one *milk* cow was nutritionally sufficient for feeding a large family of six to eight [Emphasis added]." This statement implies complementaries in the diet of those families that were able to consume both potatoes and milk, where isolated consumption of either food source would be insufficient in feeding such a large family. Estimations in NQ, however, don't account for the varied consumption of milk. I therefore augment the explanatory power of potatoes by including a measure for the suitability of milk consumption, the country-level frequency of lactase persistence, or lactose

[1] See for example, Almond and Currie 2011, Arora 2001, Dasgupta and Ray 1987, and Headey 2012. The lessened burden of infectious disease is especially pronounced in periods prior to the major medical discoveries of the mid-20th century that led to substantial declines in mortality and incidence of many infectious diseases (Acemoglu and Johnson 2007, Arora 2001).

[2] Large populations serve as a proxy for economic development in the Malthusian economy in which the introduction of the potato occurred, and as outlined by the conceptual framework of NQ, increases in agricultural productivity are positively associated with the fraction of the labor force working in the urban, non-agricultural manufacturing industry. A further channel considered by NQ considers the shift from the Malthusian to the post-Malthusian era, which corresponds roughly with the introduction of the potato. The post-Maltusian economy of 1750 CE and later provides support for increasing incomes due to economic development. Considering urbanization as a proxy for income, the economic advantages from the complementarity between potatoes and milk are likely to result in changing rates of urbanization.

tolerance.

Country-level differences in the frequency of lactase persistence are the product of population, or ethnic, level differences. The beneficial effects of consuming milk throughout the life-course have resulted in the relative recent natural selection of lactase persistence within certain populations, where this population-level variation, and subsequent country-level variation, in the frequency of lactase persistence is due in part to the differential timing of the adoption of agriculture, the availability of milk producing domesticate animals, and differences in the cultural practice of dairying (Cook 2013; Ingram et al. 2009a; Simoons 1969). Therefore, in some sense the main hypothesis of this paper represents a gene-environment interaction in which the favorable advantages of the potato are supplemented by a latent population difference that allows for the consumption of the complement in diet, milk.

With this idea in mind, my main estimating equation explores the within-country multiplicative interaction between the agricultural suitability of potatoes and the frequency of lactase persistence after the introduction of potatoes. In so doing, I treat milk and potatoes as complementary inputs in the production of larger populations and greater urbanization rates. To preview my findings, the coefficient of the interaction, my coefficient of interest throughout the paper, is positive and statistically significant in numerous estimations, supporting the complementarity between the two foods. For countries composed entirely of lactase persistent individuals, my estimates imply that the marginal effect of potatoes on population and urbanization is more than double that found in NQ. This result is robust to the inclusion of continent fixed effects and potentially omitted variables, and placebo tests provide no support for alternative unobserved complementaries that may potentially bias my main findings.

1.1 Complementarity between Potatoes and Milk

In a companion work, I show that milk is strongly associated with population density in 1500 CE, which can be seen as a proxy for precolonial economic development (Cook 2013). Two main reasons are given for this relationship.[3] First, dairy provided a quantitative caloric benefit to early farmers. Second, milk provided a qualitative improvement to a farmer's diet. Of primary focus to the current work is the qualitative improvement in diet.

The proposed hypothesis in this paper is that milk consumption complemented the nutritionally superior potato. In other words, if two farmers adopted the potato, the one who is able to consume

[3] A third potential reason is also discussed. Milk provided an obvious substitute to mother's milk. The availability of this substitute led to an increase in the fecundity of women by shortening the weaning period of infants, and thereby, allowing for a shorter postpartum infertility period in women. The shorter infertility period allowed mothers of lactase persistent children to have more children.

milk would be able to support a larger family, all else equal. The reason for this relationship lies in the nutritional benefit of each food source. Milk is high in fats and proteins, while potatoes contain high amounts of calories relative to other staple crops. For a 30 year old male weighing 150 pounds a quart of milk would contain 69% of daily recommended protein, 46% of daily fat, 19% of daily carbohydrates, and 30% of daily calories (USDA 2005).[4] Additionally, a quart of milk contains 138% of daily calcium, 72% of vitamin A, 10% of vitamin D, 150% of riboflavin, and 30% of potassium. In contrast, one large potato (300 grams; baked) contains 17% of daily recommended protein, 0.01% of daily fat, 25% of daily carbohydrates, and 14% of daily calories.[5] One 300 gram potato also contains 38% of vitamin C, 53% of iron, and 26% of folate. This implies a farmer could subsist on one quart of milk and 5 potatoes a day. Additionally, according to the WHO (2009, p.3): "The profile of amino acids in milk complement those in grains and cereals, which is of considerable benefit in communities where grains and cereals predominate."

Fats, or more broadly lipids, which are absent in a diet composed solely of potatoes, are important in the supply of essential fatty acids (e.g., DHA, AA, etc.), the absorption of fat-soluble vitamins A, D, E, and K, the creation of cell membranes, and neurological development in early childhood (Milner and Allison 1999). Fatty acids are also easier to digest, implying that of two food sources that are equal in calorie content the one higher in fat provides greater a number of digested calories (Sims and Danforth 1987). The composition of fatty acids in milk are also favorable to neurological development and later-life health with 2.3% of the fat being essential fatty acids (IOM 2002, Mansson 2008).[6] In addition to fatty acids, milk also supplemented the quantity and quality of proteins in a diet composed solely of potatoes. As mentioned previously, more than two-thirds of daily protein requirements can be obtained from a quart of milk; furthermore, the protein from milk is more easily digested than that of potatoes (Eppendorfer and Eggum 1992; Hoffman and Falvo 2004).[7]

A secondary complementarity between potatoes and milk is in the micro nutrient composition of each food source. Potatoes contain more micronutrients compared to other staple crops but lack

[4]The recommended amount of protein for 19-30 year old males is 0.66 grams per kilogram of adult weight. The recommended daily fat intake is 65 grams. Calorie intake is based on a 2,000 calorie diet. A quart of whole milk (without added vitamin A or D) contains 595 calories, 30.74 grams of protein, and 31.92 grams of fat (USDA 2005). Additionally, it contains 1,100 mg of calcium, 449 mg of vitamin A, 1 mg of vitamin D, 1.65 mg of riboflavin, and 1,288 mg of potassium (USDA 2005)

[5]An unsalted 300 gram baked potato contains 7.47 grams of protein, 0.39 grams of fat, 63.24 grams of carbohydrates, and 278 calories. Additionally, a potato contains 28.7 mg of vitamin C, 3.23 mg of iron, and 84 mg of folate

[6]Essential fatty acids linolenic (omega-6) and alpha-linolenic (omega-3) account for 1.6% and 0.7% of fat, respectively. Additionally, 27.3% of fatty acids in milk are unsaturated, 70% are saturated fatty acids, and 2.7% are trans fatty acids (Mansson 2008). Using a measure that captures cholesterol and saturated fat, whole milk is comparable to lean (10% fat) ground sirloin (Connor et al. 1986).

[7]The usability of a protein is determined by biological value, which is the proportion of a digested protein that is converted into protein for the digester (Mitchel 1924). The biological value of milk is 91 (Hoffman and Falvo 2004), whereas the biological value for a cooked white potato is 65 (Eppendorfer and Eggum 1992), implying a greater fraction of milk protein is being used in digestion.

vitamin A and calcium. Milk is naturally high in both calcium and vitamin A, thereby providing needed vitamins for a diet rich in potatoes.[8] Historic proof of a diet composed mainly of potatoes and an absence of vitamin A is given from the Irish Potato Famine, during which many families excluded whole milk from the diet, resulting in an increased frequency of xerophthalmia, or vitamin A deficiency (Crawford 1984).[9] An additional benefit of adding milk to a diet composed solely of potatoes is the addition of calcium, which can help offset rickets and other problems associated with bone development. Old World crops contained adequate amounts of calcium, but potatoes contain no calcium.[10] Furthermore, the added vitamin C from potatoes aids in the absorption of calcium and iron.[11]

Figure 1 plots the percent of the recommended daily amount for macro and micro nutrients contained within both potatoes and milk.[12] The difference in potatoes and milk in regards to fatty acids, vitamins C and A, calcium, and all other nutrients of importance is shown within Figure 1. To analyze this difference as well as potential relationships between potatoes and other foods, Table 1 gives the correlation of nutrient composition between potatoes, milk, New World crops (i.e., sweet potatoes, corn, and cassava), Old World crops (i.e., wheat and rice), and beef.[13] A negative correlation in Table 1 implies that two food sources differ in composition, or are complements in diet, while a positive correlation implies the two foods have similar compositions and are substitutes in diet. As shown in Table 1, a negative and statistically significant correlation exists between potatoes and milk, implying complementarity, while potatoes are not significantly correlated with any other food considered. The findings of Table 1 provide further support for the complementarity between potatoes and milk.

An additional non-dietary complementarity is found between the other products of domesticate animals, particularly manure, and potatoes.[14] Potatoes were often fed as fodder to domesticate animals, while manure help to supplement the soil of farmers. This is especially true for farmers who used

[8] The role of vitamin A in the complementarity between potatoes and milk is partially checked in Table 5. Table 5 examines the complementarity between milk and other New World staple crops, including sweet potatoes. Sweet potatoes are very similar to white potatoes, except in vitamin A content: sweet potatoes contain large amounts of vitamin A, while vitamin A is absent in white potatoes. From Table 5, it is shown that milk does not complement sweet potatoes, implying the complementarity between potatoes and milk may be heavily influenced by the presence of vitamin A in milk.

[9] Xerophthalmia is a dryness of the eyes, which can result in blindness. For some, buttermilk or skim milk replaced whole milk. These substitutes, however, are insufficient in vitamin A.

[10] For 100 grams, Old World crops–i.e., wheat and rice–contain an average of 22 mg of calcium (34mg from wheat and 10mg from rice). Roughly 300 mg of calcium are needed to prevent rickets (Kooh et al. 1977); therefore, 1.36 kg of Old World crops provide sufficient calcium to help offset rickets.

[11] High levels of calcium intake potentially interfere with the absorption of iron (Hallburg 1998). This effect can be offset, however, by the inclusion of vitamin C, which aids in iron absorption (Hallburg et al. 1989).

[12] A consistent unit of mass (100g) is used for each food source. For Figure 1, a consistent y-axis for each sub-figure is not used.

[13] For Old and New World crops the average amount of each nutrient is used to calculate the correlation.

[14] This implies a complementarity between domesticate animals and potatoes not tied to the consumption of milk. This idea is tested in Table 5.

potatoes as a rotational crop. Traditional rotational crops–i.e., legumes and clover–increase nitrogen in the soil; potatoes, however, do not. This implies a greater marginal benefit of manure for farmers using potatoes as a rotational crop.

Today, a positive relationship exists between country-level potato consumption and a country's contemporary frequency of lactase persistence.[15] This relationship is shown for Old World countries, including Oceania, in Figure 2. A strong positive relationship remains between the two food sources as shown by the slope coefficient of 68.63, which is significant at the 1 percent level.[16] This contemporary relationship between potatoes and lactase persistence provides further support for the historic complementarity in the diet between the two food sources.

Potatoes provide a greater number of micro nutrients and calories than other staple crops; however, a diet composed solely of potatoes lacks essential nutrients. Adding milk to a diet of potatoes provides needed fatty acids, additional protein, and essential micro nutrients. Together milk and potatoes provided an adequate diet that led to larger populations. The next section outlines the data to be used, while section 3 provides evidence for the role of milk in augmenting the introduction of the potatoes in the creation of larger populations and cities.

2 Data

2.1 The Frequency of Lactase Persistence

Not all people are able to consume milk. The reason for this varied consumption is due to differences in the presence of an enzyme in the small intestine, lactase. Lactase is responsible for breaking down lactose, a sugar found in all milks. If lactase is not present, lactose will pass to the colon and lead to cramping or diarrhea (Simoons 1969). The presence of lactase in some people, and not others, is one of the most famous examples for the continued natural selection in humans (Ingram et al. 2009a). The persistent production of lactase is the product of a specific gene variant. The particular variant, however, differs across populations (Ingram et al. 2009b; Tishkoff et al. 2006). Therefore, the measure of lactase persistence is based on the observed ability to consume lactose, which is the product of latent genetic variation.

The data for frequencies of lactase persistence come from Ingram et al. (2009a). The authors collect lactase persistence frequencies for a wide number of ethnic groups from previous studies.[17] The

[15] Potato consumption data are from the FAO and are for the year 2009. Contemporary lactase persistence frequencies are first tabulated in Cook (2013). The extended sample of countries described in Section 2.1 and the Supplemental Appendix is also used in Figure 2.

[16] Interpreting the coefficient, a 1 percentage point increase in the frequency of lactase persistence is associated with an increase of roughly 0.7 kilograms of potato consumption in 2009.

[17] The sampling techniques for collecting lactase persistence frequencies are consistent in all past studies. For collection, either blood glucose or breath hydrogen tests are conducted. For a full discussion see Cook (2013).

data present two problems: First, data are on the ethnic level, while I am interested in explaining the country-level differences. Second, the collection dates for the frequency of lactase persistence range from roughly 1960 to 1990; data from this period may not be relevant to explaining population changes of the 18th and 19th century.

In order to aggregate ethnic lactase persistence data to the country level, I use ethnic compositions from Alesina et al. (2003).[18] The ethnic data of Alesina et al. (2003), however, give compositions for roughly the mid 1990's. In order to find ethnic compositions for the pre-industrial period, I use data from Putterman and Weil (2010) on global migration between 1500-2000 CE.[19] The frequency of lactase persistence using historical ethnic composition does not differ substantially from a measure of lactase persistence calculated using the contemporary ethnic compositions from Alesina et al.; the correlation between the two measures is roughly 0.98. This implies that Old World migration between my periods of interest,1000-1900 CE, should not be a major source of bias for my country-level measure of lactase persistence. An additional issue involves the natural selection of lactase persistence occurring over this period. As argued in Cook (2013), I cannot rule out the possibility that population size influenced the selection of lactase persistence; however, given the relatively short period in which this potential difference in selection is able to occur (roughly 20 to 40 generations) and the fact that the frequency of lactase persistence has no significant relationship with cross-country differences in more historic population density and urbanization, any non-monotonic cross-country differences in the frequency of lactase persistence over time are assumed to be minor.

One further issue lies in comparing the sample of countries of NQ to those for which I have historic lactase persistence frequencies. The sample of 130 countries in NQ represents most Old World countries, including Oceania. For these 130 countries, 110 are matched with data on historic lactase persistence frequencies from Cook (2013).[20] The 20 excluded countries, however, are not random. These countries tend to have lower initial populations, slower population growth over the period considered, and are less suited for potato production. Therefore, I extend the sample of countries by using the contemporary majority ethnic group as a representative for the historic ethnic composition. This representative ethnicity is then matched to a similar ethnicity (by language, Lewis 2009) for which there is data in Ingram (2009a), creating a country-level measure for the frequency of lactase persistence. Performing an identical process for the base sample of Cook (2013), historic lactase persistence from the majority ethnic group is found to have a correlation of 0.98 with lactase persistence calculated

[18]Ethnic groups from Ingram et al. (2009a) are not a perfect match to ethnic groups in Alesina et al. (2003). The use of ethnic language classifications, however, allows for the matching of related groups (Lewis 2009).

[19]A complete discussion of the migration adjustments can be found in Section 2 of Cook (2013).

[20]The excluded countries are Australia, Bhutan, Central African Republic, Cote d'Ivoire, Djibouti, Western Sahara, Fiji, Iceland, Israel, Mauritania, New Zealand, Papua New Guinea, Qatar, Russia, Solomon Islands, Sierra Leone, Swaziland, Chad, Togo, and Timor-Leste. A complete discussion is given in the Supplemental Appendix.

with the Putterman and Weil (2010) migration matrix. After extending the sample, my analysis uses the same sample of countries as NQ.[21] The country-level frequency of lactase persistence is shown graphically in Figure 3.

The resulting country-level data for lactase persistence gives the percent of a country's population that is able to consume milk. This measure is similar qualitatively to the agricultural suitability measure employed by NQ. The frequency of lactase persistence is an inherent difference that gives the *suitability* of milk consumption for a given country.

2.2 Agricultural Suitability

Data for crop suitability come from the Food and Agriculture Organization (FAO)'s Global Agro-Ecological Zones. The FAO's data set takes into account many environmental factors to determine individual crop yields. The environmental factors come from the Climate Research Unit and include precipitation, frequency of wet days, mean temperature, diurnal temperature range, vapor pressure, cloud cover, sunshine, ground-frost frequency, and wind speed. The FAO data also take into account soil and slope conditions. Potential crop yields are then calculated for within country grids. The grids are 0.5 degrees latitude and 0.5 degrees longitude and span the globe. Suitability is determined by classifying grid yields relative to the maximum yield; e.g., a grid is said to be very suitable if it can produce 80-100% of the maximum possible output.[22]

NQ define land to be suitable for cultivation if it can produce 40% of the maximum output. With this understanding, NQ define country-level crop suitability as the number of suitable hectares within a country. In addition to the suitability of potatoes, agricultural suitability measures are also found for sweet potatoes, silage maize, grain maize, cassava, wetland rice, dryland rice, wheat, and a measure for the suitability of all crops. These data are for all Old World countries, including Oceania. The country-level measure for potato suitability is displayed by Figure 4 and the interaction between the agricultural suitability of potatoes and the country-level frequency of lactase persistence is given in Figure 5.

A few concerns arise in using crop specific agricultural suitability. First, the measures are obtained in the 1990's, roughly 200 years after the population boom. The suitability measures, however, are based on climatic conditions that have changed little over the last 200 years. Second, a number of differing potato varieties have evolved over time. Given this fact, it is possible farmer's manipulated potatoes to grow in regions that were densely populated. This issue of reverse causality brings into question the causative properties of potatoes on population growth. The manipulation of potato

[21] Complete documentation of the extended sample of lactase persistence is given in the Supplemental Appendix.
[22] Maximum output is obtained from the best possible conditions.

varieties, however, has been shown to be mostly for visual reasons, not to supplement high population areas. According to NQ (P. 613), "To the best of our knowledge, the focus was not on developing varieties that could be grown in climates with rapid population growth." Therefore, crop suitability measures are considered an exogenous determinant of crop yields across countries.

2.3 Other Variables

The primary dependent variables are country-level population and urbanization rates between 1000 and 1900 CE. Population data are from McEvedy and Jones (1978) and are widely used in related work (see e.g., Acemoglu et al. 2002; Ashraf and Galor 2011, 2013). Population can be seen as a proxy for the level of economic development in the Malthusian economy of the time (Ashraf and Galor 2011). In addition to populations, the use of urbanization rates, defined as the fraction of a country's population living within a city containing 40,000 or more residents, intends to measure the effects of the proposed complementarity on improving agricultural productivity and income (Acemoglu et al. 2002).

Covariates that make up the baseline estimating equation include the natural log of the number of hectares suitable for all agriculture, the presence of large domesticate animals, the suitability of land for pasture, the intensity of animal husbandry, the years a country has practiced agriculture, an index for historic economic complexity, an index for historic political hierarchy, the natural log of average elevation, the natural log of average ruggedness, and the percent of a country within the tropics. Definitions and sources of all variables used throughout the paper are found within the Variable Appendix. Summary statistics for my main variables of interest as well as those not directly from NQ are given in the Supplemental Appendix.

3 Results

The primary estimations follow those found in NQ. Towards this end, I will first show that the complementarity between milk and potatoes is a significant explanatory factor of population and urbanization growth after NQ's proposed date for the introduction of potatoes to the Old World. Secondly, I will estimate the baseline interaction model. In essence, this is a difference-in-differences estimation, in which the suitability variables are continuous measures of receiving the treatment. Further estimations test plausible complementarities between lactase persistence and other New World crops as well as other beneficial factors associated with lactase persistence frequencies–e.g., other advantages of domesticate animals and cultural variation–that may be complementary to a diet of potatoes. Finally, I will consider robustness to continent-level fixed effects and the inclusion of potentially omitted variables.

3.1 Baseline

This section provides empirical evidence for the complementarity between the agricultural suitability of potatoes and the frequency of lactase persistence in explaining within-country population and urbanization growth. First as in NQ, flexible estimations will be used to show that the positive and significant interaction between potatoes and milk occurs after the proposed introduction date of the potato, i.e., 1700. This is measured by the joint significance of the coefficient of the interaction between potato suitability and lactase persistence for within year estimations, and is given by the following estimating equation:

$$\begin{aligned} y_{it} = \; & \sum_{j=1100}^{1850} \beta_j^M \ln FLP_i \cdot I_t^j + \sum_{j=1100}^{1850} \beta_j^P \ln PSA_i \cdot I_t^j + \sum_{j=1100}^{1850} \beta_j^{PM} \ln PSA_i \cdot \ln LPF_i \cdot I_t^j \\ & + \sum_{j=1100}^{1850} \mathbf{X'}_i \mathbf{I}_t^j \phi_j + \sum_c \gamma_c I_i^c + \sum_{j=1100}^{1850} \rho_j I_j^t + \epsilon_{it} \end{aligned} \quad (1)$$

where i is a country indicator, t is an indicator for the year, and y_{it} represents either the natural log of population or the fraction of the country living within a city of country i in year t, FLP_i is the frequency of lacatse persistence in country i, and PSA_i represents the agricultural suitability of potatoes. My coefficient of interest, β_j^{PM}, gives the complementarity between milk and potatoes in year j. A positive coefficient on the interaction term implies that the marginal productivity of potatoes is influenced by the ability to consume milk in country i, where $\partial^2 y^j / \partial PSA \partial LPF$ is given by β_j^{PM}. Therefore, I expect β_j^{PM} to be positive and significant for $j > 1700$, where as in NQ, I use 1750 as the introduction date of potatoes. β_j^P's represent the within year effect of potatoes, $\sum_{j=1100}^{1850} \mathbf{X'}_i \mathbf{I}_t^j \phi_j$ represents year specific controls, country fixed effects are given by $\sum_c \gamma_c I_i^c$, year fixed effects are given by $\sum_{j=1100}^{1850} \rho_j I_j^t$, and standard errors are clustered by country.

Table 2 displays the within-year effects of the interaction between potato suitability and lactase persistence for 1100-1900 CE. Columns (1) and (2) use the natural log of population as the dependent variable and columns (3) and (4) use the city population share, or urbanization, as the dependent variable. Odd numbered columns include main and interactive effects for the frequency of lactase persistence and the natural log for the number of potato suitable hectares and year fixed effects, while even numbered columns include all baseline controls. Figure 6 displays the point estimates from columns (2) and (4) of Table 2, from which it is clear that the coefficient of association between milk and potatoes is tied to the introduction date of 1700. Prior to 1750, a weak (but statistically significant) and positive association exists between milk and potatoes in the production of larger populations; however, no statistically significant effect is shown for the interaction on urbanization prior to 1750. Using the estimates from Table 1, Figure 7 plots the marginal effect of potato suitability on populations and urbanization for varied levels of milk consumption. The most obvious attribute of Figure 7 is that the marginal effect of potatoes is greater for countries which were better able to consume milk, and as in NQ, this marginal effect of potatoes increases exponentially after the established introduction date. After the potato becomes more widely dispersed throughout the Old World, the coefficient of the interaction increases exponentially, implying the marginal effect of potatoes on population and urbanization is tied to the frequency of lactase persistence in each country.[23]

The estimates of Table 2, displayed by Figures 6 and 7, give credence to the use of the difference-in-differences specification of NQ. For my baseline estimation, the primary focus is on the relationship of milk and potatoes after 1700. This is done by interacting both the frequency of lactase persistence and the suitability of potatoes with an indicator variable for the post-introduction period. This is seen in the baseline estimating equation:

$$\begin{aligned} y_{it} = \; & \beta^M \ln LPF_i \cdot I_t^{Post} + \beta^P \ln PSA_i \cdot I_t^{Post} + \beta^{PM} \ln LPF_i \cdot \ln PSA_i \cdot I_t^{Post} \\ & + \textstyle\sum_{j=1100}^{1850} \mathbf{X'}_i \mathbf{I}_t^j \phi_j + \sum_c \gamma_c I_i^c + \sum_{j=1100}^{1850} \rho_j I_j^t + \epsilon_{it} \end{aligned} \tag{2}$$

where I_t^{Post} is the post 1700 indicator, $\sum_c I_i^c$ and $\sum_{j=1100}^{1850} I_j^t$ represent country and year fixed effects, respectively, and $\mathbf{X'}_i$ is a vector of country-specific controls for agriculture, the use and presence of domesticate animal, historic economic and political development, and geography. Following the empirical specification of Equation 2, β^M and β^P give the respective main effect of milk and potatoes on population growth or urbanization within a country after introduction of the potato from the New World to the Old. My coefficient of interest, β^{PM}, measures the relationship between potatoes and milk in explaining either population or urbanization growth after the introduction period, where a positive coefficient implies a complementarity between the two food sources. The estimates of Equation 2 are shown in Table 3 and are given by the following form: column (1) includes country and year fixed effects but no country-specific controls, columns (2)-(5) piecemeal include the baseline controls–crops suitability, the usage and presence of domesticate animals, measures for historic economic and political development, and geography–into the estimation of column (1), and column (6) represents the baseline estimating equation given by Equation 2 above. Table 3A considers the effect of the interaction on the within country growth in population, while Table 3B considers an equivalent effect on urbanization. All estimations cluster standard errors at the country level.

Column (1) in Table 3A gives the estimates for regressing the natural log of population on the suitability of potatoes, the frequency of lactase persistence, and the interaction between the two foods as well as country and year fixed effects. From column (1), there are no significant main effects for either potatoes or milk in explaining the within country population growth after NQ's introduction date of 1700; however, the interaction between the two food sources is positive and highly significant.

[23] Using alternative years, confirms the cutoff of 1750. These estimates are given in the Supplemental Appendix.

This finding suggests that the effect of the potato in explaining larger, post-introduction populations is dependent upon the frequency of lactase persistence within a country. This is further supported by the marginal effect of potato suitability for varied frequencies of lactase persistence. In a parallel estimation within NQ (column (1) of Table IV, p. 628), which focuses only on the effect of potato suitability and not its interaction with lactase persistence, the potato elasticity of population is found to 0.059. Comparing this coefficient to the marginal effects given in column (1) of Table 3A, the effect of potatoes on population growth is significantly smaller (p-value = 0.0049) for countries with a lactase persistence frequency at the 25th percentile of the distribution, while the estimate of NQ is indistinguishable from my own for countries with a frequency of lactase persistence above the median. For the frequency of lactase persistence approaching unity, the effect of potatoes on population growth would be roughly equal to the coefficient on the interaction term.[24] The magnitude of this coefficient is more than twice that for similar estimation in NQ.

Columns (2)-(5) of Table 3A piecemeal include the baseline controls, while column (6) represents Equation 2 and gives the baseline estimates. Baseline controls are divided into 4 sets–crop suitability, domesticate animals, historic economic/political development, and environment–which correspond, respectively, to the piecemeal inclusion of controls in columns (2)-(5). Crop suitability is measured by the suitability of all crops. The use of this control is intended to capture the beneficial effects of favorable agricultural environments, which may be driving the positive population effects of the suitability of potatoes. The set of controls for the historic use and presence of domesticate animals is intended to capture the potentially positive effects of domesticate animals outside of dairying. In addition to milk, domesticate animals provide other forms of nutrition (i.e., meat) and labor, which could also complement potatoes.[25] The third set of baseline controls account for historic differences in economic development. As argued in Cook (2013), cross-country differences in the frequency of lactase persistence are strongly and positively associated with population density in 1500 CE, a commonly used measure for precolonial economic development. Therefore, the complementarity between milk and potatoes may be accounting for an unobserved complementarity between potatoes and the level of economic development at the time of introduction.[26] Finally, I control for a number of environmental differences between countries, which are also used for estimation in NQ.

The inclusion of our baseline controls, either separately in columns (2)-(5) or jointly in column (6), does not alter the relationship between potatoes and milk in explaining post-1700 population growth. Main effects for both food sources are insignificant, while the interaction between the two remains

[24]Given a lactase persistence frequency equal to one, the marginal effect of potato suitability is 0.1150.
[25]This idea is further checked in Table 5.
[26]This idea is further checked in Table 6.

positive, similar in magnitude to the simple estimation of column (1), and statistically significant at conventional levels. Given the consistency in estimation across columns in Table 3A, it is not likely that the positive and statistically significant interaction between potatoes and milk is being driven by either crop suitability, domesticate animals, historic economic development, or environmental differences across countries. These potential sources of bias are checked further in Section 3.2.

Table 3B mirrors the estimation of Table 3A, replacing the natural log of population with the fraction of the population living within a city of at least 40,000 individuals. Focusing on urbanization in place of populations does not change my main findings. The effect of potatoes in explaining urbanization is tied to the frequency of lactase persistence within a country. Countries with a lessened ability to consume milk did not significantly benefit from the introduction of the potato. This is seen in the insignificant marginal effect of potatoes evaluated at the 25th percentile of the frequency of lactase persistence. However, as the frequency of lactase persistence increases so too does the effect of potatoes in explaining increasing urbanization. As with populations, the benefits of potatoes are moderated by the ability of the population to consume milk. This is due to the differential nutrient composition of the two food sources. While potatoes were able to provide more calories and an increased array of nutrients compared to the previously used Old World crops, potatoes alone are unable to make up a complete diet. The supplementation of milk, which is significantly different in its nutrient composition, fills the gaps in nutrition from a diet strictly of potatoes.

The estimates of Tables 3A and 3B support the main hypothesis of this paper: Countries that were better able to consume milk received greater benefits from the introduction of the nutritionally superior potato than those countries that were composed of non-milk drinking populations. The marginal effect of potatoes more than doubles as the frequency of lactase persistence approaches unity, and this finding is consistent throughout the numerous specifications of Tables 3A and 3B.

3.2 Placebo Tests

Table 4 explores the relationship between milk consumption, as measured by the country-level frequency of lactase persistence, and other New World staple crops. This is done by considering potential interactions between the frequency of lactase persistence and measures for the suitability of other New World staple crops. Columns (1) and (2) consider maize, columns (3) and (4) consider sweet potatoes, columns (5) and (6) consider cassava, and columns (7) and (8) consider silage maize. Odd numbered columns explore the interaction model while controlling only for year and country fixed effects, and even numbered columns represent the baseline estimating equation, including a control for potato suitability. For Panel A, the natural log of populations is used as the dependent variable, while for Panel B, the share of the population living within a city is the dependent variable.

Column (1) looks at the interaction model for maize and milk in explaining within-country population and urbanization growth. Column (1) controls only for country and year fixed effects, while column (2) includes the baseline controls and the agricultural suitability of potatoes.[27] The estimates of columns (1) and (2) show that maize and milk are not complements in the production of larger populations or greater rates of urbanization; instead, milk and maize appear to be substitutes, where the marginal effect of maize is increased for low lactase persistence frequencies. Maize contains substantially more fatty acids, particularly polyunsaturated, and vitamin A when compared to potatoes (USDA 2005). This may be one reason as to why maize is not complemented by increased milk consumption. Columns (3) and (4) consider the relationship between sweet potatoes and milk in measuring population growth. As with maize, milk is shown to not complement sweet potatoes, but is seen as a substitute in the production of larger populations. Like maize, sweet potatoes are high in vitamin A but are nutritionally similar to white potatoes in terms of other macro and micro nutrients. This implies that the complementarity between white potatoes and milk may be primarily driven by the added vitamin A from milk. Columns (5) and (6) consider cassava, and find no association with milk when all relevant controls are included. Finally, columns (7) and (8) consider silage maize. Silage maize is typically used to feed domesticate animals; therefore, I expect to find a complementarity between the agricultural suitability of silage maize, which can be used to feed milk producing cattle, and lactase persistence. Column (7) indeed shows silage maize and lactase persistence do have a complementary effect on both population and urbanization growth; however, this relationship is sensitive to the baseline controls and the suitability of potatoes. For all estimations of Table 4, main effects and interactions are similar for both population or urbanization. For no other New World crop is a significant complementarity found, implying that the macro and micro nutrients found within potatoes are indeed complemented by milk consumption. This is further supported by the correlation matrix of Table 1, from which no significant relationship is seen between the nutrient composition of New World crops and milk.

Table 5 considers the potential complementarity between the beneficial effects of domesticate animals, which are associated with a high prevalence of lactase persistence, and the suitability of white potatoes. The estimates of Table 5 intend to check for alternative explanations for the complementarity found in Table 3 and follow a similar form to that of Table 4 with odd-numbered columns controlling for country and year fixed effects and even-numbered columns comprising the base estimation including a control for the frequency of lactase persistence interacted with year indicators.[28] Again,

[27] The agricultural suitability of potatoes is included in even number columns to more directly measure the complementarity between milk and other New World crops, which may be correlated with potato suitability.

[28] For even-numbered columns, the controls for each domesticate animal measure are excluded when considering its complementarity with potatoes. As with Table 4, I control for the frequency of lactase persistence to measure the

Panel A considers the effect on the natural log of population, and Panel B considers the effect on urbanization. Columns (1) and (2) consider the complementarity between potato suitability and the intensity of animals husbandry; columns (3) and (4) consider the potential complementarity between the suitability of land for pasture and the suitability of land for potatoes; and columns (5) and (6) consider the complementarity between the presence of large domesticate animals and potatoes. For all estimations of Table 5, no significant interaction is found, implying that the measure of lactase persistence and its interaction with the agricultural suitability of potatoes is not accounting for the differential use of domesticate animals.

For all measures of domesticate animals, no complementarity is found with potatoes in explaining either growth in population or urbanization. The results of Table 5 further suggest that milk, not domesticate animals, complements the introduction of the potato in the production of larger populations. A major source for the potential complementarity between domesticate animals and potatoes lies in the substitution of milk for meat. But as suggested by Table 1, no significant relationship is shown between beef (ground) and potatoes. This insignificant relationship is further supported by the estimates of Table 5.

Table 6 repeats the estimation strategy of Tables 4 and 5, but focuses on the potential complementarity between potatoes and historic economic or political development. High frequencies of lactase persistence are tied to dairying cultures. These dairying cultures may be related to other advantageous or harmful factors for population or urbanization growth. Table 6 tests whether the complementarity between potatoes and milk is driven by a complementarity between potatoes and cultural variation. Columns (1) and (2) consider the potential complementarity between economic complexity, an index from 1 to 8 ranging from nomadic to complex state organization, and potatoes; columns (3) and (4) look at the potential complementarity between precolonial population density and potatoes; and columns (5) and (6) look at the complementarity between the millennia a country has practiced agriculture and potato suitability.[29] As with domesticate animals, no significant complementarity in explaining population growth is found between the suitability of potatoes and measures for historic economic and political development.[30]

potential complementarity between potato suitability and the domesticate animal measure absent the lactase persistence channel.

[29] Due to the Malthusian economy of the time, population density in 1500 CE, or precolonial population density, is used widely as a proxy for economic development (see e.g., Acemoglu et al. 2002, Ashraf and Galor 2011).

[30] Of note is the coefficient of the interaction in Panel A of column (6). Interpreting this coefficient implies that countries that have practiced agriculture for a longer amount of time benefited less from the introduction of the potato. This is plausible as these countries contained larger populations prior to the introduction date, and the coefficient is capturing a catch-up process for lesser populated countries, everything else equal (Putterman 2008). Any bias from this association is unlikely. The frequency of lactase persistence and the millennia a country has practiced agriculture are positively related; therefore, the negative interaction coefficient in Panel A of column (7) will bias the estimated interaction coefficient between potatoes and milk downward. As a further control on this source of bias, the years a country has practiced

Using a number of plausible alternatives to the observed complementarity between potatoes and milk, Tables 4-6 estimate a number of placebo tests. Table 4 provides support that the complementarity between potatoes and milk does not extend to other New World crops, while Tables 5 and 6 provide evidence that the complementarity of milk is not driven by the additional benefits of domesticate animals or dairying cultures. These estimates further support our main hypothesis that the introduction of the potato led to larger population increases in countries that more widely consumed milk.

3.3 Robustness

In our baseline estimation we control for a full and theoretically valid set of controls. However, the possibility for omitted variable bias remains, particularly in regards to unobserved continent-level variation. This section will attempt to alleviate these concerns by checking the robustness of the complementarity to continent-level variation as well as controlling for previously omitted variables, which may potentially affect our estimates of interest.

In order to address unobserved continent-level variation, Table 7 includes continent fixed effects (interacted with year indicators) into the baseline estimating equation. Column (1) of Table 7 re-estimates the baseline results, whereas column (2) estimates the effect of the complementarity when controlling for country, year, and continent-by-year fixed effects. As with Tables 4-6, Panel A gives the estimates with the natural log of population as the dependent variable, and Panel B gives estimates with the share of the population living within a city as the dependent variable. The estimates of column (2) remain positive, statistically significant, and similar in magnitude to previous estimation that excludes continent-by-year fixed effects (i.e., column (1) of Tables 3A and 3B). However, the loss of variation from using within continent estimation does lead to a slight loss in precision. The effect of the interaction between the frequency of lactase persistence and potato suitability when including all baseline controls and continent-by-year fixed effects is given in column (3). Comparing columns (1) and (3), the magnitude of the interaction remains roughly constant when including continent effects; however, for population, significance of the interaction is slightly reduced due to the loss in precision from using within continent estimation.[31] The inclusion of unobserved continent-level variation does not alter the estimated interaction between potatoes and the frequency of lactase persistence. The effect of potatoes in explaining population and urbanization growth remains tied to the frequency of lactase persistence within a particular country.

agriculture is included within the baseline controls.

[31] For Panel A, the p-value for the coefficient of the interaction between lactase persistence and potato suitability goes from 0.022 in column (1) to 0.102 in column (3). The coefficient of the interaction for column (3) of both Panels A and B are statistically indistinguishable from the estimates given by the baseline estimation of column (1); the p-values of this test are 0.93 and 0.65, respectively.

Table 8 includes a number of potentially omitted variables (interacted with year indicators) to the base estimation. These controls include latitude, mean distance to the coast, malaria ecology index, an indicator for Roman heritage, predicted genetic diversity, and the genetic distance from the United Kingdom. The additional controls are piecemeal included in columns (2)-(7) with column (8) including all additional controls and column (1) giving the baseline estimation.[32] Panel A regresses the natural log of population, while Panel B regresses the rate of urbanization.

The first set of additional controls intends to capture environmental or geographic conditions that were favorable for population growth and possibly the frequency of lactase persistence. The inclusion of latitude in column (2) is intended as a broad geographic and environmental control which is potentially correlated with both potato suitability and the frequency of lactase persistence. Additionally, absolute latitude has been shown to be a strong predictor of economic development and is used frequently as an exogenous control in similar research (Hall and Jones 1999; Ashraf and Galor 2011). Column (3) controls for the average distance a country is away from the coast. Given that the period considered comprises the colonization era, the mean distance from an ice-free coast intends to capture the ease of trade and seafaring during this period. Additionally, the practice of dairying may be associated with more prevalent trade or technological advancement; including distance from the coast controls for these alternative channels of lactase persistence. As a final environmental control, the suitability of malaria within a country is considered in column (4). The global distribution of country-level lactase persistence frequencies given by Figure 3 is inversely related to the prevalence of malaria.[33] One reason for this relationship may be due to the sensitivity of cows to the tsetse fly, which is found within similar areas as malaria in sub-Saharan Africa. Therefore, the frequency of lactase persistence may be associated with malarial environments, and given the harmful effects of malaria to population growth, the population effects of lactase perssitence may be driven by malarial environments. The piecemeal inclusion of all geographic and environmental controls in columns (2)-(4) does not alter magnitude or significance of the interaction between lactase persistence and potato suitability, providing little support for a potential omitted environmental variable bias.[34]

The second set of additional controls considers population specific differences that may be tied to lactase persistence and population growth. These are considered in columns (5)-(7). Column (5) controls for a shared Roman heritage amongst European countries. This control intends to capture

[32]Additional omitted variables considered within NQ that are omitted from Table 8 are considered in the Supplemental Appendix. The use of the additional controls does not alter the magnitude of significance of my estimated coefficients of interest.

[33]The cross-country correlation between the malaria ecology index and the frequency of lactase persistence is -0.24.

[34]For Panel B, the interaction is insignificant throughout Table 8. However, when comparing the estimated coefficient of the interaction to the baseline estimate (column (6) of Table 3B), there is little difference in magnitude, implying the inclusion of the potentially omitted variables are not the source of the positive marginal effects of potato suitability for higher frequencies of lactase persistence.

the shared cultural, economic, and political histories of countries formerly belonging to the Roman Empire. Column (6) and (7) consider genetic variation across and within countries that may be responsible for economic conditions both historically and presently. Lactase persistence is conferred by a genetic variant. This genetic variant may be correlated with an unobserved, favorable genetic endowment. Therefore, the use of genetic controls in columns (6) and (7) are intended to control for any unseen genetic variation that may be favorable for economic growth as well as controlling for cultural similarity across countries. Column (6) includes the level of genetic diversity within a country into the baseline estimating equation.[35] As argued in Ashraf and Galor (2013), genetic diversity has a quadratic relationship with both historic and contemporary economic development, from which genetic diversity is positively associated with both innovation and ethnic fractionalization. An alternative measure of genetic differences is considered in column (7). Spolaore and Wacziarg (2009) argue that genetic similarities amongst countries represents a proxy for the diffusion of technology. And considering the United Kingdom as the technological frontier in the year 1500 CE, genetic distance from this country should be negatively associated with the level of technological development as well as serving as a proxy for cultural differences from the U.K., which contains a high frequency of lactase persistence. As with columns (2)-(4), the piecemeal inclusion of population specific controls in columns (5)-(7) does not alter the magnitude or significance of the interaction between potatoes and milk in explaining either within-country population or urbanization growth. As with the baseline estimates, neither milk or potatoes has a significant main effect on population growth after the introduction of the potato; rather, the marginal effect of each food source on population or urbanization growth is dependent upon the availability of the other. This is shown by the positive (and statistically significant for Panel A) coefficient on the interaction.

Going further, column (8) includes all previously omitted controls into the baseline regression. Again as with the piecemeal addition, the inclusion of all relevant omitted variables does not alter the estimated coefficients of interest. The estimates of column (8) are similar in magnitude and significance to the baseline estimates given by column (6) of Tables 3A and 3B. This implies the relationship between potatoes and milk is not being driven by either environmental, geographic, or varied cultures or genes associated with lactase persistent populations, providing further support for the main hypothesis of this paper.

[35] The measure is constructed with historic precolonial population compositions.

4 Conclusion

The effect of potatoes on Old World populations is well documented (Nunn and Qian 2011). Potatoes provided nutritional advantages to the staple crops of the Old World, thereby raising the carrying capacity of potato suitable countries. This paper questions whether the effect of potatoes was augmented by the ability to consume milk—measured by the country-level frequency of lactase persistence, or lactose tolerance. Milk provided necessary nutrients not found within potatoes and therefore serves as a complement in diet. This is shown graphically in Figure 1 and by the significant difference in nutrient composition in Table 1.

By considering the interaction between the frequency of lactase persistence and the agricultural suitability for potatoes, I show that after introduction from the New World the effect of potatoes on population and urbanization growth is tied to the frequency of lactase persistence within a country. Countries with low frequencies of lactase persistence, a proxy for the low consumption of milk, have a lessened effect on population and urbanization from the introduction of the potato. Often this effect is insignificantly different than zero. However, as the frequency of lactase persistence increases the effect of potatoes in explaining growth in population and urbanization also rises in magnitude. As shown in Tables 4-6, this relationship between potatoes and milk is not the byproduct of an unobserved complementarity between milk and other New World crops or potatoes and either domesticate animals or historic economic development. The complementarity between potatoes and milk is also robust to unobserved continent-level variation as well as to the inclusion of potentially omitted variables. All estimations provide strong evidence for the main hypothesis of this work: the consumption of milk, for which the frequency of lactase persistence serves as a quantitative, country-level proxy, complemented the introduction of the potato in contributing to the large growth in Old World population and urbanization between the 18th and 19th centuries.

References

Almond, D., & Currie, J. (2011). Human capital development before age five. Handbook of Labor Economics, Vol. 4b. Ed. O. Ashenfelter and D. Card. Elsevier, Ch. 15, 1315-1486.

Acemoglu, D., Johnson, S., & Robinson, J., (2002). Reversal of fortune: Geography and institutions in the making of the modern world income distribution. *Quarterly Journal of Economics*, 107, 12311294.

Ashraf, Q., & Galor, O. (2011). Dynamics and stagnation in the Malthusian epoch. American Economic Review, 101(5), 2003-2041.

Ashraf, Q., & Galor, O. (2013). The "Out of Africa" hypothesis, human genetic diversity, and comparative economic development. American Economic Review, 103(1), 1-46.

Alesina, A., Devleeschauwer, A., Easterly, W., Kurlat, S., & Wacziarg, R. (2003). Fractionalization. *Journal of Economic Growth*, 8(2), 155-194.

Alesina, A., Giuliano, P., & Nunn, N. (2013). On the origins of gender roles: Women and the plough. *Quarterly Journal of Economics*, 128(2), 469-530.

Arora, S. (2001). Health, human productivity, and long-term economic growth. The Journal of Economic History, 61(3), 699-749.

Cook, C.J. (2013). The role of lactase persistence in precolonial development. Working Paper: http://dl.dropbox.com/u/96311558/Cook%20Lactase%20Persistence%202.7.13.pdf

Connor, S., & others (1986). The cholesterol/saturated-fat index: An indication of the hypercholesterolaemic and atherogenic potential of food. The Lancet, 1(8492), 1229-1232.

Crawford, E.M. (1984). Dearth, diet, and disease in Ireland, 1850: A case study of nutritional deficiency. Medical History, 28(2), 151161.

Dasgupta, P., & Ray, D. (1986). Inequality as a determinant of malnutrition and unemployment: Theory. The Economic Journal, 96, 1011-1034.

Eppendorfer, W.H., & Eggum, B.O. (1994). Effects of sulphur, nitrogen, phosphorus, potassium, and water stress on dietary fibre fractions, starch, amino acids and on the biological value of potato protein. Plant Foods for Human Nutrition, 45(4), 299-313.

Fogel, R. (1994). Economic growth, population theory, and physiology: The bearing of long-term processes on the making of economic policy. American Economic Review, 84(3), 369-395.

FAO (2013). FAOSTAT Data Set. http://faostat.fao.org.

Galor, O., & Weil, D. (2000). Population, technology, and growth: From Malthusian stagnation to the demographic transition and beyond. American Economic Review, 90(4), 806-828.

Hallberg, L. (1998). Does calcium interfere with iron absorption? American Journal of Clinical Nutrition, 68, 3-4.

Hallberg, L., Brune, M., & Rossander, L. (1989). The role of vitamin C in iron absorption. International Journal for Vitamin and Nutrition Research, 30, 103-108.

Headey, D. (2013). Developmental drivers of nutritional change: A cross-country analysis. World Development, 42, 76-88.

Hoffman, J., & Falvo, M. (2004). Protein–which is best?. Journal of Sports Science and Medicine, 3(3), 118-130.

Ingram, C., Mulcare, C., Itan, Y., Thomas, M., & Swallow, D. (2009a). Lactose digestion and the evolutionary genetics of lactase persistence. *Human Genetics*, 124(6), 579-591.

Ingram, C., Raga, T., Tarekegn, A., Browning, S., Elamin, M., Bekele, E., Thomas, M., Weale, M., Bradman, N., & Swallow, D. (2009b). Multiple rare variants as a cause of a common phenotype: Several different lactase persistence associated alleles in a single ethnic group. *Journal of Molecular Evolution*, 69, 577-588.

IOM (2002). Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. Washington, D.C.: The National Academies Press.

Kooh, S. W., Graser, D., Reilly, B. J., Hamilton, J. R., Gall, D. G. & Bell, L. (1977). Rickets due to calcium deficiency. New England Journal of Medicine, 297, 1264-1266.

Lewis, M.P. (2009). *Ethnologue: Languages of the World, Sixteenth Edition.* Dallax, TX: SIL International.

Mansson, H. (2008). Fatty acids in bovine milk. Food and Nutrition Research, 52.

McEvedy, C., & Jones, R. (1976). *Atlas of World Population History.* New York, NY: Facts on File.

McNeil, W. (1999). How the potato changed the world's history. Social Research, 66, 67-83.

Milner, J., & Allison, R. (1999). The role of dietary fat in child nutrition and development: Summary of ASNS workshop. The Journal of Nutrition, 129(11), 20942105.

Mitchell, H.H. (1923). A method of determining the biological value of protein. Journal of Biological Chemistry, 58(3), 873-903.

Nunn, N., & Qian, N. (2011). The potato's contribution to population and urbanization: Evidence from a historical experiment. Quarterly Journal of Economics, 126(2), 593-650.

Nunn, N., & Puga, D. (2012). Ruggedness: The blessing of bad geography in Africa. Review of Economics and Statistics, 94(1), 20-36.

Putterman, L., & Trainor (2006). Agricultural Transition Year Country Data Set. http://www.econ.brown.edu/fac/L Putterman

Putterman, L., & Weil, D. (2010). Post-1500 population flows and the long-run determinants of economic growth and inequality. *Quarterly Journal of Economics*, 125(4), 1627-82.

Simoons, F. (1969). Primary adult lactose intolerance and the milking habit: A problem in biological and cultural interrelations. I. Review of the medical research. *The American Journal of Digestive Diseases*, 14, 819-836.

Sims, E., & Danforth, J. (1987). Expenditure and storage of energy in man. Journal of Clinical Investigation, 79(4), 1019-1025.

Tishkoff, S., Reed, F., Ranciaro, A., Voight, B., Babbitt, C., Silverman, J., Powell, K., Mortensen, H., Hirbo, J., Osman, M., & others (2006). Convergent adaptation of human lactase persistence in Africa and Europe. *Nature Genetics*, 39, 31-40.

USDA (2005). USDA National Nutrient Database for Standard Reference, Release 18. Nutrient Data Laboratory Home Page, http://www.nal.usda.gov/fnic/foodcomp

World Health Organization (2009). *Milk Fluoridation for the Prevention of Dental Carries*. Geneva: WHO Press.

Variable Definitions and Sources (Alphabetical Order)

Distance from Coast or Navigable River

The average distance in thousands of kilometers from an ice-free coast or navigable river. This variable is from the *Center for International Development*, which is derived from Gallup et al. (1999).

Economic Complexity

An aggregated country-level index from 1 to 8 that represents historic economic development–nomadic or fully migratory, semi-nomadic, semi-sedentary, compact but temporary settlements, neighborhoods of dispersed family homes, separated hamlets forming a single community, compact and relatively permanent, complex settlements–for ethnicities within modern country borders. Data are at the ethnic level and mapped to the country-level by contemporary ethnic compositions. These data are from Alesina et al. (2013).

Elevation

The average elevation of a country in meters. These data are from Nunn and Puga (2012) by way of Nunn and Qian (2011).

Fraction within Tropics

The fraction of a country with a Koppen-Geiger tropical climate. These data come from Nunn and Puga (2012) by way of Nunn and Qian (2011).

The Frequency of Lactase Persistence

Lactase persistence frequencies for Old World ethnicities are given by Ingram et al. (2009a). Ethnic data are then aggregated to the country level by matching ethnic groups from Ingram et al. (2009a) to compositions in Alesina et al. (2003) by language group similarities. This gives a contemporary, country-level measure for the frequency of lactase persistence. Contemporary ethnic compositions are modified by the inverse of the Putterman and Weil Migration Matrix (2010) to create representative ethnic compositions for the year 1500 CE.

Genetic Distance from the U.K.

Genetic distance is a measure of genetic diversity between societies. This measure is calculated with the fixation index, or F_{ST}, from population genetics and measures the variation in gene frequencies across differing groups. F_{ST} scores are given for 42 indigenous populations; the data come from

Cavalli-Sforza et al. (1994). The genetic distance measures are then aggregated to the country level by Spolaore and Wacziarg (2009), from which genetic distance to the UK is found for 206 countries. The UK is chosen as the technology frontier in 1500 CE. Genetic distance from this frontier is intended to convey difficulty in the diffusion of technology.

Genetic Diversity

Genetic diversity is the predicted country-level heterozygosity based on migratory distance from East Africa. These data represent the probability that two randomly selected individuals contain different gene variants at the same locus. The data are from Ashraf and Galor (2013).

Indicator for Presence of Large Animals

An indicator equaling one for the presence of pigs, sheep, goats, equine animals, deer, camels, alpacas, llamas, and bovine animals for an ethnic population. Data are at the ethnic level and mapped to countries by contemporary ethnic compositions. These data are from Alesina et al. (2013).

Intensity of Animal Husbandry

A measure from 0 to 1 percent that measures an ethnicity's historic dependency on animal husbandry. The measure is aggregated to the country-level by the contemporary ethnic composition of a country found within the Ethnologue (Lewis 2009). These data are from Alesina et al. (2013).

Malaria Ecology Index

The malaria ecology index takes into account differences in the environment and mosquito vectors that contribute to the spread of malaria. These data come from Kiszewski et al. (2004) by way of Nunn and Qian (2011).

Member of the Roman Empire

An indicator variable coded to one for countries with Roman heritage that were part of the Roman Empire but not belonging to the Ottoman Empire. These include Belgium, Britain, France, Italy, the Netherlands, Portugal, Spain, and Switzerland. These data are from Acemoglu et al. (2005) by way of Nunn and Qian (2011).

Political Hierarchy

An index from 1 to 5 that measures he number of jurisdictional hierarchies beyond the local community. Data are at the ethnic level and mapped to countries by contemporary ethnic compositions.

These data are from Alesina et al. (2013).

Ruggedness

Ruggedness represents the average standard deviation of grid elevation within a country. These data come from Nunn and Puga (2012) by way of Nunn and Qian (2011).

Suitability of Land for Pasture

A suitability index, ranging from 0 to 1, for pasture within 5 arc-minute by 5 arc-minute grids, which is then averaged within modern country borders. This index takes into account climate, soil, and and terrain conditions necessary in developing grasslands. The raster data can be found at http://www.fao.org/geonetwork/srv/en/metadata.show?id=14167.

Suitability for All Crops

The number of hectares suitable for any non-fodder crop. These data are from Nunn and Qian (2011).

Years of Agriculture

The millennia since the majority of a country's population adopted agriculture for subsistence. These data are from Putterman and Trainor (2006).

5 Tables and Figures

Table 1. Evidence for Nutritional Complementarity:
Correlation Across Nutrients

Food Source	Potato (1)	Milk (2)	Old World (3)	New World (4)
Potato	1			
Milk	-0.35* (0.08)	1		
Old World Crops	-0.01 (0.96)	-0.02 (0.93)	1	
New World Crops	0.01 (0.95)	-0.11 (0.61)	0.03 (0.89)	1
Beef	-0.25 (0.23)	0.40** (0.04)	0.16 (0.43)	-0.22 (0.27)

Summary: This table gives the correlation across the fraction of daily recommended values for all nutrients considered–macro, vitamins, and minerals–between food sources. A negative correlation coefficient implies complementarity in the diet, as this implies foods differ in nutritional content. Milk and potatoes significantly differ in nutrient composition, supporting my main hypothesis.

Notes: (i) p-values are in parantheses, and * represents signficance at the 10% level. (ii) All nutrition data is from the National Nutrient Database from the USDA. A consistent unit of mass(100 grams) is used for all food sources. (iii) Old World crops is the average nutritional value of wheat and rice. New world crops is the average nutritional value of yellow corn, sweet potatoes, and cassava. (iv) Nutrient information for potatoes is for raw white potatoes including skin and flesh. Nutrient information for milk is for whole, 3.25% fat, milk without added vitamin A or D. Nutrient information for Old World crops is for durum wheat and cooked long-grained brown rice. Nutrient information for New World crops is for yellow corn, cassava, and sweet potatoes–all raw. Nutrient information for beef is for broiled ground meat, 70% lean and 30% fat.

(v) The daily recommendation for all nutrients is from:

http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm064928.htm.

Table 2. The Interaction between Potatoes and Milk over Time

Dependent Variable:	ln Population		City Pop. Share	
	(1)	(2)	(3)	(4)
ln *Potato Area* × ln *Freq. of Lactase Persistence* × 1100	-0.0092	0.0243	0.0035	0.0024
	(0.0191)	(0.0181)	(0.0034)	(0.0043)
ln *Potato Area* × ln *Freq. of Lactase Persistence* × 1200	0.0402**	0.0648***	0.0026	0.0006
	(0.0181)	(0.0219)	(0.0032)	(0.0040)
ln *Potato Area* × ln *Freq. of Lactase Persistence* × 1300	0.1001***	0.1366***	0.0002	0.0022
	(0.0212)	(0.0259)	(0.0035)	(0.0038)
ln *Potato Area* × ln *Freq. of Lactase Persistence* × 1400	0.0600**	0.0922***	0.0085**	0.0084
	(0.0238)	(0.0287)	(0.0039)	(0.0055)
ln *Potato Area* × ln *Freq. of Lactase Persistence* × 1500	0.0781***	0.0999***	0.0042	0.0069
	(0.0259)	(0.0351)	(0.0034)	(0.0049)
ln *Potato Area* × ln *Freq. of Lactase Persistence* × 1600	0.0893***	0.1055***	0.0092	0.0121
	(0.0258)	(0.0375)	(0.0080)	(0.0107)
ln *Potato Area* × ln *Freq. of Lactase Persistence* × 1700	0.1101***	0.1324***	0.0039	0.0002
	(0.0339)	(0.0443)	(0.0034)	(0.0052)
ln *Potato Area* × ln *Freq. of Lactase Persistence* × 1750	0.1218***	0.1342***	0.0033	-0.0007
	(0.0353)	(0.0473)	(0.0038)	(0.0070)
ln *Potato Area* × ln *Freq. of Lactase Persistence* × 1800	0.1511***	0.1462***	0.0046	0.0011
	(0.0408)	(0.0541)	(0.0033)	(0.0059)
ln *Potato Area* × ln *Freq. of Lactase Persistence* × 1850	0.1551***	0.1757***	0.0084**	0.0074
	(0.0495)	(0.0548)	(0.0042)	(0.0054)
ln *Potato Area* × ln *Freq. of Lactase Persistence* × 1900	0.2168***	0.2013***	0.0383***	0.0334***
	(0.0467)	(0.0585)	(0.0057)	(0.0078)
Main Terms (× Year fixed effects):				
Freq. of Lactase Persistence (FLP)	Y	Y	Y	Y
Potato Suitable Area (PSA)	Y	Y	Y	Y
Baseline Controls (× Year fixed effects):				
Crop Suitability				
ln Suitability for All Crops	N	Y	N	Y
Domesticate Animals				
Suitability for Pasture	N	Y	N	Y
Indicator for Presence of Large Animals	N	Y	N	Y
Intensity of Animal Husbandry	N	Y	N	Y
Historic Political/Economic Development				
Years of Agriculture	N	Y	N	Y
Political Hierarchy	N	Y	N	Y
Economic Complexity	N	Y	N	Y
Environment				
ln Elevation	N	Y	N	Y
ln Ruggedness	N	Y	N	Y
ln Tropical Area	N	Y	N	Y
Observations	1552	1552	1552	1552
R Sqr.	0.9897	0.9928	0.5090	0.5468
p-value for joint sig. of FLP 1750-1900	0.6247	0.0863	0.6983	0.3474
p-value for joint sig. of PSA 1750-1900	0.7960	0.1975	0.0123	0.4186
p-value for joint sig. of PSA × FLP 1750-1900	0.0004	0.0028	0.0000	0.0003

Summary: This table illustrates the effect of the interaction between potatoes and milk over time. The coefficient represents the association between the two variables in producing larger populations. After the introduction of the potato in 1750 CE, the coefficient of the interaction increases in magnitude, implying milk complemented the marginal effect of potatoes after the widespread distribution.

Notes: (i) Observations are at the country-year level. All regressions use the base sample of 130 Old World countries from Nunn and Qian (2011). (ii) All regressions include country and year fixed effects. Standard errors are clustered at the country level with *, **, and *** representing significance at the 10, 5, and 1% significance level, respectively. (iii) The frequency of lactase persistence is the fraction of a country's population able to digest milk. This variable is a proxy for milk consumption.

Table 3A. Baseline Estimation: Interaction of Milk and Potatoes

	Dependent Variable: ln Population					
	(1)	(2)	(3)	(4)	(5)	(6)
ln Potato Area × Post	0.0008	-0.0086	0.0042	-0.0208	0.0024	-0.0211
	(0.0174)	(0.0167)	(0.0178)	(0.0185)	(0.0180)	(0.0165)
Freq. of Lactase Persistence × Post	-0.0610	0.1352	0.0829	-0.2369	-0.0674	-0.0348
	(0.2127)	(0.1889)	(0.2226)	(0.2501)	(0.2158)	(0.2404)
ln Potato Area × Lactase Persistence × Post	0.1142***	0.0967***	0.0850**	0.1395***	0.1259***	0.0939**
	(0.0361)	(0.0319)	(0.0389)	(0.0427)	(0.0357)	(0.0405)
Baseline Controls (× Year fixed effects):						
Crop Suitability						
ln Suitability for All Crops	N	Y	N	N	N	Y
Domesticate Animals						
Suitability for Pasture	N	N	Y	N	N	Y
Indicator for Presence of Large Animals	N	N	Y	N	N	Y
Intensity of Animal Husbandry	N	N	Y	N	N	Y
Historic Political/Economic Development						
Years of Agriculture	N	N	N	Y	N	Y
Political Hierarchy	N	N	N	Y	N	Y
Economic Complexity	N	N	N	Y	N	Y
Environment						
ln Elevation	N	N	N	N	Y	Y
ln Ruggedness	N	N	N	N	Y	Y
ln Tropical Area	N	N	N	N	Y	Y
Observations	1552	1552	1552	1552	1552	1552
R Sqr.	0.9886	0.9896	0.9905	0.9909	0.9895	0.9925
ME of Potato Area: FLP = 25th percentile	0.0271**	0.0136	0.0238**	0.0113	0.0313***	0.0005
	(0.0112)	(0.0119)	(0.0116)	(0.0107)	(0.0116)	(0.0120)
ME of Potato Area: FLP = median	0.0453***	0.0291***	0.0374***	0.0337***	0.0515***	0.0155
	(0.0091)	(0.0105)	(0.0101)	(0.0084)	(0.0092)	(0.0126)
ME of Potato Area: FLP = 75th percentile	0.0659***	0.0465***	0.0527***	0.0588***	0.0741***	0.0324*
	(0.0107)	(0.0118)	(0.0125)	(0.0115)	(0.0102)	(0.0165)

Summary: This table gives the baseline findings, which are tied to the coefficient of the interaction between the agricultural suitability of potatoes and the frequency of lactase persistence. A positive coefficient on the interaction implies a complementarity between potatoes and milk in the production of larger populations after the introduction of the potato from the New World to the Old. For all estimations in Table 4, the coefficient of the interaction is positive and significant at conventional levels, supporting my main hypothesis.

Notes: (i) Observations are at the country-year level. All regressions use the base sample of 130 Old World countries from Nunn and Qian (2011). (ii) All regressions include country and year fixed effects. Standard errors are clustered at the country level with *, **, and *** representing significance at the 10, 5, and 1% significance level, respectively. (iii) The frequency of lactase persistence is the fraction of a country's population able to digest milk. This variable is a proxy for milk consumption.

Table 3B. Baseline Estimation: Interaction of Milk and Potatoes

	Dependent Variable: City Population Share					
	(1)	(2)	(3)	(4)	(5)	(6)
ln Potato Area × Post	-0.0021	-0.0023	-0.0016	-0.0017	-0.0019	-0.0003
	(0.0014)	(0.0014)	(0.0015)	(0.0015)	(0.0015)	(0.0015)
Freq. of Lactase Persistence × Post	0.0367	0.0407*	0.0452*	0.0440*	0.0353	0.0488
	(0.0223)	(0.0240)	(0.0247)	(0.0226)	(0.0219)	(0.0298)
ln Potato Area × Lactase Persistence × Post	0.0108***	0.0104***	0.0085**	0.0114***	0.0114***	0.0076
	(0.0034)	(0.0034)	(0.0039)	(0.0037)	(0.0036)	(0.0051)
Baseline Controls (× Year fixed effects):						
Crop Suitability						
ln Suitability for All Crops	N	Y	N	N	N	Y
Domesticate Animals						
Suitability for Pasture	N	N	Y	N	N	Y
Indicator for Presence of Large Animals	N	N	Y	N	N	Y
Intensity of Animal Husbandry	N	N	Y	N	N	Y
Historic Political/Economic Development						
Years of Agriculture	N	N	N	Y	N	Y
Political Hierarchy	N	N	N	Y	N	Y
Economic Complexity	N	N	N	Y	N	Y
Environment						
ln Elevation	N	N	N	N	Y	Y
ln Ruggedness	N	N	N	N	Y	Y
ln Tropical Area	N	N	N	N	Y	Y
Observations	1552	1552	1552	1552	1552	1552
R Sqr.	0.4267	0.4314	0.4608	0.4479	0.4573	0.5166
ME of Potato Area: FLP = 25th percentile	0.0004	0.0001	0.0004	0.0009	0.0007	0.0014
	(0.0008)	(0.0009)	(0.0008)	(0.0008)	(0.0008)	(0.0010)
ME of Potato Area: FLP = median	0.0021***	0.0018**	0.0017**	0.0028***	0.0025***	0.0027**
	(0.0007)	(0.0008)	(0.0007)	(0.0007)	(0.0007)	(0.0013)
ME of Potato Area: FLP = 75th percentile	0.0041***	0.0037***	0.0033***	0.0048***	0.0046***	0.0040**
	(0.0010)	(0.0011)	(0.0012)	(0.0011)	(0.0010)	(0.0020)

Summary: This table replicates Table 3, replacing the natural log of population with the fraction of the population living within a 40,000+ population city as the dependent variable.

Notes: (i) Observations are at the country-year level. All regressions use the base sample of 130 Old World countries from Nunn and Qian (2011). (ii) All regressions include country and year fixed effects. Standard errors are clustered at the country level with *, **, and *** representing significance at the 10, 5, and 1% significance level, respectively. (iii) The frequency of lactase persistence is the fraction of a country's population able to digest milk. This variable is a proxy for milk consumption.

Table 4. Placebo Test: Complementarity in Alternative New World Crops?

Crop:	Maize		Sweet Potato		Cassava		Silage Maize	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A. Dependent Variable: ln Population							
ln Crop Area × Post	0.0379**	-0.0199	0.0389**	0.0296	0.0312**	0.0378*	-0.0050	-0.0165
	(0.0158)	(0.0211)	(0.0157)	(0.0279)	(0.0146)	(0.0204)	(0.0216)	(0.0249)
Freq. of Lactase Persistence × Post	0.9273***	0.3543	0.9797***	0.3510	0.9031***	0.2914	0.1614	0.3175
	(0.2687)	(0.2666)	(0.1940)	(0.2213)	(0.1836)	(0.2132)	(0.2755)	(0.2501)
ln Crop Area × Freq. of Lactase Persistence × Post	-0.0340	-0.0086	-0.0679	-0.0009	-0.0503	0.0201	0.0914*	0.0078
	(0.0422)	(0.0346)	(0.0438)	(0.0374)	(0.0455)	(0.0424)	(0.0469)	(0.0467)
Obs.	1552	1552	1552	1552	1552	1552	1552	1552
R Sqr.	0.9874	0.9925	0.9874	0.9925	0.9873	0.9925	0.9879	0.9925
	Panel B. Dependent Variable: City Population Share							
ln Crop Area × Post	0.0010	0.0017	0.0028	0.0050**	0.0021	0.0008	-0.0047***	-0.0039*
	(0.0016)	(0.0020)	(0.0017)	(0.0024)	(0.0016)	(0.0016)	(0.0017)	(0.0022)
Freq. of Lactase Persistence × Post	0.1091***	0.1032***	0.1181***	0.0956***	0.1120***	0.0909***	0.0316	0.0454
	(0.0362)	(0.0366)	(0.0256)	(0.0294)	(0.0243)	(0.0282)	(0.0242)	(0.0295)
ln Crop Area × Freq. of Lactase Persistence × Post	-0.0022	-0.0060	-0.0069	-0.0064	-0.0056	-0.0054	0.0149***	0.0098
	(0.0054)	(0.0053)	(0.0055)	(0.0042)	(0.0058)	(0.0043)	(0.0040)	(0.0061)
Obs.	1552	1552	1552	1552	1552	1552	1552	1552
R Sqr.	0.4135	0.5249	0.4166	0.5251	0.4152	0.5231	0.4308	0.5264
Baseline Controls (× Year fixed effects):								
Crop Suitability								
ln Suitability for All Crops	N	Y	N	Y	N	Y	N	Y
ln Suitability for Potatoes	N	Y	N	Y	N	Y	N	Y
Domesticate Animals								
Suitability for Pasture	N	Y	N	Y	N	Y	N	Y
Indicator for Presence of Large Animals	N	Y	N	Y	N	Y	N	Y
Intensity of Animal Husbandry	N	Y	N	Y	N	Y	N	Y
Historic Political/Economic Development								
Years of Agriculture	N	Y	N	Y	N	Y	N	Y
Political Hierarchy	N	Y	N	Y	N	Y	N	Y
Economic Complexity	N	Y	N	Y	N	Y	N	Y
Environment								
ln Elevation	N	Y	N	Y	N	Y	N	Y
ln Ruggedness	N	Y	N	Y	N	Y	N	Y
ln Tropical Area	N	Y	N	Y	N	Y	N	Y

Summary: Table 3 examines the relationship the frequency of lactase persistence has with other New World crops. Columns (2)-(3) consider maize, columns (4)-(5) consider sweet potatoes, columns (6)-(7) consider cassava, while columns (8)-(9) consider sillage maize. No other crop is complemented by a greater fraction of the population being able to consume milk, implying the macro and micro nutrients of potatoes are uniquely complemented by the inclusion of milk in the diet.

Notes: (i) Observations are at the country-year level. All regressions use the base sample of 130 Old World countries from Nunn and Qian (2011). (ii) All regressions include country and year fixed effects. Standard errors are clustered at the country level with *, **, and *** representing significance at the 10, 5, and 1% significance level, respectively. (iii) The frequency of lactase persistence is the fraction of a country's population able to digest milk. This variable is a proxy for milk consumption.

Table 5. Placebo Test: Complementarity between Potatoes and Domesticate Animals?

Measure for Domesticate Animals:	Intensity of Husbandry		Suitability of Land for Pasture		Presence of Large Animals	
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A. Dependent Variable: ln Population					
Measure for Domestic Animals × Post	-0.5212**	-0.2632	0.4849**	0.2983	-0.6233	-0.0104
	(0.2071)	(0.3905)	(0.2159)	(0.2018)	(0.5156)	(0.4745)
ln Potato Area × Post	0.0414*	0.0115	0.0332*	0.0023	-0.0259	0.0029
	(0.0210)	(0.0231)	(0.0181)	(0.0199)	(0.0538)	(0.0515)
Domesticate Animals × ln Potato Area × Post	0.0541	-0.0094	0.0363	0.0180	0.0868	0.0054
	(0.0673)	(0.0753)	(0.0437)	(0.0464)	(0.0563)	(0.0571)
Obs.	1552	1552	1552	1552	1552	1552
R Sqr.	0.9879	0.9925	0.9885	0.9923	0.9877	0.9922
	Panel B. Dependent Variable: City Population Share					
Measure for Domestic Animals × Post	-0.0067	-0.0151	0.0176	0.0407**	-0.0287	0.0060
	(0.0108)	(0.0302)	(0.0130)	(0.0190)	(0.0228)	(0.0299)
ln Potato Area × Post	0.0049***	0.0042***	0.0017	0.0027*	0.0058**	0.0034
	(0.0017)	(0.0015)	(0.0018)	(0.0016)	(0.0023)	(0.0041)
Domesticate Animals × ln Potato Area × Post	-0.0020	-0.0076	0.0053	-0.0016	-0.0016	-0.0015
	(0.0058)	(0.0056)	(0.0041)	(0.0040)	(0.0026)	(0.0046)
Obs.	1552	1552	1552	1552	1552	1552
R Sqr.	0.3802	0.5224	0.3869	0.5199	0.3823	0.5115
Baseline Controls (× Year fixed effects):						
Crop Suitability						
ln Suitability for All Crops	N	Y	N	Y	N	Y
Domesticate Animals						
Frequency of Lactase Persistence	N	Y	N	Y	N	Y
Suitability for Pasture	N	Y	N	N	N	Y
Indicator for Presence of Large Animals	N	Y	N	Y	N	N
Intensity of Animal Husbandry	N	N	N	Y	N	Y
Historic Political/Economic Development						
Years of Agriculture	N	Y	N	Y	N	Y
Political Hierarchy	N	Y	N	Y	N	Y
Economic Complexity	N	Y	N	Y	N	Y
Environment						
ln Elevation	N	Y	N	Y	N	Y
ln Ruggedness	N	Y	N	Y	N	Y
ln Tropical Area	N	Y	N	Y	N	Y

Summary: This table examines the relationship between the agricultural suitability of potatoes and a number of proxies for the presence and intensity of use of domesticate animals. The frequency of lactase persistence may be capturing unobserved benefits of domestic animals, implying the previously found complementarity is the spurious byproduct of domesticate animals, not solely milk, and potatoes. Colums (1) and (2) consider the complementarity between the fraction of calories from animal husbandry and potatoes; columns (3) and (4) consider the complementarity between the suitability of pasture and the suitability of potatoes; and columns (5) and (6) consider the complementarity for the presence of large animals and potatoes. Using all measures for domesticate animals, no significant complementarity is found with the suitability of potatoes.

Notes: (i) Observations are at the country-year level. All regressions use the base sample of 130 Old World countries from Nunn and Qian (2011). (ii) All regressions include country and year fixed effects. Standard errors are clustered at the country level with *, **, and *** representing significance at the 10, 5, and 1% significance level, respectively. (iii) The frequency of lactase persistence is the fraction of a country's population able to digest milk. This variable is a proxy for milk consumption.

Table 6. Placebo Test: Complementarity between Potatoes and Economic/Political Development?

Measure for Economic/Political Development:	Economic Complexity		Population Density in 1500 CE		Millennia of Agriculture	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Dependent Variable: ln Population						
Measure for Economic/Political Development × Post	0.0462**	-0.0168	0.0056	-0.0228***	-0.0294	0.0057
	(0.0197)	(0.0429)	(0.0048)	(0.0081)	(0.0178)	(0.0268)
ln Potato Area × Post	0.0203	-0.0073	0.0635***	0.0017	0.0628***	0.0602***
	(0.0323)	(0.0369)	(0.0117)	(0.0133)	(0.0211)	(0.0200)
Economic/Political Development × ln Potato Area × Post	0.0050	0.0027	-0.0009	0.0011	-0.0002	-0.0123**
	(0.0050)	(0.0061)	(0.0007)	(0.0009)	(0.0035)	(0.0055)
Obs.	1552	1552	1552	1552	1552	1552
R Sqr.	0.9880	0.9924	0.9877	0.9929	0.9879	0.9925
Panel B. Dependent Variable: City Population Share						
Measure for Economic/Political Development × Post	0.0017	-0.0045	0.0006	-0.0003	-0.0011	0.0025
	(0.0015)	(0.0039)	(0.0007)	(0.0006)	(0.0016)	(0.0021)
ln Potato Area × Post	0.0041	0.0021	0.0027***	0.0014	0.0024	0.0026
	(0.0047)	(0.0034)	(0.0009)	(0.0011)	(0.0021)	(0.0017)
Economic/Political Development × ln Potato Area × Post	0.0000	-0.0000	0.0001	0.0001	0.0004	-0.0001
	(0.0007)	(0.0006)	(0.0001)	(0.0001)	(0.0004)	(0.0004)
Obs.	1552	1552	1552	1552	1552	1552
R Sqr.	0.3805	0.5224	0.3907	0.5262	0.3809	0.5194
Baseline Controls (× Year fixed effects):						
Crop Suitability						
ln Suitability for All Crops	N	Y	N	Y	N	Y
Domesticate Animals						
Frequency of Lactase Persistence	N	Y	N	Y	N	Y
Suitability for Pasture	N	Y	N	Y	N	Y
Indicator for Presence of Large Animals	N	Y	N	Y	N	Y
Intensity of Animal Husbandry	N	Y	N	Y	N	Y
Historic Political/Economic Development						
Years of Agriculture	N	Y	N	Y	N	N
Political Hierarchy	N	Y	N	Y	N	Y
Economic Complexity	N	N	N	Y	N	Y
Environment						
ln Elevation	N	Y	N	Y	N	Y
ln Ruggedness	N	Y	N	Y	N	Y
ln Tropical Area	N	Y	N	Y	N	Y

Summary: This table examines the relationship between the agricultural suitability of potatoes and a number of proxies for historic political and economic development. As with domesticate animals, the frequency of lactase persistence may be capturing the unobserved of cultural development. Therefore, Table 5 checks the complementarity between potato suitability and a number of historic economic and political controls. Columns (1) and (2) consider an index for economic complexity, ranging from 1 to 8–i.e., nomadic to complex state organization. Columns (3) and (4) consider population density in 1500 CE–a widely used measure for economic development in the Malthusian economy of the precolonial era. And columns (5) and (6) consider the complementarity between potatoes and the millennia a country has practiced agriculture. No significant complementarity in found within Table 5.

Notes: (i) Observations are at the country-year level. All regressions use the base sample of 130 Old World countries from Nunn and Qian (2011). (ii) All regressions include country and year fixed effects. Standard errors are clustered at the country level with *, **, and *** representing significance at the 10, 5, and 1% significance level, respectively. (iii) The frequency of lactase persistence is the fraction of a country's population able to digest milk. This variable is a proxy for milk consumption.

Table 7. Robustness: Continent Fixed Effects

	(1)	(2)	(3)
	Panel A. Dependent Variable: ln Pop.		
ln Potato Area × Post	-0.0211	-0.0065	-0.0163
	(0.0165)	(0.0176)	(0.0189)
Freq. of Lactase Persistence × Post	-0.0348	-0.1900	-0.1224
	(0.2404)	(0.2087)	(0.2564)
ln Potato Area × Lactase Persistence × Post	0.0939**	0.1171**	0.0890†
	(0.0405)	(0.0510)	(0.0541)
Observations	1552	1552	1552
R Sqr.	0.9925	0.9900	0.9936
	Panel B. Dependent Variable: City Pop. Share		
ln Potato Area × Post	-0.0003	-0.0018	-0.0001
	(0.0015)	(0.0014)	(0.0016)
Freq. of Lactase Persistence × Post	0.0488	0.0498**	0.0588**
	(0.0298)	(0.0208)	(0.0294)
ln Potato Area × Lactase Persistence × Post	0.0076	0.0133***	0.0103*
	(0.0051)	(0.0045)	(0.0060)
Observations	1552	1552	1552
R Sqr.	0.5166	0.4867	0.5354
Controls (× Year fixed effects):			
Baseline Controls	Y	N	Y
Continent Fixed Effects	N	Y	Y

Summary: This table includes continent by year fixed effects into the base estimation. Column (1) repeats the baseline estimation, column (2) controls for continent by year fixed effects, and column (3) gives the baseline estimates while controlling for continent-level differences.

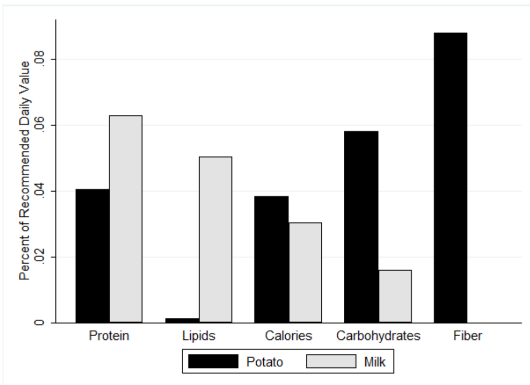
Notes: (i) Observations are at the country-year level. All regressions use the base sample of 130 Old World countries from Nunn and Qian (2011). (ii) All regressions include country and year fixed effects. Standard errors are clustered at the country level with †, *, **, and *** representing significance at the 11, 10, 5, and 1% significance level, respectively. (iii) The frequency of lactase persistence is the fraction of a country's population able to digest milk. This variable is a proxy for milk consumption. (iv) The baseline controls include the suitability for all crops, the suitability of land for pasture, the presence of domesticate animals, the intensity of animal husbandry, the millennia a country has practiced agriculture, indexes of historic political and economic development, elevation, land ruggedness, and the fraction of a country within the tropics.

Table 8. Robustness: Omitted Variables

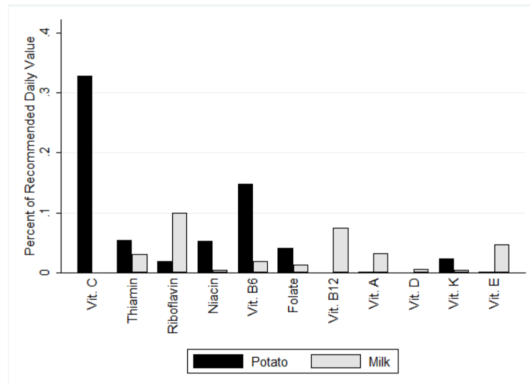
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A. Dependent Variable: ln Population							
ln Potato Area × Post	-0.0211	-0.0216	-0.0191	-0.0266	-0.0226	-0.0208	-0.0230	-0.0331
	(0.0165)	(0.0169)	(0.0164)	(0.0181)	(0.0168)	(0.0174)	(0.0160)	(0.0211)
Freq. of Lactase Persistence × Post	-0.0348	-0.0374	-0.0328	0.0041	-0.0258	-0.0340	0.0317	0.0592
	(0.2404)	(0.2458)	(0.2416)	(0.2625)	(0.2406)	(0.2474)	(0.2277)	(0.2503)
ln Potato Area × Lactase Persistence × Post	0.0939**	0.0859**	0.0924**	0.0924**	0.0994**	0.0938**	0.1031**	0.0965**
	(0.0405)	(0.0414)	(0.0405)	(0.0408)	(0.0416)	(0.0411)	(0.0413)	(0.0435)
Observations	1552	1552	1552	1552	1552	1552	1552	1552
R Sqr.	0.9925	0.9927	0.9926	0.9927	0.9927	0.9926	0.9927	0.9932
	Panel B. Dependent Variable: City Population Share							
ln Potato Area × Post	-0.0003	-0.0002	-0.0007	-0.0005	0.0002	-0.0003	-0.0003	-0.0010
	(0.0015)	(0.0015)	(0.0015)	(0.0016)	(0.0014)	(0.0016)	(0.0015)	(0.0015)
Freq. of Lactase Persistence × Post	0.0488	0.0493*	0.0483*	0.0502	0.0462	0.0490	0.0503*	0.0492*
	(0.0298)	(0.0297)	(0.0289)	(0.0306)	(0.0311)	(0.0297)	(0.0287)	(0.0284)
ln Potato Area × Lactase Persistence × Post	0.0076	0.0073	0.0079	0.0075	0.0059	0.0076	0.0077	0.0066
	(0.0051)	(0.0051)	(0.0048)	(0.0051)	(0.0046)	(0.0051)	(0.0053)	(0.0046)
Observations	1552	1552	1552	1552	1552	1552	1552	1552
R Sqr.	0.5166	0.5196	0.5326	0.5192	0.5335	0.5180	0.5215	0.5604
Controls (× Year fixed effects):								
Baseline Controls	Y	Y	Y	Y	Y	Y	Y	Y
ln Latitude	N	Y	N	N	N	N	N	Y
ln Dist. from Coast	N	N	Y	N	N	N	N	Y
Malaria	N	N	N	Y	N	N	N	Y
Roman Heritage	N	N	N	N	Y	N	N	Y
Genetic Diversity	N	N	N	N	N	Y	N	Y
Genetic Dist. from U.K. in 1500 CE	N	N	N	N	N	N	Y	Y

Summary: This table includes a number of potential omitted variables. A description of each variable is given within the variable appendix. The piecemeal inclusion of each and all potentially omitted variables does not alter the significance or magnitude on the interaction between potato suitability and the country-level frequency of lactase persistence.

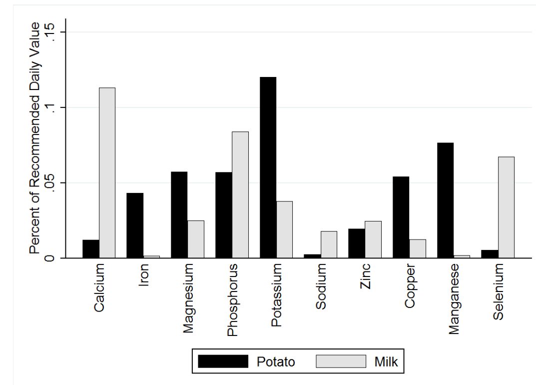
Notes: (i) Observations are at the country-year level. All regressions use the base sample of 130 Old World countries from Nunn and Qian (2011). (ii) All regressions include country and year fixed effects. Standard errors are clustered at the country level with *, **, and *** representing significance at the 10, 5, and 1% significance level, respectively. (iii) The frequency of lactase persistence is the fraction of a country's population able to digest milk. This variable is a proxy for milk consumption. (iv) The baseline controls include the suitability for all crops, the suitability of land for pasture, the presence of domesticate animals, the intensity of animal husbandry, the millennia a country has practiced agriculture, indexes of historic political and economic development, elevation, land ruggedness, and the fraction of a country within the tropics.



(a) Macro Nutrients



(b) Vitamins



(c) Minerals

Figure 1

Differences in the Nutrient Composition of Potatoes and Milk

Summary: This figure gives the nutritional composition for both potatoes and milk. Sub-figure (a) gives macro-nutrient information–i.e., calories, protein, etc.; Sub-figure (b) gives information on vitamins; and Sub-figure (c) gives information for the mineral composition of each food source. Major divergences occur for vitamin C, vitamin A, and calcium.

Notes: (i) The scale of the y-axis is not consistent across sub-figures. (ii) All nutrition data is from the National Nutrient Database from the USDA. A consistent unit of mass(100 grams) is used for all food sources. The percent of the daily recommended value is the amount of a nutrient within 100 grams of a particular food source relative to the total daily recommended value. (iii) Nutrient information for potatoes is for raw white potatoes including skin and flesh. Nutrient information for milk is for whole, 3.25% fat, milk without added vitamin A or D. (iv) The daily recommendation for all nutrients is from: http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm064928.htm.

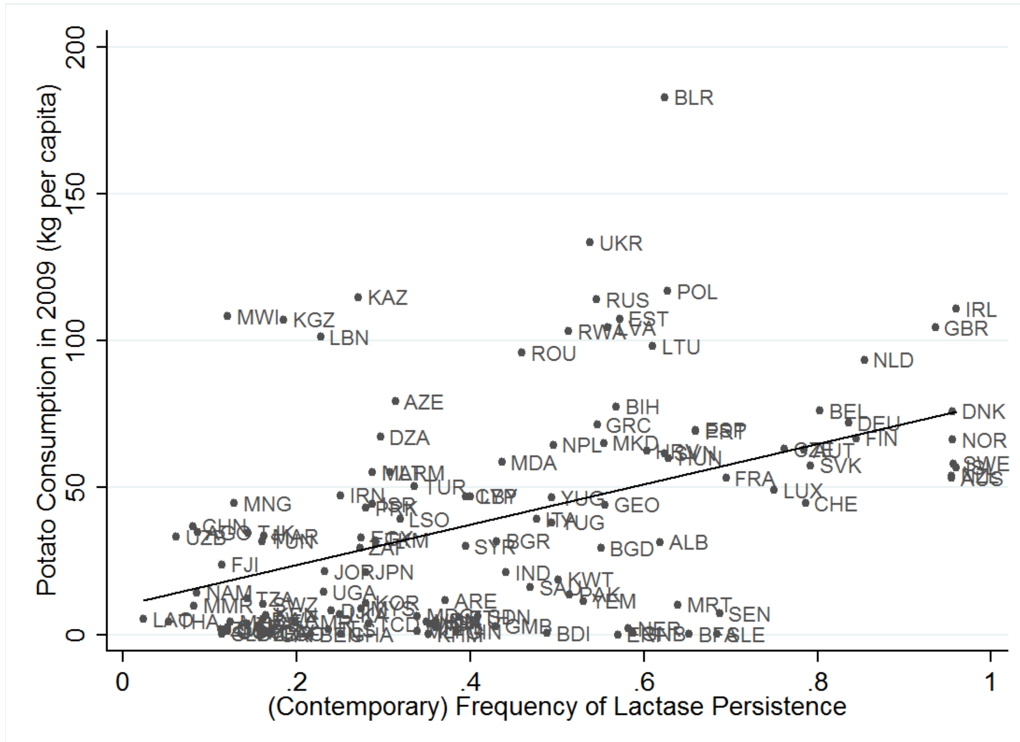


Figure 2

Potato Consumption and Lactase Persistence

Summary: This figure plots the relationship between the contemporary frequency of lactase persistence and the country-level potato consumption (kg per capita) in 2009. The bivariate slope coefficient of this relationship is 68.63. Data for 2009 potato consumption are from the FAO.

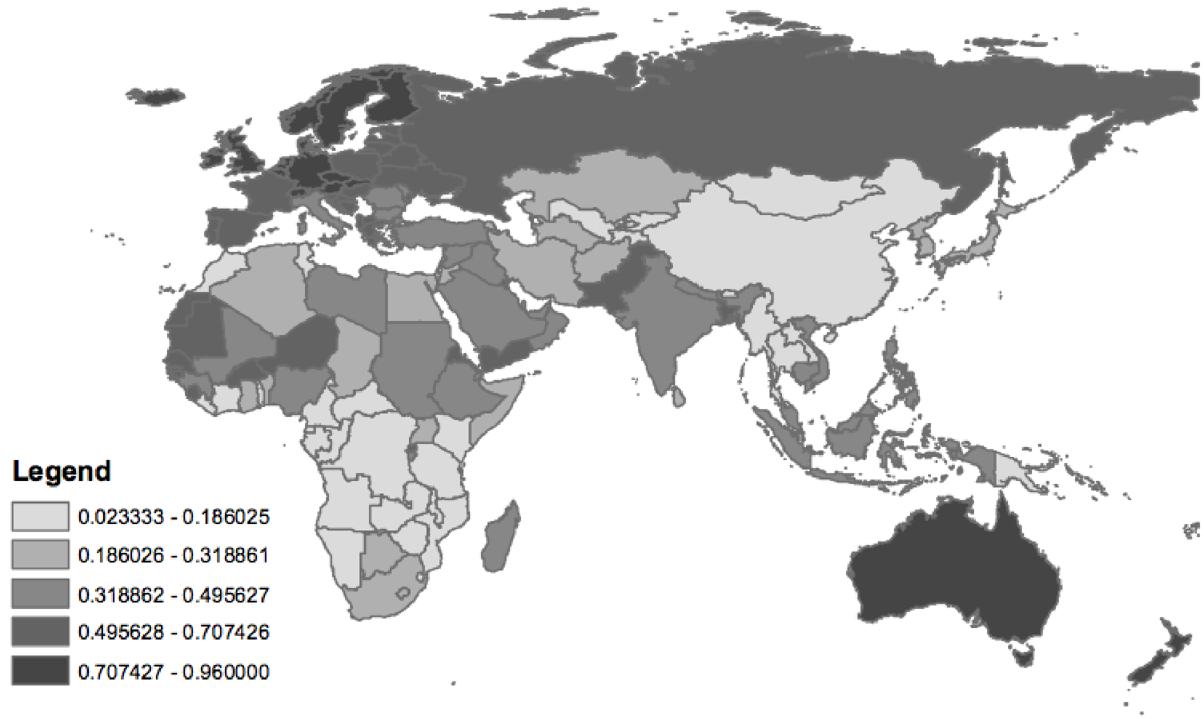


Figure 3
Old World Frequency of Lactase Persistence

Summary: This figure gives the country-level frequency of lactase persistence for the Old World and Oceania. Darker areas represent higher frequencies of lactase persistence.

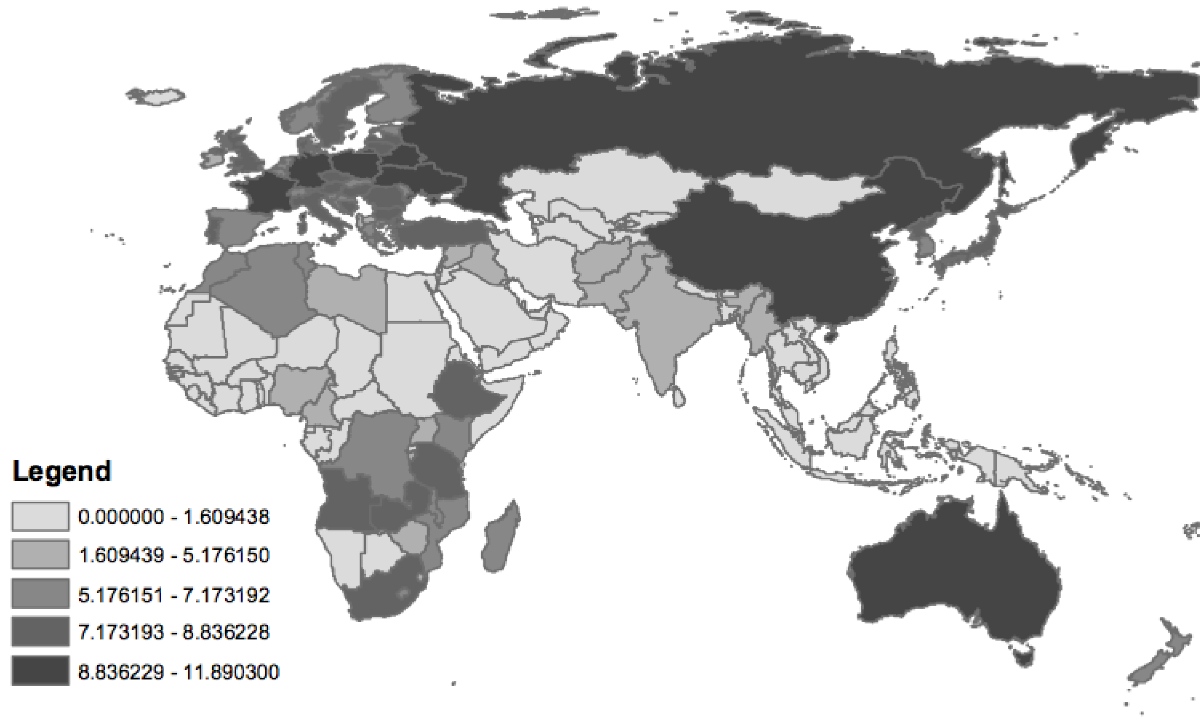


Figure 4
Old World Potato Area

Summary: This figure gives the country-level suitability for potatoes for the Old World and Oceania. Darker areas represent greater potato suitability.

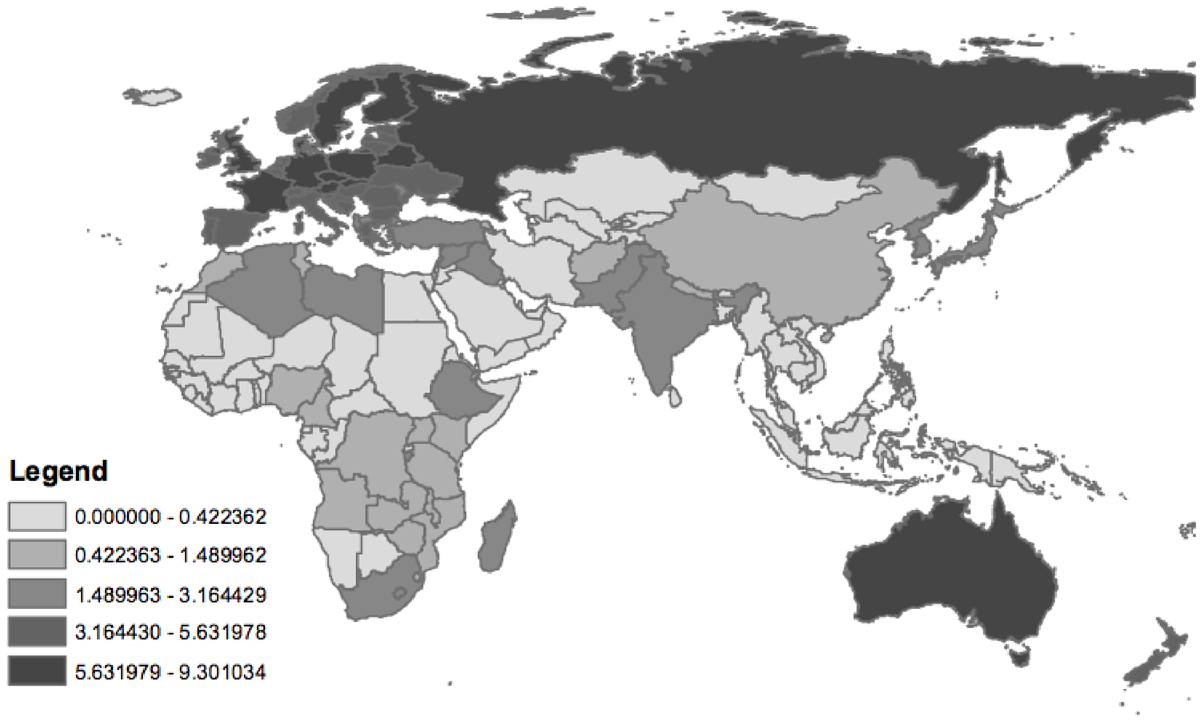
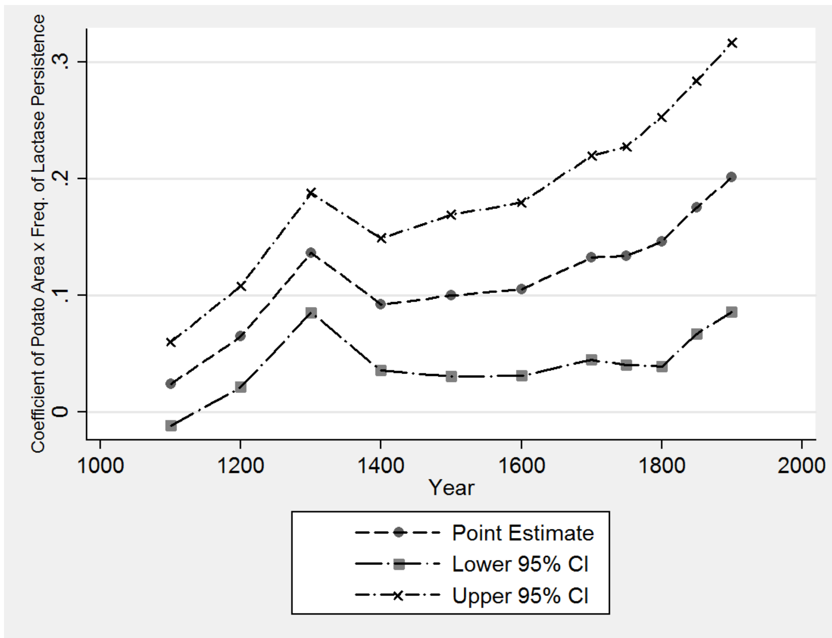
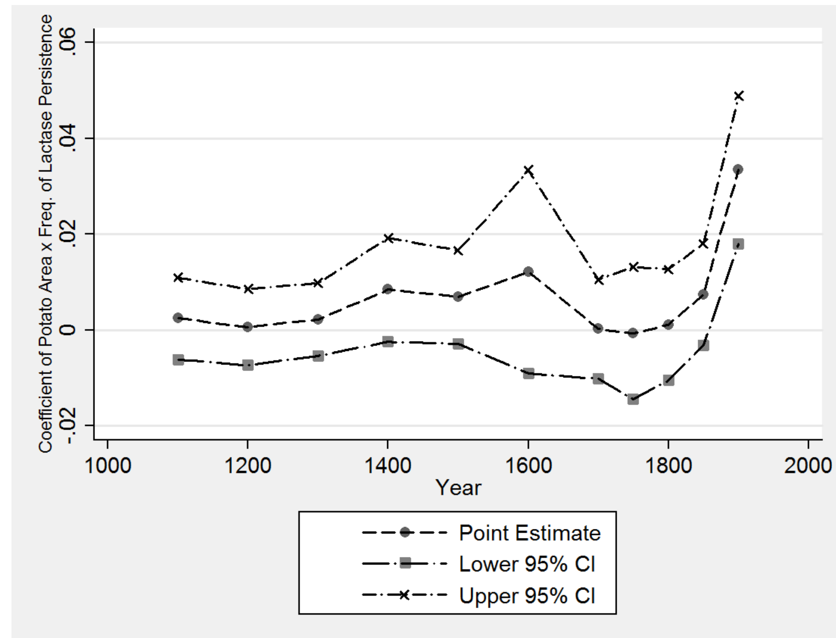


Figure 5
Old World Interaction between Potato Suitability and Lactase Persistence

Summary: This figure gives the country-level value for the interaction between the frequency of lactase persistence and potato suitability. Darker areas represent greater values, implying areas with high frequencies of lactase persistence and/or high suitability for potatoes.



(a) ln Population

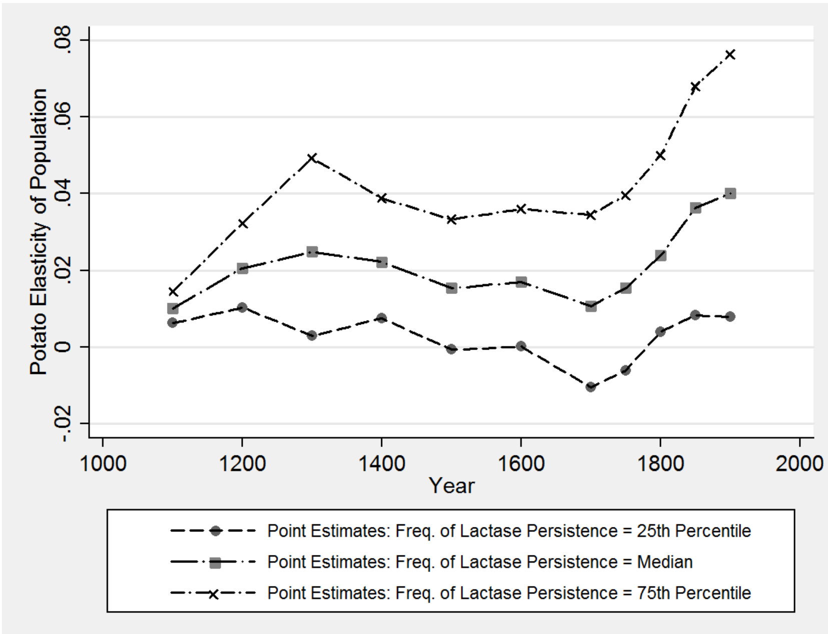


(b) City Population Share

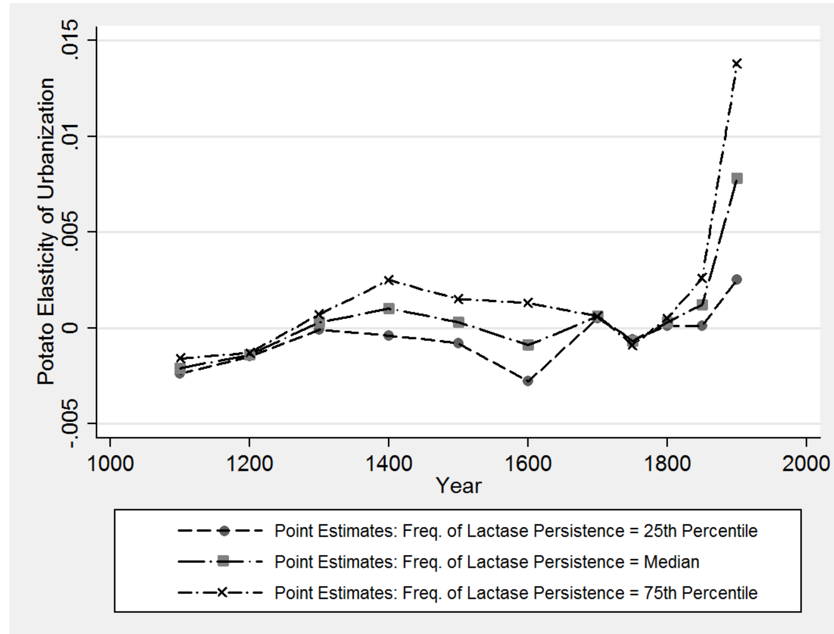
Figure 6

Complementarity over Time

Summary: This figure plots the point estimates of the interaction between lactase persistence and potato suitability for the flexible estimates of Table 2. Of note is the increase after the proposed introduction date of potatoes.



(a) ln Population



(b) City Population Share

Figure 7

Marginal Effect of Potatoes with Differing Levels of Milk Consumption

Summary: This figure plots the marginal effect of potatoes for three levels of lactase persistence–the 25th percentile, the median, and the 75th percentile. Marginal effects are calculated from the flexible estimates of Table 2. Of note is the differential effect of potatoes from the level of lactase persistence.