Maize and Precolonial Africa*

Jevan Cherniwchan†
Alberta School of Business
University of Alberta

Juan Moreno-Cruz‡
School of Economics
Georgia Institute of Technology

August 2017

Abstract

Columbus's arrival in the New World triggered an unprecedented movement of people and crops across the Atlantic Ocean. We study an overlooked part of this *Columbian Exchange*: the effects of New World crops in Africa. Specifically, we test the hypothesis that the introduction of maize during the exchange increased population density and Trans-Atlantic slave exports in precolonial Africa. We find robust empirical support for these predictions. We also examine the effects of maize on economic growth and conflict, and find that it had little effect on either channel. Our results suggest that rather than stimulating development, the introduction of maize simply increased the supply of slaves from Africa during the Trans-Atlantic slave trade.

JEL Codes: J10, N00, O10, Q10

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[*] We would like to thank Branko Bošković, Byung-Cheol Kim, David Laband, Runjuan Liu, Arvind Magesan, Barry Scholnick and seminar participants at Georgia State, Georgia Tech, the University of Alberta, and the 2014 Canadian Economic Association meetings for helpful discussions and suggestions. We would also like to thank Nathan Nunn for sharing his slave export data with us. The usual disclaimer applies.

[†] Email: jevan@ualberta.ca.

[‡] Email: juan.moreno-cruz@econ.gatech.edu

1 Introduction

Christopher Columbus's voyage in 1492 precipitated an unprecedented exchange between the Old and New Worlds. Among other things, this so-called "Columbian Exchange" led to the movement of both peoples and crops across the Atlantic Ocean.[1] While most of this movement took place between Europe and the Americas, it is clear that Africa was also affected in profound ways. Over ten million people were forcibly taken from Africa to the New World as slaves between the sixteenth and nineteenth centuries during an episode that has had lasting effects on African societies.[2] Yet, little is known about how other aspects of the exchange have shaped Africa and its history.

In this paper, we examine the effects of crop movements during the Columbian Exchange on precolonial Africa.[3] Our examination is motivated by observations made by the historians Alfred Crosby and Philip Curtin that suggest the introduction of new crops from the Americas created an agricultural productivity shock that changed the dynamics of both populations and slavery in Africa. In his classic book, *The Columbian Exchange: Biological and Cultural Consequences of 1492*, Crosby discusses the potential effects of these crops, writing:

> "...we might hypothesize that the increased food production enabled the slave trade to go on as long as it did...The Atlantic slave traders drew many, perhaps most, of their cargoes from the rain forest areas, precisely those areas where American crops enabled heavier settlement than ever before." (Crosby, 1972, p. 188).

A variant of this statement is put forth by Curtin in *The Atlantic Slave Trade: A Census*:

> "...at least two New-World crops were introduced into Africa by the sixteenth century: manioc and maize spread very widely and came to be two of the most

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[1] See Nunn and Qian (2010) for a brief overview of the Columbian Exchange. A detailed account is given in Crosby (1972).

[2] See, for example, the work of Nunn (2008) or Nunn and Wantchekon (2011).

[3] For a recent overview of the literature examining the effects of crop movements during the Columbian Exchange, see Nunn (2014).

> important sources of food on that continent. If other factors affecting population size had remained constant, the predictable result would have been population growth wherever these crops replace less efficient cultigens...It seems possible and even probable that population growth resulting from new food crops exceeded population losses through the slave trade." (Curtin, 1969, p. 270)

Together, these observations suggest that the introduction of New World crops had a material effect on Africa by increasing both i) population density and ii) slave exports during the precolonial era. We test this two-part conjecture, which we term the *Crosby-Curtin Hypothesis*, and examine how the resulting changes shaped precolonial Africa.

While the population effects of maize envisioned by Crosby and Curtin follow directly from the Malthusian forces present in Africa during the Columbian Exchange, the link to slavery is less obvious. As such, the first step in our analysis is to develop a simple theoretical framework to illustrate how these same Malthusian forces may have also increased slave exports. Our starting point for this exercise is the Malthusian growth model featuring endogenous slavery developed by Lagerlof (2009). This model is well suited for our purposes; as highlighted by Fenske (2013), the Lagerlof (2009) model matches several key stylized facts about African societies during the Columbian Exchange. In the original Lagerlof framework, elites choose property rights for land and labor to maximize their income, while the incentive to enslave people to work in agriculture is increasing in the productivity of land. We adapt this framework to allow for the possibility that elites sell slaves to foreign markets. This alters the effects of an increase in agricultural productivity; while the elite's incentive to keep slaves to work in domestic agriculture increases, decreasing returns to agriculture mean that the relative return to exporting slaves also increases. Thus, an agricultural productivity shock, such as that created by the introduction of New World Crops, will increase both the population density of and slave exports from an affected country.

The second step in our analysis is to test the predictions of the Crosby-Curtin Hypothesis empirically. We start by examining which New World crops, if any, could have created the change in agricultural productivity envisioned by Crosby and Curtin. Such a crop needs to satisfy three conditions. First, it must have had enough calories and nutrients to function as a primary dietary source. Second, it must have had a higher yield than existing African staples, so its adoption would have resulted in an increase in agricultural productivity. Finally, it must have been introduced and widely adopted in Africa in the midst of the slave trades.

Many New World crops were introduced into Africa following Columbus's discovery of the Americas, but only maize (*Zea mays*) satisfies these three conditions. Maize first arrived on the African coast during the seventeenth century. It was initially introduced by the Portuguese to supply their trading forts, but the crop was quickly adopted by African farmers due to its high energy yield, its low labor requirements, and its short growing season. Cultivation spread quickly; as we discuss further below, the available historical evidence indicates that maize functioned as a staple crop for much of the African continent by the mid-eighteenth century. Given its characteristics and the timing of its introduction, maize is the most likely cause of any agricultural productivity shock. Hence, we focus our attention on maize.

While maize is the most likely source of an agricultural productivity shock, identifying its effects is complicated by the fact that we do not observe the specific dates at which it was first adopted as a staple crop in various parts of Africa. To address this challenge we exploit cross-country differences in geographic characteristics and the timing of the crop's introduction into Africa to identify the effects of maize.[4] Our approach relies on the fact that while maize diffused rapidly across the African continent after its introduction in the mid-seventeenth century, it could not be grown everywhere due to differences in time invariant geo-climatic conditions. This means that only the subset of countries that were suitable for the cultivation of maize could have been affected (or "treated") by the crop when it was introduced into Africa. Hence, testing the Crosby-Curtin Hypothesis amounts to identifying the effects of maize on this group of countries. To do so, we adopt a variant of a simple

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[4] Nunn and Qian (2011) use a similar approach to identify the effects of the introduction of the potato on population level and urbanization rates in the Old World.

difference-in-difference research design that compares outcomes from countries with large amounts of maize-suitable land to outcomes from countries with small amounts of maize-suitable land, before and after maize was introduced into Africa.[5] This approach allows us to control for time-invariant country characteristics, such as geography, as well as continent-wide trends such as ongoing technological change and changes in the global demand for slaves, that would otherwise confound identification. We implement this design using a country-level panel data set that contains information on population levels between 1000-1900, Trans-Atlantic slave exports between 1400-1800, the suitability of maize as a crop, and several other country characteristics.

We find robust evidence in support of both parts of the Crosby-Curtin Hypothesis. Specifically, we find that African countries that were suitable for the cultivation of maize experienced larger increases in both population density and Trans-Atlantic slave exports after the crop was first introduced into Africa. The estimates from our preferred specifications suggest that following the introduction of maize, a 1% increase in maize-suitable land is associated with a 0.040% increase in population density and a 0.029% increase in Trans-Atlantic slave exports.[6] These estimates imply that the introduction of maize during the Colombian Exchange played a significant role in shaping precolonial Africa; for the average country, nearly 23% of the population growth over the period 1600-1900, and 7% of the increase in Trans-Atlantic slave exports at the height of the slave trades can be attributed to the introduction of maize.

The third, and final, step in our analysis is to ask whether the introduction of maize had effects on African societies beyond those envisioned by Crosby and Curtin. Our motivation for doing so stems from recent research that has shown that the introduction of New World crops during the Colombian Exchange (particularly, the white potato and sweet potato)

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[5] The key difference between our approach and a traditional difference-in-difference design is that we utilize a continuous measure of treatment in our analysis.

[6] These findings are robust to controlling for a number of other factors that have been identified as affecting either population levels of slavery, including disease environment, terrain ruggedness, and distance to the nearest Atlantic slave market, our measure of maize suitability, and the effects of other New World crops.

increased economic growth (Nunn and Qian, 2011) and reduced conflict (Jia, 2014; Iyigun et al., 2015) in the Old World. In light of the evidence presented by Nunn (2008) and Nunn and Wantchekon (2011) indicating the slave trades negatively affected development in much of Africa, it is possible that the deleterious effects of increased slavery brought about by the introduction of maize may have been at least partially offset by the crop's effects on both growth and conflict. We examine the effects of maize on both channels using the same difference-in-difference strategy described above.

We find little evidence that the introduction of maize increased economic growth or reduced conflict in Africa. Instead, we find maize had no meaningful effect on either channel. This means that affected African countries were unable to utilize maize as a means to escape the Malthusian trap.

Altogether, our estimates suggest that the introduction of maize during the Columbian Exchange played a significant role in shaping precolonial Africa. As such, our findings contribute to a recent literature examining the effects of the Columbian Exchange. This literature has looked at how various aspects of the exchange have affected both the Old and New Worlds, but to date, the majority of the literature examining Africa's experience has focused on the effects of the slave trades (eg. Nunn (2008), Nunn and Wantchekon (2011)). We contribute to this line of research by examining how another aspect of the exchange, the introduction of maize, affected Africa.

By providing the first evidence of how the introduction of maize affected Africa, our findings also contribute to a burgeoning literature examining the effects of agricultural productivity shocks created by the introduction of New Word crops in the Old World. Some of this research, particularly the study of the effects of the white potato by Nunn and Qian (2011), finds that the introduction of New World crops stimulated economic growth in affected parts of the Old World. In contrast, recent work by Chen and Kung (2016) finds that the introduction of maize failed to increase economic growth in China. Our results suggest that maize also failed to lead to economic growth in Africa, providing further evidence that agricultural productivity shocks alone are not sufficient for generating economic growth.

Our findings also contribute to the literature studying precolonial Africa. Much of this research has focused on precolonial institutions, in part because they have been shown to be an important determinant of development in Africa today (e.g. Gennaioli and Rainer (2007), Michalopoulos and Papaioannou (2013)). We contribute to this literature by highlighting an event that likely shaped these institutions; given that land abundance and slavery were key determinants of precolonial institutions in Africa (Fenske, 2013), our results suggest that by introducing maize, Europeans affected Africa's institutions prior to the colonial period.

Finally, our findings contribute to a large literature that directly examines the determinants of the African slave trades. To date, this literature has largely focused on factors that affected the demand for slaves (e.g. Eltis et al. (2005)) or the cost of transporting slaves (e.g. Dalton and Leung (2015), Eltis et al. (2010)). However, some recent research has begun to examine the supply side determinants of the slave trades, such as the ruggedness of terrain (Nunn and Puga, 2012), climate shocks (Fenske and Kala, 2015), and the guns-for-slave cycle (Whatley, 2017). We contribute to this literature by demonstrating how the agricultural productivity shock created by the introduction of maize increased the supply of slaves from Africa during the slave trades.

The remainder of this paper proceeds as follows. Section 2 describes our simple Malthusian framework that links changes in agricultural productivity to changes in populations and slave exports. Section 3 provides a background of the key New World crops that were introduced into Africa during the Columbian Exchange, highlights why maize is the most likely source of an agricultural productivity shock, and describes our strategy for identifying the effects of maize, our data, and the specification we use in our empirical analysis. Section 4 presents our empirical findings. Section 5 concludes.

2 Malthus in Africa: Agricultural Productivity, Population, and the Slave Trades

As we noted above in the introduction, our examination of the effects of New World crops in Africa is motivated by observations made by the historians Alfred Crosby and Philip Curtin linking these crops to changes in both population density and slavery during the Columbian Exchange.[7] Together, their observations form the basis for what we term the *Crosby-Curtin Hypothesis*: the hypothesis that increases in agricultural productivity created by the introduction of New World crops increased both i) population density in, and ii) slave exports from affected parts of Africa. While neither Crosby nor Curtin explicitly stated their observations in these terms, both parts of this hypothesis can be understood through a Malthusian lens.

Part one of the hypothesis links the introduction of New World crops with increased population density in Africa. This linkage is relatively straightforward. At the time New World crops were introduced, Africa was governed by a Malthusian regime, with per-capita incomes at subsistence levels (Clark (2007) and Ashraf and Galor (2011)). This means that equilibrium income levels were unaffected by the productivity of land. Any income in excess of the subsistence level, such as that created by an agricultural productivity shock, was translated into an increase in population levels, necessarily increasing population density. Hence, if the hypothesis is true, we should observe significant changes in population density in the parts of Africa that were affected by the introduction of maize.

The second part of the Crosby-Curtin hypothesis ties the introduction of New World crops to increased slave exports. Although this linkage was never formalized by either Crosby or Curtin, we can illustrate this relationship with the aid of the model developed by Lagerlof (2009) to examine slavery in Mathusian societies. As discussed by Fenske (2013), the model developed by Lagerlof (2009) matches several key stylized facts about African societies and

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[7] For a brief overview of the Columbian Exchange, see Nunn and Qian (2010). A detailed look at the exchange is given in Crosby (1972).

their institutions during the precolonial era, making it well suited for our purposes. Lagerlof presents a Malthusian growth model featuring land and labor with endogenously determined property rights. For our purposes, this model's key prediction is that, in a society with slavery, the incentive to enslave people is increasing in the productivity of land. Lagerlof's model, however, does not allow for the export of slaves. Below we develop a variant of the Lagerlof (2009) model that allows for this, and use the model to highlight a potential channel via which agricultural productivity shocks may affect slave exports.[8]

We assume societies are ruled by an elite that maintains slaves and holds all land.[9] The ruling elite enslaves a fraction of their population to either work in agriculture or to sell to foreign markets. The agricultural productivity of land is a function of the current set of crops available for cultivation and technology.

In period t, elites choose the number of slaves to employ in agriculture and the number of slaves to sell to foreign markets to maximize their income:

$$\pi_t = \max_{S_t, X_t} \{F(A_t, S_t) - \bar{c} S_t + v_t X_t | S_t + X_t \leq P_t\} \tag{1}$$

where $F(A_t, S_t) = A_t^{\alpha} S_t^{1-\alpha}$, A_t denotes agricultural productivity, S_t denotes the population of domestic slaves used in agriculture, X_t denotes the population of slaves exported to foreign markets, and P_t denotes the size of the society's population at time t.[10] Slaves are fed a

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[8] While we utilize our theoretical framework to highlight the possible effects of changes in agricultural productivity on slave exports, maize may have also affected slave exports via other channels. For example, maize may have also affected slave exports by directly reducing transportation costs. The introduction of maize may have affected these costs in two ways. First, it may have lowered transport costs directly by providing a cheaper foodstuff for feeding slaves while they were being transported; maize had a number of advantageous qualities that made it particularly well suited for transport (McCann, 2005). Second, it may have indirectly reduced transport costs by decreasing mortality rates for slaves during transport. A key determinant of total slave exports, particularly from the interior of the African continent, was the mortality rate (Vansina, 1990; Lovejoy, 2000). Hence, a cheap, easily transportable food such as maize may have increased the number of slaves exported during the Trans-Atlantic slave trade by reducing the number of deaths due to malnourishment.

[9] In the Lagerlof (2009) model the economy potentially transitions from an egalitarian regime, to a despotic regime where society is ruled by an elite that maintains slaves and holds all land, to a society featuring free labor. We focus on the second case; we are not interested in modeling the transition between these states given the pervasiveness of slavery in Africa during the Columbian Exchange.

[10] This formulation contains an implicit assumption that there are diminishing returns to agriculture. This is a common assumption in Malthusian models (e.g. Ashraf and Galor (2011)).

subsistence level of consumption, $\bar{c}$.[11] If slaves are exported, elites receive an exogenous price of v_t.[12]

Solving equation (1) yields the size of the domestic slave population:

$$S_t^* = \left[\frac{1-\alpha}{\bar{c}+v_t}\right]^{\frac{1}{\alpha}} A_t \tag{2}$$

and the number of exported slaves $X_t^* = P_t - S_t^*$.[13] The elite's income is then given by:

$$\pi_t^* = \alpha \left[\frac{1-\alpha}{\bar{c}+v_t}\right]^{\frac{1-\alpha}{\alpha}} A_t + v_t P_t \tag{3}$$

As in Lagerlof (2009), population growth is determined by the choices of elites. Slaves do not have children; because they are fed at subsistence levels, slaves cannot allocate any resources to offspring. Members of the elite live forever; for convenience we normalize the size of the elite to one. All members have the same utility function given by:

$$u(c_t, n_t) = \ln c_t + \rho \ln n_t \tag{4}$$

where c_t is consumption and n_t is the number of the elite member's children. Elites maximize their utility subject to the the budget constraint $\pi_t = c_t + qn_t$, where q is the consumption cost of raising a child, and π_t is the income derived from agricultural output and from selling slaves. It follows from the elite's maximization problem that the optimal number of children is $n_t = \frac{\rho}{q}\pi_t$. The population in period $t+1$ is then equal to the number of children at time

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[11] We could allow for variable guarding costs, as in Lagerlof (2009), by assuming that each slave requires γ guards who are paid the subsistence level of income, so that the costs of maintaining slaves are equal to $(\bar{c}+\gamma)$. Doing so does not affect our results.

[12] The underlying assumption is that there are many elites providing slaves to the export market, thus making them price-takers in the export market, as in Gillezeau and Whatley (2011).

[13] The assumption here is that P_t is large enough so that $X_t > 0$. Otherwise, $S_t = P_t$ and the analysis proceeds as in Lagerlof (2009).

t; that is:

$$P_{t+1} = \frac{\rho}{q}\left[\alpha\left[\frac{1-\alpha}{\bar{c}+v_t}\right]^{\frac{1-\alpha}{\alpha}} A_t\right] + \frac{\rho v_t}{q} P_t \tag{5}$$

Given our interest in understanding how agricultural productivity shocks affected societies with positive levels of domestic slavery and slave exports, we assume that the return to export slavery is not too high relative to the return to agricultural production; that is $q/\rho > v_t$. This ensures that consumption cannot be maximized solely through the sale of slaves on export markets, meaning the economy features both domestic and export slavery.[14] In this case, the steady state is given by:

$$\bar{P} = \left[\frac{\rho\alpha}{(q-v\rho)}\right]\left[\frac{1-\alpha}{\bar{c}+v}\right]^{\frac{1-\alpha}{\alpha}} A \tag{6}$$

$$\bar{S} = \left[\frac{1-\alpha}{\bar{c}+v}\right]^{\frac{1}{\alpha}} A \tag{7}$$

$$\bar{X} = \left[\frac{\rho\alpha}{q-v\rho} - \frac{1-\alpha}{\bar{c}+v}\right]\left[\frac{1-\alpha}{\bar{c}+v}\right]^{\frac{1-\alpha}{\alpha}} A \tag{8}$$

where $\bar{P}$, $\bar{S}$ and $\bar{X}$ denote the steady state levels of population, domestic slavery and slave exports, respectively.[15]

Having solved for the economy's steady state, we are now able to formalize the effects of an agricultural productivity shock such as that created by the introduction of maize:

Crosby-Curtin Hypothesis. *If the relative returns of export slavery to agricultural production are not too high, that is if $q/\rho > v_t$, then an increase in the productivity of agriculture:*

(i) increases population levels, and

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[14] To see this, note that $c_t/n_t = q/\rho$ from the elite's utility maximization problem. This means that $c_t > v_t n_t$; that is, the payoff from selling all children as slaves is less than the value of consumption obtained when some slaves are employed in agriculture.

[15] The dynamics of the model are straightforward. The population growth equation is a straight line with slope given by $\rho v_t/q$. Under the assumption that $q/\rho > v_t$, we have the slope is less than 1. The intercept is always positive and given by $[\rho/q]\left[\alpha\left[1-\alpha/\bar{c}+v_t\right]^{[1-\alpha]/\alpha} A_t\right] > 0$. Thus, the system evolves monotonically towards the unique steady state. This also implies that for all times, the transition path under increased land productivity is always higher than the low productivity path.

(ii) increases the number of domestic slaves and the number of slaves that are exported.

Proof. Both (i) and (ii) follow from taking derivatives of equations (6), (7), and (8) with respect to A. □

This proposition shows that the Crosby-Curtin Hypothesis can be rationalized with the aid of a Malthusian framework. Part (i) of the proposition states that, as in Malthusian models in which there is no slavery (such as Ashraf and Galor (2011)), an agricultural productivity shock can increase population levels, leading to an increase in population density. This means that if the hypothesis is true, we should observe an increase in population density following the introduction of maize into Africa. Part (ii) of the proposition indicates that an agricultural productivity shock increases the benefit of holding domestic slaves, leading to an increase in the domestic slave population. However, not all people are allocated to agriculture; decreasing returns to agriculture ensure that the relative return to slave exports increases, meaning that a larger fraction of slaves are sold to foreign markets.[16] As such, for a given area of land, we should also observe an increase in slave exports following the introduction of maize into Africa. In what follows, we test the two parts of this hypothesis empirically.

3 Research Design

3.1 A Digression on Maize

Several New World crops, including capsicum peppers, cassava, maize, peanuts, white potatoes, sweet potatoes, and tomatoes, were introduced into Africa following Columbus's discovery of America in 1492. Testing the Crosby-Curtin hypothesis requires determining which crops, if any, were capable of creating the change in agricultural productivity necessary to

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[16] While our model assumes the returns to export are constant at global prices v, the results would also hold with diminishing returns to exports provided that the marginal returns to export slavery diminish at a lower rate than those of agricultural productivity.

change population levels and slavery during the slave trade.

We make this determination on the basis of three conditions. First, such a crop must be a staple with enough calories and nutrients to function as a primary dietary source. If it does not, it is unlikely that the adoption of the crop would result in the change in nutrition required to affect populations or slavery. Second, the crop must be more productive than indigenous African staples, so that adoption results in an increase in agricultural productivity. Finally, the crop must have been introduced and widely adopted across the African continent during the course of the African slave trade.

While several new plants were introduced into Africa as part of the Columbian Exchange, only a few had the calories and nutrients required for use as a staple crop. These crops are listed in Table I, which reports the nutritional content of various African staples using data from the United States Department of Agriculture.[17] Four of these plants (maize, cassava, sweet potatoes and white potatoes) originate in the New World. The remaining two crops (sorghum, and millet) are indigenous to Africa and were the main cereal crops before the Columbian Exchange (McCann, 2005). Table I indicates that sorghum and millet have substantially more calories, protein, fat and fibre than all but one of the New World crops. Only maize has a similar nutrient content. This means that in terms of nutrition, New World plants were largely poor substitutes for indigenous crops. As such, any change in agricultural productivity arising from the introduction of new staples must have been a product of a change in the physical productivity of agriculture.

There is substantial variability in the agricultural productivity of staple crops within Africa. This can be seen in Table II, which reports the earliest available estimates of average annual crop yields in Africa in terms of both physical output and energy content. These estimates are based on data reported in Miracle (1966), Nunn and Qian (2011) and Table I. As the first column of the table shows, maize, cassava, and sweet and white potatoes all have a higher physical yield than millet and sorghum. This suggests that the adoption of any new

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[17] The table reports the nutrient value by weight to ensure the direct comparability of the nutrients available from consuming the same quantity of various crops.

Table I: Nutrient Contents of Various Staple Crops

Crop	Water (g)	Energy (kcal)	Nutrients per 100 grams Protein (g)	Fat (g)	Carbohydrates (g)	Fibre (g)
Sorghum	12.40	329	10.62	3.46	72.09	6.7
Millet	8.67	378	11.02	4.22	72.85	8.5
Maize	10.37	365	9.42	4.74	74.26	7.3
Cassava	59.68	160	1.36	0.28	38.06	1.8
Sweet Potato	77.28	86	1.57	0.05	20.12	3.0
White Potato	79.34	77	2.02	0.09	17.47	2.2

Notes: Data taken from the USDA National Nutrient Database for Standard Reference 26 Software v.1.3.1. http://ndb.nal.usda.gov

Table II: Annual Crop Yields of Various Staple Crops

Crop	Yield (kg/ha)	Energy MJ/ha
Millet-Sorghum	1,200	17,800
Maize	1,700	26,000
Cassava	4,000	26,800
Sweet Potatoes	8,000	28,800
White Potatoes	4,400	14,200

Notes: With the exception of white potatoes, annual yield data based on Miracle (1966), Table 11-1, p. 207. Annual yield for white potatoes taken from Nunn and Qian (2011). Energy yields calculated using data from Table I.

crops would have increased raw agricultural output from existing farmland. There are also important differences in physical characteristics (such as water and carbohydrate content) across plants that could affect adoption. This is accounted for in the second column of Table II, which displays the energy value corresponding to the yield listed in the first column. This column shows that maize, cassava and sweet potatoes all yield more energy per acre than millet and sorghum. This means each of these crops could have functioned as a substitute for millet and sorghum.

This, however, ignores the significant differences in the quantity of labor required to grow and harvest each plant. Of the staple crops in Africa, maize has the lowest labor requirements (Purseglove, 1972; Hogendorn and Gemery, 1991; McCann, 2001), particularly after processing, storage and transport are taken into account (Miracle, 1966). Given that a hectare of maize has a similar energy content to a hectare of cassava or sweet potatoes, this suggests that maize was the most productive of the New World crops introduced into Africa, and had the greatest potential to create an agricultural productivity shock.

Maize has several other characteristics not found in other New World plants that would have made it an attractive substitute to indigenous crops for African farmers. As noted by the botanist J.W. Purseglove, "…it provides nutrients in a compact form; it is easily transportable; the husks give protection against birds and rain, it stores well if properly dried; [and] it can be harvested over a long period, first as immature cobs, and can be left standing in the field at maturity before harvesting" (Purseglove, 1972, p. 301). Moreover, maize was grown in a manner similar to sorghum and millet, making adoption relatively straightforward. Agricultural economist William Jones indicates that, "To grow [maize], the African farmer had only to acquire the seed; all the rest of the process was familiar" (Jones, 1959, p. 74). Maize also grew in areas where crops were not previously planted, increasing the amount of land available for agriculture, and could be harvested multiple times during a single growing season, providing a source of food while other crops were still growing (McCann, 2001).

The timing of maize's introduction into Africa also suggests that it is the most likely source of an agricultural productivity shock. Although the exact date of introduction is not known, historians suggest that maize was first brought to West Africa by the Portuguese.[18] Initially, it was introduced to the islands of Cape Verde and Sao Tomé; the crop was present on both islands by the mid 16th century (McCann, 2005). It travelled from these islands to the Gold Coast sometime during the 17th century (McCann, 2005). Recent archaeological research indicates that maize diffused rapidly inland from the coast; there is evidence of maize cultivation over 500 kilometres (300 miles) from the coast of Ghana by 1700 (Stahl,

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[18] It has also been suggested that maize was introduced into West Africa by traders from Egypt who obtained maize from Spain (Miracle, 1965), however recent genetic research tracing the diffusion of maize has not been able to substantiate this hypothesis (Mir et al., 2013).

1999). By the start of 18th century it had replaced millet and sorghum to become the main crop in West Africa (Juhé-Beaulaton, 1990).

It is likely that the Portuguese were also responsible for the arrival of maize in other parts of Africa, although the timing of these introductions are not well documented and there is limited evidence of the diffusion of the crop inland. Maize appears to have arrived in West-Central Africa during the early part of the 17th century; there is evidence of maize in the Congo Basin and Angola around this time, however it appears that it was not a primary crop until the latter third of the century (Miracle, 1966). There is also some evidence that maize was cultivated as a crop in East Africa during this period. The limited historical evidence indicates that maize had arrived in Tanzania by 1668, Madagascar by 1717 and Mozambique by 1750 (Miracle, 1966). Recent archaeological evidence (Lamb et al., 2003; Kusimba, 2004) suggests that maize was also present in interior Kenya at this time.

Altogether, the evidence suggests that maize had diffused widely across the African continent by the middle of the slave trades, meaning a maize induced agricultural productivity shock most likely occurred in the early 1700s. This is in stark contrast to the other New World crops with high yields. While sweet potatoes were introduced into Africa by the Portuguese around the same time as maize (Alpern, 1992), the crop did not spread until the 19th century due to British influences (O'Brien, 1972). The Portuguese also brought cassava to Africa, but did so after the introduction of maize (Alpern, 1992). Cassava was not widely adopted until the 19th century, in part because it contains dangerous amounts of hydrogen cyanide; thus, widespread adoption required learning how to process the crop to avoid poisoning (Jones, 1959). The white potato also arrived later, towards the end of the nineteenth century (Nunn and Qian, 2011). As such, the timing of the diffusion and adoption of sweet potatoes, white potatoes, and cassava each coincide with the end of the slave trades.

In sum, the available evidence suggests that maize is the most likely cause of any agricultural productivity shock. Maize has similar nutrient levels to the indigenous staples millet and sorghum, but is much more productive as it has both a higher yield and lower labor requirements. Moreover, it is more productive than other New World staples and has several other advantageous characteristics. Finally, it was the only crop whose cultivation diffused widely during the slave trades. As such, we focus our analysis on the effects of maize.[19]

3.2 Identifying the Effects of Maize in Africa

Testing the Crosby-Curting Hypothesis requires that we identify the effects of changes in agricultural productivity arising from the introduction of New World crops on both population density and slave exports in Africa. As we discussed above, these productivity changes were most likely caused by the introduction of maize, meaning that we must identify its effects on both outcomes. Doing so is complicated by the fact the historical record is incomplete; we do not observe the exact dates at which maize was adopted as a staple crop in different countries in Africa. To address this issue and test both parts of the Crosby-Curtin Hypothesis, we follow the approach used by Nunn and Qian (2011) to identify the effects of the introduction of the white potato in the Old World and exploit two sources of identifying variation: (i) cross-country differences in the suitability of land for growing maize as a crop, and (ii) temporal variation in the availability of maize created by its introduction onto the African continent.

Our first source of identifying variation arises from the fact that maize could not be grown everywhere in Africa due to cross-country differences in time-invariant geo-climactic conditions. This can be seen from Figure 1, which depicts data on the suitability of maize as a crop from the Food and Agriculture Organization of the United Nations (FAO)'s Global Agro-Ecological Zones (GAEZ) database. The GAEZ database provides 0.5 degree by 0.5 degree grid-cell measures of potential crop yield on the basis of geo-climatic constraints and different agricultural inputs.[20] The figure illustrates maize suitability with low input

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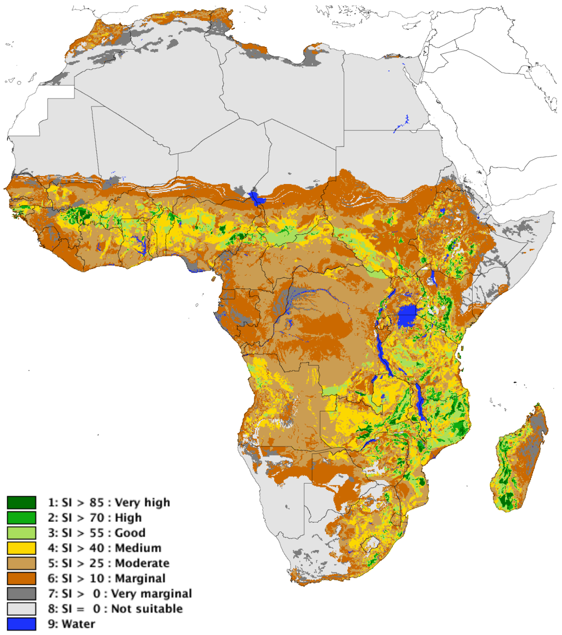
[19] While maize is the main focus of our analysis, we also explore the effects of the introduction of cassava, sweet potatoes, and white potatoes in our empirical analysis below.

[20] For an overview of the FAO's GAEZ database, see Nunn and Qian (2011).



Source: GAEZ database (IIASA/FAO, 2012).

Figure 1: The Suitability of Land for Cultivating Maize in Africa

intensity and rain-fed irrigation, reflecting the agricultural technology typically available in Africa during our period of study.

As shown in the figure, there is significant variation in the suitability of maize as a crop across Africa. The figure divides suitability into eight possible categories, from "Very High", in dark green, to "Not Suitable" in light grey. These categories reflect differences in the potential capacity of land to produce maize at the maximum yield due to differences in geographical, soil and climatic conditions. For example, very high suitability locations are able to produce at least 85% of their constrained-free crop yields, while marginal suitability locations are able to produce at 10% of their benchmark. These differences create variation we can use to identify the effects of maize; we can compare average outcomes from places where it is highly suitable (such as parts of Nigeria or Madagascar) with average outcomes from locations where it is not (such as much of Namibia or Gabon).

Our second source of identifying variation arises from changes in the availability of maize in Africa over time. As we discussed above, maize is not indigenous to Africa; it was first introduced into the Gold Coast sometime in the seventeenth century, at which point it diffused rapidly across the continent. Given that we do not observe the exact timing or direction of this diffusion, we treat the introduction of maize as a shock common to all countries. This yields temporal variation we can exploit by comparing average outcomes before and after maize was introduced into Africa.

We identify the effects of the introduction of maize on both population density and slave exports by exploiting these two sources of variation using differences-in-differences. This approach compares either the average population densities of, or the average slave exports from, countries where land was suitable for adopting maize as a crop with the same outcome from countries where adoption was not possible due to an absence of suitable land. This means we are able to control for a number of time-invariant factors, such as a country's geographic characteristics and advantages, and trends common to all African countries, such as ongoing technological change, and changes in the global demand for slaves, that would otherwise confound identification.

The credibility of this research design relies, in part, on the fact that maize was only suitable as a crop in a subset of countries. This means that, while it was potentially available everywhere in Africa after its introduction, maize could only be adopted in places where it could be grown due to exogenous geo-climatic factors. As such, while all countries may have tried to adopt maize once it was introduced due to factors such as existing population pressures, adoption was not possible everywhere due to geography. Given that the suitability of land for growing maize was not known before the crop was introduced, this rules out the possibility that our estimates are capturing the effects of factors such as existing population pressure rather than the effects of maize.[21]

In order to credibly identify the effects of maize, our research design also requires an assumption that there are no other country-specific factors related to the introduction of

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[21] While the fact that the maize suitability was unknown prior to the crop's introduction into Africa meaning that populations could not have sorted according to the suitability of land for growing maize, populations may have sorted according to the land's suitability for growing indigenous staple crops. This creates the potential that the population pressures at the time of maize's introduction actually reflect the suitability of maize as a crop if maize and indigenous crops are highly correlated. We examine this possibility further in our empirical analysis below.

maize driving differences in outcomes across countries over time. Given that Africa experience many significant changes around the time maize was introduced, we examine the veracity of this assumption in our analysis below.

3.3 Data

As discussed above, our research design requires cross-country data on the suitability of maize. We follow the approach taken by Nunn and Qian (2011) and construct this measure using the FAO-GAEZ data. In our main analysis, we define each parcel of land in the FAO-GAEZ data as suitable for maize if it is classified as having very high, high, good or medium suitability index under low-input productivity and rain irrigation conditions.[22] These conditions reflect the agricultural technology available in Africa during our period of study.[23] Based on this definition of suitability, any parcel of land that produces at at least 40% of the benchmark capacity is assumed to be suitable for the production of maize. We then calculate the total area that is classified as suitable in each country.[24]

Our empirical analysis also requires data on population density and Trans-Atlantic slave exports by country (both measured in persons per km^2) before and after the introduction of maize. We create these variables using data from two main sources.

Our population data comes from Nunn and Qian (2011). These data are based on research by McEvedy and Jones (1978), and contain information on population levels for each country in Africa by century from 1000 to 1700, and by half century from 1750 to 1900. Some authors have expressed doubts about the accuracy of these data (e.g. Austin (2008) and Hopkins (2009)), meaning one of our dependent variables is potentially measured

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[22] We examine the robustness of our baseline results to this definition in section 4.3.2.

[23] As indicated by the GAEZ, "Under the low input, traditional management assumption, the farming system is largely subsistence based and not necessarily market oriented. Production is based on the use of traditional cultivars (if improved cultivars are used, they are treated in the same way as local cultivars), labor intensive techniques, and no application of nutrients, no use of chemicals for pest and disease control and minimum conservation measures." (IIASA/FAO, 2012).

[24] One potential concern with our use of the FAO-GAEZ data is whether a modern measure of maize suitability captures historical conditions. In Figure A1 of the appendix, we show that there is a strong correlation between our measure of maize suitability and both historical maize cultivation and historical maize production.

with error. However, any classical measurement error will not bias our estimates, and any systematic non-classical error will be captured by the country and year fixed effects that we include in our empirical specifications.

We obtain data on Trans-Atlantic slave exports from Nunn (2008).[25] These data contain information on total number of slaves exported by country for the periods 1450-1521, 1527-1599, 1600-1699, 1700-1799 and 1800-1866. For convenience, we subsequently refer to these periods as the 1400s, 1500s, 1600s, 1700s, and 1800s, respectively.

Combining these three data sources yields the two main panel data sets that we utilize in our analysis. The first contains information on population density and maize suitability by country and by century for the period 1000-1700 and by half century for the period 1750-1900. The second contains information on Trans-Atlantic slave exports (measured in persons exported per km^2) and maize suitability by country and century for the period 1400-1800. As we discuss further below, we supplement each with data from additional sources to account for other factors that may potentially confound our analysis. Summary statistics for each data set are presented in Table A1 of the appendix.

3.4 Empirical Specification

We implement our research design using the following empirical specification:

$$y_{it} = \beta[Maize_i \times Post_t] + X_{it}\Gamma + \eta_i + \lambda_t + \mu_{it} \tag{9}$$

where y_{it} is the outcome of interest (either the natural log of population density (in persons per km^2), or the inverse-hyperbolic sine of Trans-Atlantic slave exports (in persons per km^2)) in country i at time t.[26] Each country's treatment is captured by $[Maize_i \times Post_t]$, which is

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[25] We utilize the slave export data constructed by Nunn (2008) rather than the sourced data from the Trans-Atlantic Slave Trade database(Voyages Database, 2016) because the Trans-Atlantic Slave Trade database does not contain information on the country where slaves were initially taken from, making it impossible to identify how the introduction of maize affected slave exports.

[26] We adopt these transformations to address the skewness in each variable. We employ the inverse-hyperbolic sine transformation for total slave exports given that its minimum value is zero.

the inverse-hyperbolic sine of the total area in country i that is suitable for growing maize (the area "treated" by maize) interacted with a post-introduction indicator.[27] We assign the post-introduction indicator a value of 1 for the period 1700 onward, given that the available historical evidence suggests that the diffusion and adoption of maize primarily occurred in the early 1700s.[28] X_{it} are additional controls that capture other factors that may have also affected the adoption of maize. η_i is a country fixed effect that capture unobserved time-invariant factors such as soil quality and elevation that affect population or slavery. λ_t is a time period fixed effect that captures aggregate shocks common to all countries that would affect population or slavery, such as ongoing technological progress or worldwide changes in the demand for slaves. μ_{it} is an error term that captures idiosyncratic changes in either population density, or slave exports.

The coefficient of interest in equation (9) is β, which captures the effect of the introduction of maize on the outcome of interest. When population is the outcome of interest, the estimated coefficient $\hat{\beta}$ measures the change in population density in countries suitable for growing maize following its introduction into Africa relative to the change in population in countries that were not capable of growing maize. Similarly, when slave exports are the outcome of interest, $\hat{\beta}$ measures the change in slave exports in countries suitable for suitable for growing maize following its introduction into Africa relative to the change in slave exports in countries that were not capable of growing maize. In each case, $\hat{\beta}$ is identified from within-country comparisons over time. For the Crosby-Curtin hypothesis to hold, the introduction of maize must have a positive and significant effect on both population density and Trans-Atlantic slave exports, meaning we should observe $\hat{\beta} > 0$ from both regressions.

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[27] We again adopt the inverse-hyperbolic sine transformation to address the fact that the distribution of maize-suitable land area across countries is highly skewed, with a minimum value of zero.

[28] We examine whether our assumption that the post-introduction period corresponds to the years 1700 onward is reasonable in Section 4.2.1, below.

4 Results

4.1 The Crosby-Curtin Hypothesis

Table III reports estimates from three specifications based on equation (9) that we use to test the Crosby-Curtin hypothesis. Each panel of the table reports estimates for a different part of the hypothesis: Panel A reports estimates for population density, while Panel B reports estimates for Trans-Atlantic slave exports. The first specification, reported in column (1) of each panel, includes time and country fixed effects. This specification controls for time-invariant cross-country differences, such as geography, and continent wide trends, such as technological change, that may have affected the introduction and adoption of maize. The second specification, reported in column (2), adds the natural log of average distance to an ice-free coast, the inverse hyperbolic sine of the fraction of land that is within 100 km of an ice-free coast and region indicators for north, west, east, south and central Africa, all interacted with time fixed effects. This allows us to account for differential trends in European contact. Controlling for these trends is important given that European contact created one of our sources of identifying variation: the introduction of maize. This creates the possibility that our estimates are capturing the effects of other time-varying aspects of European contact, such as the sale of firearms, that may have affected both population density and slave exports.[29] In our preferred specification, reported in column (3), we add the natural logs of two key determinants of climate, distance to the equator and elevation, interacted with time fixed effects to account for the possibility of differential climate trends across countries. Accounting for these trends is also important given that geo-climatic factors are a key determinant of crop suitability, our other source of identifying variation.[30] Finally, the table reports two sets of standard error estimates. The first, reported in round parentheses,

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[29] The importance of this type of contact is highlighted by the work of Whatley (2017), who shows that the guns-for-slave cycle was an important driver slave supply during the slave trades.

[30] Accounting for differential climate trends is also important in light of recent research by Fenske and Kala (2015), who show that climate shocks are an important determinant of slave exports during our period of study.

Table III: The Crosby-Curtin Hypothesis: Baseline Estimates

	Panel A: Population Density		
	(1)	(2)	(3)
Maize × Post	0.026^{a}	0.024^{a}	0.025^{a}
	(0.008)	(0.008)	(0.008)
	[0.008]	[0.007]	[0.007]
European Contact		X	X
Climate			X
Observations	588	588	588
Adjusted R^2	0.84	0.92	0.92

	Panel B: Trans-Atlantic Slave Exports		
	(1)	(2)	(3)
Maize × Post	0.018^{b}	0.024^{b}	0.027^{b}
	(0.008)	(0.009)	(0.010)
	[0.008]	[0.009]	[0.010]
European Contact		X	X
Climate			X
Observations	245	245	245
Adjusted R^2	0.18	0.41	0.41

Notes: Table reports estimates of the effect of maize on population density and Trans-Atlantic slave exports. Panel A reports estimates from OLS regressions of the natural log of population density (persons/km^2) on the inverse hyperbolic sine of maize suitable land area interacted with a post introduction indicator and other controls. Panel B reports estimates from OLS regressions of the inverse hyperbolic sine of slave exports (persons exported/km^2) on the inverse hyperbolic sine of maize suitable land area interacted with a post introduction indicator and other controls. In all cases, each set of control variables is interacted with a full set of year fixed effects. In all specifications, the post-introduction indicator period takes the value 1 for the post 1700 period. All regressions include year fixed effects and country fixed effects. Standard errors clustered by country are reported in round parentheses. Conley (1999) standard errors are reported in square parentheses. ^{a}, ^{b}, and ^{c} denote significance at the 1 , 5 and 10 percent levels, respectively.

are clustered by country. The second set, reported in square parentheses, correct for spatial autocorrelation using the approach of Conley (1999) assuming spatial dependence for observations less than 5 degrees apart.[31]

Panel A of Table III reports estimates of the effect of the introduction of maize on population density. These estimates reveal that maize significantly increased population density in countries suitable for its cultivation. For example, the estimate reported in column

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[31] We also explored adopting 1, 10 and 15 degree cutoffs, but doing so had little effect on inference. As such they are not reported for the sake of brevity.

(1) indicates that a 1 percent increase in the area of land suitable for growing maize is associated with a 0.026 percent increase in population density on average. The estimates reported in columns (2)-(3) show that this effect is robust to allowing for differential trends in European contact and climate across countries; controlling for these trends has little effect on our estimates. Our preferred estimate, reported in column (3), indicates that a 1 percent increase in maize suitable land increased population density by 0.025 percent. Moreover, this effect is statistically significant at conventional levels regardless of whether we cluster standard errors by country, or use Conley (1999) standard errors to correct for spatial correlation. Indeed, our choice of standard errors has little effect on inference; the estimated standard errors from both approaches are nearly identical.

Panel B of Table III reports estimates of the effect of the introduction of maize on Trans-Atlantic slave exports. These estimates suggest that maize led to a significant increase in slavery; for example, the estimate reported in column (1) indicates that conditional on country and year fixed effects, a 1 percent increase in maize suitable land area is associated with a 0.018 percent increase in slave exports on average. This estimate is quite robust; after controlling for differential trends in European contact and climate, our preferred estimate, reported in column (3), indicates that a 1 percent increase in maize suitable land is associated with a 0.027 percent increase in Trans-Atlantic slave exports on average. As with the population estimates presented in Panel A, these effects are significant regardless of whether standard errors are clustered by country or corrected for spatial correlation using the approach of Conley (1999). As such, we only report standard errors clustered by country in subsequent tables.

While the estimates reported in Table III provide qualitative support for the Crosby-Curtin Hypothesis, it remains to be seen if the introduction of maize led to economically meaningful changes in outcomes. To this end, we perform two simple calculations to get a better sense of the magnitude of each effect.

First, we determine how maize affected population growth in the average country in

Africa. We obtain the population growth attributable to maize by multiplying the benchmark estimate reported in column (3) of Panel A (0.025) by the mean level of our measure of maize suitable land (8.90). This calculation indicates that maize increased the population density of the average country by 22 percent (0.025×8.90=0.22). Based on our data, in 1600 the average country had a population density of 3.45 people/km^2, and in 1900 the average country had a population density of 6.74 people/km^2. These numbers suggest that the population of the average country grew by 95% ((6.74/3.45)-1=0.95). Hence, close to 23% (0.22/0.95=0.23) of the population growth in the average country can be attributed to the effects of maize. This suggests that maize had a larger effect on population growth in Africa than in other parts of the world, although in the same order of magnitude; Chen and Kung (2016) find that maize increased population growth in China by 19% following its introduction.[32]

Second, we determine how maize affected slave exports from the average country at the height of the slave trades. As with our calculation for population growth, we obtain the increase in slave exports attributable to maize by multiplying our benchmark estimate from column (3) of Panel B (0.027) by the mean level of our measure of maize suitable land (8.90). This indicates that slave exports from the average country increased by close to 24 percent (0.027×8.9=0.24) due to maize. Based on our data, the average country exported 0.09 people/km^2 in the 1600s, and 0.39 people/km^2 in the 1700s. This means that slave exports from the average country grew by approximately 333 percent ((0.39/0.09)-1=3.33) at the height of the slave trades. Accordingly, over 7 percent (0.24/3.33=0.07) of the total increase in slave exports at this time can be attributed to the effects of maize.

Altogether, the estimates reported in Table III are broadly supportive of the Crosby-Curtin Hypothesis. It is worth noting that, despite the large differences in maize's total effect on population growth and slave exports implied by our calculations, our coefficient estimates indicate that maize had very similar effects on population density and slave exports.[33] This

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[32] Our estimates also suggest that maize had similar effects on population growth as the white potato; as shown by Nunn and Qian (2011), the introduction of the white potato explains 26% of the Old World population growth over the period 1700-1900.

[33] Indeed, the estimates reported in column (3) of both panels of the table are not statistically different

means that maize had little to no effect on the intensity of slavery (the number of slaves exported as a fraction of the population), suggesting that the crop effectively functioned as a supply-side shock that simply amplified the magnitude of the slave trade.

4.2 The Crosby-Curtin Hypothesis: Robustness

The estimates presented above suggest that the introduction of maize significantly increased population levels and Trans-Atlantic slave exports in affected African countries. We now turn to examine the robustness of these findings. We begin by examining robustness of our results to our definition of treatment; particularly the timing of maize's introduction and our measure of agricultural productivity. We then turn to examine whether our baseline results are capturing the effects of other factors.[34]

4.2.1 Measurement: Timing

We start by examining the timing of maize's arrival in Africa. In the analysis presented above, we have assumed that the cultivation of maize throughout Africa begins in 1700. While we choose this introduction date to fit with the historical evidence presented above, it is possible that this choice of cutoff is incorrect given the paucity of hard evidence documenting the spread of maize throughout much of the African continent. As such, we adopt two strategies used by Nunn and Qian (2011) to examine whether this cutoff is consistent with the data.

First, we examine how the relationship between maize suitable land area and population density and the relationship between maize suitable land area and Trans-Atlantic slave exports evolved over time. To do so, we estimate a fully flexible version of equation (9) that

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from each other.

[34] In the appendix, we present additional results documenting the robustness of our baseline results to using the transformation $\ln(1 + x)$ to address skewness in the distributions of slave exports and maize suitable land area, and accounting for dynamics in slave exports and population density.

takes the form:

$$y_{it} = \sum_{t=1100}^{1900} \beta_t [Maize_i \times \lambda_t] + X_{it}' \Gamma + \eta_i + \lambda_t + \mu_{it} \tag{10}$$

where, as in equation (9), y_{it} is either the natural log of population density (in persons/km^2) or the inverse hyperbolic sine of slave exports (in persons exported/km^2) in country i at time t, and all other variables are defined as before. The resulting estimated vectors of βs reflect the correlation between the suitability for maize and either population density or slave exports in each year relative to the baseline year of 1000. This allows us to examine the timing of maize's introduction because the estimated coefficients reflect changes in the relationship between population density or slave exports and maize suitability over time. If maize was adopted in 1700 as we have assumed, then for both sets of estimates, our estimated coefficients should be positive and significant from 1700 onward, as this would indicate that both population density and slave exports both increased in maize suitable areas during the period in which the crop was present in Africa.

The estimates from equation (10) also allow us to examine the possibility that our baseline estimates are capturing the effects of pre-existing differences in trends across countries. Given that the estimated coefficients reflect differences in the correlation between treatment status and either population density or slave exports in each year, if there are no pre-existing differences in trends, the estimated coefficients should not be statistically different from zero prior to the introduction of maize.

The results of this exercise are displayed in the two panels of Figure 2. Figure 2a on the left displays estimates of β that reflect the correlation between maize suitable land area and population density over time. Similarly, Figure 2b on the right displays estimates of β that capture the correlation between maize suitable land area and slave exports over time. In both cases, the reported estimates are from specifications analogous to our preferred specifications in Table III.[35] As such, they both include the controls for differential trends in European

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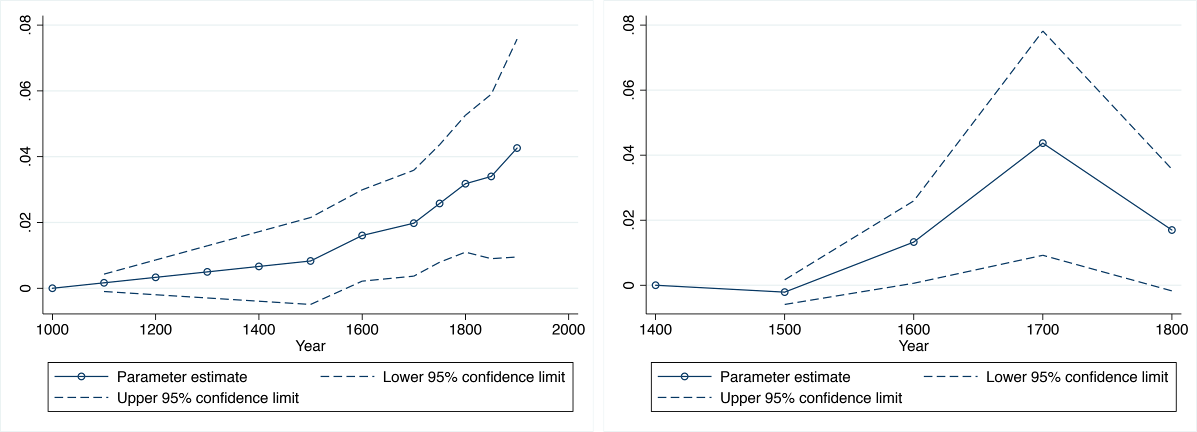
[35] The underlying estimates, and the results of additional specifications corresponding to the other speci-



(a) Population Density

(b) Trans-Atlantic Slave Exports

Figure 2: The Relationship Between Maize Suitability and both Population Density and Slave Exports Over Time

contact, and climate described above. In each figure, the parameter estimates are given by the hollow circles connected by the solid line, while the corresponding 95% confidence interval is depicted by the two dashed lines.

Together, the estimates presented in Figure 2 provide two key insights. First and foremost, as shown in the figures, the correlations between maize suitable land area and population density, and between maize suitable land area and slave exports are both positive and significant after 1700, which is consistent with our choice of post-introduction date. However, the figures also suggest that our choice of 1700 as a cutoff date is potentially too conservative; maize appears to have had modest effects on both population density and slave-exports in the 1600s. This is not unexpected, as we discussed above in section 2, the available evidence suggests maize entered some countries in the 1600s. Despite this, adopting 1600 as the cutoff for post-introduction period has little effect on our estimates.[36] As such, we maintain our assumption of a post-1700 introduction throughout our analysis. Second, our estimates for both population density and slave exports are not statistically different from zero in any year prior to 1600. This is an important validation of our research design as it indicates that, conditional on controlling for differential trends in European contact and climate, our base-

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fications reported in Table III, are reported in Tables B1 and B2 of the appendix.

[36] These estimates are reported in Table B3 of the appendix.

line estimates presented above are not simply capturing the effects of pre-existing differences in trends across countries.[37]

Our second strategy for examining the timing of maize's arrival exploits the fact our population data spans a long time period with several observations in the pre-introduction period. This allows us to conduct a series of placebo tests, each examining the effects of maize on population density during a four hundred year window from our period of study. In each test we estimate our baseline equation given by (9), but artificially designate the last two hundred years of the subsample as the post introduction period. As such, in each test, the estimated coefficient for the inverse hyperbolic sine of maize suitable area interacted with the artificial post-introduction indicator reflects the average increase in population density in maize suitable countries relative to maize unsuitable countries before and after the artificial introduction date. This coefficient should be close to zero prior to the introduction of maize in Africa if maize is the only factor driving differential population growth in maize suitable countries.

The results of these placebo tests are reported in Table IV. Each column of the Table corresponds to a test for a different four hundred year sample period. Columns (1)-(3) report estimates from regressions for the periods 1000-1300, 1100-1400, and 1200-1500, respectively. In each case, the estimated effect of [Maize × Post] is small and statistically insignificant. As these periods predate the introduction of maize into mainland Africa, this suggests that there is no differential population growth in maize suitable countries before the crop is introduced.

The remaining three columns report estimates from periods that at least partially overlap the introduction and adoption of maize in Africa. Column (4) reports estimates for 1300-1600, a period which coincides with the first reports of maize adoption in Africa. This means

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[37] The estimates reported in Tables B1 and B2 of the appendix further highlight the importance of accounting for differential trends in both European contact and climate. As we discuss further in the appendix, when we only condition on country and time fixed effects, the estimates from equation (10) reveal an increasing correlation between population density and maize suitability even prior to the adoption of maize. This would suggest that our estimates are capturing the effects of a pre-existing trend, however when we also allow for differential trends in European contact, this correlation disappears, suggesting that the trend is due to differences in contact with other parts of the world before the introduction of maize.

Table IV: The Effects of Maize Suitable Land Area on Population: Alternative Cut-offs

	1000-1300: Post=1200-1300 (1)	1100-1400: Post=1300-1400 (2)	1200-1500: Post=1400-1500 (3)	1300-1600: Post=1500-1600 (4)	1400-1750: Post=1600-1750 (5)	1500-1900: Post=1700-1900 (6)
Maize × Post	0.003	0.003	0.003	0.006^a	0.010^a	0.014^a
	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)
Observations	196	196	196	196	196	245
Adjusted R^2	0.95	0.95	0.95	0.95	0.93	0.85

Notes: Table reports estimated coefficients from OLS regressions of the natural log of population density (in persons/km^2) on the inverse hyperbolic sine of maize suitable land area interacted with a post introduction indicator and other controls. The post-introduction indicator varies across columns; for each specification the post introduction takes the value 1 for the last 200 years of the period defined in the column heading and is 0 otherwise. All regressions include year fixed effects and country fixed effects, and controls for differences in European contact and climate. These control variables are interacted with a full set of year fixed effects. Standard errors clustered by country are reported in parentheses. ^{a}, ^{b}, and ^{c} denote significance at the 1 percent, 5 percent and 10 percent levels, respectively.

the estimated coefficient should begin to capture the effects of maize, but the estimated effect should be small reflecting the limited usage of maize as a staple crop at this time. Our results are consistent with this; the estimated coefficient on [Maize × Post] is statistically significant, but small in magnitude. In the remaining two columns, the sample periods (1400-1750 and 1500-1900 respectively) include our chosen cutoff date of 1700 for the post-introduction period. These coefficient estimates are statistically significant and much larger in magnitude than in the first four columns, reflecting the prevalence of maize during this period. These results provide further evidence that our choice of cutoff-date is reasonable.

4.2.2 Measurement: Maize Suitability

Next we examine if our baseline results are driven by our measure of maize suitability. In the specifications presented above, we follow the approach taken elsewhere in the literature (e.g. Nunn and Qian (2011)), and measure the suitability of land for growing maize using the index developed by FAO-GAEZ. In constructing this measure we adopt conditions that are meant to resemble the agricultural conditions present in Africa during our period of study. As such, we have assumed that land is suitable for growing maize if it is classified as having a very high, high, good or medium value on the suitability index in conditions with low input intensity and rain-fed irrigation. We probe the robustness of this assumption in two ways. First, we adopt different points on the maize suitability index as cutoffs for determining whether land is suitable for growing maize when constructing our measures to check if our definition of suitability is driving our results. Second, we maintain our baseline cutoff, but assume that cultivation requires medium input intensity to check if our results are driven by our assumption of low input agriculture.[38]

These results are presented in Table V. The dependent variable in Panel A is the natural log of population density. In Panel B, the dependent variable is the inverse-hyperbolic sine of Trans-Atlantic slave exports. For ease of comparison, column (1) reports the corresponding

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[38] As noted by the GAEZ (e.g. IIASA/FAO (2012)), low levels of input use are meant to reflect subsistence farming practices, while medium levels are meant to reflect a farming system that is partly market oriented.

Table V: Alternative Measures: Maize Suitable Land

	(1)	(2)	(3)	(4)
		Panel A: Population Density		
Maize × Post	0.025^a	0.025^c	0.022^a	0.024^a
	(0.008)	(0.014)	(0.007)	(0.008)
Observations	588	588	588	588
Adjusted R^2	0.92	0.92	0.92	0.92
		Panel B: Trans-Atlantic Slave Exports		
Maize × Post	0.027^b	0.012	0.024^a	0.027^b
	(0.010)	(0.010)	(0.009)	(0.011)
Observations	245	245	245	245
Adjusted R^2	0.41	0.37	0.41	0.40

Notes: Table reports estimates of the effect of maize on population density, and Trans-Atlantic slave exports. In Panel A, the dependent variable is the natural log of population density (in persons/km^2). In Panel B, the dependent variable is the inverse-hyperbolic sine of Trans-Atlantic slave exports (in persons/km^2). In column (1) of each panel, maize suitable land area is defined as the area that has a least medium suitability under low input intensity. In column (2), maize suitable land area is defined as the area that has a least moderate suitability under low input intensity. In column (3), maize suitable land area is defined as the area that has a least good suitability under low input intensity. Finally, in column (4), maize suitable land area is defined as the area that has a least medium suitability under medium input intensity. In all specifications, the post-introduction indicator period takes the value 1 for the post 1700 period. All regressions include year fixed effects, country fixed effects, and controls for differential trends in European contact, and climate. Each control variable is interacted with a full set of year fixed effects. Standard errors clustered by country are reported in parentheses. ^{a}, ^{b}, and ^{c} denote significance at the 1, 5 and 10 percent levels, respectively.

baseline estimate from Table III. Columns (2) and (3) report estimates with different cutoffs for the maize suitability index. In column (2), maize suitable is defined as having at least moderate suitability under low input intensity, a more expansive definition of treatment. Similarly, in column (3), maize suitable is defined as having at least good suitability under low input intensity, a more stringent definition of treatment. Finally, in column (4), maize suitable land area is defined as the area that has a least medium suitability under medium input intensity. In all cases, standard errors clustered by country are reported in parentheses.

As the estimates reported in Table V show, adopting different measures of maize suitable land area has little effect on the majority of our estimates. The one exception to this is when we adopt a lax definition of maize suitability and classify moderately suitable parcels of land as capable of growing maize. In this case, reported in column (2) of panel B, panels, the estimated effect of maize on slave exports drops in magnitude and becomes statistically

Table VI: Alternative Measures: Caloric Suitability

	(1)	(2)	(3)
		Panel A: Population Density	
Maize × Post	0.086^a	0.060^a	0.077^a
	(0.017)	(0.021)	(0.023)
European Contact		X	X
Climate			X
Observations	588	588	588
Adjusted R^2	0.86	0.92	0.92
		Panel B: Trans-Atlantic Slave Exports	
Maize × Post	0.057^a	0.055^b	0.066^b
	(0.016)	(0.025)	(0.028)
European Contact		X	X
Climate			X
Observations	245	245	245
Adjusted R^2	0.20	0.40	0.40

Notes: Table reports estimates of the effect of maize on population density and Trans-Atlantic slave exports. In Panel A, the dependent variable is the natural log of population density (in persons/km^2). In Panel B, the dependent variable is the inverse-hyperbolic sine of Trans-Atlantic slave exports (in persons/km^2). In all specifications, maize suitability is defined as the total number of calories produced by maize and the post-introduction indicator period takes the value 1 for the post 1700 period. All regressions include year fixed effects, country fixed effects, and controls for differential trends in European contact and climate. Each control variable is interacted with a full set of year fixed effects. Standard errors clustered by country are reported in parentheses. ^{a}, ^{b}, and ^{c} denote significance at the 1, 5 and 10 percent levels, respectively.

insignificant. This is likely due to the fact that allowing moderately suitable parcels of land to be classified as capable of growing maize leads to an elimination of one of our control groups; under this definition of suitability all slave-exporting countries are “treated” by maize, making it more difficult to identify the effects of the crop.

While the results presented in Table V indicate that our baseline results are not being driven by our definition of maize suitable land area, it is possible that our measure does not adequately capture changes in agricultural productivity. As such, we also examine the robustness of our results to adopting the caloric suitability data created by Galor and Özak (2016). Unlike the FAO-GAEZ data underlying our measure of land suitability, the Galor and Özak caloric suitability data explicitly accounts for the nutritional value of crops. We use this data to determine the caloric output from maize production in each country and then re-estimate equation (9) using caloric output as our measure of agricultural suitability.[39]

These results are presented in Table VI. As the estimates show, even when we adopt a different measure of agricultural productivity, maize still has significant effects on both population density and slave exports. Moreover, while the estimated coefficients are more than twice as large as the baseline estimates reported in Table III, the fact that the mean level of our measure of maize suitability is now almost half as large (4.48), means that the implied changes in population growth and slave exports in the average country are similar to our baseline results (close to 36 percent and 9 percent, respectively).

4.2.3 Alternative Explanations

Finally, we turn to examine whether our empirical estimates are capturing the effects of other factors. To this end, we perform two additional robustness checks. First, we examine whether our estimates are capturing the effects of other New World crops that were introduced into Africa during our period of study. Second, we examine whether our estimates are robust to controlling for the effects of other factors that have been identified as important determinants of either population density or slave exports in Africa.

To check if our estimates are capturing the effects of the introduction of other New World crops, we supplement our main estimating equation with measures analogous to $[Maize_i \times Post_t]$ for cassava, the sweet potato and the white potato. As with $[Maize_i \times Post_t]$, we construct these variables by interacting the inverse-hyperbolic sine of the land area suitable for the growth of each crop with a post-introduction indicator. However, unlike the case of maize where the indicator is equal to one for the period from 1700 onward, for the three other crops, the indicator is equal to one for the period from 1800 onward. This ensures that we are consistent with the available evidence as to the timing of their introductions; as we discussed above in Section 3.1, cassava, sweet potatoes and white potatoes were not adopted as staple crops in Africa until the 19th century.

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[39] We again utilize the inverse-hyperbolic sine transformation to address the underlying skewness in the distribution of total caloric output.

Table VII: The Effects of Other New World Crops

	Panel A: Population Levels				
	(1)	(2)	(3)	(4)	(5)
Maize × Post	0.025^a	0.021^a	0.016^a	0.025^a	0.019^a
	(0.008)	(0.006)	(0.005)	(0.007)	(0.005)
Cassava × Post		0.009			0.012
		(0.008)			(0.009)
White Potato × Post			0.023^a		0.024^a
			(0.008)		(0.009)
Sweet Potato × Post				0.000	-0.024
				(0.013)	(0.016)
Observations	588	588	588	588	588
Adjusted R^2	0.92	0.92	0.93	0.92	0.93

	Panel B: Trans-Atlantic Slave Exports				
	(1)	(2)	(3)	(4)	(5)
Maize × Post	0.027^b	0.024^b	0.026^b	0.027^b	0.027^b
	(0.010)	(0.012)	(0.011)	(0.013)	(0.013)
Cassava × Post		0.006			0.017^c
		(0.008)			(0.010)
White Potato × Post			0.001		-0.001
			(0.008)		(0.008)
Sweet Potato × Post				-0.003	-0.021^c
				(0.011)	(0.011)
Observations	245	245	245	245	245
Adjusted R^2	0.41	0.41	0.41	0.41	0.41

Notes: Table reports estimates of the effect of various New World crops on population density, and Trans-Atlantic slave exports. In Panel A, the dependent variable is the natural log of population density (in persons/km^2). In Panel B, the dependent variable is the inverse-hyperbolic sine of Trans-Atlantic slave exports (in persons/km^2). For maize, the post-introduction indicator period takes the value 1 for the period from 1700 onward and is 0 otherwise, while for cassava, white potato, and sweet potato, the post-introduction indicator takes the value 1 for the period from 1800 onward and is 0 otherwise. All regressions include year fixed effects, country fixed effects, and controls for differential trends in European contact and climate. Standard errors clustered by country are reported in parentheses. ^{a}, ^{b}, and ^{c} denote significance at the 1 percent, 5 percent and 10 percent levels, respectively.

These results are presented in the two panels of Table VII. For convenience, column (1) of each panel reports the baseline estimates previously reported in Table III. Column (2)-(4) add measures to capture the introduction of cassava, white potatoes, and sweet potatoes, respectively. Finally, column (5) controls for the introduction of all four New World crops simultaneously. Each specification includes country and year fixed effects as well as controls for differential trends in European contact and climate. Standard errors clustered by country are reported in parentheses.

The estimates reported in Table VII suggest that our baseline results are not simply capturing the effects of the introduction of other New World crops. For the most part, the estimated effects of maize change little once we control for the other crops. The key exception to this is the effect of the white potato on population density; as the estimates reported in columns (3) and (5) of panel A show, separately controlling for the effects of the white potato leads to modest decreases in the estimated effect of maize. This suggests that our baseline results for population density are, in part, capturing the effects of the introduction of the white potato at the end of the 1800s. This timing explains the absence of a corresponding change in slave exports; by the time of the potato's introduction into Africa, the Trans-Atlantic slave trade had ended.

As a final robustness check, we examine if our results are capturing the effects of other factors that have been identified as important determinants of either population density or slave exports. These results are reported in Table VIII. In panel A, the dependent variable is the natural log of population density (in persons/km^2). In panel B, the dependent variable is the inverse hyperbolic sine of slave exports (in persons/km^2). For convenience, column (1) in each panel reports the baseline estimates previously reported in column (3) of the corresponding panel of Table III. Columns (2)-(6) in each report estimates from specifications that include controls for an alternative explanation for the effects of maize. The final column controls for all of these determinants simultaneously. All errors are clustered by country.

We begin by examining the possibility that our results are not capturing the effects of maize, but rather the effects of preexisting population trends created by cross-country differences in the suitability of land for growing sorghum and pearl millet, the two primary staple crops in Africa before the introduction of maize. As such, in the specification reported in column (2) we include the inverse hyperbolic sine of both sorghum suitable and pearl millet suitable land area, both interacted with time fixed effects. As the estimate reported in column

(2) of Panel A shows, controlling for these crops leads to an increase in the estimated effect of maize on population density, suggesting that our baseline estimate may underestimate the true effect of maize. The same is not true for slave exports, however; the estimate reported in column (2) of Panel B shows that controlling for these crops has little effect on our baseline result.

In columns (3) and (4), we investigate whether our estimates are capturing the effects of differential trends in factors that would affect the demand for and supply of slaves. The supply of slave exports depended, in part, on the ruggedness of terrain; ruggedness reduced slavery by making raids more difficult (Nunn and Puga, 2012). Hence, in column (3), we include the natural log of average ruggedness interacted with time-period fixed effects to account for differential trends in the ease of raiding across countries. Slaves were often exported to the nearest source of demand, meaning that our estimates could be capturing the effects of differential demand shocks across destination markets. To account for this, in column (4), we include the log of distance to the nearest Atlantic market interacted with time-period fixed effects.[40] As the estimates reported in column (3) and (4) show, controlling for these factors has little effect on our results.

Next we investigate whether our estimates are capturing the effects of differences in disease environment. As indicated by Acemoglu et al. (2001), malaria was a key determinant of European contact in much of the world; given that maize was introduced by Europeans, it is possible that our results are capturing differential trends in European contact due to differences in the prevalence of malaria. Furthermore, recent research by Alsan (2015) has shown that the TseTse fly inhibited agriculture and affected both population growth and slavery in much of Africa. We control for these factors by including the malaria ecology index of Kiszewski et al. (2004) and the TseTse Suitability Index of Alsan (2015), both interacted with time period fixed effects (columns (5) and (6) respectively). Controlling for these factors does not significantly change our baseline results. Allowing for differential trends based on

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[40] The data on distances comes from Nunn and Puga (2012).

Table VIII: The Effects of Maize: Alternative Explanations

	Panel A: Population Density						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Maize × Post	0.025^{a}	0.040^{a}	0.022^{b}	0.024^{a}	0.020^{a}	0.026^{a}	0.029^{b}
	(0.008)	(0.014)	(0.009)	(0.008)	(0.006)	(0.008)	(0.013)
Baseline Controls	X	X	X	X	X	X	X
Old World Crops		X					X
Ruggedness			X				X
Atlantic Market Distance				X			X
TseTse Suit. Index					X		X
Malaria Index						X	X
Observations	588	588	588	588	588	588	588
Adjusted R^2	0.92	0.93	0.93	0.92	0.93	0.92	0.94

	Panel B: Trans-Atlantic Slave Exports						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Maize × Post	0.027^{b}	0.029^{c}	0.025^{b}	0.028^{a}	0.026^{b}	0.026^{b}	0.026^{c}
	(0.010)	(0.015)	(0.010)	(0.010)	(0.010)	(0.010)	(0.015)
Baseline Controls	X	X	X	X	X	X	X
Old Staple Crops		X					X
Ruggedness			X				X
Atlantic Market Distance				X			X
TseTse Suit. Index					X		X
Malaria Index						X	X
Observations	245	245	245	245	245	245	245
Adjusted R^2	0.41	0.40	0.40	0.42	0.40	0.40	0.40

Notes: Table reports estimates of the effect of maize on population density and Trans-Atlantic slave exports. Panel A reports estimates from OLS regressions of the natural log of population density (in persons/km^2) on the inverse hyperbolic sine of maize suitable land area interacted with a post introduction indicator and other controls. Panel B reports estimates from OLS regressions of the inverse hyperbolic sine of slave exports (in persons/km^2) on the inverse hyperbolic sine of maize suitable land area interacted with a post introduction indicator and other controls. In all specifications, the post-introduction indicator period takes the value 1 for the period 1700-1900 and is 0 otherwise. All regressions include year fixed effects and country fixed effects, and baseline controls for differential trends in European contact and climate. All control variables are interacted with a full set of year fixed effects. Standard errors clustered by country are reported in parentheses. ^{a}, ^{b}, and ^{c} denote significance at the 1 percent, 5 percent and 10 percent levels, respectively.

TseTse suitability modestly decreases the estimated effect of maize on population density, but the effect is still significant and is not statistically different than our baseline estimate.

Finally, in column (8) we control for all of these factors simultaneously. Doing so changes does not significantly change the estimated effects of maize on either population density or

Trans-Atlantic slave exports, further suggesting that our baseline estimates are not driven by other important factors that shaped Africa's history.

4.3 Maize, Economic Growth, and Conflict

Altogether, the estimates presented above suggest that the introduction of maize affected both population density and slave exports in a manner consistent with the Crosby-Curtin Hypothesis. What remains to be seen is if maize had effects beyond those envisioned by either Curtin or Crosby. Recent research has shown that the introduction of the white potato and the sweet potato to the Old World during the Columbian Exchange increased economic growth (Nunn and Qian, 2011) and reduced conflict (Jia, 2014; Iyigun et al., 2015). As such, we investigate if maize affected either chanel; if maize had similar effects in Africa, it would suggest that the negative effects of slavery (Nunn, 2008; Nunn and Wantchekon, 2011) may have been at least partially offset by the introduction of maize.

We identify the effects of the introduction of maize on both economic growth and conflict by again exploiting the research design that we outlined above in Section 3. Hence, we again employ equation (9) to estimate the effects of maize, but for specifications using measures of either economic growth or conflict as the dependent variable.

Estimating the effect of maize on economic growth is complicated by the fact that reliable GDP estimates are not available for Africa throughout our period of study. To deal with this issue, we follow the approach taken by both Nunn and Qian (2011) and Chen and Kung (2016) and use urbanization rates as a proxy for economic growth.[41] Our urbanization data comes from Nunn and Qian (2011), and measures the fraction of total population located in cities with more the 40,000 inhabitants.

Our data on conflict comes from Brecke (1999), who constructed a database of major historical conflicts (defined as at least 32 battle deaths) over the period 1400-1900.[42] We

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[41] As shown by Acemoglu et al. (2002), there is a strong correlation between urbanization and income per capita.

[42] Fenske and Kala (2017) employ this data to study how the suppression of the slave trade in 1807 affected

Table IX: The Effects of Maize on Economic Growth and Conflict

	(1)	(2)	(3)	(4)	(5)	(6)
Maize × Post	-0.001	-0.002	0.003	0.019	0.033	0.091
	(0.001)	(0.002)	(0.012)	(0.033)	(0.030)	(0.067)
Baseline Controls	X	X	X	X	X	X
Alt. Explanations		X		X		X
Observations	588	588	245	245	245	245
Adjusted R^2	0.09	0.07	0.26	0.27	0.36	0.43

Notes: Table reports estimates of the effect of maize on economic growth and conflict. In columns (1) and (2) the dependent variable is the urbanization rate. In columns (3) and (4), the dependent variable is an indicator equal to one if any conflicts occurred during century t. In columns (5) and (6) the dependent variable is the inverse hyperbolic sine of the number of conflicts that occured during century t. In all specifications, the post-introduction indicator period takes the value 1 for the period 1700-1900 and is 0 otherwise. All regressions include year fixed effects and country fixed effects, and baseline controls for differential trends in European contact and climate. All control variables are interacted with a full set of year fixed effects. Standard errors clustered by country are reported in parentheses. ^{a}, ^{b}, and ^{c} denote significance at the 1 percent, 5 percent and 10 percent levels, respectively.

use this data to construct two measures of conflict in each country by century. First, we construct an indicator variable equal to one if any conflicts occurred in country j during century t. This allows us to examine if the introduction of maize had an effect on the likelihood of conflict. Second, we determine the total number of conflicts in country j that occurred during century t. This allows us to examine if maize had any effect on the number of conflicts that occurred in Africa.

Our estimates of the effects of maize on our measures of both economic growth and conflict are reported in Table IX. In columns (1) and (2), we report the effects of maize on urbanization. In both cases, the dependent variable is the urbanization rate. The remaining columns of the table report the effects of maize on conflict. In columns (3) and (4), the dependent variable is the conflict indicator, meaning the estimate reflects the effects of maize on the likelihood any major conflict occurred. In columns (5) and (6), the dependent variable is the inverse hyperbolic sine of the number of conflicts. In this case the each estimate captures the effect of maize on the number of major conflicts. In the table, the specifications reported in odd columns have controls corresponding to the baseline estimates reported in

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conflict in Africa.

Table III, while the specifications reported in even columns also include controls for the additional explanations examined in Table VIII. In all cases, standard errors clustered by country are reported in parentheses.

Altogether, the results presented in Table IX indicate that the introduction of maize did not significantly affect either economic growth or conflict. Our estimates indicate that maize had no meaningful effect on urbanization rates, and little-to-no impact on either the likelihood or number of conflicts.

Our finding that maize did not affect urbanization suggests that maize failed to stimulate economic growth in Africa. This result stands in sharp contrast to those presented by Nunn and Qian (2011), who suggest that the introduction of the potato stimulated economic growth in much of the Old World. Instead, our results mirror those of Chen and Kung (2016), who find that maize failed to increase economic growth in China. As such, our findings provide further evidence that agricultural productivity shocks alone are not sufficient to generate sustained economic growth.

5 Conclusion

In this paper, we examine how the introduction of maize, a New World crop, affected population levels and Trans-Atlantic slave exports in precolonial Africa. Our analysis is motivated by a hypothesis implicit in observations made by the historians Alfred Crosby (1972) and Philip Curtin (1969). This hypothesis, which we term the *Crosby-Curtin Hypothesis*, predicts that the introduction of New World Crops into Africa during the Columbian Exchange increased population levels and Trans-Atlantic slave exports in affected countries.

Our reading of a combination of modern evidence on the productivity of various crops and historical evidence on the spread of New World crops to Africa suggests that maize is the likely source of the effects envisioned by Crosby and Curtin. As such, we exploit cross-country variation in the suitability of maize as a crop and temporal variation arising from the timing of maize's introduction in Africa to test the two parts of the hypothesis. We find robust support for these predictions; we find that the arrival of maize significantly increased population density and Trans-Atlantic slave exports in affected countries. Given that the linkage between agricultural productivity changes, population and slavery are not made explicit by either Crosby or Curtin, we show that these effects can be rationalized with the aid of a simple Malthusian growth model.

We also explore whether the introduction of maize had effects aside from those envisioned by Crosby and Curtin. To this end, we examine whether maize had effects on either economic growth or conflict, and find little evidence that suggests maize affected either channel. As such, our results suggest that the introduction of maize did not allow Africa to escape the Malthusian trap; rather, it appears that the introduction of maize simply contributed to an increase in the magnitude of the slave trades.

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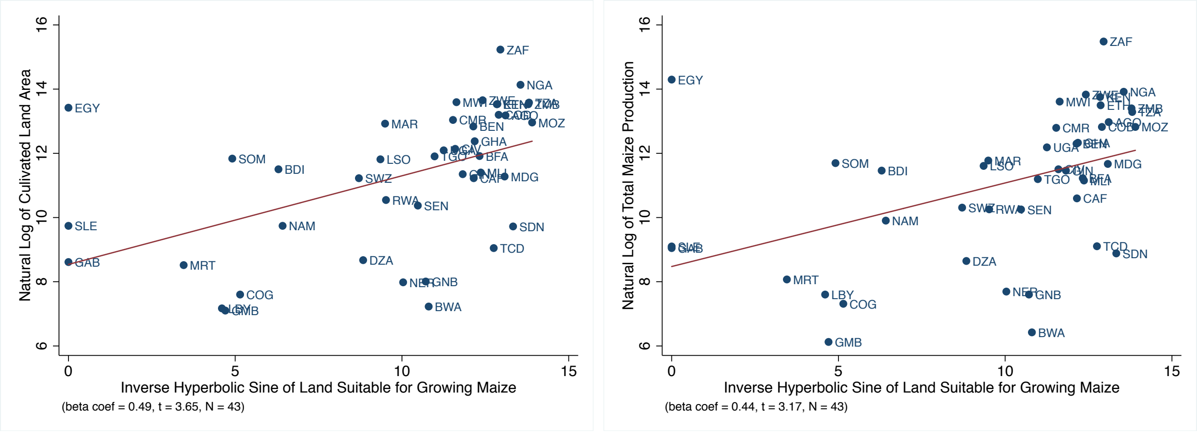
A Appendix: Data Details and Summary Statistics

A.1 The Correlation Between Maize Suitable Land Area and Modern Maize Cultivation



(a) Maize Cultivation

(b) Maize Production

Figure A1: The Relationship Between Maize Suitability and both Maize Cultivation and Maize Production

One potential concern with our use of the FAO-GAEZ data is whether a modern measure of maize suitability captures historical conditions. To address this concern we collected data from FAO on both the area used for cultivating maize, and total maize production by country in 1961 (the earliest year available). FAO has information on maize cultivation and production for 43 African countries in our sample at this time. As Figure A1 shows, there is a strong positive correlation between our measure of maize suitability and both variables. The standardized beta coefficient from a bivariate regression of the inverse hyperbolic sine of maize suitable land area on the natural log of the area of land used to cultivate maize is 0.49 and is statistically significant at the 1 percent level. Similarly, the standardized beta coefficient from a bivariate regression of the inverse hyperbolic sine of maize suitable land area on the natural log of the total quantity of maize produced is 0.44 and is statistically significant at the 1 percent level. These results suggest that there is a strong positive correlation between maize suitability and historical maize cultivation.

A.2 Descriptive Statistics

Table A1: Summary Statistics

Variable	Obs.	Mean	Std. Dev.	Median
A: Dependent Variables				
Population Density (Persons/km^2)	588	3.494	5.674	1.800
Slave Exports (Persons/km^2)	245	0.1385	0.4957	0.0000
Urbanization Rate	588	0.007	0.025	0.000
Conflict Indicator	245	0.465	0.500	0.000
Number of Conflicts	245	2.747	5.194	0.000
Panel B: Crop Suitability Measures				
Maize Suitable Area	588	96,258	140,412	24,556
Sorghum Suitable Area	588	123,791	171,791	46,722
Pearl Millet Suitable Area	588	98,680	140,334	35,882
Cassava Suitable Area	588	112,317	287,332	11,857
White Potato Suitable Area	588	9,567	21,278	0
Sweet Potato Suitable Area	588	106,188	217,098	16,558
Panel C: Other Determinants of Population Levels and Slave Exports				
Elevation (Meters)	588	631.16	451.38	485.63
Distance to Equator (Degrees)	588	13.78	9.06	12.30
Terrain Ruggedness Index	588	0.91	1.09	0.51
Distance to Atlantic Slave Market (1000 km)	588	7.37	3.31	5.69
Tse-Tse Suitability Index	588	0.00	0.99	0.11
Malaria Suitability Index	588	10.31	8.47	7.57

Notes: Table reports summary statistics for the dependent and independent variables used in our analysis. The unit of observation is country and year. For further details see the text.

As described in the main text, our dependent variables come from the data on historical population levels and urbanization rates reported by Nunn and Qian (2011), Trans-Atlantic slave exports reported by Nunn (2008) and conflict data reported by Brecke (1999).

We supplement these data with additional data from a variety of sources. We construct measures of the suitability of other New World crops (cassava, the white potato, and the sweet potato), and the two primary indigenous African crops (pearl millet and sorghum) using the FAO-GAEZ database.[43] We obtain data on elevation and distance to equator from Nunn and Qian (2011). Measures of the stability of malaria transmission in each country are taken from Kiszewski et al. (2004). We construct the Tse-Tse fly suitability index for each

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[43] We construct these measures using the same procedure used for maize described in the main text.

country using the procedure developed in Alsan (2015). Data on each country's ruggedness and distance to the closest Trans-Atlantic slave market is taken from Nunn and Puga (2012). These variables are all summarized in Table A1.

B Appendix: Additional Results

B.1 The Timing of Maize's Introduction into Africa

As noted in the main text, to examine how the relationship between maize suitable land area and population density and the relationship between maize suitable land area and Trans-Atlantic slave exports evolved over time, we estimate a fully flexible version of our baseline estimating equation. This equation is numbered (10) in the main text. The resulting coefficient estimates allow us to examine how the relationship between population density or slave exports and maize suitability have changed over time.

These coefficient estimates are presented in Tables B1 and B2. Each table reports estimates from three specifications. The specifications reported in Table B1 correspond to those reported in Panel A of Table III, while the specifications reported in Table B2 correspond to those reported in Panel B. In each table, the specification reported in column (1) only includes country and time-period fixed effects. Column (2) adds controls for differences in the ease of European contact interacted with time period fixed effects, while column (3) also includes controls for differences in climate interacted with time-period fixed effects. The estimates reported in column (3) of each table were used to construct Figures 2a and 2b.

The estimates reported in Tables B1 and B2 further highlight the importance of accounting for differential trends in both European contact and climate. As can be seen from the estimates reported in column (1) of Table B1, when we only condition on country and time fixed effects, there appears to be an increasing correlation between population density and maize suitability even prior to the adoption of maize. This would suggest that our estimates are capturing the effects of a pre-existing trend, however as shown in column (2), when we also allow for differential trends in European contact, this correlation disappears, suggesting that the correlation between population density and maize suitability prior to the adoption of maize is due to differences in contact with other parts of the world before the introduction of maize.

Table B1: The Relationship Between Maize Suitable Land Area and Population Density Over Time

	(1)	(2)	(3)
Maize×1100	0.006^b	0.001	0.002
	(0.002)	(0.001)	(0.001)
Maize×1200	0.011^b	0.003	0.003
	(0.004)	(0.003)	(0.003)
Maize×1300	0.017^b	0.004	0.005
	(0.007)	(0.004)	(0.004)
Maize×1400	0.022^b	0.006	0.007
	(0.009)	(0.005)	(0.005)
Maize×1500	0.028^b	0.007	0.008
	(0.011)	(0.007)	(0.007)
Maize×1600	0.026^a	0.014^b	0.016^b
	(0.010)	(0.007)	(0.007)
Maize×1700	0.038^a	0.018^b	0.020^b
	(0.014)	(0.008)	(0.008)
Maize×1750	0.041^a	0.024^b	0.026^a
	(0.014)	(0.009)	(0.009)
Maize×1800	0.045^a	0.030^a	0.032^a
	(0.015)	(0.011)	(0.010)
Maize×1850	0.044^a	0.032^b	0.034^a
	(0.014)	(0.013)	(0.012)
Maize×1900	0.042^a	0.041^b	0.043^b
	(0.013)	(0.016)	(0.016)
European Contact		X	X
Climate			X
Observations	588	588	588
Adjusted R^2	0.85	0.92	0.92

Notes: Table reports estimated coefficients from OLS regressions of the natural log of population density (in persons/km^2) on the inverse hyperbolic sine of maize suitable land area interacted with year fixed effects and other controls. All other control variables are interacted with a full set of year fixed effects. All regressions include year fixed effects and country fixed effects. Standard errors clustered by country are reported in parentheses. ^{a}, ^{b}, and ^{c} denote significance at the 1 percent, 5 percent and 10 percent levels, respectively.

Table B2: The Relationship Between Maize Suitable Land Area and Slave Exports Over Time

	(1)	(2)	(3)
Maize×1500	0.001	-0.003	-0.002
	(0.002)	(0.002)	(0.002)
Maize×1600	0.008^{b}	0.011^{b}	0.013^{b}
	(0.004)	(0.005)	(0.006)
Maize×1700	0.029^{b}	0.040^{a}	0.044^{b}
	(0.011)	(0.015)	(0.017)
Maize×1800	0.013^{c}	0.015^{c}	0.017^{c}
	(0.007)	(0.009)	(0.009)
European Contact		X	X
Climate			X
Observations	245	245	245
Adjusted R^2	0.18	0.43	0.42

Notes: Table reports estimated coefficients from OLS regressions of the inverse hyperbolic sine of slave exports (in persons/km^2) on the inverse hyperbolic sine of maize suitable land area interacted with year fixed effects and other controls. All other control variables are interacted with a full set of year fixed effects. All regressions include year fixed effects and country fixed effects. Standard errors clustered by country are reported in parentheses. ^{a}, ^{b}, and ^{c} denote significance at the 1 percent, 5 percent and 10 percent levels, respectively.

B.2 Baseline Results: Alternative Post-Adoption Period

As we discussed in section 4.2.1 of the main text, our choice of 1700 as the cutoff date for the adoption of maize is potentially too conservative; our flexible estimates suggest that maize had modest effects on both population density and Trans-Atlantic slave exports in the 1600s, reflecting the fact that maize entered some countries as early as the late 1600s. As such, we re-estimated our baseline specifications using 1600 as the cutoff date for the post-introduction period. These estimates are reported in panels A and B of Table B3. The estimates are very similar to our baseline estimates reported in Table III, suggesting that our choice of cut-off date has little effect on our results.

Table B3: The Crosby-Curtin Hypothesis: Baseline Estimates with an Alternative Post-Adoption Period

	Panel A: Population Density		
	(1)	(2)	(3)
Maize × Post	0.025^a	0.023^a	0.024^a
	(0.008)	(0.007)	(0.007)
European Contact		X	X
Climate			X
Observations	588	588	588
Adjusted R^2	0.84	0.92	0.92
	Panel B: Trans-Atlantic Slave Exports		
	(1)	(2)	(3)
Maize × Post	0.016^b	0.023^a	0.026^a
	(0.007)	(0.008)	(0.009)
European Contact		X	X
Climate			X
Observations	245	245	245
Adjusted R^2	0.17	0.41	0.41

Notes: Table reports estimates of the effect of maize on population density and Trans-Atlantic slave exports. Panel A reports estimates from OLS regressions of the natural log of population density (persons/km^2) on the inverse hyperbolic sine of maize suitable land area interacted with a post introduction indicator and other controls. Panel B reports estimates from OLS regressions of the inverse hyperbolic sine of slave exports (persons exported/km^2) on the inverse hyperbolic sine of maize suitable land area interacted with a post introduction indicator and other controls. In all cases, each set of control variables is interacted with a full set of year fixed effects. In all specifications, the post-introduction indicator period takes the value 1 for the period 1600-1900 and is 0 otherwise. All regressions include year fixed effects and country fixed effects. Standard errors clustered by country are reported in round parentheses. ^{a}, ^{b}, and ^{c} denote significance at the 1 percent, 5 percent and 10 percent levels, respectively.

B.3 Baseline Results: Log Transformations

As we discussed in section 3.4 of the main text, in our main analysis we relied on inverse hyperbolic sine transformations to correct for any potential skewness in the distribution of slave exports/total area and in the distribution of maize suitable land area. In order to examine the robustness of our results to using this transformation, we re-estimated our baseline specifications using the transformation $\ln(1 + x)$ to address skewness in the distribution of slave exports/total area and in the distribution of maize suitable land area. These estimates are reported in panels A and B of Table B4. The estimates are very similar to our baseline

Table B4: The Crosby-Curtin Hypothesis: Baseline Estimates with Log Transformed Variables

	Panel A: Population Density		
	(1)	(2)	(3)
Maize × Post	0.020^a	0.026^a	0.030^a
	(0.007)	(0.007)	(0.007)
European Contact		X	X
Climate			X
Observations	588	588	588
Adjusted R^2	0.77	0.85	0.86

	Panel B: Trans-Atlantic Slave Exports		
	(1)	(2)	(3)
Maize × Post	0.015^b	0.019^b	0.021^b
	(0.006)	(0.008)	(0.008)
European Contact		X	X
Climate			X
Observations	245	245	245
Adjusted R^2	0.18	0.42	0.42

Notes: Table reports estimates of the effect of maize on population density and Trans-Atlantic slave exports. Panel A reports estimates from OLS regressions of the natural log of population density (persons/km^2) on ln(1 + maize suitable land area) interacted with a post introduction indicator and other controls. Panel B reports estimates from OLS regressions of the ln(1 + slave exports/total land area) on ln(1 + maize suitable land area) interacted with a post introduction indicator and other controls. In all cases, each set of control variables is interacted with a full set of year fixed effects. In all specifications, the post-introduction indicator period takes the value 1 for the period 1700-1900 and is 0 otherwise. All regressions include year fixed effects and country fixed effects. Standard errors clustered by country are reported in round parentheses. ^{a}, ^{b}, and ^{c} denote significance at the 1 percent, 5 percent and 10 percent levels, respectively.

estimates reported in Table III, suggesting that the transformations have little effect on our results.

B.4 Baseline Results: Lagged Dependent Variable

The estimating equation we rely on in our main analysis ignores the possibility of dynamics in either population density or slave exports. To test the robustness of our baseline results

Table B5: The Crosby-Curtin Hypothesis: Lagged Dependent Variables

	Panel A: Population Density		
	(1)	(2)	(3)
Maize × Post	0.015^c	0.016	0.022^c
	(0.009)	(0.012)	(0.012)
European Contact		X	X
Climate			X
Observations	539	539	539
Adjusted R^2	0.89	0.90	0.90

	Panel B: Trans-Atlantic Slave Exports		
	(1)	(2)	(3)
Maize × Post	0.019^c	0.031^b	0.033^b
	(0.010)	(0.013)	(0.015)
European Contact		X	X
Climate			X
Observations	196	196	196
Adjusted R^2	0.23	0.48	0.46

Notes: Table reports estimates of the effect of maize on population density and Trans-Atlantic slave exports. Panel A reports estimates from OLS regressions of the natural log of population density (persons/km^2) on the inverse hyperbolic sine of maize suitable land area interacted with a post introduction indicator and other controls. Panel B reports estimates from OLS regressions of the inverse hyperbolic sine of slave exports (persons exported/km^2) on the inverse hyperbolic sine of maize suitable land area interacted with a post introduction indicator and other controls. In all cases, each set of control variables is interacted with a full set of year fixed effects. In all specifications, the post-introduction indicator period takes the value 1 for the period 1700-1900 and is 0 otherwise. All regressions include year fixed effects and a lagged dependent variable. Standard errors clustered by country are reported in round parentheses. ^{a}, ^{b}, and ^{c} denote significance at the 1 percent, 5 percent and 10 percent levels, respectively.

to accounting for dynamics, we estimated various specifications of the following:

$$y_{it} = \eta + \beta[Maize_i \times Post_t] + y_{it-1} + X_{it}\Gamma + \lambda_t + \mu_{it}$$

This equation is based on equation (9); the key difference is that it contains a lagged dependent variable (y_{it-1}) rather than country fixed effects. This allows us to directly assess the robustness of our results to accounting for dynamics in either outcome variable. These estimates are reported in panels A and B of Table B5. The estimates are very similar to our baseline estimates, suggesting that accounting for dynamics has little effect on our results.