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Ancient Technological Diffusion and Comparative Development: The Case of Pottery

Marcello D'Amato* **and Francesco Flaviano Russo**†

Abstract

We explore the long-term economic and institutional consequences of an early exposure to a fundamental technological innovation in human history, pottery. Using a data set on radiocarbon-dated pottery discoveries, we show that regions that were ex-posed to pottery earlier have been subsequently characterized by higher historical population density and by an earlier development of complex political organizations. These results hold after controlling for the timing of the Neolithic transition, bio-geographic variables, and migratory distance from East Africa. We argue that the dual role of pottery, both as a cooking and fermentation tool that improved nutritional efficiency and as a storage technology that enabled surplus management, shifted Malthusian constraints and contributed to the emergence of social stratification, institutional complexity, and early state formation.

JEL classification: O11; O33; O47; N00.

Keywords: Neolithic; Pottery Antiquity; Population, State.

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1 Introduction

The idea that technology influences the organization of human societies is a foundational theme in economics and history. From Adam Smith's emphasis on the division of labor, to Marx's theory of how production modes shapes human relationships, and to Schumpeter's notion of creative destruction, economists have long viewed technological innovation as a driver of institutional and social transformation. This paper contributes to studies in that tradition by exploring, empirically, the impact of pottery in shaping growth and political complexity.

The development of clay pots, vessels and storage jars was arguably one of the most fundamental invention of early humans. Archaeological and biochemical evidence increasingly supports the view that pottery functioned as a multi-purpose technological innovation with far-reaching effects in both foraging and farming societies.

First, pottery significantly improved food efficiency by enabling new, and better, methods of cooking and fermenting, thereby increasing the digestibility and caloric yield of diverse foods. Among hunter-gatherers, this included the thermal processing of acorns, chestnuts, fish, and aquatic plants, resources that were previously less accessible or nutritionally limited (Craig et al. 2013; Craig 2021; Kaner 2009), as well as fish and wild fruit fermentation. In early agricultural societies, ceramic vessels facilitated porridge-making, beer fermentation, and the detoxification of some wild or marginal crops, especially cereals (Rice 2015; Hayden 2001). Fermentation allowed also to more easily assimilate nutrients from dairy products at a time when most humans did not digest lactose, thereby increasing the caloric potential of big cattle herding, especially cows. The resulting increase in the carrying capacity of local environments increased fertility and infant survival without requiring major changes in land use, thereby shifting the parameters of the Malthusian trap, with an effect on ancient population density.

Second, pottery served as a storage technology, enabling the accumulation, preservation, and redistribution of seasonal surpluses. According to archaeologists, this function is evident in both semi-sedentary forager contexts (e.g., Jōmon Japan, Mesolithic Sudan, early China) and in early farming settlements of the Neolithic Near East and East Asia. Large ceramic vessels and jars were used to store[1] dried fish, seeds, grains, beans, and fermented products, often

[1] While roots and tubers were less frequently stored due to their perishability, there is evidence suggesting that their processed forms (e.g., dried, boiled, or fermented) were sometimes stored in ceramic containers.

buried or sealed to protect contents from pests, rodents and environmental degradation (Wu et al. 2012; Jesse and Keding 2007; Fuller and Rowlands 2011). By extending the temporal reach of subsistence, pottery reduced exposure to seasonal risk and facilitated social differentiation by allowing certain individuals or households to control and exchange surpluses. This laid the groundwork for the emergence of possessory property rights, trade, credit, hierarchies, institutionalized and more articulate redistribution schemes, and bureaucracies, and proto-political formations, even in the absence of agriculture.

Third, pottery laid the technical and cognitive foundations for early metallurgy: high-temperature kilns, clay-based crucibles, and refractory linings are a direct transfer from ceramic firing to the demands of smelting and casting metals, so that, from the Bronze Age onward, pottery and metallurgy became mutually reinforcing technologies, accelerating material innovation and enabling the rise of complex production economies over the long run (Vandiver 1987).

The main goal of this paper is to explore, empirically, the impact of early pottery exposure on the diffusion of development of early human societies. In particular, using data on the radiocarbon dating of ancient pottery discoveries by Jordan et al. (2016), that we supplement with additional data for the Americas, we show that the areas within modern-day country borders with earlier exposure to pottery are characterized by higher historical population density and by more antique states in the sense of Bockstette et al. (2002) and Borcan et al. (2018), meaning that complex political organizations developed earlier in the areas with more ancient exposure to pottery.

This empirical evidence is consistent with the idea of pottery giving a comparative technological advantage that jump-started a process of development that promoted the transformation of the social and political organization of earlier human communities. The results hold controlling for the agricultural transition timing, which insures that the estimated effect of pottery is not the by-product of the switch to hunter-gathering to farming communities. Moreover, the main results hold also after controlling for several bio-geographic factors, including continent fixed effects, and for genetic diversity measured by the migratory distance from east Africa (Ashraf and Galor 2013), which captures the innovation potential and the incentives for domestication (Rihai 2024).

For identification, we exploit the exogeneity of the invention of pottery which, according to recent evidence provided by archaeologists (Silva et al. 2014; Jordan et al. 2016), emerged independently among hunter-gatherer societies in Eastern China around 20000 BP and Sub-Saharian Africa around 12000 BP, and then spread throughout the World along kinship-driven ancient communication networks (Dolbunova et al. 2023). So our hypothesis is that the distribution of pottery arrival in World locations is randomly assigned to regions within current country borders and ethnic groups homelands, according to their position with respect to the innovation source.

This paper contributes to the literature on the role of ancient technological innovations on development, which, so far, has been mostly focused on the role of agriculture and of its bio-geographic determinants, emphasizing a transition to bigger and organized, hierarchical, societies spurred by food surpluses allowed by agriculture and by the transfer of resources through taxation to support elites (Carneiro 1970; Diamond 1997; Hibbs and Olsson 2004; Olsson and Hibbs 2005; Olsson and Paik 2020; Bockstette et al. 2022; Borcan et al. 2018). Recently, Mayshar et al. (2022) challenged this theory, showing that hierarchies and complex organizations arose because of the storability of available cereals, rather than by agricultural transition in general[2]. In a related contribution, Matranga (2024) provides evidence that food storage for consumption smoothing was spurred by an increase in climatic seasonality, and this facilitated the transition to sedentarism and agriculture. Bowles and Choi (2019) argue instead that agriculture was not adopted because of its productivity advantage, but that it emerged as a consequence of the establishment of property rights among sedentary groups of hunter gatherers near to concentrated and defendable natural resources.

With respect to these contributions, our analysis provides evidence that the exposure to pottery, has a detectable effect on long run development. With respect to Mayshar et al. (2022) and Matranga (2024), we highlight that the storage technology was available in different parts of the World at different times, and this differential diffusion had an impact on

[2]It is in principle possible that pottery cooking technologies, by allowing a better extraction of nutrients from cereals, shifted the incentives to turn to cereal agriculture, thereby spurring the process of development highlighted in Mayshar et al. (2022). In this respect our contribution complements their analysis: the availability of wild relatives of cereals, determined by bio-geographic factors, was a necessary but perhaps not a sufficient condition for staple crop adoption, the availability of a storage technology such as pottery is an important factor that deserves to be considered.

the ensuing societal development and political organization. With respect to Bowles and Choi (2019), our contribution highlights the role of a technology that, by increasing the storability of food, facilitated the emergence of possessory property rights, thereby shifting again the focus and the interpretation on technological drivers of institutional innovations.

Our work is also closely related to Comin et al. (2010), who study the effect of early technological adoption on long-run development but, differently from their contribution, we focus on historical outcomes and on early technological arrival. We also contribute to the literature on state antiquity (Bockstette et al. (2002) Borcan et al 2018), by documenting the role of an historical technological innovation for early state development and, therefore, on state antiquity itself. Conceptually our results complement this contribution: state antiquity is part of a mechanism linking an ancient technology to long-run development.

The rest of the paper is organized as follows: section 2 describes the data; section 3 illustrates the empirical results; section 4 concludes.

2 Pottery Antiquity: Data and Measurement

We leverage information from the dataset of geo-localized radiocarbon dates of earliest pottery discoveries in Africa, Europe and Asia assembled by Jordan et al. (2016), which is, to date, the largest archaeological information source on pottery available. According to their evidence, pottery originated from two innovation centers: in China (Xianrendong cave, 20815 BP) and East Africa (Saggai, 11670 BP), and then spread around the World. Since there is no information for the Americas in this dataset, we supplement it with information on about 20 early pottery discoveries scattered in North and South America from various archaeological records (full list of sites available upon request). Importantly, the pottery discoveries collected in the dataset cannot be taken as evidence of an intensity of use or of a homogeneous diffusion of pots in the area near the finding. Rather, we interpret archeological dating as evidence of exposure, and assume that human groups living in the area around the finding were familiar with that technology at the date registered in the archaeological records.

To assign a pottery antiquity date to countries, we match each discovery site in the Jordan et al. (2016) database to modern country borders, computing averages whenever more findings are recorded within the same borders (see section 3.3 for a discussion of the robustness of the results in case the oldest findings are used instead of the average). This is possible for 84 countries. For the countries without a direct matching, that is without a dated pottery discovery within the borders, we implement two alternative strategies, whcih we describe in detail in the next sections.

2.1 Pottery Antiquity: Benchmark Measure

The first strategy to assign pottery antiquity to countries without a direct matching of a dated discovery site entails computing averages over the closest discovery sites to the borders. In the few cases of closest findings at a considerable distance (above 1000 km) from the border, we adjust the dates according to the estimates Jordan et al. (2016), according to which the speed of diffusion of pottery is 0.3 km per year from the Asian innovation site, and 0.8 km per year from the African. For instance, in case of a dated discovery site at 8000 BP in a neighboring country in Asia at a 1000 km distance westwards from the country capital, the assigned pottery antiquity will be 7700 BP (it takes 300 year to cover 1000 km from the innovation site). To assign an innovation site, we use the frontiers estimated by Jordan et al. (2016). For the countries in the Americas, in the absence of diffusion estimate from Jordan et al. (2016), we simply keep the ones with a direct matching.

The median, country-level, benchmark pottery antiquity date in our sample (130 countries) is 7099 BP, with mean 6698 BP, standard deviation 2098 and inter-quartile range [5624 BP ; 7846]. Clearly, the earliest dated potteries, or the most ancient exposure to the technology, are for countries with, or close to, the innovation centers, such as China, Japan and Korea.

Given the emphasis given to agriculture in previous contributions on the effects of ancient technological innovations, it is interesting to compare pottery antiquity with the neolithic transition timing from Borcan et al. (2018). Consistently with the archaeological literature, we find that pottery exposure predates neolithic transition. Importantly, pottery antiquity and neolithic transition timing are positively correlated (0.519), an issue that will be further discussed in section 3.3.

It is also instructive to compare pottery antiquity to the ancient seasonality peak used by Matranga (2024) as an index of the increased demand for storability, because these changes, exogenously determined by geo-astronomical modifications, can potentially affect the incentive to adopt pottery. From a simple comparison of the dates, however, it appears that the peak lasted until about 7000 BP, which is about the median of our pottery antiquity index. This implies that the hypothesis of a demand-driven technology adoption of pottery is empirically plausible for about half of the countries in the sample, and in particular for those closer to the innovation sites. For the rest of them, the more recent exposure suggests that a technological supply shock is the plausible hypothesis, that is for many countries the exposure to pottery took place after the climatic shock that potentially determined a higher incentive for its adoption[3].

2.2 Diffusion-Based Pottery Antiquity

The second strategy that we implement to assign a pottery antiquity date to the countries without a directly matched pottery discovery site within the borders, entails using a diffusion model similar, but not equal, to the one used by Silva et al. (2014) and Jordan et al. (2016). In particular, we first fit a regression to the 952 data points in the Jordan et al. (2016) dataset, modeling the pottery radiocarbon dates of each discovery site as a function of the distance from the innovation center, and then predict the arrival date at the country capital using the fitted values from the regression. Since pottery is fundamentally made of clay[4], we also use the clay content of the topsoil around the country capital, alongside the distance, as an explanatory variable (although the results are robust in case of exclusion of clay content from this regression, see section 3.3). Moreover, we add orientation dummies as additional explanatory variables (North-West, North-East, South-East or South-West of the innovation center) to capture the potentially different speed at which innovations, in general, spread along the East-West axis compared to the North-South axis. The model that we estimate is the following:

[3]This result also justifies why we did not pursue an instrumental variable approach, where geo-climatic shocks, that have been documented as heterogeneous across world locations, used to instrument pottery adoption, because of the increased demand for storability.

[4]Pottery making involves mixing clay with water, shaping it, drying and then fired at a very high temperature, meaning that mastering of heating is essential. A higher clay content insures an easier production process and better results in terms of durability. Importantly, soils with high clay content are less suitable to agriculture because of a lower permeability to water and air, because they are harder to work and because they do not allow roots to grow deep.

$$Date_{is} = \beta_0 + \beta_1 Dist_i + \beta_2 Clay_i + \eta_s + \varepsilon_{is} \quad (1)$$

where $Date_{is}$ is the radiocarbon dating of the pottery discovery at the archaeological site i which is in the orientation quadrant s with respect to the innovation site (NE, NW, SE, SW), $Dist_i$ is the geodesic distance between the site and the pottery innovation center or earliest dated site, $Clay_i$ is the clay content of the top soil around the pottery discovery site from Ito and Wagai (2017), η_s are orientation dummies and ε_{is} the error term. We estimate separate regressions for pottery discoveries in Asia and Africa, using the boundary indicated by Jordan et al. (2016) for separation (see section 3.3 for a discussion on the robustness of the results). Overall, the model in-sample fit is satisfactory: for the Asian sample and innovation center, the R^2 of the regression is equal to 0.422, and the correlation between the actual and predicted arrival date is 0.650; for the African sample and innovation, the R^2 is 0.660 and the correlation between the actual and predicted date 0.650.

For countries in the Americas, since archaeologists argue that pottery spread through the Bering strait (Tachè and Craig 2015), we first computed an arrival date at Prince Rupert[5] from China according to equation 1, and then estimated a separate regression, using the same empirical model but with no orientation dummies, because nearly all discovery sited in our sample are South-East of the Bering strait.

The median, diffusion-based, pottery antiquity (209 countries) is 6676 BP, with mean 5997 BP, standard deviation 2020, and inter-quartile range [5000 BP ; 7828 BP]. The correlation coefficient between the two measures is, as expected, very high, 0.955, given that the difference between the two is an alternative assignment of pottery antiquity to a small number of countries. The great advantage of this measure, however, is that we can assign a pottery antiquity to many more countries.

[5]Prince Rupert is chosen, over other possible location, because it is used as a migratory midpoint in the out-of-Africa literature (Ramachandran et al. 2005; Ashraf and Galor 2013).

3 Empirical Evidence

We now study the effect of the exposure to pottery on two historical outcome variables: population density (section 3.1), as a proxy for the development stage in the pre-modern era, and State antiquity (section 3.2), a measure of political and societal complexity. In both cases, the empirical model that we estimate is the following:

$$Y_{ij}^{k} = \alpha_0 + \alpha_1\, Pot_i + \Gamma X_{ij} + \eta_j + \varepsilon_{ij} \tag{2}$$

where Y_i^k is the outcome variable measured in the (historical) period k within the current boundaries of country i in continent j, Pot_i is pottery antiquity, X_{ij} is a vector of covariates, η_j are continent dummies, and ε_{ij} is the error term.

The set of controls X_{ij} includes the agricultural transition timing from Borcan et al. (2018), an index of land suitability to agriculture, and the percentage of arable land, to isolate the effect of pottery exposure from the effect of the adoption of agriculture. The positive correlation between pottery antiquity and agricultural transition reported in the previous section, together with the fact that pottery, in most areas of the World, pre-dates agriculture, opens to the possibility that pottery enabled groups to the agricultural transition, i.e. a technology-push. For instance, possessing the technology to cook cereals, and to ferment milk, undoubtedly increased the incentives to switch from hunting and gathering to settlement, cultivation and animal herding. If this was actually the case, the neolithic transition timing would be a transmission channel, rather than a confounding factor, and, therefore, a "bad control". In the absence of a consensus among the archaeologists on the possibility that the exposure to pottery caused the transition to agriculture, we remain agnostic, including neolithic transition in the baseline specification, checks of the robustness of the results to its exclusion will be reported later in the text (see section 3.3).

As additional controls we include the predicted genetic diversity based on the migratory distance from east Africa to the country capitals, to control for the effect of ancient migrations on the innovation potential and on the within group diversity of early community (Ashraf and Galor 2013). Moreover, as shown by Rihai (2024), out-of-Africa migrations influenced also the bio-geographic environment (co-evolution), contributing to set incentives for agriculture and domestication. Notice that this control is particularly important, since one of the two innovation sites of pottery is very close to the starting point of the Out-of-Africa migrations, a possible confounder. We also include the absolute value of the latitude, and the average terrain ruggedness and average elevation, to control for climatic factors that might have influenced demic movements, technological diffusion and population density (Diamond 1997). We also use a dummy for country-islands to further control for geographic isolation that might have delayed the arrival of the pottery technology, over and above the effect of the continental diffusion corridors.

The identification of the empirical model is based on the exogeneity of pottery antiquity with respect to the outcome variables measured several centuries after the exposure to pottery[6]. Following Jordan et al. (2016), we assume that pottery is an exogenous innovation, first developed independently among hunter-gatherers groups in Easter China and East Africa, and which then spread along kinship-driven communication networks as a form of knowledge and technological transfers[7] through random copying (Dolbunova et al. 2022). In other words, we consider the distribution of pottery antiquity, allocated to different regions of the globe, as the result of the position with respect to the (itself randomly located) innovation point.

3.1 Population Density

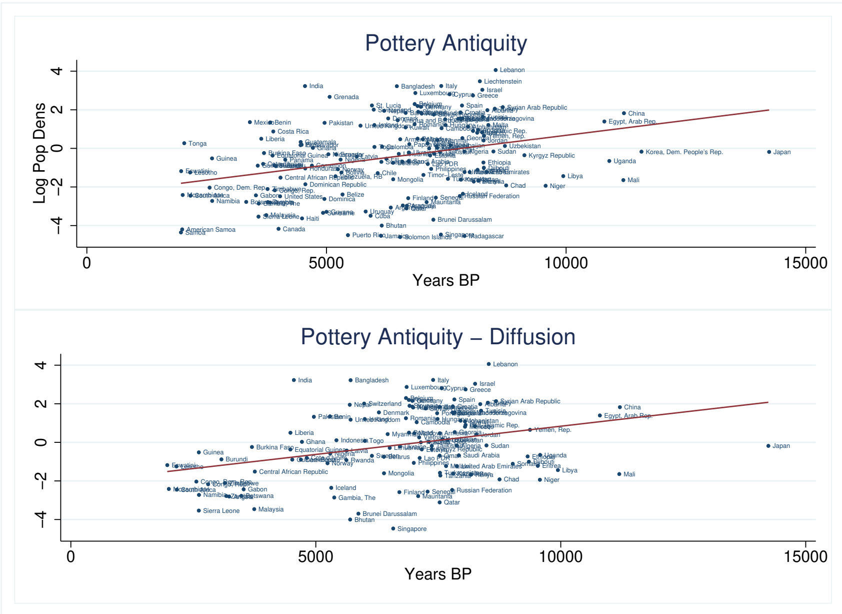
We use historical population data from the HYDE (2017) database, based on the Atlas of World population history by McEvedy and Jones (1978), and we compute population density using the country surface area (the results are the same when using log population as dependent variable). We arbitrarily chose 6 points in time to illustrate the empirical results: 3000 BC, 2000 BC, 1000 BC, 0 AD, 1000 AD and 1500 AD. Before 3000 BC, very few areas of the World were populated, so there is not enough variability in the outcome variable to

[6]Notice that our identification hypothesis pertains to the extensive margin in the diffusion process of the technology: while it is in principle possible, for the simple law of large numbers argument, to have a higher probability to find archaeological evidence of intensity of pottery use, everything else equal, in areas where larger and more complex societies flourished, there is however no reason why such findings should be earlier dated.

[7]Similarities in pottery shapes, sizes, and functions, the latter inferred through the biochemical analysis of the organic residuals found in the pots, prove the existence of ancient communication networks for the technological transfer to take place. See Dolbunova et al. (2022) for details and also for the reasons why the spread of pottery was unlikely to be determined by demic movements, differently from the agricultural transition which is often considered as a demic spread.

estimate the model; we stop at 1500 AD, before the great modern migration, because the ethnic composition of many countries changes significantly after that date.

Figure 1: **Pottery Antiquity and Population Density, O AD**



Notes: Y-axis: log population density at 0 AD. X-axis: Pottery antiquity benchmark measure (top panel, see section 2.1) and with a diffusion model (bottom panel, see section 2.2), in years BP.

In figure 1 we plot the scatter of log population density at 0 AD on average pottery antiquity (year BP), together with a linear fit for both the benchmark antiquity measure and for the one computed using a linear diffusion model. The raw correlation coefficient are 0.343 for the benchmark measure (125 countries) and 0.325 (170 countries). The regression results are reported in table 1, and are indeed very similar across the two alternative antiquity measures. Overall, pottery antiquity (earlier values of the average radiocarbon dates), that is a more ancient exposure to pottery as a technology, is associated with higher historical population density. Quantitatively, moving from the first quartile of pottery antiquity (5000 BP) to the third (7828 BP) according to the measure computed with the diffusion model (available for more countries), which is equivalent to a more ancient exposure of about 2800 years, is associated with a 32% bigger population density at 0 AD. As for the controls considered in the regression, the coefficient on the neolithic transition timing is positive and statistically significant, so the results confirm, in line with previous literature, the importance of an early transition to agriculture; the coefficient on genetic diversity, conversely, is not statistically significant at most time horizons.

3.2 State Antiquity

In this section we explore the relationship between the exposure to pottery and the extent to which complex societal organization emerged within the current country borders at various times in history. In particular, we use the state antiquity data from Bockstette et al. (2002), and the extension by Borcan et al. (2018). The raw data consists in scores assigned, for 50 years periods starting from 3500 BC, according to answers to the following three questions: 1) Is there a government above the tribal level? 2) Is this government foreign or locally based? 3) How much of the territory of the modern country was ruled by this government?. The scores are then summed and discounted to compute state antiquity dates at different point in times. Starting from their raw data, we compute antiquity at three different dates, 1000 BC, O AD, 1000 AD, using a benchmark 5% discounting rate. Note that at earliest dates there are very few territories with state organizations, resulting in a cross-sectional dataset with zeros for the large majority of countries. For instance, at 2000 BC, only 17 out of 190 territories/countries have non-zero values of the state antiquity index, and only 4 have a non-zero state antiquity index value at 3000 BC. Moreover, at 1000 BC there is evidence of very organized societies at 1000 BC, but characterized by very complex organizations, such as those in the territory of modern Egypt, Iraq, Pakistan, Syria and Lebanon. Given the quite high number of zeros in the dataset, we employ the pseudo-Poisson MLE for estimation, with the same set of control variables described in the previous section.

The regression results are summarized in table 2, and they show that an earlier exposure to pottery is associated with more ancient states, that is with more complex organizations. Quantitatively, moving from the first to the third quartile of pottery antiquity measure computed with a diffusion model implies a 58% increase in the state antiquity index at O AD. The coefficient on neolithic transition is also positive and statistically significative in most empirical specifications, and decreasing for antiquity at more recent dates, evidence of the importance of an earlier transition to agriculture as in Borcan et al. (2018).

3.3 Robustness and Additional Results

In the direct assignment of a date pottery antiquity findings to countries, which is the same across the two alternative measures of antiquity that we use, we computed a simple average over all the ancient findings in the Jordan et al. (2016) database located within the modern country borders. The motivation is to account for the generalized exposure to pottery in a territory or, in other words, for internal, within-country, diffusion, which is especially important for countries such as Russia, with an eastern part of the country with a more ancient pottery antiquity due to its proximity to the innovation site in China, but with an Western part where pottery arrived many centuries later, as argued in Jordan et al. (2016). For robustness, we tried an alternative assignment using the earliest-date pottery finding in the regions within a country, finding similar empirical results for both measures of antiquity[8]

The results are also robust when assigning pottery antiquity to countries using only the predicted values from equation 1, that is without using the direct matching. Note that we used the clay content in the topsoil to predict pottery exposure because a high clay content is crucial for the production of stable ceramic, that is to minimize breaks and to prolong its life. We tried however excluding clay from equation 1, obtaining similar empirical results.

We find similar results when excluding the countries in America, which entails using the original pottery radiocarbon dating database in Jordan et al. (2016). Finally, we also found robust results when considering Pedra Pintada as an independent innovation site for pottery when computing predicted values according to the diffusion model in equation 1.

Following Jordan et al. (2016), we assumed that pottery arrived in Western Europe and in most parts of the Middle East from Africa. We tried alternative approaches, namely for countries (Europe, Middle-East) at the frontier of the diffusion process from the two innovation centers, we assigned the earliest predicted pottery arrival date among those obtained with diffusion from an origin in Asia and Africa, finding the same empirical results.

Ancestry adjustment. We also considered an alternative way to date the exposure to pottery following the literature on ancestry adjustment (Putterman and Weil 2010). In partic-

[8]We excluded China and Russia from the sample, in this case, because of the very big difference between the oldest and the average pottery finding within the country borders, which is due to the presence of the innovation site in Eastern China and to the very big area of the countries: a throughout diffusion took a very long time, meaning that using the oldest dated pottery to impute antiquity will be a poor proxy for exposure to the technology in the country.

ular, we computed the average ethnic-group level pottery antiquity dates over all ethnic groups listed in the Ethnographic Atlas with centroid, or ancestral location, within the modern-day country borders. To assign a pottery antiquity to groups, consistently with the rest of the analysis we implemented two alternative procedure, either computing averages over the closest dated pottery discovery sites to the ethnic group centroid, adjusting with the Jordan et al. (2016) coefficients in case of very far sites, or using the linear diffusion model in equation 1 based on the distance between the innovation point and the ethnic group centroid. For countries with no records of an ethnic groups with ancestral locations listed in the Ethnographic Atlas, we supplement the information with the predicted pottery arrival date at the centroid of the dominant, ancestral, ethnic groups, using the information in Spolaore and Wacziarg (2009) to identify such groups, and following the same regression procedure detailed above to compute predicted arrivals. When using this ancestry-adjusted pottery antiquity, we find robust results to the benchmark (detailed evidence available upon request).

Neolithic Transition. To further delve into the relationship between pottery and the neolithic, we regressed the neolithic transition timing on pottery antiquity (which, in many cases, pre-dates the arrival of agriculture) and controls, using the same empirical specification in equation 2, finding a positive and strongly significant coefficient for both measures. So the neolithic transition happened earlier in the areas with earlier exposure to pottery as a technology. Most likely, potteries, because of their role as cooking and fermenting vessels, increased the nutritional potential of several crops, especially cereals, and of milk, thereby shifting the incentives to turn to agriculture and animal husbandry, thereby playing an important role in the neolithic transition over and above the environmental factors stressed, among other, in Diamond (1997). Since this empirical relationship between pottery antiquity and agricultural transition opens to the possibility that neolithic transition is a "bad control" in the main regression specification in 2, we also run regressions excluding it. We find the same qualitative empirical results as the benchmark, and quantitatively larger regression coefficients on pottery antiquity for both outcome variables.

4 Conclusions

Our empirical results support the hypothesis that an early exposure to the pottery exerted a profound and long-lasting influence on demographic and institutional development. We document that countries and ethnic groups where exposed to pottery earlier subsequently experienced higher population densities and more complex political structures. These effects are robust to alternative specifications and persist when controlling for the Neolithic transition, confirming that pottery arrival had an independent influence on societal organization.

These findings contribute to the broader literature on long-run development by highlighting the importance of specific enabling technologies— on the top of biological or geo-climatic endowments—in shaping the demographic and organizational trajectories of early civilizations. Pottery not only facilitated food storage and fermentation, but also created conditions favorable to surplus accumulation, social differentiation, and institutional innovation. In light of recent archaeological discoveries showing that pottery predates agriculture in many regions, this study suggests that early material technologies spurred the adoption of the broader Neolithic package and played a catalytic role in in triggering the transformation of human societies from small-scale foragers to complex agrarian states.

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Table 1: **Pottery Antiquity and Population Density**

	Population Density											
	3000 BC		2000 BC		1000 BC		0 AD		1000 AD		1500 AD	
Pot Antiquity	0.1949***		0.1952***		0.1911***		0.1839***		0.2782***		0.2077***	
	(0.0375)		(0.0309)		(0.0225)		(0.0254)		(0.0587)		(0.0781)	
Pot Diffusion		0.1245***		0.1289***		0.1240***		0.1146***		0.2258***		0.1773***
		(0.0343)		(0.0353)		(0.0361)		(0.0471)		(0.0634)		(0.0709)
Neolithic	1.1492***	1.1355***	1.2525***	1.1975***	1.2337***	1.1971***	1.2946***	1.2214***	0.6191***	0.5211***	0.4523***	0.3206**
	(0.1516)	(0.1674)	(0.1117)	(0.1518)	(0.0681)	(0.1346)	(0.0258)	(0.1306)	(0.0775)	(0.1631)	(0.0302)	(0.1397)
R^2	0.350	0.368	0.363	0.372	0.329	0.349	0.319	0.320	0.176	0.175	0.102	0.089
Observations	116	146	116	146	116	146	116	146	116	146	116	146

Notes: Observations are for countries. Dependent variable is the population density in the year specified in column. Pot Antiquity is the benchmark pottery antiquity in years BP (see section 2.1 Pot Diffusion is the pottery antiquity date with a diffusion model used to fill missings (see section 2.2). Neolithic is the time since the agriculture transition. All regressions include: the predicted genetic diversity based on the out-of-Africa migratory distance, the land suitability to agriculture, the percentage of arable land, the absolute value of the latitude, the average terrain ruggedness and elevation, a dummy for country-islands, and Continent fixed effects. Clustered standard errors at the level of the continent in brackets. Right-hand side variables are standardized. *** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level.

Table 2: **Pottery Antiquity and State Antiquity**

	State Antiquity					
	1000 BC		0 AD		1000 AD	
Pot Antiquity	0.5951***		0.6328***		0.6059***	
	(0.0649)		(0.1022)		(0.1553)	
Pot Diffusion		0.3938***		0.3234***		0.3487*
		(0.0891)		(0.1168)		(0.1987)
Neolithic	2.1849**	2.1881**	0.8791*	1.0481**	0.3998	0.4914**
	(0.9445)	(0.9741)	(0.4692)	(0.4578)	(0.2833)	(0.2347)
Pseudo R^2	0.412	0.407	0.248	0.242	0.158	0.151
Observations	109	109	109	136	111	136

Notes: Observations are for countries. Dependent variable is the state antiquity index from Borcan et al. (2018) in the year specified in column. Pot Antiquity is the benchmark pottery antiquity in years BP (see section 2.1 Pot Diffusion is the pottery antiquity date with a diffusion model used to fill missings (see section 2.2). Neolithic is the time since the agriculture transition. All regressions include: the predicted genetic diversity based on the out-of-Africa migratory distance, the land suitability to agriculture, the percentage of arable land, the absolute value of the latitude, the average terrain ruggedness and elevation, a dummy for country-islands, and Continent fixed effects. Clustered standard errors at the level of the continent in brackets. All variables are standardized. *** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level.

Appendix

Archaeological Background

Recent archaeological discoveries have significantly reshaped our understanding of the Neolithic transition, particularly concerning the role of pottery. Contrary to earlier models that viewed pottery as a secondary artifact of agricultural sedentism, multiple independent research programs have shown that pottery often preceded plant domestication and agriculture by millennia. This appendix reviews core contributions in the archaeological literature that document the independent emergence of ceramic technology, its functional role in food processing and storage, and its implications for demography, social hierarchy, and institutional development.

Pottery before Agriculture: New Chronologies and Paradigms. One of the foundational breakthroughs comes from McGovern et al. (2004), who identified chemical residues of fermented beverages in pottery from Jiahu, China, dated to 7000 BCE. This early application of pottery for fermentation supports the argument that ceramic innovation preceded staple crop cultivation. Their findings mark one of the earliest functional uses of pottery to support caloric diversification in a non-agricultural setting.

More definitively, the work of Wu et al. (2012) documented pottery shards from Xianrendong Cave, China, dating as early as 18,000 BCE—well before the onset of agriculture in East Asia. These pots were associated with hunter-gatherer occupation layers, providing irrefutable evidence that mobile foraging societies adopted ceramic technology long before plant domestication.

In Jōmon Japan, pottery appears by 16,000 BCE. According to Kaner (2009) and more recent excavations analyzed by Jordan et al. (2022), Jōmon pottery was used for boiling, storage, and possibly fermenting aquatic and forest-based resources. These findings challenge the old dichotomy between "Neolithic" and "pre-agricultural" societies and reveal a complex transition in which technological innovation preceded and enabled economic transformation.

In China, Fuller et al. (2009) Document archaeological contexts where pottery is closely associated with early agriculture and subsequent metallurgical development.

Functional Roles of Pottery: Cooking, Storage, and Fermentation. Craig et al. (2013) employed residue analysis on pottery from hunter-gatherer contexts in Northern Europe and East Asia, finding biomarkers for aquatic oils and starchy tubers. Their research emphasizes that early ceramics allowed for the thermal processing of previously inedible or toxic foods, increasing the digestible calorie yield of wild diets and supporting demographic expansion.

Similarly, Wang et al. (2016) demonstrated that the Mijiaya culture in Neolithic China used specialized ceramic vessels for beer production—combining barley, tubers, and fermentation. This suggests that pottery facilitated not just storage but also biochemical transformation of food, with implications for nutrition, ritual practice, and social status.

In Neolithic Europe, Salque et al. (2013) found chemical residues of fermented dairy products in strainers from Poland dating to ca. 5500 BCE, suggesting that ceramic vessels were crucial in the spread of secondary product economies, particularly dairying. Pottery thus contributed to both dietary diversification and technological specialization.

Bernard et al. (2011) document chemical evidence of grape fermentation in ceramic jars, explicitly linking pottery to wine fermentation.

Social Consequences: Surplus, Sedentarism, and Political Stratification. The social implications of ceramic storage were made clear by Brian Hayden (2001), who argued that pottery-enabled food surplus provided the material basis for competitive feasting and status differentiation. In this model, technological control over surplus—and the symbolic use of pottery in ritual consumption—contributed directly to the emergence of prestige economies and proto-political hierarchies.

Fuller and Rowlands (2011) emphasized the role of pottery in spatial storage strategies, allowing households and villages to accumulate and defend food surpluses. This, in turn, supported larger, more permanent settlements, which became necessary precursors to territorial governance and taxation systems in early agrarian states.

Hayden (2001) argues that pottery-enabled storage and processing played key roles in enabling social differentiation and subsequently fostering technological innovations.

The idea that pottery diffused through cultural interaction rather than demic expansion is further supported by Dolbunova et al. (2023), who analyze regional variations in ceramic technology across Eurasia. They find that stylistic and functional elements of pottery often spread along trade and kinship networks, pointing to skilled artisanship and social learning as key channels for transmission.

Social Consequences: Property Rights. Archaeological analysis shows also that pottery, by allowing a more effective storage of surplus, also facilitated the emergence of more complex systems of possessory and property rights. Akkermans and Schwartz (2003), discuss the development of large ceramic storage containers in Neolithic Syria, and how they helped delimit property rights over surpluses. Along the same lines, Pollock (1999) discusses the emergence of property rights over large containers of stored food in Mesopotamia. In terms of the social consequences, Earle (1991) argues that property rights over staples are essential to the development of social stratification.

Pyrotechnological Spillovers: Pottery and the Origins of Metallurgy. Archaeologists and historians of technology agree that mastery of ceramic pyrotechnology—particularly in controlling oxygen flow and thermal gradients—was a necessary precondition for copper and bronze metallurgy. Innovations in kiln design improved smelting efficiency, while advances in metal tools enabled finer ceramic shaping. The same raw materials (clay, temper, ash), thermal control principles (oxidation vs. reduction atmospheres), and processing knowledge (e.g., drying, layering, and insulating) were applicable across both domains.

Among others, Roberts and Thornton (2014) document how ceramic technological knowledge diffused into metallurgical practice across ancient societies. Vandiver (1987) showed that the kiln and firing techniques developed for pottery—especially temperature control and refractory lining—were prerequisites for extractive metallurgy. In fact ceramic and metallurgical installations are found in close spatial and stratigraphic association in early Anatolian (Çatalhöyük). Along the same lines, Radivojević et al. (2010) found spatial co-location of pottery and copper smelting at early Balkan sites like Pločnik. Wertime (1964) and Tylecote (1992) similarly emphasized the continuity between ceramic and metallurgical practices, noting that both required control over heat, atmosphere, and material composition. Finally, macro-historical syntheses by Anthony (2007) and Sherratt (2006) trace the tandem spread of ceramic and metallurgical innovation across Eurasia through long-distance exchange networks. Their work supports the notion that early material technologies, including pottery, formed the core infrastructure upon which later civilization advancements—such as bronze and iron metallurgy—were built.

Concluding Remarks. Taken together, these studies reframe pottery not as an outcome of the Neolithic transition, but as a catalyst for it. By enhancing food processing, enabling surplus accumulation, and facilitating long-term storage, ceramics provided the material and social conditions necessary for population growth, settlement nucleation, and institutional complexity. Pottery was not a secondary innovation trailing agriculture—it was an integral part of the broader technological substrate that made agrarian and political transformations possible.

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