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ESSAYS ON THE SOCIO-ECONOMICS OF RECENT DEMOGRAPHIC CHANGE AND ANCIENT TECHNOLOGY DIFFUSION

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Abstract

In Chapter 1, we study an under-explored implication of population ageing, i.e., its effect on country-level environmental outcomes and on individual-level environmental attitudes. In doing so, we propose a novel classification of country-level environmental outcomes, namely *action-requiring* and *nature-concerning*. The borderline between these two categories lies in the level of civic engagement required to fulfill them. Using panel data from a broad set of countries (1995–2018), we find that population ageing is linked to improvements in environmental outcomes that require minimal civic engagement, while it shows no clear association with outcomes that depend on active participation. Analysis of individual-level survey data (2005–2016) further suggests that ageing societies tend to exhibit lower levels of environmental engagement, without affecting individuals' underlying environmental concern.

In Chapter 2, we investigate how population ageing affects economic growth by altering the composition of government expenditure. We develop and test a political economy model in which an ageing population shifts the preferences of the median voter, leading to increased spending on the elderly at the expense of investment in growth-enhancing areas, thereby reducing growth. Using OECD data from 2007–2018 and both OLS and IV regression analyses, we find strong evidence that population ageing raises spending on elderly and healthcare services, while having no significant effect on productive expenditure categories such as education and infrastructure. Extending the analysis to a broader sample of countries with GMM estimation, we confirm that elderly spending, proxied by healthcare expenditure, has a negative impact on economic growth.

In Chapter 3, I study the emergence and diffusion of production techniques using archaeological artefacts from the British Museum. I construct a dataset of over 800,000 artefacts containing geographic and chronological information. I develop a method to identify the techniques employed in their production using large-language and vision-language models. Using these data, I reconstruct the spatial and temporal distribution of the earliest adopters of production techniques, referred to as *pioneering sites*, and examine how distance from these points of origin relates to the delay in the adoption of techniques. Overall, the results show that sites located closer to pioneering sites tend to adopt production techniques earlier.

Chapter 1

Population Ageing and the Environment: A Comparative Study of Nature-Concerning and Action-Requiring Outcomes

1.1 Introduction

Population ageing is one of the most prominent issues globally with the proportion of those aged 65 and above growing faster than any other age group (United Nations, 2024). Over this period of demographic transformation, climate change has also become one of the most salient matters in international and national affairs, resulting in growing pro-environmental efforts. Figure 1.1 shows that, globally, the old-age dependency ratio (OADR), i. e., the share of the population aged 65 and above relative to the population aged between 15 and 64, has risen from 8.50 in 1960 to 14.65 in 2020. Similarly and over this period, there has been a notable upward trend in the number of climate change policies and laws, climbing from a national average of 1.67 to 11.58.[1]

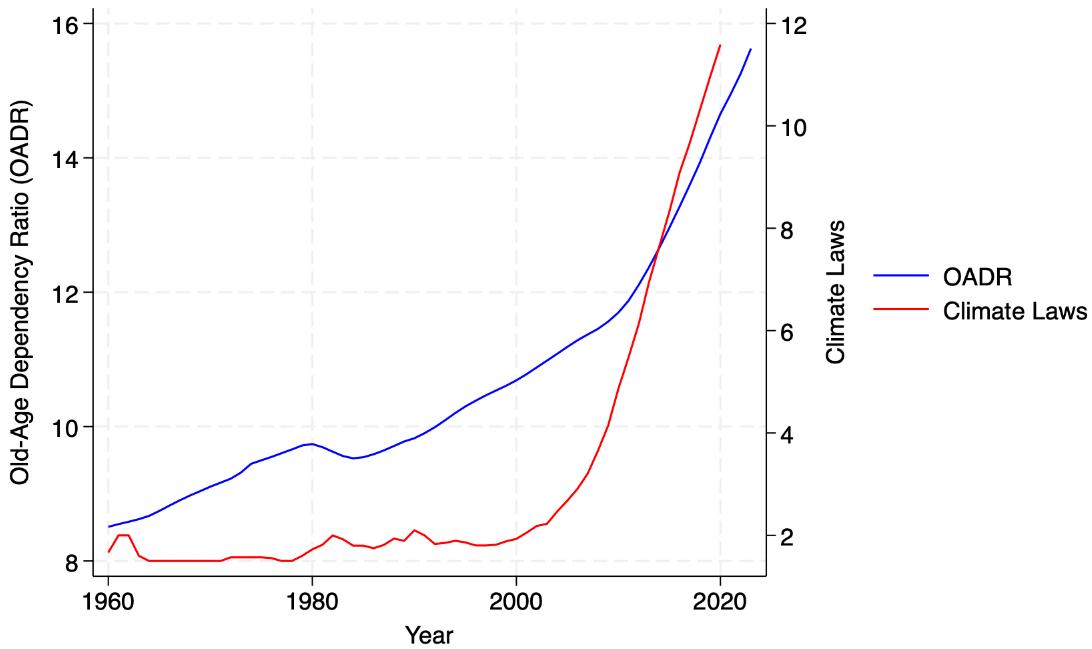


Figure 1.1: Population ageing and climate change laws and policies

In this study, we examine the relationship between population ageing and two proposed categories of environmental outcomes that differ in the level of civil engagement required to fulfil them. We refer to these as *action-requiring* and *nature-concerning*.

[1] Figure 1.1 depicts the evolution of the old age dependency ratio (% of working-age population) and the number of climate change laws and policies between 1960 and 2020. It is produced using data from the World Bank Development Indicators (World Bank, 2022), Grantham Research Institute on Climate Change and the Environment and Sabin Center for Climate Change Law (2021) and The Quality of Government Environmental Indicators Dataset (Povitkina et al., 2021).

Our country-level findings indicate that population ageing has an equivocal effect on action-requiring environmental outcomes and an environmentally favourable one on nature-concerning counterparts.

We argue that action-requiring environmental outcomes rely on the collective adoption of new practices and habits. Older individuals may be less inclined to adopt recently emerging environmental behaviours, as age may hinder the formation of new habits such as recycling and sustainable energy use. As this pattern scales to the societal level, population ageing may result in lower participation, potentially weakening the uptake of action-requiring environmental measures at the aggregate level. Within this category, we examine three variables pertaining to recycling, transportation and residential activities.

In contrast, nature-concerning environmental outcomes are primarily driven by government policies and land use, rather than direct engagement from the population. The existing literature suggests that older individuals exhibit higher attachment to nature (e.g., Hughes et al., 2019). As a result, population ageing may be associated with stronger nature-concerning pro-environmental outcomes at the country level. Within this category, we consider six variables such as species protection and the share of forest land.

To examine the effect of ageing on these two proposed categories, we explore a dataset of 140 countries over the 1995–2018 period. Our findings indicate that ageing has a pro-environmental effect on nature-concerning environmental outcomes and an equivocal one on action-requiring counterparts.

Ensuring the validity of our results requires addressing potential endogeneity concerns, particularly those related to reverse causality. For instance, environmental outcomes such as air pollution, driven by CO_2 emissions from transport and building activities, can adversely affect health outcomes. This, in turn, may reduce life expectancy and negatively affect population ageing. To mitigate this concern, we employ an instrumental variable (IV) strategy. Following Acemoglu and Restrepo (2022), we instrument population ageing using historical crude birth rates. Past fertility patterns strongly determine present population ageing, by contrast, they are unlikely to directly impact contemporary environmental outcomes. The results show that population ageing has a causal and pro-environmental effect on all variables pertaining to nature-concerning environmental outcomes and no clear effect on action-requiring outcomes.

Similar to our country-level results, we uncover a differential effect of population ageing on individual-level environmental attitudes. Specifically, we show that living in a country with higher population ageing reduces environmental participatory effort captured by *Environmental organisation membership*. By contrast, we do not find a significant association between living in an ageing society and subjective attachment to the environment. Instead, we show that the latter is driven by individual ageing.

The remainder of this paper is organised as follows. Section 1.2 explores the related literature. Section 1.3 elaborates on the notions of action-requiring and nature-concerning environmental outcomes and describes the data. Section 1.4 outlines our empirical strategy. Our main results appear in Section 1.5. Section 1.6 investigates the effects of population and individual ageing on environmental attitudes. Finally, Section 1.7 concludes. The Appendix contains additional tables and figures.

1.2 Related Literature

Our work lies at the intersection of two strands of the literature. The first one is concerned with the impact of population ageing on aggregate environmental outcomes, whereas the second one focuses on the effect of both societal (i. e., population) and individual ageing on individual attitudes regarding the environment.

This paper, to the best of our knowledge, is the first to evaluate the direct impact of population ageing on aggregate environmental outcomes. Studies investigating the effect of population ageing on environmental attitudes are also limited; a notable exception is the work of Wang et al., 2021. Using data from 31 countries, the authors found a positive association between ageing, both at the country level and at the individual level, and pro-environmental behaviour.

To build on this limited economic literature, we draw on insights from other disciplines, such as anthropology and psychology. Although these fields do not directly link ageing to environmental outcomes, they provide a valuable framework to motivate our proposed mechanisms and intuitions. In doing so, our study advances the economic literature by introducing a novel approach to evaluating the effect of ageing on environmental outcomes at both the country and individual levels.

Relevant to our work and borne from the anthropological literature, Erikson (1993) developed the theory of generativity which states that during old age, individuals experience a reevaluation of life roles and develop an intrinsic need to care for future generations. Arguably, pro-environmental actions are subject to a generativity response since they involve careful and constrained use of current resources for the sake of future sustainability. Using this framework and exploring the case of environmental volunteers in Queensland, Australia, Warburton and Gooch (2007) showed that, relative to younger individuals, the cited motives of elderly respondents regarding their environmental action were related to long-term legacy for future generations and associated satisfaction in helping generations to come.

Also within this literature, Atchley (1989) proposed the continuity theory. The latter suggests that the elderly make adaptive choices and attempt to preserve their internal and external structures by adopting behaviours that are consistent with their past histories. Again, within the context of relatively new sustainability efforts, this could translate into lower participation levels from the elderly in pro-environmental action. In aggregate, this may result in a negative effect of population ageing on action-requiring environmental outcomes.

More recently and amidst an increasing academic interest in sustainability, a literature concerned with attachment to nature has been blossoming. Connectedness, or attachment, to nature describes the subjective perception of closeness between individuals and their natural environment (Brügger et al., 2011; Nisbet et al., 2009). According to recent research, it is the strongest determinant of pro-environmental behaviour, with most studies finding approximately 60 percent of common variance between the two measures (e. g., Pensini et al., 2016; Roczen et al., 2014), even surpassing the contribution of environmental knowledge (Otto and Pensini, 2017).

Closer to our research question is the relationship between age and connectedness to nature. Using face-to-face interviews on a sample of respondents in the United Kingdom, Hughes et al. (2019) found that the elderly display higher levels of attachment to nature relative to younger counterparts. These results were corroborated by a study conducted on a larger sample of participants using the Monitor of Engagement with the Natural Environment (MENE) survey.[2] It revealed considerable differences in nature attachment scores between different age groups, with those aged between 61 and 70 achieving the highest average score (Richardson et al., 2019).

[2] The objective of this survey is to measure time spent in nature and to track the different ways in which individuals interact with their natural environment.

Habit-formation and related emotional processes play an important role in determining pro-environmental behaviours. Works conducted in this specific area fall primarily within the discipline of psychology. For example, Aarts et al. (1998), Smith et al. (1994) and Staats (2003) demonstrated that deliberate behaviour is considerably driven by past behaviour. According to Ouellette and Wood (1998), there are two paths through which past behaviour influences future behaviour. First, through habit-formation which is mainly present in stable contexts, meaning that action initiation is produced through automatic processes. Second, through intention-formation which applies primarily to non-stable contexts where the effect of past behaviour is mediated by conscious reasoning. These propositions were supported by subsequent empirical research. For example, when examining a sample of college students in Hong Kong, Cheung et al. (1999) found that the rate of paper recycling was strongly predicted by the one-month lag relating to the engagement in the same behaviour. Past behaviour, through habit-formation, was also found to be a significant determinant of the choice of travel modes (Bamberg et al., 2003).

This paper makes several key contributions to the literature. First, it introduces a novel classification of environmental outcomes into action-requiring and nature-concerning categories. This distinction offers a more elaborate framework and reveals the differing effects of population ageing across these two categories. Second, it extends the scope of existing research by conducting a dual-level analysis. At the country level, the study examines the relationship between population ageing and environmental outcomes using a panel dataset of 140 countries and employs an instrumental variable strategy to address potential endogeneity concerns. At the individual level, it explores the effect of population and individual ageing on environmental attitudes and behaviours using survey panel data from 68 countries. By integrating these levels of analysis, this study provides a detailed understanding of the complex relationship between population and individual ageing and environmental outcomes and attitudes.

1.3 Data

We explore the effect of population ageing on environmental outcomes using a baseline panel of 140 countries over the 1995–2018 period. Figure 1.A.1 in the Appendix shows a map of the countries sampled. The remainder of this section further explains the data employed and describes the data sources.

1.3.1 Population Ageing

Throughout this paper, we distinguish between *population ageing* and *individual ageing*. Population ageing refers to the varying proportion of elderly individuals within a society; we use the terms *population ageing* and *societal ageing* interchangeably. In contrast, *individual ageing* refers to differences in age between individuals. This distinction enables us to assess the effects of ageing at both the societal level and the individual level in Section 1.6. In this section, our independent variable of interest is country-level population ageing, proxied by the old-age dependency ratio *(OADR)*. The OADR measures the number of old people (aged 65 and above) per 100 people from the working population, belonging to the 15–64 age bracket. The data for this variable are drawn from the World Development Indicators (WDI) dataset (World Bank, 2022). As shown in Table 1.1, the average *OADR* in the sample is estimated at 11.33 varying from 0.80, for the United Arab Emirates in 2010, to 34.96, for Finland in 2018.

1.3.2 Environmental Outcomes

This paper proposes a distinction between action-requiring and nature-concerning environmental outcomes. The former category pertains to environment-related outcomes that require active engagement from the general population and for which large-scale behavioural changes are necessary. Recycling, for example, falls within this category due to its participatory nature. In contrast, nature-concerning environmental outcomes refer to policy measures and land use outcomes that relate to the natural environment and that do not demand substantial engagement from the civil society. These two broad categories are further detailed below.

Action-Requiring Environmental Outcomes

To study the effect of population ageing on action-requiring environmental outcomes, we identify the following three dependent variables: *Recycling, Transport CO2 and Building CO2*.

Recycling refers to the share of recyclable post-consumer material that is recycled in each country.[3] The data are compiled and retrieved from the Environmental Performance Index (EPI) (Wendling et al., 2020) and originally sourced from Chen et al., 2020. *Transport CO2* captures annual country-level carbon dioxide emissions from transportation as a share of total fuel combustion.[4] Considering that road transport—mainly from private vehicles—accounts for a large share of these emissions (Ritchie and Roser, 2021), and that alternatives such as public transport or electric vehicles require widespread behavioural shifts and individual choices (Nordfjærn et al., 2014), this measure falls within the action-requiring category.

Building CO2 measures emissions from residential, commercial, and public buildings relative to total fuel combustion. In 2021, building operations accounted for 30 percent of energy use and 27 percent of emissions globally, with residential buildings contributing more than non-residential ones (Delmastro et al., 2022). Since these emissions are shaped by household energy behaviour, this variable is classified as action-requiring. Data for both variables are drawn from the World Development Indicators (WDI) dataset (World Bank, 2022).

As shown in Table 1.1, recycling rates vary considerably in the sample from 0.86 to 66.88 percent, respectively corresponding to Chile in 1995 and in 1996 and the Republic of Korea in 2018. *Transport* and *Building CO2* also show substantial variation and have respective mean values of 32.06 and 10.42.

Nature-Concerning Environmental Outcomes

Nature-concerning outcomes are further decomposed into targeted policies and land use subcategories.

Targeted Policies

[3] Recycled material encompasses glass, plastic, metal and paper.
[4] This measure excludes international marine bunkers and international aviation.

The subcategory of targeted policies outcomes refers to variables that measure the degree of government-induced efforts in favour of the natural environment and that do not require considerable alterations in collective behaviours from the civil society. For the baseline analysis, we focus our attention on three outcomes: *Biome protection, Species protection* and *Protected areas* for which data are available through EPI.

The biome protection indicator measures the share of each biome that lies within a protection area.[5] A score of 100 is assigned to countries that place at least 17 percent of each of their biome types under protection. The latter figure corresponds to the protection level prescribed by the Aichi Target 11 of the Convention on Biological Diversity that 193 countries participated in (Zafra-Calvo et al., 2019).

Additionally, we include *Species protection* which measures the overlap between a country's terrestrial protected areas and the ranges of its plant, vertebrate and invertebrate species. A score of 100 signifies full coverage of all terrestrial species' ranges by national protected areas whilst a score of 0 implies no overlap. Similarly, protected areas representativeness index (PARI), hereafter referred to as *Protected areas* estimates the extent to which a country's ecological diversity is represented in its terrestrial protected areas. A score of 100 indicates close-to-perfect protected areas pepresentativeness; by contrast, a score of 0 indicates low representativeness (i. e., less than 5th percentile of values).

There is also considerable variation across the sample with regards to targeted policies, ranging from a minimum possible value of 0 to 100 for both biome and species protection indices. In 1995, three countries were assigned a score of zero regarding *Biome protection*; these were El Salvador, the United Arab Emirates and Iraq. The latter country received this score over multiple years and also obtained the lowest score when considering *Species protection* in 1995. By 2018, no country received a null score for *Species protection*.

At the onset of the period studied, only Denmark scored perfectly on the latter index; by the year 2018, 8 countries were assigned the highest score, namely Belgium, Denmark, Estonia, Hungary, Poland, Slovakia, Slovenia and the United Kingdom. This ecological trend was also observed for the biome protection index; in 1995, 5 countries received a score of 100, these were Japan, Malaysia, Poland, Senegal and Zambia. By 2018,

[5] Biomes are defined as ecological regions with distinct vegetation, climate and ecophysiology such as dry tropical forests and continental semideserts (Mucina, 2019). To produce scores, EPI uses the MAP of Life from the World Database on Protected Areas and measures the share of each biome within a country that is categorised as a protected area. Prevalent biomes are given smaller weights compared to more scarce ones, the proportions are aggregated into a 0–100 score.

25 countries had perfect biome protection, including Latvia, Morocco, Namibia and Slovakia.

Land Use

We consider three land use variables: *Forest land*, *Meadow land*, and *Crop land*, each measured as a share of total country area. Forests support biodiversity and are beneficial for ecosystems (Gibson et al., 2011), while croplands are linked to environmental degradation through biodiversity loss (Molotoks et al., 2020). Meadows and pastures have mixed effects, offering plant diversity but also contributing to environmental stress through cattle grazing. As these outcomes stem largely from land use and policy, with limited direct public involvement, they are classified as nature-concerning. Data come from Povitkina et al. (2021), based on FAO (2020).

There is substantial heterogeneity in the sample; the country with the smallest share of forest land is Qatar with a null value over the 2000–2018 period. By contrast, Suriname was the country with the highest share, estimated at 98.46 percent in 1995 and 1996. Djibouti has the smallest share of cropland in the sample, consistently estimated at 0.09 between 2013 and 2018, compared to a sample maximum of 68.26 for Bangladesh in both 1998 and 1999.

Control Variables

Using the WDI dataset, we control for total population expressed in millions (*Total population*). Larger populations may exert additional pressure on the environment through increased demand for extractive resources and intensified urbanisation. Consistently with the environmental performance literature (e. g., Esty and Porter, 2001; Fiorino, 2011; Lau et al., 2014), we also include the natural logarithm of Gross Domestic Product per capita (*Log of GDP per capita*) and *Institutional quality* measured per V-DEM's rule of law index (Coppedge et al., 2021). Additionally, we account for climate-related covariates, namely average yearly temperatures and rainfall as well as CO2 emissions per capita using data compiled in the Quality of Government Environmental Indicators Dataset Povitkina et al. (2021).[6]

Table 1.1 below presents the descriptive statistics for a sample of 140 countries. The panel has 2,173 observations for the variables *Transport CO2* and *Building CO2* and 3,262

[6] The original sources are Crippa et al. (2020), Harris et al. (2020) and World Bank (2020).

observations for all the other variables. The average total population over the period considered is 44.21 million. The mean of *log of GDP per capita* is 9.01 corresponding to an average annual per capita GDP of 8,184 in constant 2017 USD. The *Institutional quality* variable, measured on the 0–1 scale, is 0.54, hence suggesting a rather even representation of institutional quality in the sample.

Table 1.1: Descriptive statistics – Baseline sample

Variable	Description	Mean	SD	Min	Max	Count
Main independent variable						
OADR	Age dependency ratio, old (% of working-age population	11.33	7.45	0.80	34.96	3262
Action-requiring dependent variables						
Recycling	Share of recyclable post-consumer material	18.31	12.71	0.86	66.88	3262
Transport CO2	CO2 emissions from transport (% of total fuel combustion)	32.06	17.55	1.90	96.97	2173
Building CO2	CO2 emissions from residential buildings and commercial and public services (% of total fuel combustion)	10.42	7.33	0.11	39.66	2173
Nature-concerning dependent variables						
Biome protection	Terrestrial biome protection (national)	57.53	33.69	0.00	100.00	3262
Species protection	Species protection index	68.42	27.66	0.00	100.00	3262
Protected areas	Protected areas representativeness index	25.44	16.74	0.00	98.04	3262
Forest land	Forest land (% of Land area)	33.89	24.02	0.00	98.46	3262
Meadowland	Land under perm meadows and pastures (% of Land area)	22.79	18.62	0.07	83.22	3262
Cropland	Cropland (% of Land area)	18.29	15.77	0.09	68.26	3262
Controls						
Total population	Total population (in millions)	44.21	153.51	0.17	1392.73	3262
Institutional quality	Rule of law	0.54	0.30	0.03	1.00	3262
Log of GDP per capita	Natural logarithm of GDP per capita, PPP (constant 2017 international $)	9.01	1.19	6.15	11.56	3262
CO2 per capita	CO2 emissions per capita	4.40	6.06	0.02	56.04	3262
Rainfall	Annual average rainfall	94.66	67.06	1.17	412.36	3262
Temperature	Annual average temperature	18.46	8.35	-7.43	29.37	3262

Summary: This table presents descriptive statistics for the main variables used in the analysis. For each variable, we show the mean, standard deviation, minimum and maximum values as well as the number of observations.

1.4 Methodology

Our main specification relates population ageing to environmental outcomes:

$$Y_{it} = \alpha + \beta\Omega_{it} + \mathbf{X}_{it}\theta + \gamma_i + \lambda_t + \epsilon_{it} \tag{1.4.1}$$

Y_{it} represents the set of dependent variables on environmental outcomes as described in Section 1.3. Ω_{it} denotes the old-age dependency ratio (*OADR*) for country i at year t. This specification suggests that we are examining the contemporaneous effect of ageing on environmental outcomes. $\mathbf{X}_{it}$ is a vector of control variables. We also include country fixed effects, γ_i, to capture unobserved heterogeneity at the country level such as geography. λ_t is the vector of year fixed effects, capturing time-specific shocks such as the presence of a baby-boom generation across countries sampled or a shock affecting several countries in a particular year. Finally, ϵ_{it} is the country- and time-specific error term. We estimate this specification using ordinary least squares (OLS).

Although we control for many sources of unobserved heterogeneity by including time-varying control variables as well as country and year fixed effects, omitted variable bias and reverse causality could still render our regression results spurious. We are particularly concerned with reverse causality as environmental factors, especially pollution, are causally associated with increased deaths and deteriorated health outcomes (Fuller et al., 2022). This, in turn, could reduce life expectancy, thereby affecting population ageing.

To address these plausible endogeneity concerns, we adopt an instrumental variable (IV) strategy. We instrument population ageing using historical crude birth rates, following the approach adopted by Acemoglu and Restrepo (2022). Specifically, we employ the country-level birth rates 30 years prior using WDI data on crude birth rates per 1,000 people.

Intuitively, it is unlikely that historical birth rates varied across countries in anticipation of future environmental outcomes. Furthermore, it is reasonable to also assume that the IV satisfies the exclusion restriction implying that it only impacts environmental outcomes through contemporary values of the old-age dependency ratio. This is especially plausible when considering the large set of controls included in our analysis.

We employ a two-stage least squares (2SLS) estimation as our identification strategy.

The dependent variable of interest (i. e., the *OADR*) is first regressed on the instrumental variable (IV) along with all other control variables. This yields the fitted values of the *OADR* which are then used in the second stage estimation. The IV estimates are reported and further discussed in Section 1.5.2.

1.5 Empirical Findings

This section outlines both the OLS and the IV regression results pertaining to the relationship between population ageing and the two categories of environmental outcomes proposed, i. e., *action-requiring* and *nature-concerning*.

1.5.1 Ordinary Least Squares Estimation

Action-Requiring Environmental Outcomes

Table 1.2 shows the OLS estimates for equation (1) pertaining specifically to action-requiring environmental outcomes i. e., recycling rates as well as the CO2 emissions from transportation and building activities. All specifications include both year and country fixed effects in addition to the controls described in Section 1.3. The estimated coefficient on the *OADR* when considering recycling rates as a dependent variable, shown in column (1), is negative and significant at the 1-percent significance level. It indicates that a 1 percent increase in the share of the elderly relative to the working population, corresponding to a 1 unit increase in the *OADR*, is matched with a 0.089 percentage point decrease in recycling rates. In Finland, the *OADR* increased from 21.40 in 1995 to 34.96 in 2018, representing a rise of 13.56 units over this period. Accordingly and holding all else constant, the model predicts that this change in population ageing is associated with a 1.21 percentage point decrease in the proportion of recycled waste.

From column (2) of Table 1.2, the coefficient estimate on the *OADR* for *Transport CO2* is 0.202 and significant at the 5 percent significance level. This suggests that a one unit increase in our ageing measure is associated with an increase of 0.202 units in per capita CO2 emission from transportation activities relative to total fuel combustion. Finally, the results shown in column (3) demonstrate that there is no significant association between population ageing and CO2 emissions from building activities.

Overall, population ageing appears not to foster action-requiring environmental efforts. Plausibly, this may be consistent with the presence of habit inertia where ageing countries, displaying a higher share of elderly individuals, fail to adopt novel collective behaviours to preserve their natural environment.

Nature-Concerning Environmental Outcomes

Table 1.3 shows that population ageing significantly increases pro-environmental outcomes for both targeted policies and land use variables. From columns (1), (2) and (3), holding everything else constant, a 1 unit increase in the *OADR* is associated with respective changes of 1.285, 0.645 and 0.898 in *Biome protection*, *Species protection* and *Protected areas*. Furthermore, all the coefficient estimates are significant at the 1 percent significance level. Considering again the example of Finland, the model predicts that *ceteris paribus*, the change of 13.56 in the *OADR* over the period studied is matched with an increase of 17.43, 8.75 and 12.18 in *Biome protection*, *Species protection* and *Protected areas*, respectively.

Turning to land use outcomes, we find results that further corroborate the pro-environmental effect of population ageing on nature-concerning outcomes. From column (4) of Table 1.3, it is revealed that population ageing is positively associated with the share of forest land with a coefficient estimate of 0.324. From columns (5) and (6), a one unit increase in the old-age dependency ratio is associated with a 0.104 decrease in the share of meadow and pasture relative to the total land area and a 0.472 decrease in the share of cropland. These results seem to corroborate the proposition that population ageing has a pro-environmental impact on nature-concerning outcomes.

Table 1.2: Population ageing and *action-requiring* environmental outcomes (OLS)

	(1) Recycling	(2) Transport CO2	(3) Building CO2
OADR	-0.089***	0.202**	-0.026
	(0.011)	(0.102)	(0.062)
Total population	0.003**	-0.024***	-0.020***
	(0.001)	(0.006)	(0.004)
Institutional quality	0.249	5.514***	-1.576
	(0.178)	(1.517)	(1.118)
Log of GDP per capita	3.354***	2.088*	1.808***
	(0.129)	(1.199)	(0.600)
Rainfall	0.002***	0.024***	0.008*
	(0.001)	(0.009)	(0.005)
Temperature	0.002	0.796***	-0.621***
	(0.030)	(0.212)	(0.153)
CO2 emissions per capita	-0.017	-0.477***	-0.041
	(0.014)	(0.070)	(0.045)
Year fixed effects	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes
Observations	3262	2173	2173
Adjusted R-squared	0.998	0.930	0.876

Summary: OLS estimates of the relationship between population ageing and action-requiring environmental outcomes, namely Recycling, Transport CO2 and Building CO2. The regression results indicate the absence of a pro-environmental effect of population ageing on these specific outcomes. The analysis controls for total population, institutional quality, natural logarithm of GDP per capita, average yearly rainfall and temperatures as well as CO2 emissions per capita. All regressions include both year and country fixed effects.
Notes: (i) OADR is the ratio of the elderly population (aged 65 and above) to the working population (aged 15 to 64) (ii) standard errors are clustered at country and year level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 1.3: Population ageing and *nature-concerning* environmental outcomes (OLS)

	Targeted policies			Land use		
	(1) Biome protection	(2) Species protection	(3) Protected areas	(4) Forest land	(5) Meadows land	(6) Crop land
OADR	1.285***	0.645***	0.898***	0.324***	-0.104***	-0.472***
	(0.201)	(0.130)	(0.057)	(0.019)	(0.039)	(0.039)
Total population	-0.114***	-0.057***	-0.044***	0.003*	0.002	0.004**
	(0.012)	(0.006)	(0.005)	(0.002)	(0.001)	(0.002)
Institutional quality	16.119***	12.913***	2.012*	-1.487***	-0.457	0.871
	(2.397)	(1.627)	(1.090)	(0.480)	(0.538)	(0.668)
Log of GDP per capita	2.999*	2.378**	0.152	0.579**	0.591*	-0.819***
	(1.723)	(1.149)	(0.318)	(0.244)	(0.303)	(0.262)
Rainfall	0.003	0.011	-0.002	0.001	0.001	0.004*
	(0.012)	(0.008)	(0.006)	(0.003)	(0.002)	(0.002)
Temperature	0.528	0.046	-0.065	0.217***	-0.130	-0.290***
	(0.585)	(0.337)	(0.164)	(0.061)	(0.108)	(0.108)
CO2 emissions per capita	-0.696***	-0.324**	0.160***	-0.014	-0.024	0.100***
	(0.252)	(0.152)	(0.058)	(0.018)	(0.035)	(0.029)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3262	3262	3262	3262	3262	3262
Adjusted R-squared	0.890	0.935	0.949	0.996	0.989	0.983

Summary: This table presents OLS estimates of 'the relationship between population ageing and nature-concerning environmental outcomes which are decomposed into targeted policies and land use variables; the regression results indicate the presence of a pro-environmental effect of population ageing on these outcomes. The analysis controls for total population, institutional quality, natural logarithm of GDP per capita, average yearly rainfall and temperatures as well as CO2 emissions per capita. All regressions includes both year and country fixed effects.
Notes: (i) OADR is the ratio of the elderly population (aged 65 and above) to the working population (aged 15 to 64) (ii) standard errors are clustered at country and year level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

1.5.2 Instrumental Variable Estimation

Since there are some gaps in the data for the variables *Transport CO2* and *Building CO2*, we characterise two distinct panels to implement our instrumental variable estimation. First, *Sample A* which is defined by all observations from the baseline sample excluding *Transport CO2* and *Building CO2*. Second, *Sample B* which is bound by observations for the variables *Transport CO2* and *Building CO2* outcomes.

The first-stage regression results are presented in columns (1) and (2) in Table **??** and in column (1) in Table 1.5. The coefficient estimates are -0.142 and -0.104 for *Sample A* and *Sample B*, respectively, and are significant at the 1 percent significance level, thus providing confidence in the fulfilment of the relevance condition.

The second stage results pertaining to action-requiring environmental outcomes are shown in columns (3), (4) and (5) of Table **??**. For *Recycling*, the IV coefficient is estimated at -0.037 and is insignificant at the 10 percent significance level, suggesting that the significance observed in the OLS estimation may have been driven by omitted variable bias or reverse causality.

For Transport CO2, the IV results reveal a significant and negative effect estimated at -2.773, in sharp contrast to the OLS coefficient of 0.202 which implied a positive association. The IV results suggest that population ageing is associated with a reduction in transport-related emissions. This finding may reflect shifts in mobility patterns and is consistent with the observation made by the European Environment Agency 2025 which suggest that older populations demand fewer transportation services. In the case of CO2 emissions from building operations, the IV coefficient, estimated at 0.059, is not statistically significant, consistently with the OLS result.

Overall, the second stage estimation results confirm the findings of the OLS estimation which suggest that, holistically, population ageing does not have a clear effect on action-requiring environmental outcomes.

The second-stage IV results for nature-concerning outcomes highlight substantial pro-environmental effects of population ageing. For *Biome protection*, the IV coefficient is 3.091 and is considerably larger than the corresponding OLS estimate of 1.285, indicating that the baseline model underestimated the effect of interest. This result implies that a one-unit increase in the *OADR* leads to a 3.091 unit increase in the proportion of biomes under protection. Similarly, the IV coefficient is estimated at 4.256 when considering *Species protection* and is also larger in magnitude than to the OLS counterpart. The IV estimate suggests that a 1 percent increase in the share of the elderly relative to the working population, i. e., a 1 unit increase in the *OADR* results in a 4.256 unit increase in the Species Protection Index. Finally, for *Protected areas*, the IV coefficient is significant at the 1 percent significance level and estimated at 2.644 which is also considerably larger than the OLS estimate of 0.898.

The findings of the IV estimation show that population ageing has a positive and significant effect on the share of forest land. Furthermore, the IV estimate of 0.836 is larger than that obtained under OLS which was estimated at 0.324. Similarly, the IV regression result further establishes the negative effect of population ageing on the share of cropland, with an IV estimate of -1.055. This IV coefficient is also larger in magnitude than its OLS counterpart, estimated at 0.472. Finally, for *Meadow land*, the IV coefficient is insignificant at the 10 percent significance level, in contrast to the OLS estimate, which was statistically significant. Since *Meadow land* has an ambiguous ecological role, falling between conservation and agricultural use, its lack of significance does not weaken the broader finding that population ageing has a pro-environmental effect on nature-concerning outcomes.

Overall, the results of the instrumental variable (IV) approach confirm the differential impact of population ageing on action-requiring and nature-concerning environmental outcomes. Specifically, the impact of ageing on nature-concerning environmental outcomes is unanimously pro-environmental. By contrast, there is an equivocal relationship between population ageing and the category of action-requiring environmental outcomes.

Summary: This table combines the first and second-stage IV regression results for action-requiring environmental outcomes. Columns (1) and (2) present the results for the first stage showing the relationship between historical crude birth rates (instrument) and population ageing (OADR). Sample A is delimited by observations of all environmental outcomes bar Transport CO2 and Building CO2. Sample B is delimited by observations on Transport CO2 and Building CO2. Columns (3), (4) and (5) show the second stage IV estimation results of the relationship between population ageing and action-requiring environmental outcomes; it further establishes the equivocal relationship between population ageing and this category of variables. All models control for total population, institutional quality, average rainfall and temperature, CO2 per capita and log of GDP per as well as time and country fixed effects. *Notes:* (i) Historical crude birth rates are 30-year lags on births per 1,000 people; (ii) standard errors are clustered at the country and year levels; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 1.5: Population ageing and *nature-concerning* environmental outcomes (IV approach)

	First Stage	Second Stage					
	(1) Sample A	(2) Biome Protection	(3) Species Protection	(4) Protected Areas	(5) Forest Land	(6) Meadows Land	(7) Crop Land
Historical crude birth rates	-0.142***						
	(0.013)						
OADR (predicted)		3.091***	4.256***	2.644***	0.836***	0.049	-1.055***
		(0.905)	(0.531)	(0.281)	(0.106)	(0.108)	(0.139)
Total population	-0.009***	-0.101***	-0.033***	-0.032***	0.006***	0.003**	0.000
	(0.002)	(0.016)	(0.009)	(0.006)	(0.002)	(0.001)	(0.003)
Institutional quality	-0.469*	16.641***	14.144***	2.758**	-1.307**	-0.408	0.727
	(0.269)	(2.505)	(1.767)	(1.182)	(0.513)	(0.538)	(0.702)
Log of GDP per capita	0.668***	1.802	0.181	-1.177***	0.273	0.508*	-0.531*
	(0.205)	(1.897)	(1.236)	(0.414)	(0.274)	(0.302)	(0.291)
Rainfall	0.002*	-0.001	0.004	-0.005	0.000	0.001	0.005**
	(0.001)	(0.013)	(0.009)	(0.006)	(0.003)	(0.002)	(0.002)
Temperature	0.556***	-0.444	-1.935***	-1.004***	-0.063	-0.216*	0.030
	(0.071)	(0.781)	(0.474)	(0.247)	(0.089)	(0.120)	(0.137)
CO2 emissions per capita	-0.126***	-0.601**	0.091	0.376***	0.048**	-0.009	0.030
	(0.035)	(0.273)	(0.162)	(0.085)	(0.022)	(0.039)	(0.036)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3231	3231	3231	3231	3231	3231	3231
Adjusted R-squared	0.973	0.889	0.936	0.946	0.996	0.989	0.982

Summary: This table combines the first and second-stage IV regression results for action-requiring environmental outcomes. Columns (1) presents the results for the first stage showing the relationship between historical crude birth rates (instrument) and population ageing (OADR). Columns (2) through (7) show the second stage IV estimation results of the relationship between population ageing and action-requiring environmental outcomes. The results further establish the presence of a pro-environmental effect of population ageing on this category of variables. All models control for total population, institutional quality, average rainfall and temperature, CO2 per capita and log of GDP per as well as time and country fixed effects.

Notes: (i) Historical crude birth rates are 30-year lags on births per 1,000 people; (ii) standard errors are clustered at the country and year levels; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

1.6 Ageing and Environmental Attitudes

The findings in Section 1.5 demonstrate a differential effect of population ageing on environmental outcomes per the classification proposed in this study. We defined action-requiring environmental outcomes as a category of environmental variables that requires engagement from the population. By contrast, we suggested that nature-concerning environmental outcomes require relatively little participation from the population.

Since pro-environmental concerns and related efforts are a relatively new phenomenon, we conjectured that the elderly are perhaps less likely to adopt them, ultimately resulting in weaker action-requiring environmental outcomes at the country-level. We extended this reasoning and hypothesised that since individual ageing is positively associated with attachment to nature (e.g., Hughes et al., 2019; Richardson et al., 2019), then perhaps population ageing fosters nature-concerning environmental outcomes.

Overall, our results suggested that population ageing, at the country level, has a pro-environmental effect on nature-concerning outcomes and no clear impact on action-requiring counterparts. A cursory interpretation of the aforementioned results would imply that individual ageing improves concern for the natural environment and has no effect on action-requiring environmental attitudes, in line with our intuition. However, a group-level association does not systematically identify a similar relationship at the individual level; the latter error is known as the ecological fallacy (e.g., Robinson, 1950; Selvin, 1958). In this section, we explore the relationship between ageing, both individual and population (i. e., societal), and environmental attitudes.

1.6.1 Data

We explore the relationship between societal ageing and environmental attitudes using data from the Integrated Values Survey (IVS) covering respondents from 68 countries (listed in Table 1.B.1 shown in the Appendix) over the 2005–2016 period. We identify two dependent variables that are relevant for our analysis: *Importance of environment* and *Environmental organisation membership*. These align conceptually with the broad categories of action-requiring and nature-concerning environmental outcomes.

Importance of environment serves as a proxy for individual subjective attachment to the environment and is measured on a 6-point scale with higher values representing stronger attachment. Since it does not require individual active engagement, this variable is conceptually similar to nature-concerning environmental outcomes that also, per our definition, do not rely on the participation of the population.

Environmental organisation membership captures the degree of participatory effort for the environment at the individual level. For this variable, a value of 0 is assigned to respondents that are not members of an environmental organisation while 1 and 2 denote inactive and active memberships, respectively. This individual-level variable serves as a counterpart for country-level action-requiring environmental outcomes which demand active engagement and participation.

First, we examine the effect of population ageing on environmental attitudes by including the *OADR* as an independent variable in our regression analysis. The model incorporates the same controls used in the country-level analyses, namely *Total population*, *Institutional quality*, *Log of GDP per capita*, *Rainfall* and *Temperature*, as well as *CO2 emissions per capita*. Additionally, we include the following individual-level covariates: *Sex*, *Age*, *Marital status*, *Employment status*, *Educational level*, and subjective income level, referred to as *Income level*. Second, we investigate the relationship between individual ageing and environmental attitudes by incorporating age dummies into the regression analysis. The regression analyses also include both country fixed effects as well as time dummies capturing the survey year.

Table 1.6 displayed below presents the descriptive statistics for the individual-level variable used in the analysis. The average score of 4.52 for *Importance of environment* suggests a rather high attachment to the environment from respondents in the sample. By contrast, the mean value for *Environmental organisation membership* is 0.15, indicating low participatory effort for the environment.

There are 124,615 respondents in the sample of which 63, 973 are female and 60,642 are male. 68, 724 respondents are married and 41,895 work full-time, retirees account for 12.7 percent of the sample with a total count of 15, 785. Most respondents, i. e., 80, 317, completed at least secondary school education and 75, 333 report a medium subjective income level.

Table 1.6: Descriptive statistics – Environmental attitudes sample

Description	Mean	SD	Min	Max	Count
Importance of environment (i. e., it is important to this person looking after the environment)	4.52	1.26	1.00	6	124615
Environmental organisation membership (i. e., Active /Inactive membership of environmental organisation)	0.15	0.45	0.00	2	124615
Sex	1.51	0.50	1.00	2	124615
Age	41.0 3	16.28	15.00	98	124615
Marital status	2.75	2.20	1.00	6	124615
Employment status	3.37	2.18	1.00	8	124615
Educational level	4.83	2.19	1.00	8	124615
Income level	1.84	0.61	1.00	3	124615

Summary: This table presents descriptive statistics for the main variables used in the analysis. For each variable, we show the mean, standard deviation, minimum and maximum values as well as the number of observations.

1.6.2 Methodology

We examine the relationship between ageing and individual environmental attitudes by considering two distinct dimensions: population ageing at the societal level and individual ageing. This dual approach enables us to differentiate between the broader contextual effects of living in an ageing society and the specific effects associated with individual ageing.

We use the following specification to study the relationship between population ageing and individual environmental attitudes:

$$Y_{jit} = \alpha_1 + \beta_1 \Omega_{jit} + \mathbf{Z}_{jit}\theta_1 + \gamma_i + \lambda_t + \epsilon_{jit} \tag{1.6.1}$$

Y_{jit} denotes the environmental attitudes of individual j residing in country i at year t. Ω_{jit} is our population ageing variable and represents the old-age dependency ratio ($OADR$). $\mathbf{Z}_{jit}$ encompasses both individual and country-level control variables, as described in Section 1.6.1. Finally, γ_i and λ_t are country and survey year fixed effects, respectively.

To analyse the relationship between individual ageing and environmental attitudes, we extend the specification to include age dummies:

$$Y_{jit} = \alpha_2 + \beta_2 \Omega_{jit} + \sum_{a=2}^{A} \eta_a D_{ja} + \mathbf{Q}_{jit}\theta_2 + \gamma_i + \lambda_t + \epsilon_{jit} \tag{1.6.2}$$

D_{ja} represents age group dummies and captures whether individual j belongs to age group a. The age groups used in the analysis are: 25–34, 35–44, 45–54, 55–64 and *Above* 65; our reference category is 15–24. Here, we replace the continuous age variable to study non-linear effects of age on environmental attitudes. Consequently, the vector of controls, $\mathbf{Q}_{jit}$, is the same as $\mathbf{Z}_{jit}$ except that it excludes the variable *Age*.

1.6.3 Empirical Findings

This subsection presents the findings on the relationship between societal ageing and individual ageing with environmental attitudes.

Societal Ageing

Table 1.7 reports estimates of the effect of population ageing on the variables *Importance of environment* and *Environmental organisation membership*. Columns (1) and (2) only include the OADR of the country of residence, country-level controls as well as country and survey year fixed effects. In the subsequent columns, we add the individual-level covariates described above.

When considering *Importance of environment* as a dependent variable, the coefficient estimates on the *OADR*, displayed in columns (1) and (3), are not statistically significant. This implies that living in an ageing society is not associated with subjective attachment to the environment. Of interest, as shown in column (3), the coefficient estimate on *age* is positive and significant at the 1 percent significance level. The estimate indicates that each additional year of age is associated with a 0.007 unit increase in the variable *Importance of environment*.

Columns (2) and (4) of Table 1.7 show that the coefficient on the *OADR* is negative and significant at the 1 percent significance level when evaluating *Environmental organisation membership*. This implies that societal ageing decreases individual participatory effort for the environment. In particular, from column (4), the point estimate shows that a 1 unit increase in the *OADR* of the country of residence is associated with a 0.028 unit decrease in the environmental organisation membership index.

Table 1.B.2 in the Appendix shows the results with displayed coefficient estimates for the country-level controls.

Table 1.7: Societal ageing and environmental attitudes (OLS)

	(1) Importance of environment	(2) Environmental organisation membership	(3) Importance of environment	(4) Environmental organisation membership
OADR	-0.036	-0.027***	-0.042	-0.028***
	(0.027)	(0.007)	(0.028)	(0.007)
Sex			0.060***	-0.012***
			(0.012)	(0.004)
Age			0.007***	0.000**
			(0.001)	(0.000)
Marital status			-0.012***	-0.000
			(0.003)	(0.001)
Employment status			0.005*	-0.004***
			(0.003)	(0.001)
Educational level			0.031***	0.011***
			(0.003)	(0.001)
Income level			-0.012	0.020***
			(0.015)	(0.005)
Country fixed effects	Yes	Yes	Yes	Yes
Survey year fixed effects	Yes	Yes	Yes	Yes
Observations	124615	124615	124615	124615
Adjusted R-squared	0.101	0.096	0.110	0.101

Summary: The table presents the results of the OLS estimation of the relationship between country-level ageing and individual environmental attitudes. It demonstrates that population ageing has no significant effect on subjective attachment to the environment (*Importance of environment)* and has a negative effect on participatory effort for the environment (*Environmental organisation membership*). All specifications include country-level controls: total population, institutional quality, log of GDP per capita, annual rainfall and temperature levels as well as CO2 emissions per capita. The individual level controls, age, sex, marital status, employment status and educational level are only included in the specifications shown in columns (3) and (4). All regressions feature country and survey year fixed effects.

Notes: (i) OADR is the ratio of the elderly population (aged 65 and above) to the working population (aged 15 to 64) (ii) standard errors are clustered at country and year level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Individual Ageing

The estimated coefficients on the different age groups shown in column (1) of Table 1.8 indicate that individual ageing is an important determinant of subjective attachment to the environment. The effect strengthens with age, with all age groups displaying a positive and significant association compared to the reference group, 15–24. The coefficient increases from 0.046 for individuals aged 25–34 to 0.121 for those aged 35–44, 0.183 for the 45–54 age group, and 0.270 for those aged 55–64. The largest effect is observed for individuals aged *Above* 65, with a coefficient of 0.349, suggesting a stronger attachment to the environment among older respondents. By contrast, column (2) does not reveal clear differences in *Environmental organisation membership* across the age groups considered.

It is plausible that the aforementioned results are driven by cohort effects, hence resulting in generation-specific differences. This could be due to the presence of formative large-scale experiences such as wars, school curricula or specific policies. To untangle those effects from individual age, we include cohort fixed effects in the analysis and report the results in columns (3) and (4) of Table 1.8.

Column (3) of Table 1.8 shows that, overall, accounting for cohort fixed effects reduces the estimated coefficients on the age groups for the variable *Importance of environment*. The only exception is the 25–34 group, where the coefficient increases slightly from 0.046 to 0.047. The highest coefficient is observed for the 55–64 group at 0.167, followed by the *Above* 65 age group at 0.164. The coefficients for the other age groups also decline but remain substantial, with the estimate for 35–44 decreasing to 0.097 and for 45–54 to 0.131. These regression results further establish the findings that individual ageing is associated with stronger subjective attachment to the environment.

In contrast, the results for *Environmental organisation membership* shown in column (3) remain largely unchanged. The coefficient estimates for all age groups are close to zero and statistically insignificant, providing no evidence that individual ageing increases participatory effort for the environment. Instead, the negative and significant coefficient on *OADR* suggests that the decline in *Environmental organisation membership* is driven by population ageing at the societal level.

In this section, we document a distinct relationship between ageing and environmental attitudes. Our results showed that subjective importance of the environment (i. e., *Importance of environment*) is positively associated with individual ageing, and not by societal ageing. By contrast, we found that individual ageing has no statistically significant association with participatory effort for the environment, proxied by *Environmental organisation membership*, and that the latter is determined by societal (population) ageing. Our results suggested that increasing ageing at the societal level reduces participatory effort for the environment. Table 1.B.3 in the Appendix reports the results with displayed coefficients for country-level controls.

Table 1.8: Societal ageing, individual ageing and environmental attitudes (OLS)

	(1) Importance of environment	(2) Environmental organisation membership	(3) Importance of environment	(4) Environmental organisation membership
OADR	-0.042	-0.029***	-0.040	-0.028***
	(0.028)	(0.007)	(0.028)	(0.007)
Respondents' age groups				
25-34	0.046**	-0.002	0.047**	-0.000
	(0.021)	(0.006)	(0.021)	(0.007)
35-44	0.121***	0.007	0.097***	0.009
	(0.020)	(0.007)	(0.029)	(0.010)
45-54	0.183***	0.018**	0.131***	0.014
	(0.024)	(0.007)	(0.037)	(0.012)
55-64	0.270***	0.013	0.167***	0.002
	(0.030)	(0.008)	(0.045)	(0.014)
Above 65	0.349***	0.014	0.164***	-0.007
	(0.032)	(0.010)	(0.052)	(0.018)
Country FE	Yes	Yes	Yes	Yes
Survey year FE	Yes	Yes	Yes	Yes
Cohort FE	No	No	Yes	Yes
Observations	124615	124615	124615	124615
Adjusted R-squared	0.110	0.101	0.111	0.101

Summary: The table presents the results of the OLS estimation of the relationship between ageing and individual attitudes towards the environment. It shows that country-level population ageing has no significant effect on subjective attachment to the environment (*Importance of environment*) and has a negative impact on participatory effort for the environment (*Environmental organisation membership*). Furthermore, the regression results show significant differences in subjective attachment to the environment across age groups. All specifications include country-level controls: total population, institutional quality, log of GDP per capita, annual rainfall and temperature levels as well as CO2 emissions per capita as well individual level controls, age, sex, marital status, employment status and educational level. Specifications presented in column (3) and (4) also include cohort fixed effects. All regressions feature country and survey year fixed effects.
Notes: (i) Omitted age category is *Below* 24. (ii) OADR is the ratio of the elderly population (aged 65 and above) to the working population (aged 15 to 64) (iii) standard errors are clustered at country and year level; robust and clustered standard errors are reported in parentheses; (iv) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

1.7 Conclusion

In this paper, we explore the association between population ageing and the environment by proposing a novel classification of environmental outcomes which depends on the involvement of the population. We identify two categories of environmental outcomes, namely action-requiring and nature-concerning, where the former is defined as requiring considerably stronger engagement from the population relative to the latter. Our empirical analysis finds a distinct effect of population ageing on these two categories. Specifically, we establish that country-level population ageing has a pro-environmental effect on nature-concerning outcomes and no clear effect on action-requiring environmental outcomes. Using an instrumental-variable strategy, we confirmed the presence of a differential impact of population ageing on the two categories of environmental outcomes.

We also investigate the relationship between ageing (at the societal level through the *OADR* and individual ageing) and individual environmental attitudes. At this level, we uncover the presence of a distinct pattern where being a resident in a country with higher population ageing has a negative and statistically significant effect on individual participatory effort for the environment. By contrast, population ageing is found to have no effect on subjective attachment to the environment. Instead, the latter is driven by individual ageing with older age groups displaying higher attachment to the environment.

Our findings suggest several questions that future research ought to address. First, it is worthwhile to extend the analysis to identify the mechanisms that give rise to this differential impact of population ageing on environmental outcomes. One possible avenue would be through the effect that ageing may have on government expenditure. Perhaps population ageing puts significant strain on governments to provide costly public services such as pensions and healthcare. This, in turn, may reduce the funds needed to support action-requiring environmental outcomes such as investments in green infrastructure. It may also be the case that the elderly, who display a higher subjective attachment to the environment, support governments that are more prone to implement policies that preserve the natural environment. Finally, the results could be driven by the combined effect of the novelty of pro-environmental outcomes in the public sphere and the presence of habit inertia pertaining to pro-environmental behaviours. In that sense, the relatively high prominence of the elderly in ageing societies may be hindering the adoption of pro-environmental action at the individual level, thus resulting in the poor uptake of pro-environmental actions at the collective level.

Appendix

1.A Supplementary Figures

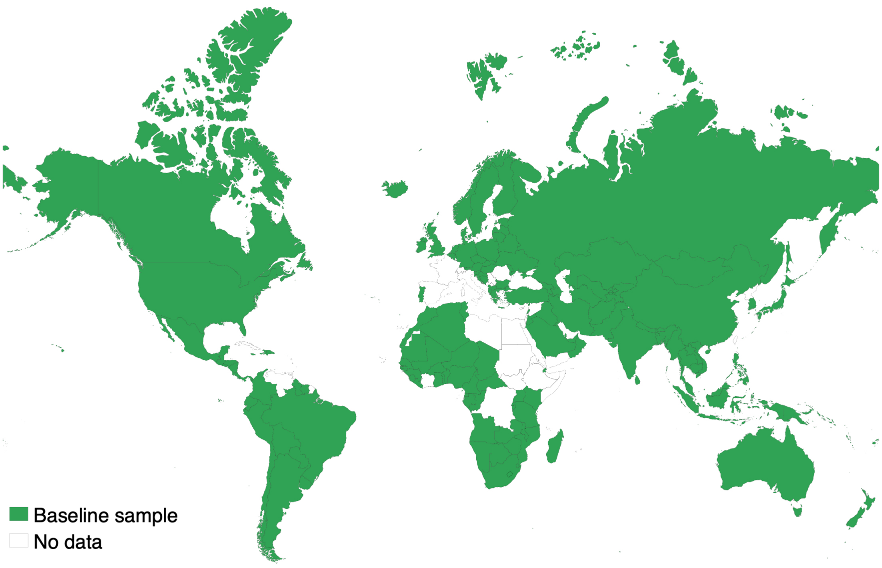


Figure 1.A.1: Countries in the baseline sample

1.B Supplementary Tables

Table 1.B.1: Countries in the environmental attitudes sample

Algeria	Armenia	Australia	Azerbaijan	Belarus
Brazil	Bulgaria	Burkina Faso	Canada	Chile
China	Colombia	Cyprus	Ecuador	Egypt
Estonia	Ethiopia	Finland	Georgia	Germany
Ghana	Haiti	Hungary	India	Indonesia
Iran (Islamic Republic of)	Iraq	Japan	Jordan	Kazakhstan
Kuwait	Kyrgyzstan	Lebanon	Libya	Malaysia
Mali	Mexico	Morocco	Netherlands	New Zealand
Nigeria	Norway	Pakistan	Peru	Philippines
Poland	Qatar	Republic of Korea	Republic of Moldova	Romania
Russian Federation	Rwanda	Singapore	Slovenia	South Africa
Sweden	Thailand	Trinidad and Tobago	Tunisia	Turkiye
Ukraine	United Kingdom	United States of America	Uruguay	Uzbekistan
Viet Nam	Zambia	Zimbabwe		

Table 1.B.2: Societal ageing and environmental attitudes (OLS) – All controls displayed

	(1) Importance of environment	(2) Environmental organisation membership	(3) Importance of environment	(4) Environmental organisation membership
OADR	-0.036	-0.027***	-0.042	-0.028***
	(0.027)	(0.007)	(0.028)	(0.007)
Sex			0.060***	-0.012***
			(0.012)	(0.004)
Age			0.007***	0.000**
			(0.001)	(0.000)
Marital status			-0.012***	-0.000
			(0.003)	(0.001)
Employment status			0.005*	-0.004***
			(0.003)	(0.001)
Educational level			0.031***	0.011***
			(0.003)	(0.001)
Income level			-0.012	0.020***
			(0.015)	(0.005)
Population	-0.005***	-0.006***	-0.004***	-0.006***
	(0.001)	(0.000)	(0.001)	(0.000)
Rule of law	0.769	-0.206	0.861	-0.158
	(0.732)	(0.205)	(0.705)	(0.202)
Log of GDP per capita	0.192	-0.187*	0.123	-0.223**
	(0.401)	(0.107)	(0.403)	(0.109)
Rainfall	0.006*	-0.001	0.006*	-0.001
	(0.003)	(0.001)	(0.003)	(0.001)
Temperature	0.168***	-0.028	0.156***	-0.023
	(0.059)	(0.018)	(0.059)	(0.017)
CO2 emissions per capita	0.018	-0.007	0.033	-0.001
	(0.047)	(0.017)	(0.046)	(0.015)
Country fixed effects	Yes	Yes	Yes	Yes
Survey year fixed effects	Yes	Yes	Yes	Yes
Observations	124615	124615	124615	124615
Adjusted R-squared	0.101	0.096	0.110	0.101

Summary: The table presents the results of the OLS estimation of the relationship between country-level ageing and individual attitudes towards the environment. It demonstrates that population ageing has no significant effect on subjective attachment to the environment (*Importance of environment*) and a negative effect on participatory effort for the environment (*Environmental organisation membership*). All specifications include country-level controls: total population, institutional quality, log of GDP per capita, annual rainfall and temperature levels as well as CO2 emissions per capita. The individual level controls, age, sex, marital status, employment status and educational level are only included in the specifications shown in columns (3) and (4). All regressions feature country and survey year fixed effects.

Notes: (i) OADR is the ratio of the elderly population (aged 65 and above) to the working population (aged 15 to 64) (ii) standard errors are clustered at country and year level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 1.B.3: Societal ageing, individual ageing and environmental attitudes (OLS) – All controls displayed

	(1) Importance of environment	(2) Environmental organisation membership	(3) Importance of environment	(4) Environmental organisation membership
OADR	-0.042	-0.029***	-0.040	-0.028***
	(0.028)	(0.007)	(0.028)	(0.007)
25-34	0.046**	-0.002	0.047**	-0.000
	(0.021)	(0.006)	(0.021)	(0.007)
35-44	0.121***	0.007	0.097***	0.009
	(0.020)	(0.007)	(0.029)	(0.010)
45-54	0.183***	0.018**	0.131***	0.014
	(0.024)	(0.007)	(0.037)	(0.012)
55-64	0.270***	0.013	0.167***	0.002
	(0.030)	(0.008)	(0.045)	(0.014)
Above 65	0.349***	0.014	0.164***	-0.007
	(0.032)	(0.010)	(0.052)	(0.018)
Sex	0.061***	-0.012***	0.061***	-0.012***
	(0.012)	(0.003)	(0.012)	(0.003)
Marital status	-0.013***	0.000	-0.013***	0.000
	(0.003)	(0.001)	(0.003)	(0.001)
Employment status	0.005	-0.004***	0.004	-0.004***
	(0.003)	(0.001)	(0.003)	(0.001)
Educational level	0.031***	0.011***	0.032***	0.011***
	(0.003)	(0.001)	(0.003)	(0.001)
Income level	-0.013	0.020***	-0.013	0.020***
	(0.015)	(0.005)	(0.015)	(0.005)
Population	-0.004***	-0.006***	-0.004***	-0.006***
	(0.001)	(0.000)	(0.001)	(0.000)
Rule of law	0.836	-0.160	0.887	-0.154
	(0.702)	(0.202)	(0.701)	(0.201)
Log of GDP per capita	0.129	-0.220**	0.126	-0.219**
	(0.402)	(0.109)	(0.401)	(0.108)
Rainfall	0.006*	-0.001	0.006*	-0.001
	(0.003)	(0.001)	(0.003)	(0.001)
Temperature	0.158***	-0.023	0.156***	-0.023
	(0.059)	(0.017)	(0.058)	(0.017)
CO2 emissions per capita	0.032	-0.001	0.033	-0.001
	(0.046)	(0.015)	(0.045)	(0.015)
Country FE	Yes	Yes	Yes	Yes
Survey year FE	Yes	Yes	Yes	Yes
Cohort FE	No	No	Yes	Yes
Observations	124615	124615	124615	124615
Adjusted R-squared	0.110	0.101	0.111	0.101

Summary: The table presents the results of the OLS estimation of the relationship between country-level ageing and individual attitudes towards the environment. It demonstrates that population ageing has no significant effect on subjective attachment to the environment (*Importance of environment*) and a negative effect on participatory effort for the environment (*Environmental orgnisation membership*). All specifications include country-level controls: total population, institutional quality, log of GDP per capita, annual rainfall and temperature levels as well as CO2 emissions per capita. The individual level controls, age, sex, marital status, employment status and educational level are only included in the specifications shown in columns (3) and (4). All regressions feature country and survey year fixed effects.

Notes: (i) OADR is the ratio of the elderly population (aged 65 and above) to the working population (aged 15 to 64) (ii) standard errors are clustered at country and year level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Chapter 2

Population Ageing, Economic Growth and the Composition of Government Expenditure

2.1 Introduction

Most economies in the 21st century have experienced population ageing, i. e., older individuals have become a proportionally larger fraction of the total population (Weil, 2008). This trend is predicted to last (Lutz et al., 2008). Indeed, recent estimates suggest that the global share of the population aged 65 and above was 10.21 percent in 2024 and will increase to 16.33 percent by 2050 (United Nations, Department of Economic and Social Affairs, Population Division, 2024). Population ageing is predicted to especially affect industrialised economies.

This paper develops and empirically tests an original political economy model in which population ageing leads to an older median voter who, under majority voting, influences the composition of government expenditure so that it crowds out private investment. The model generates three testable predictions, which we evaluate using data: (i) population ageing increases public elderly spending (as a share of output); (ii) it has no significant effect on productive expenditure (as a share of output); and (iii) it reduces the rate of economic growth. The empirical analysis provides strong support for all three predictions.

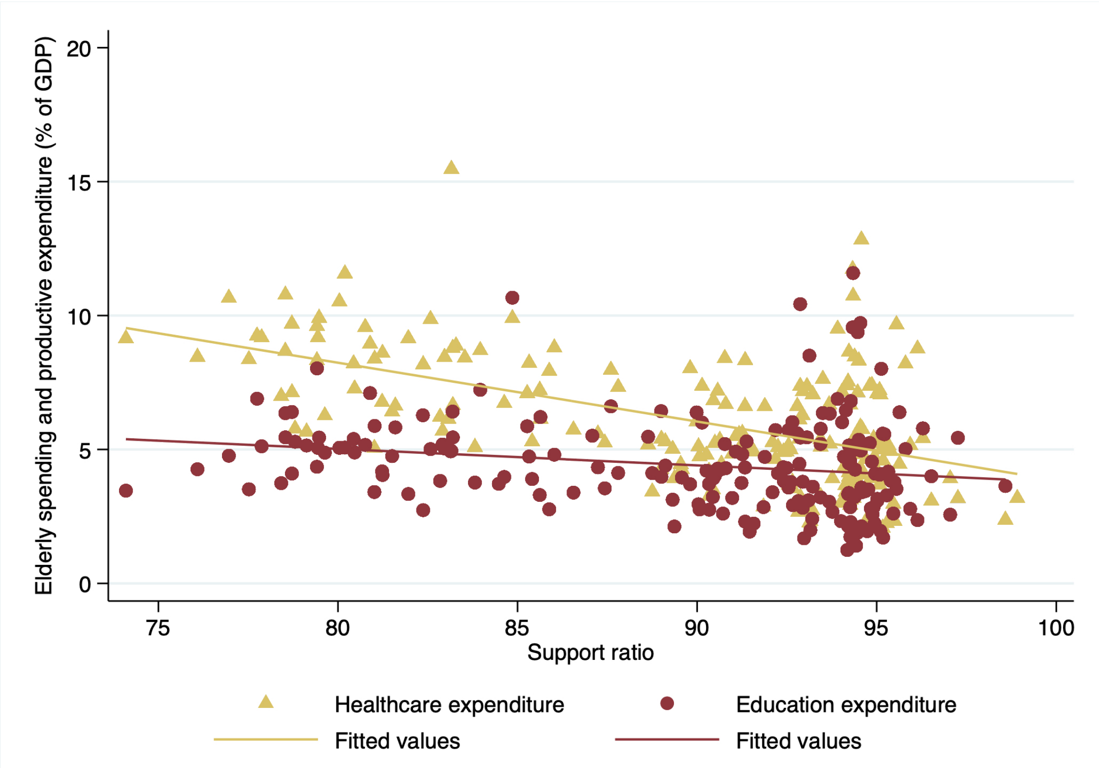
We capture a country's age structure through its support ratio, defined as the share of the population aged 15–64 relative to the population aged 15 and over. A declining support ratio indicates population ageing.[7] This measure has a natural counterpart in our theoretical analysis.

In the empirical analysis of the composition of government expenditure, we focus on two key categories: *elderly spending* and *productive expenditure*. The former directly benefits older individuals, for example through healthcare services, while the latter includes investments such as education that enhance the economy's overall productivity.

Figure 2.1.1 shows the association (time averages between 2000 and 2018) between population ageing, elderly spending, and productive expenditure across a sample of 181 countries over the period 2000–2018. We use healthcare expenditure as a proxy for elderly spending and education expenditure as a proxy for productive expenditure.

[7] To fix ideas, consider the actual and the predicted support ratios for Germany in 2022 and 2050. According to United Nations, Department of Economic and Social Affairs, Population Division (2022), these ratios are 0.74 and 0.65, respectively. Roughly, this implies that in 2022 three working members of the population had to support one economically dependent elderly whereas in 2050, two workers are expected to bear the same burden.

Figure 2.1.1: Elderly spending, productive expenditure and population ageing



[8]

Consistent with predictions (i) and (ii), the figure reveals a positive association between population ageing and elderly spending, while the link between population ageing and productive expenditure appears relatively weak.

We examine the three theoretical predictions empirically using regression analysis. First, we focus on the association between population ageing and the composition of government expenditure. For a sample of 30 OECD countries over the 2007–2018 period, we find that population ageing indeed increases elderly spending. By contrast, we find no support for an effect of population ageing on productive expenditure.

Second, we investigate the impact of elderly spending and productive expenditure on economic growth by employing various generalized method of moments (GMM) estimators on a baseline sample of 178 countries over the 2000–2018 period. Our findings suggest that healthcare expenditure, a proxy for elderly spending, reduces economic growth. This further corroborates the predictions of the theoretical model.

The remainder of this paper is organised as follows. Section 2.2 summarises the literature. Section 2.3 describes the economic framework and determines the economic as well as the political-economic equilibrium. The key predictions of the model are summarized in Corollary 1: (i) population ageing increases the share of elderly spending in total output, (ii) population ageing keeps the share of productive expenditure in total output unchanged, and (iii) population ageing reduces the economy's growth rate. Section 2.4 presents the empirical analysis. It describes the data, outlines the empirical methodology, and discusses the results. The empirical findings support predictions (i) - (iii). Section 2.5 concludes. The Appendix contains proofs, theoretical extensions and supplementary information for the empirical analysis.

2.2 Related Literature

The present paper contributes to at least three strands of the literature. The first concerns the relationship between population ageing and the composition of public expenditure. This literature is equivocal. For instance, Razin et al. (2002), Jäger and Schmidt (2016) and Tamai and Wang (2025) find that under democratic regimes, population ageing reduces public investment and welfare expenditure. In contrast, Disney (2007), Sanz and Velázquez (2007) and Kühnel (2011) report contradicting results. We depart from existing contributions by identifying two categories of public expenditure, that is elderly spending and productive expenditure. Moreover, for these categories, we explore a large set of subcategories. As to elderly spending, these include "old age" and "hospital services". As to productive expenditure, these encompass "tertiary education", "transport", "communication" and "R&D".

The second strand studies the role of government expenditure for endogenous economic growth. For example, building on the seminal work of Barro (1990), Angelopoulos et al. (2007) and Felice (2016) find that productive expenditure is positively associated with economic growth.[9] In contrast to this literature, our analysis emphasises the role of different government spending categories and their relation to the age distribution among voters.

Finally, we contribute to the literature on the relationship between population ageing and economic growth. Here, Lee and Shin (2019) show, using panel data analysis, that there is a negative and nonlinear effect of population ageing on economic growth. Studying population ageing in China, Liu et al. (2023) also demonstrate that ageing impedes growth by negatively impacting industrial structure upgrading.

[9] See Irmen and Kühnel (2009) for a survey of the literature on productive expenditure and economic growth in the spirit of Barro (1990).

Against these findings, Acemoglu and Restrepo (2017) argue that there is no direct relationship between population ageing and slow economic growth which they explain by an endogenous response of technology. Using panel data analysis, Bloom et al. (2010) find a modest negative effect of population ageing on economic growth. These authors also suggest that ageing-related demographic changes result in policy updates including increasing the legal age of retirement and behavioural amendments such as higher female labour participation to mitigate the growth impact of ageing.

Distinguishing between the underlying causes of ageing (i. e., lower fertility rates and higher longevity), Prettner (2013) and Iong (2019) reveal that higher longevity is growth-inducing whilst lower fertility is growth-impeding. Irmen (2021) shows that not only the source of ageing but also the time horizon determine the qualitative effect of population ageing on economic growth. Other studies including Fougère and Mérette (1999), Boucekkine et al. (2002), and Choi and Shin (2015) posit that ageing promotes economic growth through human capital accumulation and upskilling. In contrast to this strand of the literature, we emphasise the role of the composition of government expenditure for economic growth.

2.3 Theoretical Analysis

Consider a closed economy in continuous time, i. e., $t \in [0, \infty)$.[10] The economy is populated by a continuum of infinitely-lived household-producers of mass 1 and a government.

Each household-producer is represented by a unique real number $i \in [0, 1]$ and comprises $N^i > 0$ members, of which $L^i > 0$ are working young and the remaining $N^i - L^i$ are economically-dependent elderly. We use the support ratio $\phi^i \equiv L^i / N^i \in (0, 1]$ to capture i's age structure. Both, N^i and L^i, are time-invariant. Hence, the age structure of each household-producer is a given constant. This assumption seems particularly acceptable in our setup as we are not interested in the demographic evolution of individual household-producers over time but rather in shifts of the entire population age distribution in response to population ageing.

Household-producers behave competitively and produce one good that can be consumed or invested. At all t, prices are expressed in units of the contemporaneous output

[10] We shall often suppress the time argument in our notation whenever this does not cause confusion.

of this good. While all household members derive utility from private consumption, the elderly additionally benefit from public spending, e. g., on health care. The government taxes household-producers' income to finance the utility-enhancing public good as well as productive expenditure.

2.3.1 Production, Preferences and Government Policy

Production Technology At each t, household-producer i has access to the following production function

$$Y^i(t) = AK^i(t)^\alpha \left(G^i(t)L^i(t)\right)^{1-\alpha}. \tag{2.3.1}$$

Here, $Y^i(t)$ denotes i's output at t, $K^i(t)$ its private capital stock, $G^i(t)$ the flow of services it derives from total productive expenditure, and $L^i(t)$ its working young members. Moreover, $A > 0$ is the time-invariant total factor productivity, and $0 < \alpha < 1$ the output elasticity of capital.

The key feature of the production function (2.3.1) is constant returns to scale in private capital and public productive services. Thus, if K^i grows at the same rate as G^i then diminishing returns to the accumulation of private capital will be offset by growth in (labor-augmenting) public services. For this reason, the economy will exhibit endogenous steady-state growth.

For simplicity, private capital does not depreciate. The economy's total output at t, $Y(t)$, obtains from aggregation over all firms, i. e., $Y(t) = \int_0^1 Y^i(t)di$.

The production function (2.3.1) delivers household-producer i's output per worker at t as

$$y^i(t) \equiv \frac{Y^i(t)}{L^i} = Ak^i(t)^\alpha G^i(t)^{1-\alpha}, \tag{2.3.2}$$

where $k^i(t) \equiv K^i(t)/L^i$ denotes i's capital stock per worker.

The level of productive government services that household-producer i enjoys from aggregate productive expenditure at t, $G(t)$, is given by

$$G^i(t) \equiv G(t)\,\frac{y^i(t)}{y(t)}, \tag{2.3.3}$$

where $y(t) \equiv Y(t)/L$ is the economy's aggregate output per worker and $L \equiv \int_0^1 L^i di$ the economy's aggregate labor supply. Equation (2.3.3) describes a situation of relative congestion (see, e. g., Barro and Sala-í-Martin, 1992 or Turnovsky, 1996), i. e., the level of services household-producer i derives from the public good G at t depends on her own usage, represented by her own output per worker, relative to aggregate usage, represented by the economy's aggregate output per worker.[11]

In economic terms, (2.3.3) means that household-producers take the ratio of the aggregates, $G(t)/y(t)$, as given. Moreover, they understand that an expansion of $y^i(t)$ increases $G^i(t)$ and, hence, the productivity of both private inputs. The working young, $L^i(t)$, benefit from the labor-augmenting nature of $G^i(t)$, and private capital, $K^i(t)$, becomes more productive since both private inputs are complements. These features explain the difference between (2.3.2) and the following expression of output per worker as perceived by each household-producer i. Indeed, combining (2.3.2) and (2.3.3) gives

$$y^i(t) = A^{\frac{1}{\alpha}} \left(\frac{G(t)}{y(t)} \right)^{\frac{1-\alpha}{\alpha}} k^i(t). \tag{2.3.4}$$

Hence, for all i, production per worker has constant returns to the private input k^i as long as the government maintains a given state of congestion, i. e., as the long as the ratio G/y is constant. Moreover, the greater this ratio the greater is $y^i(t)$.

Consumer Preferences Household-producer i seeks to maximize her overall intertemporal utility given by

$$\begin{aligned} U^i(0) &\equiv \int_0^\infty \left[N^i \ln c^i(t) + (N^i - L^i) b \ln H(t) \right] e^{-\rho t}\, dt \\ &= N^i \int_0^\infty \left[\ln c^i(t) + (1 - \phi^i) b \ln H(t) \right] e^{-\rho t}\, dt; \end{aligned} \tag{2.3.5}$$

here, $c^i(t)$ denotes private consumption per household member at t, $H(t)$ aggregate public spending for the elderly at t, $b > 0$ measures the weight the elderly assign to public relative to private consumption goods, and $\rho > 0$ is the constant instantaneous

[11] The specification of congestion using per-worker magnitudes eliminates an undesirable scale effect in the accumulation path of household-producers. If the level of services derived by an individual household-producer depended on her own total output relative to the economy's aggregate output, i. e., if $G^i = GY^i/Y$, then household-producers with more workers would accumulate at a faster rate since the marginal product of private capital would positively depend on L^i.

rate of time preference. Observe that working members do not derive utility from the public consumption good. This assumption highlights the intergenerational conflict. The key point here is that the old derive considerably greater benefit from spending on health and care services than the young.[12]

Household-producer i may use her after-tax income either for consumption or investment in private capital. However, when $N^i > L^i$ and $\phi^i < 1$, then consumption per household member at t is only a fraction of after-tax output per worker net of investment per worker

$$c^i = \phi^i \left[(1-\tau) y^i - \dot{k}^i \right], \tag{2.3.6}$$

where $\tau \geq 0$ denotes a non-discriminatory income tax rate.

Government Policy In each period t, the government taxes household-producers' income at rate $\tau \equiv \tau_G + \tau_H$. Revenues collected from household-producers fund productive expenditure (the component corresponding to τ_G) as well as elderly spending (the component corresponding to τ_H). Thus, a balanced government budget requires

$$\tau Y = G + H = \tau_G Y + \tau_H Y. \tag{2.3.7}$$

Note that $\tau_G = G/Y \in [0,1]$ and $\tau_H = H/Y \in [0,1]$ also represent the ratio of the respective spending component to aggregate output. When we turn to the determination of government policy in Section 2.3.3, voting will be on the policy mix (τ_G, τ_H). This policy mix then automatically yields the overall income tax rate τ.

2.3.2 The Economic Equilibrium

The economic equilibrium is the decentralized competitive equilibrium of the economy for an exogenously given, time-invariant government policy (τ_G, τ_H). We will show in Section 2.3.3 that the tax rates τ_G and τ_H will indeed be time-invariant in the political equilibrium.

The optimization problem for each household-producer i consists in choosing the paths

[12] Two further remarks are in order. First, if all members of household-producer i work, i. e., if $\phi^i = 1$, then (2.3.5) reduces to the standard utility function $U^i(0) = \int_0^\infty N^i e^{-\rho t} \ln c^i(t)\, dt$. Second, we have chosen an additively separable utility specification. However, our key predictions stated in Corollary 1 below do not change if we use a similar utility function with non-separable preferences between private and public consumption. For details see Appendix 2.B.1.

$c^i(t)$ and $k^i(t)$ that maximize (2.3.5), subject to (2.3.4), (2.3.6), and an initial capital stock per worker $k^i(0) = k_0 > 0$.[13]

When making her consumption-savings decision each household-producer takes the paths of G, H, y, and τ as given and disregards the possible impact of her investment decision on the amount of public services provided. Then, the intertemporal optimization problem leads to the following Euler condition

$$\frac{\dot{c}^i(t)}{c^i(t)} = (1 - \tau_G - \tau_H) A^{\frac{1}{\alpha}} (\tau_G L)^{\frac{1-\alpha}{\alpha}} - \rho \equiv \gamma(\tau_G, \tau_H), \quad \text{for all } i. \tag{2.3.8}$$

Hence, irrespective of their support ratio all household-producers accumulate at the same rate in equilibrium. In addition, the equilibrium requires the following transversality condition to be met

$$\lim_{t \to \infty} \left[\lambda^i(t) k^i(t) \right] = 0, \tag{2.3.9}$$

where λ^i denotes the present-value shadow price of household-producer i's capital stock.

Then, the following proposition holds.

Proposition 1. (Economic Equilibrium)

Consider a given, time-invariant policy mix, (τ_G, τ_H).

1. There exists a unique steady-state growth path along which all variables grow at the same constant rate $\gamma(\tau_G, \tau_H)$.
2. For any admissible set of initial conditions the economy immediately jumps to this steady-state path.

According to Proposition 1 the rate at which all household-producers accumulate is given by $\gamma(\tau_G, \tau_H)$. The latter is also the growth rate of economy-wide (aggregate) variables as well as of government expenditure. The intuition is straightforward. The ratio of productive government spending per unit of the economy's output per worker consistent with condition (2.3.7) is

$$\frac{G}{y} = \tau_G L \tag{2.3.10}$$

[13] We assume that all households have the same initial capital stock per worker, i. e., $k^i(0) = k_0 > 0$. This assumption implies that households with fewer working members have a lower initial capital holding. Alternatively, one could suppose that the economy starts off with an equal distribution of capital. This assumption does not affect our qualitative results. For details see Appendix 2.B.2.

since $y = Y/L$. Hence, for all t the average product of capital is constant and equal to $A^{\frac{1}{\alpha}} (\tau_G L)^{\frac{1-\alpha}{\alpha}}$.

Since all households have the same initial capital stock per worker, the common growth rate of all household-producers implies that the capital stock per worker and output per worker is also the same for all i and t. However, each household's demographic composition determines her instantaneous level of total income

$$Y^i(t) = y^i(0)L^i e^{\gamma(\cdot)t} = A^{\frac{1}{\alpha}} (\tau_G L)^{\frac{1-\alpha}{\alpha}} k_0 L^i e^{\gamma t} \tag{2.3.11}$$

[from (2.3.4) and (2.3.10)], and of consumption per capita

$$c^i(t) = c^i(0)e^{\gamma(\cdot)t} = \phi^i \rho k_0 e^{\gamma t}, \tag{2.3.12}$$

[from (2.3.4), (2.3.6), and (2.3.8)] where the argument of γ is (τ_G, τ_H). Intuitively, the smaller a household's labor force, the smaller is her aggregate income at each t. Similarly, the smaller the share of working members in total members, i. e., the smaller the support ratio, the lower is the level of consumption per capita at each t.

As all households accumulate at the same rate and the labor supply of each household is constant, it is not surprising that the growth rate γ also applies to the economy's aggregate variables, which obtain from aggregation over all households. For instance, the economy's aggregate output is given by

$$Y(t) = \int_0^1 Y^i(t)di = A^{\frac{1}{\alpha}} (\tau_G L)^{\frac{1-\alpha}{\alpha}} k_0 L e^{\gamma t}. \tag{2.3.13}$$

Finally, as G and H are proportional to aggregate income, they also grow at rate γ.

The steady-state growth rate depends on the public policy parameters τ_G and τ_H. There is a negative relationship between the government's expenditure ratio for services that benefit the elderly and the steady-state growth rate, i. e., $\partial\gamma(\tau_G, \tau_H)/\partial\tau_H < 0$. The reason is that each household-producer in her optimization problem disregards that her choice of k^i via aggregate output, Y, affects the aggregate amount of public spending for the elderly, H, and thus the household's overall per-period utility. Thus, τ_H only affects the steady-state growth rate by reducing each household's net income.

In contrast, a rise in τ_G has two opposing effects on $\gamma(\tau_G, \tau_H)$. According to (2.3.10) a greater τ_G increases the provision of G and, thus, the private marginal product of private capital increases. At the same time, it reduces the after-tax value of the private marginal product of private capital due to the distortionary tax financing of government expenditure.[14]

2.3.3 The Political-Economy Equilibrium

This section endogenises government policy. For this purpose, we first characterize each household's policy preferences and then determine the policy mix that will be implemented by the government under pure majority voting.

Policy Preferences Let $\left(\tau_G^i, \tau_H^i\right)$ denote household-producer i's most preferred policy mix. This mix maximizes i's overall intertemporal utility in an economic equilibrium where the tax rates τ_G^i and τ_H^i apply to all household-producers. In other words, household-producer i's most preferred policy mix is the solution to

$$\begin{aligned}
\max_{\tau_G, \tau_H} U^i(0) &= N^i \int_0^\infty \left[\ln c^i(t) + (1-\phi^i) b \ln H(t)\right] e^{-\rho t}\, dt \\
\text{s.t.} & \\
c^i(t) &= \phi^i \rho k_0 e^{\gamma(\tau_G, \tau_H)t} \\
H(t) &= \tau_H A^{\frac{1}{\alpha}} \left(\tau_G L\right)^{\frac{1-\alpha}{\alpha}} k_0 L e^{\gamma(\tau_G, \tau_H)t},
\end{aligned}$$

where $H(t)$ follows from (2.3.7) and (2.3.13). The constraints make clear how the choice of policy affects household i's indirect utility. First, a rise in τ_G has two effects on U^i. On the one hand, a higher τ_G increases utility by raising aggregate production today and thus today's provision of H. On the other hand, a change in τ_G affects U^i by altering the steady-state growth rate. The direction of this effect depends on the size of τ_G compared to its growth-maximizing size $(1-\alpha)(1-\tau_H)$ (see Footnote 14). A greater growth rate is utility-enhancing because it increases future private as well as public consumption possibilities. Second, a rise in τ_H positively affects households' well-being by directly increasing the provision of H but impinges on U^i by reducing the steady-state growth

[14] For a given τ_H, the steady-state growth rate $\gamma\left(\tau_G, \tau_H\right)$ is maximized at $\tau_G = (1-\alpha)\left(1-\tau_H\right)$. Overall, maximum growth is obtained at $\tau_H = 0$ and $\tau_G = 1-\alpha$. Observe also that the steady-state growth rate depends on the economy's aggregate labor supply, L, i. e., there is a scale effect. The latter occurs since a greater labor supply increases aggregate household income and, thus, the tax base form which productive expenditure is financed.

rate.

Henceforth, we make the following assumption, which will be motivated below:

Assumption 1. It holds that $\rho \leq \frac{1+b}{b} A^{\frac{1}{\alpha}} \left[(1-\alpha)L\right]^{\frac{1-\alpha}{\alpha}}$.

Then, the following proposition holds.

Proposition 2. (Most-Preferred Policy Mix)

For each household-producer i there is a unique most-preferred policy mix, $\left(\tau_G^i, \tau_H^i\right)$, given by

$$\tau_G^i = 1-\alpha \quad \text{and} \quad \tau_H^i = \frac{(1-\phi^i)b\rho}{\left[1+(1-\phi^i)b\right] A^{\frac{1}{\alpha}} \left[(1-\alpha)L\right]^{\frac{1-\alpha}{\alpha}}}. \tag{2.3.14}$$

Since time does not appear in these expressions, we find our conjecture confirmed that the actual policy mix, will involve time-invariant tax rates. Thus, a behavior of household-producers based on time-invariant tax rates, τ_G and τ_H, is fully consistent with the actual equilibrium outcome. Moreover, Assumption 1, which is easily met for a small ρ or a large A, assures that $\tau_H^i \leq 1$ for any ϕ^i.

According to Proposition 2, for all households the ideal share of productive expenditure, τ_G^i, is equal to $1-\alpha$. The latter is the output elasticity of productive expenditure, which is the same for all households. As productive expenditure affects all household-producers in the same way, it is intuitive that the preferred expenditure ratio is independent of the households' demographic composition, i. e., $\partial \tau_G^i / \partial \phi^i = 0$.[15]

By contrast, equation (2.3.14) reveals that household-producer i's preferred spending ratio for services that benefit the elderly, τ_H^i, depends on ϕ^i. Thus, households with different support ratios prefer different tax rates. Since τ_H^i affects the steady-state growth rate, this difference also translates into the preferred growth rate. Assuming that i's most preferred policy mix is the one implemented by the government, one readily establishes that

$$\frac{d\tau_H^i}{d\phi^i} < 0 \quad \text{and} \quad \frac{d\gamma(\tau_G^i, \tau_H^i)}{d\phi^i} > 0. \tag{2.3.15}$$

[15] It is noteworthy that at τ_G^i productive expenditure satisfies the so-called natural condition of productive efficiency, i. e., the marginal contribution of government expenditure to aggregate output is one (see, e. g., Barro, 1990). In the present context, as aggregate equilibrium output can be written as $Y = AK^\alpha (GL)^{1-\alpha}$, we have $dY/dG = (1-\alpha)(Y/G) = (1-\alpha)/\tau_G^i = 1$.

Intuitively, households with a greater share of elderly members (i. e., a lower ϕ^i) are willing to pay higher taxes for the provision of public services that benefit these members and to accept lower growth rates of private consumption.

Policy Choice under Majority Voting Let's turn to the policy mix that will be implemented by the government under a pure majority rule. In particular, we will show that the median voter theorem can be applied to this voting problem.

For all household-producers the optimal policy mix involves $\tau_G = 1 - \alpha$. Thus, voters only differ in their preferences for τ_H and the voting problem becomes one-dimensional. Moreover, each voter's preferences for τ_H are single-peaked because the indirect utility function U^i is strictly concave in τ_H^i for $\tau_G = 1 - \alpha$. In addition, there exists a monotonic relationship between household i's ideal tax rate τ_H^i and her support ratio ϕ^i. Thus, the median voter theorem can be applied to this voting problem and the share of public spending for the elderly that the government implements coincides with the one preferred by the median voter. The following proposition summarizes the political equilibrium, i. e., the actual choice of policy under majority rule.

Proposition 3. (Political-Economic Equilibrium)

The actual policy mix involves

$$\tau_G^* = 1 - \alpha \quad \text{and} \quad \tau_H^* = \frac{(1-\phi^m)b\rho}{[1+(1-\phi^m)b]\, A^{\frac{1}{\alpha}}\, [(1-\alpha)L]^{\frac{1-\alpha}{\alpha}}}, \tag{2.3.16}$$

where ϕ^m denotes the support ratio of the median household. The corresponding steady-state growth rate of household and economy-wide variables is

$$\gamma^* = \alpha A^{\frac{1}{\alpha}}\, [(1-\alpha)L]^{\frac{1-\alpha}{\alpha}} - \frac{(1-\phi^m)b\rho}{1+(1-\phi^m)b} - \rho. \tag{2.3.17}$$

Implicitly, we have assumed that taxes are voted on and implemented with full commitment at time zero. However, due to the infinite time horizon and exponential discounting, this policy choice is time-consistent (see Laibson, 2003). Thus, it has to coincide with the solution that would be obtained if the government could not commit itself to future policies. Intuitively, as households only differ in their support ratio (which does not affect the accumulation path) and as the identity of the median voter does not change over time, strategic intertemporal voting cannot occur.[16]

2.3.4 Implications of Population Ageing

How does population ageing affect actual government spending and long-run economic growth? Population ageing corresponds to an (exogenous) change in the distribution of households such that there are more households with a large fraction of elderly members and the median household has a lower support ratio. The following Corollary follows from Proposition 3 and equation (2.3.15).

Corollary 1. (Population Ageing, Government Spending, and Growth)

It holds that

$$\frac{d\tau_H^*}{d\phi^m} < 0, \quad \frac{d\tau_G^*}{d\phi^m} = 0, \quad \text{and} \quad \frac{d\gamma^*}{d\phi^m} > 0. \tag{2.3.18}$$

Corollary 1 reveals that a fall in the median voter's support ratio, ϕ^m, involves a higher τ_H^*, an unchanged τ_G^*, and a lower γ^*. Thus, our theory predicts that population ageing increases public spending for the elderly (as a share of output), does not affect productive expenditure (as a share of output), increases the overall tax burden (because $\tau = \tau_G + \tau_H$), and lowers the economy's growth rate.[17] The following section confronts these predictions with the data.

[16] Equation (2.3.16) reveals that $\tau_H^* > 0$ for any $\phi^m < 1$. Thus, as long as the median household is not solely composed of working members, majority voting cannot yield the economy's maximum growth rate (which requires $\tau_H = 0$).

[17] One readily verifies that the political-economic equilibrium implies for $t = 0$ that $Y(0) = A^{\frac{1}{\alpha}}\left((1-\alpha)L\right)^{\frac{1-\alpha}{\alpha}} K_0$, $C(0) = \rho K_0$, $G(0) = (1-\alpha)Y(0)$, $\dot{K}(0) = \gamma(1-\alpha, \tau_H(\phi^m))K_0$, and $H(0) = \tau_H(\phi^m)Y(0)$. Hence, a decline in ϕ^m increases τ_H^* which crowds our private investment in physical capital one to one, i. e., $-d\dot{K}(0)/d\phi^m = dH(0)/d\phi^m$.

2.4 Empirical Analysis

The following section confronts the predictions of Corollary 1 with the data.

2.4.1 Data

The support ratio measures the share of the working-age population (ages 15 to 64) relative to the total adult population (ages 15 and above). We construct country-level support ratios using demographic data from the World Bank Development Indicators (World Bank, 2022). These support ratios serve as our independent variable of interest.

To examine the impact of population ageing on the composition of government expenditure, we use a sample of 30 countries from the Organisation for Economic Co-operation and Development (OECD) over the 2007−2018 period. The list of sampled countries is presented in Appendix 2.C.1.

This sample was selected for two main reasons. First, the OECD imposes a *sine qua non* condition of pluralist democratic regimes to its entering members (Organisation for Economic Co-operation and Development (OECD), 2020) which aligns with our theoretical framework that studies the impact of ageing on public spending through a majority voting mechanism. Second, the OECD follows a standardised system for categorising government expenditure according to the Classification of the Functions of Government (COFOG). This classification provides consistently measured data across all OECD countries, facilitating cross-country comparisons and enabling a comprehensive analysis of different public expenditure subcategories.

We associate the following two subcategories with elderly spending: "old age" and "hospital services," hereafter referred to as *Old age* and *Hospitals*, respectively. *Old age* encompasses both in-kind and cash benefits directed specifically towards the elderly. In-kind benefits refer to elderly-targeting services such as lodging and the provision of special services including in-home help and allowances paid to persons looking after an elderly. Cash benefits include old-age pensions paid upon reaching the standard retirement age and other one-time or lump-sum payments made on account of old age. We use hospital services as a measure of elderly spending since the elderly are a highly vulnerable demographic group with a high demand for healthcare services (Fong, 2019).

This subcategory pertains to services of general and specialist hospitals in addition to those of convalescent and nursing homes.

For productive expenditure, we select the following four subcategories "tertiary education", "transport", "communication" and "R&D", and denote them by *Education*, *Transport*, *Communication*, and *R&D*. *Education* refers to the provision of tertiary education. The selected subcategory includes spending on universities and other tertiary educational institutions as well as scholarships and other grants paid to students. *Transport* relates to costs incurred for the administration, maintenance and construction of transportation infrastructure and services. *Communication* concerns the expenditure associated with the administration of services for the construction as well as the maintenance of communication systems, including postal, telephone and wireless communication systems. Finally, R&D denotes spending on programs aimed at acquiring knowledge with the purpose of generating novel materials and products as well as to establish new systems, services and processes. In practice, this spending subcategory includes funds paid to governmental and non-governmental agencies that are engaged in applied research.

All data pertaining to expenditure is retrieved from Organisation for Economic Co-operation and Development (OECD) (2023). In line with our theoretical framework, the subcategories on elderly spending and on productive expenditure are recorded as a percentage of annual gross domestic product.

For the regression analyses shown in Section 2.4.2 below, we include the following country-level control variables: population density, unemployment rates, inflation rates, government effectiveness as well as total government expenses and current account balance (CAB), both as shares of GDP. In the regression tables, these are respectively labeled *Population density*, *Unemployment*, *Inflation*, *Government effectiveness*, *Expenses* and *CAB*.

Population density defines the average number of people living within one square kilometer. The latter may affect demand for public goods and services, particularly infrastructure. More densely populated countries may require higher spending to maintain public services. *Unemployment* measures the proportion of the workforce that is unemployed. Higher unemployment rates could strain fiscal resources and influence allocations toward social services or subsidies, thus impacting public expenditure. *Inflation* accounts for broader economic conditions that may influence government budget allocation decisions. *Expenses* measures total government expenses as a share of GDP and reflects the overall fiscal capacity of a government. *CAB* controls for exports net of imports; it captures possible trade deficits that may results in fiscal adjustments. Lastly, *Government Effectiveness*, sourced from the V-Dem dataset (Coppedge et al., 2021), is a measure of the credibility of governments in delivering public services. Data for all the other control variables are obtained from the World Bank Development Indicators.

Table 2.4.1 presents the summary statistics for a balanced panel comprising the 30 countries mentioned above over the 2007-2018 period. The panel has 360 observations except for R&D expenditure. Data on Bulgaria is missing for the entire period, i .e., 2007 to 2018 and data for Lithuania is only available for the years 2007, 2008 and 2009.

Countries in the sample have a mean support ratio of 79.57, approximately corresponding to an average of 4 workers per 1 economically-dependent old person. Italy is the country with the lowest support ratio, estimated at 73.74 in 2018; this indicates high population ageing. By contrast, Ireland in 2007 has the highest support ratio of 86.6.

For elderly spending, the variable Old age averages 8.54 percent of GDP across the sample. Greece, for example, records the highest spending on old age, estimated at 16 percent of GDP in 2016. Conversely, Iceland has the lowest Old age spending, estimated at just 1.9 percent in 2007 and 2008. The Hospitals subcategory also exhibits substantial variability. Denmark had the highest share of GDP allocated to hospital services, reaching 6.3 percent in 2009 against only 1.3 percent for Switzerland in the years 2007 and 2008.

There is considerable variation in the sample regarding productive expenditure subcategories. Tertiary education expenditure averages 0.96 percent of GDP, with the lowest value recorded in Luxembourg at 0.2 in 2007 and 2008, and the highest in Finland at 2.1 percent in 2010. Transport spending averages 2.67 percent of GDP, with a minimum value of 0.6 percent recorded in Cyprus in 2014, 2015, and 2016, and a maximum value of 6.1 percent in Croatia in 2008 and 2015. Communication expenditure is relatively low across the panel of countries considered, averaging 0.04 percent of GDP. The minimum value of 0 is observed across various countries like Luxembourg, Switzerland, and Austria and over multiple years. Slovenia reports the highest share at 0.3 in 2008. R&D spending has an average of 0.03 percent of GDP and shows significant cross-country variation. The minimum R&D expenditure is 0 percent; it is also observed across multiple years and countries such as Lithuania and Cyprus; the maximum of 0.5 percent of

GDP is recorded in Romania in 2008.

Following the derivation of the baseline results, we implement an instrumental variable (IV) analysis to address potential endogeneity in the relationship between population ageing and government expenditure composition. Without the use of an IV, our regression results may be biased due to reverse causality or omitted variable bias. For instance, government spending decisions − particularly in areas such as healthcare or family support policies − could influence demographic outcomes, potentially affecting the support ratio. Additionally, unobserved factors, such as long-term structural policies, may be correlated with both the support ratio and government spending. To mitigate these potential biases, we instrument the support ratio using forecasts from the UN World Population Projections of 1992 (United Nations, Population Division, 1993). The instrumental variable is referred to as *Support Ratio Forecasts*.

Finally, to evaluate our theoretical prediction that population ageing lowers the economy's growth rate, we construct a panel of 178 countries over the period 2000–2018; the countries sampled are listed in Appendix 2.C.2. The expansion of the sample to include a larger cross-section of countries (with $N \gg T$) allows for the sound application of the generalised method of moments (GMM) estimation procedure. GMM is advantageous as it addresses potential endogeneity and unobserved heterogeneity, making it a robust approach for analysing the relationship between population ageing, government expenditure and economic growth.

In this analysis, we use the natural logarithm of GDP per capita in constant 2017 international dollars as our outcome variable; data are sourced from the World Bank Development Indicators. Similar to our theoretical model, we continue employing the support ratio as our measure of population ageing. For this expanded sample, we adopt proxies for elderly spending and productive expenditure that are more widely available across countries. Specifically, we use healthcare expenditure as a percentage of GDP, referred to as *Healthcare expenditure*, as a proxy for elderly spending. For productive expenditure, we use total government expenditure on education as a percentage of GDP; the latter is referred to as *Education expenditure*. Incorporating the support ratio as well as proxies of elderly spending and productive expenditure in the model allows us to distinguish between the fiscal and the demographic effects of population ageing.

To control for other factors that may affect economic growth, we include a set of time-varying, country-specific covariates. *Government effectiveness* captures the regulatory quality at the country level and across time. The latter has been found to affect economic growth (see, e.g., Nawaz 2015; Rodrik et al. 2004). Human capital is also an important determinant of long-term economic growth by improving productivity (see, e.g., Barro 1991). We use the rates of secondary school enrollment, referred to as *Secondary school enrollment*, to capture this effect. Furthermore, we control for infant mortality rates (*Infant mortality*) as an additional control for human capital. *Gross capital formation*, representing investment in physical capital such as infrastructure and equipment, is also included. Furthermore, we control for *Trade*, measured as the share of trade in GDP, to capture the degree of integration into the global economy. Greater openness is generally associated with higher economic growth (e.g., Frankel and Romer, 1999; Karras, 2003). We also incorporate *Population density* in the set of our control variables.

All data pertaining to the growth analyses are obtained from the World Bank Development Indicators except data for *Government effectiveness* which are sourced from the V-DEM dataset (Coppedge et al., 2021). Descriptive statistics are shown in Table 2.C.3 in the Appendix.

Table 2.4.1: Descriptive statistics – Expenditure sample

Variable	Description	Mean	SD	Min	Max	Count
Main independent variable						
Support ratio	Working population aged 15-64 (% of adult population aged 15 and above)	79.57	2.86	73.75	86.62	360
Government expenditure						
Hospitals	General government spending on hospital services (% of GDP)	3.11	0.99	1.30	6.30	360
Old Age	General government spending on old age (% of GDP)	8.54	2.75	1.90	16.00	360
Education	General government spending on tertiary education (% of GDP)	0.96	0.34	0.20	2.10	360
Transport	General government spending on transportation (% of GDP)	2.67	0.95	0.60	6.10	360
Communication	General government spending on communication (% of GDP)	0.04	0.05	0.00	0.30	360
R&D	General government spending on general public services (% of GDP)	0.03	0.08	0.00	0.50	339
Control variables						
Population density	Population density (people per sq. km of land area)	163.40	244.36	3.11	1514.47	360
Unemployment	Unemployment, total (% of total labor force)	8.52	4.56	2.24	27.47	360
Inflation	Inflation, GDP deflator (annual %)	2.05	2.68	-9.73	20.07	360
Expense (% of GDP)	Government expense on goods and services (% of GDP)	29.29	8.17	10.09	91.50	360
CAP (% of GDP)	Current account balance (% of GDP)	0.50	6.05	-25.76	15.77	360
Government effectiveness	Government effectiveness	1.17	0.60	-0.36	2.35	360

Summary: This table presents descriptive statistics for the variables used in the analysis examining the effect of population ageing on elderly spending and productive expenditure. For each variable, we show the mean, standard deviation, minimum and maximum values as well as the number of observations.

2.4.2 Methodology

Population Ageing and Government Expenditure Categories

To test the first two predictions of Corollary 1, i. e, the differential impact of population ageing on the share of spending for the elderly in total output, τ_H, and the share of productive expenditure in total output, τ_G, we estimate the following equations distinguishing the two subcategories of elderly spending and the four subcategories of productive government spending measured relative to total output:

$$(\tau_H)_{jit} = \alpha_j + \beta_{Hj}\phi_{it}^m + \mathbf{X}_{it}\chi_j + \mu_t + \lambda_i + \epsilon_{jit}, \tag{2.4.1}$$

$$(\tau_G)_{jit} = \alpha_j + \beta_{Gj}\phi_{it}^m + \mathbf{X}_{it}\chi_j + \mu_t + \lambda_i + \epsilon_{jit}. \tag{2.4.2}$$

Here, $(\tau_H)_{jit}$ and $(\tau_G)_{jit}$ refer to the respective share of category j of elderly spending and of productive expenditure in GDP for country i in year t. ϕ_{it}^m denotes the support ratio for country i at year t. $\mathbf{X}_{it}$ is the vector of control variables. μ_t and λ_i capture year and country fixed effects, respectively, to control for unobserved heterogeneity at the country and year level. Finally, ϵ_{jit} is the country- and time-specific error term of category j.

In equations (2.4.1) and (2.4.2), β_{Hj} and β_{Gj} are our coefficients of interest; they capture the differential impact of population ageing on government expenditure categories; elderly spending and productive expenditure. In light of Corollary 1, we expect β_{Hj} to be negative and significant corresponding to a positive effect of population ageing on elderly spending (share of output). In contrast, we expect β_{Gj} to be negative and/or insignificant. Equations (2.4.1) and (2.4.2) are initially estimated using ordinary least squares (OLS) which may suffer from endogeneity issues. Our main concern relates to reverse causality as elderly spending, especially on hospital services, may increase life expectancy and alter the support ratio. In that case, the estimated OLS coefficient may be inconsistent and biased, making the regressions results spurious.

To address these potential shortcomings, we apply a two-stage least squares (2SLS) approach. This procedure starts by regressing the independent variable of interest (i. e., the support ratio) on an instrumental variable. We choose the 1992 United Nations' forecasts of the support ratio constructed using population projections.[18] We include all other country-level covariates in addition to country and year fixed effects. This yields the fitted values for the support ratio which are employed as an explanatory variable in the second stage along with all other country-level controls and fixed effects.

Population Ageing and Economic Growth

To test the third prediction of Corollary 1, i. e., the impact of population ageing on the economy's growth rate, we estimate the following model:

$$\ln y_{it} = \alpha lny_{i,t-1} + \beta_1 \phi^m_{it} + \beta_2 (\tau_H)_{it} + \beta_3 (\tau_G)_{it} + \mathbf{X}_{it}\theta + \mu_t + \lambda_i + \epsilon_{it} \tag{2.4.3}$$

In equation (2.4.3), $\ln y_{it}$ denotes the natural logarithm of GDP per capita for country i in year t, $\ln y_{i,t-1}$ represents its lagged value to capture persistence over time. ϕ^m_{it} is the country-level support ratio in year t. $(\tau_H)_{it}$ is Healthcare expenditure; it captures elderly spending and measures healthcare expenditure as a share of GDP in country i at year t. By contrast, $(\tau_G)_{it}$, denoting Education expenditure, serves as a proxy for productive expenditure which is measured by education expenditure relative to GDP.

Country-level control variables are represented by $\mathbf{X}_{it}$. These include: Government effectiveness, Secondary school enrollment, Gross capital formation, Infant mortality, Trade and Population density as detailed in the previous section.

We begin by estimating the model using Pooled Ordinary Least Squares (POLS), which provides a preliminary estimate of the relationships between growth, population ageing and government expenditure. This method assumes that unobserved country-specific characteristics and year-specific effects are uncorrelated with the explanatory variables. If this assumption is not satisfied, the results of the POLS regression will be biased (Wooldridge, 2010). To account for unobserved heterogeneity, we then explicitly include country and year fixed effects; at both the country and year levels, we refer to the latter approach as a Fixed Effects (FE) model.

We also estimate the model using difference Generalised Method of Moments (GMM) (Arellano and Bond, 1991) and system Generalised Method of Moments (Arellano and Bover 1995 and Blundell and Bond 1998).

[18] Using 1992 population projections implies the loss of 4 countries in the sample, namely, Czechia, Croatia, Slovenia and Slovakia, which were either part of Yugoslavia or Czechoslovakia when the statistics were produced by the United Nations.

Difference GMM eliminates country-level fixed effects by first-differencing the model and uses past observations of the regressors as instruments. In this paper, we specifically use a two-step difference GMM estimation which accounts for the variance-covariance structure of the differenced disturbance term. This method employs a robust weighting matrix in the second step, thus providing standard errors that are robust to panel-specific autocorrelation and heteroskedasticity (Erickson and Whited, 2002).

We complete our analysis with a two-step system GMM estimation to address possible shortcomings associated with difference GMM. The latter method performs poorly when considering variables that are highly persistent over time since most of the variation is eliminated through first-differencing which may result in weak identification. System GMM combines difference equations with those in levels and uses the lagged first differences of the explanatory variables as instruments. This method has been shown to yield the smallest bias among the class of GMM estimators (Bun and Windmeijer, 2010).

2.4.3 Findings

Ageing and Expenditure Categories

Ordinary Least Squares Estimation

As per the theoretical predictions in Corollary 1, we anticipate a positive effect of population ageing on elderly spending categories and no significant effect on productive spending categories.

Columns (1) and (2) of Table 2.4.2 report the estimated effects pertaining to elderly spending subcategories, i. e., *Old age* and *Hospitals*. In both regressions, the coefficients on the support ratio are negative and statistically significant at the 1 percent level, indicating a strong relationship between population ageing and increased spending in these categories. The results imply that a 1 unit decrease in the support ratio is associated with a 0.076 and a 0.360 percentage point increase in spending on hospital services and old age, respectively.

In line with Corollary 1, the results for productive expenditure categories − presented in columns (3), (4), (5), and (6) − show no significant relationship with the support ratio at the 1 percent level. Albeit, the coefficient estimate on the support ratio when considering education expenditure is positive but small, estimated at 0.023, and only significant at the 5 percent significance level. Whereas, the coefficient estimate on the support ratio is −0.004 and only significant at the 10 percent significance level.

Overall, these results support the theoretical prediction that population ageing is associated with increased elderly spending and has no sizable association with productive expenditure. Nonetheless, the obtained OLS estimates are susceptible to possible endogeneity issues especially those pertaining to reverse causality. Elderly spending, especially on hospital services, may increase life expectancy and alter the support ratio. In that case, the estimated OLS coefficient are inconsistent and biased, making the regressions results spurious. We address potential endogeneity concerns in subsequent analyses through a two-stage least squares (2SLS) approach.

Table 2.4.2: Population ageing, elderly spending and productive expenditure (OLS) – Expenditure sample

	Spending for the elderly		Productive spending			
	(1) Hospitals	(2) Old Age	(3) Education	(4) Transport	(5) Communication	(6) R&D
Support ratio	-0.076***	-0.360***	0.023**	0.020	0.001	-0.004*
	(0.020)	(0.078)	(0.011)	(0.040)	(0.004)	(0.002)
Population density	0.001	-0.009***	0.002***	0.004*	-0.000***	-0.000
	(0.001)	(0.002)	(0.001)	(0.002)	(0.000)	(0.000)
Unemployment	-0.018**	0.106***	0.004	-0.016	0.001	0.002*
	(0.008)	(0.017)	(0.003)	(0.011)	(0.001)	(0.001)
Inflation	-0.010	-0.070***	-0.004	-0.049***	0.001	0.003*
	(0.009)	(0.018)	(0.004)	(0.012)	(0.001)	(0.002)
Government effectiveness	-0.027	-0.701**	-0.088	-0.464**	0.007	-0.008
	(0.109)	(0.310)	(0.059)	(0.186)	(0.020)	(0.014)
Expenses	0.012**	0.034***	0.001	0.021	-0.001	0.000
	(0.005)	(0.011)	(0.002)	(0.014)	(0.000)	(0.000)
CAB	-0.007	-0.013	-0.009***	-0.035***	-0.002***	-0.000
	(0.006)	(0.018)	(0.002)	(0.008)	(0.001)	(0.001)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	360	360	360	360	360	339
Adjusted R-squared	0.942	0.959	0.905	0.776	0.511	0.894

Summary: This table presents OLS estimates of the relationship between population ageing and different types of government spending. It illustrates that population ageing (support ratio) is associated with an increase (decrease) in public expenditure for the elderly given by spending on hospital services and spending on old age. By contrast, it shows that population ageing does not have a sizable association with productive spending subcategories, namely education, transport, communication and R&D.
Notes: (i) Support ratio is the ratio of the working population (aged between 15 and 64) to the total adult population (aged 15 and above) (ii) standard errors are clustered at country and year level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Instrumental Variable Estimation

To address potential endogeneity concerns in our analysis, we instrument the support ratio using forecasts from the 1992 United Nations World Population Projections, denoted as *Support Ratio Forecasts*].[19] These projections were produced 15 years before the start of our sample period. They were constructed based on historical trends in fertility and mortality, ensuring a plausible correlation with the support ratio during the sample period. Furthermore, these projections rely solely on demographic data available before 1992. As a result, they are likely exogenous to economic shocks, fiscal policies, or other unobserved factors that may influence government expenditure or growth during the period studied.

The first stage results, shown in Table 2.C.4 in the Appendix, indicate that the *Support Ratio Forecasts* serves as a strong and relevant instrument for population ageing. The coefficient on the instrumental variable is estimated at 0.620 and is significant at the 1 percent level for Sample A, which includes observations available for all dependent variables except R&D expenditure. In Sample B, limited to observations available for R&D, the coefficient on the instrument is 0.634 and significant at the 1 percent level. The high R-squared values from both first-stage estimations support the relevance of the instrument.

Table 2.4.3 presents the second stage results of our instrumental variable regression analysis. Under IV estimation, the coefficients on the predicted values of the support ratio are large and significant for elderly spending subcategories, i. e., *Hospitals* and *Old age*. The estimated effect of the predicted support ratio on hospital services spending is -0.234, while the effect on old age spending is -0.637; both are significant at the 1 percent level. These estimates suggest that a 1 unit decrease in the support ratio, corresponding to a 1 percent reduction in the share of the working population relative to the total adult population, results in a 0.234 percent growth in spending on hospital services relative to total GDP. A similar change in the support ratio causes a 0.637 percentage point increase in old age spending. This finding further corroborates our theoretical prediction that population ageing increases elderly spending.

The coefficient estimate on the predicted values of the support ratio is only significant for the education subcategory. However, the coefficient estimated at -0.067 is considerably smaller in magnitude than those observed for elderly spending subcategories and only significant at the 5 percent significance level. Moreover, consistent with our expectations, the IV estimation does not indicate a significant causal effect of population ageing on the remaining productive expenditure categories: *Transport*, *Communication* and *R&D*.

[19] The earliest available forecasts from the United Nations were produced in 1992.

In summary, the IV results confirm a causal link between population ageing and increased spending for the elderly, while the effects on productive expenditure remain mostly insignificant except for the education expenditure subcategory. These findings support the theoretical predictions outlined in Corollary 1, demonstrating that the primary impact of population ageing is concentrated within elderly-related spending, with only marginal and insignificant effects on productive expenditure.

Table 2.4.3: Population ageing, elderly spending and productive expenditure (IV approach) – Expenditure sample

	(1) Hospital	(2) Old Age	(3) Education	(4) Transport	(5) Communication	(6) R&D
Support ratio (predicted)	-0.234***	-0.637***	-0.067**	-0.065	-0.006	-0.007
	(0.053)	(0.179)	(0.029)	(0.081)	(0.007)	(0.008)
Population density	-0.000	-0.012***	0.001*	0.003	-0.000***	-0.000
	(0.001)	(0.002)	(0.001)	(0.002)	(0.000)	(0.000)
Unemployment	-0.017**	0.116***	0.006**	-0.011	0.001	0.002*
	(0.007)	(0.017)	(0.003)	(0.011)	(0.001)	(0.001)
Inflation	-0.012	-0.073***	-0.006	-0.052***	0.001	0.004*
	(0.009)	(0.020)	(0.004)	(0.012)	(0.001)	(0.002)
Government effectiveness	0.008	-0.534	-0.046	-0.493**	0.004	-0.008
	(0.115)	(0.326)	(0.057)	(0.193)	(0.020)	(0.014)
Expenses	0.013**	0.036**	0.001	0.022	-0.001*	0.000
	(0.006)	(0.015)	(0.002)	(0.015)	(0.000)	(0.000)
CAB	-0.012**	-0.016	-0.012***	-0.033***	-0.002***	-0.000
	(0.006)	(0.018)	(0.002)	(0.008)	(0.001)	(0.001)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	312	312	312	312	312	291
Adjusted R-squared	0.946	0.959	0.910	0.796	0.527	0.902

Summary: This table presents the second-stage IV estimates of the relationship between population ageing and different types of government spending. It illustrates that population ageing (support ratio) increases (decreases) public expenditure for the elderly given by spending on hospital services and spending on old age. By contrast, it shows that population ageing does not have a sizable impact on productive spending subcategories, namely education, transport, communication and R&D.
Notes: (i) The support ratio is the share of the working-age population (aged between 15 and 65) relative to the total adult population (aged 15 and above). (ii) Standard errors are clustered at the country and year levels; robust standard errors are reported in parentheses. (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Ageing and Economic Growth

In Section 2.4.3, we found that population ageing increases elderly spending and has no sizable effect on productive expenditure. In this section, we investigate the third prediction of Corollary 1 which stipulates that population ageing lowers the economy's growth rate. We differentiate between the demographic and the fiscal effect of population ageing by incorporating separate measures of population ageing, elderly spending and productive expenditure. As described in Section 3.5.3, population ageing is captured using the *Support ratio*, elderly spending and productive expenditure are measured using *Healthcare expenditure* and *Education expenditure*, respectively. Economic growth is measured using the natural logarithm of GDP per capita.

We investigate the effect of population ageing and the two categories of public expenditure using regression analysis. In Table 2.4.4, Column (1) shows the results of the Pooled Ordinary Least Squares analysis; it only includes the variables *Support ratio*, *Healthcare expenditure* and *Education expenditure*. Column (2) features the results of the POLS estimation including all controls. Column (3) reports the results of the Fixed Effects (FE) estimation. Columns (4) and (5) display the results of two-step Difference and System GMM estimations, respectively.

The support ratio exhibits a significant and negative association with the natural logarithm of GDP per capita under both the POLS and Fixed Effects estimations. In the baseline POLS regression in Column (1), a one unit increase in the support ratio is associated with a 0.001 percent decrease in GDP per capita. The coefficient estimate is significant at the 1 percent significance level. The inclusion of all the control variables in Column (2) leaves this coefficient estimate unchanged but the latter is only significant at the 5 percent significance level. In the Fixed Effects model shown in Column (3), the magnitude of the effect increases, with a coefficient estimated at -0.004. Surprisingly, the estimation of the POLS and Fixed Effects models suggest that population ageing, reflected by a declining support ratio, has a positive association with economic growth.

The estimates of both the POLS and the Fixed Effects models show that healthcare expenditure has negative and significant association with economic growth. In the baseline POLS estimation displayed in Column (1), a 1 percent increase in healthcare expenditure as a share of GDP is associated with a 0.003 percent decrease in GDP per capita. The inclusion of additional controls in Column (2) reduces the magnitude of the coefficient to -0.002, while the Fixed Effects model in Column (3) shows a larger absolute effect of -0.005. The results from the POLS and the Fixed Effects model suggest that elderly spending, measured by Healthcare expenditure, is associated with lower economic growth.

Education expenditure shows a negative relationship with GDP per capita only according to the POLS estimations. In the baseline POLS model shown in Column (1), the coefficient estimate is -0.001 and significant at the 5 percent significance level. Including the set of control variables in Column (2) increases the magnitude of the coefficient to -0.004 and is significant at the 1 percent significance level. However, in the Fixed Effects model in Column (3), the coefficient estimate declines in absolute terms to -0.002 and is no longer statistically significant.

Column (4) presents the results of the two-step Difference GMM estimation. The coefficient on the support ratio is estimated at -0.026, but it is not statistically significant. This suggests that once endogeneity is addressed, the direct demographic impact of population ageing on economic growth cannot be established.

Under the Difference GMM estimation, the coefficient estimate on Healthcare expenditure is -0.046 and is statistically significant at the 5 percent level. The magnitude of the coefficient estimate is considerably larger than those obtained using POLS and Fixed Effects models. By contrast, the coefficient estimate on Education expenditure is not statistically significant. This suggest that the estimates obtained under POLS and Fixed Effects models may be driven by unobserved confounders.

Column (5) of Table 2.4.4 reports the findings of the two-steep System GMM; a method which has been shown to yield the smallest bias amongst the class of GMM estimators (Bun and Windmeijer, 2010). Overall, the results of the two-step System GMM estimation are consistent with those of the two-step Difference GMM estimation.

The coefficient on the support ratio is estimated at -0.028 but is not statistically significant. This further demonstrates that, once endogeneity is accounted for, population ageing does not have a direct impact on economic growth.

Under the System GMM estimation, the coefficient estimate on Healthcare expenditure is negative and significant at the 1 percent significance level. It shows that a 1 percent increase in healthcare expenditure as a share of GDP reduces GDP per capita by 0.047 percent. The coefficient estimate on Education expenditure is not found to be statistically significant.

Employing both two-step Difference and System GMM estimation methods reveals that Healthcare expenditure reduces economic growth. Support ratio and Education expenditure, in contrast, exhibit no significant impact

For the GMM estimates to be consistent, the instruments must fulfill the exogeneity condition. This can be examined using the J-statistic of the Hansen test which assumes the exogeneity of the instruments under the null hypothesis. According to Roodman (2009), a failure to reject the null entails that the p-value associated with this test does not fall bellow a threshold of 0.1.

The validity of the instruments can also be further evaluated using the Arellano-Bond test for AR(2) serial correlation in first differences. A rejection of the null hypothesis indicates serial correlation in the residuals, thus requiring the use of higher order lags in the instruments.

A final potential issue to consider when implementing a GMM estimation technique is that of *too many instrumental variables* which results in an overfit of the endogenous variables. Although there is no gold standard, Roodman (2009) advised that the number of instruments must not exceed that of the panels (i. e., countries) in the sample examined. To limit the proliferation of instruments in this analysis, we use only up to two lags and we also employ the "collapse" function in Stata 14, which is a common technique in the literature (Ribeiro et al., 2020).

In both the difference and the system GMM specifications, the exogenous variables are represented by the year dummies whereas all the other independent variables are treated as endogenous. Reported in Table 2.4.4, the p-values associated with the Hansen and the Arellano and Bond tests are well above the 0.1 threshold for both the Difference GMM and the System GMM. The results of these tests indicate a non-rejection of the respective null hypotheses and lend credibility to the validity of the instruments employed.

Overall, the results of the two-step Difference and System GMM estimation reveal that population ageing and productive expenditure, respectively measured by Support ratio and Education expenditure, have no effect on GDP per capita. By contrast, Healthcare expenditure, capturing elderly spending, is found to have a negative and statistically significant effect. This, combined with our findings that population ageing increases elderly spending, demonstrates that there is a negative fiscal effect of population ageing on economic growth.

Table 2.4.4: Population ageing, elderly spending, productive expenditure and economic growth (GMM approach) – Growth sample

	(1)	(2)	(3)	(4)	(5)
Support ratio	-0.001***	-0.001**	-0.004***	-0.026	-0.028
	(0.000)	(0.000)	(0.001)	(0.059)	(0.026)
Healthcare expenditure	-0.003***	-0.002***	-0.005***	-0.046**	-0.047***
	(0.001)	(0.001)	(0.002)	(0.023)	(0.014)
Education expenditure	-0.001**	-0.004***	-0.002	0.011	-0.004
	(0.001)	(0.001)	(0.002)	(0.011)	(0.009)
Government effectivenesss		0.005**	0.018***	0.093	0.029
		(0.002)	(0.006)	(0.109)	(0.046)
Secondary school enrollment		0.000***	0.000	0.003	0.000
		(0.000)	(0.000)	(0.004)	(0.001)
Gross capital formation		0.001***	0.002***	0.003	0.003**
		(0.000)	(0.000)	(0.003)	(0.001)
Infant mortality		-0.000	-0.001**	0.010	-0.001
		(0.000)	(0.000)	(0.016)	(0.011)
Trade		0.000***	0.000***	0.000	0.000
		(0.000)	(0.000)	(0.001)	(0.000)
Population density		-0.000***	0.000**	0.004	0.003*
		(0.000)	(0.000)	(0.005)	(0.002)
Log GDP per capita, lag	0.994***	0.986***	0.900***	0.788***	0.925***
	(0.001)	(0.002)	(0.013)	(0.196)	(0.023)
Observations	1955	1349	1349	821	1001
Number of countries	165	138	138	107	120
Instruments	-	-	-	45	56
AR(2) p-value	-	-	-	0.894	0.541
Hansen p-value	-	-	-	0.933	0.942

Summary: This table presents the regression results of economic growth, measured by the natural logarithm of GDP per capita on population ageing, elderly spending and productive expenditure; respectively measured using the support ratio, healthcare expenditure and education expenditure. Columns (1), (2) and (3) show the results of the POLS and Fixed Effects estimation. Columns (4) and (5) report the findings of the two-step difference GMM and the two-step system GMM analyses, respectively. The GMM regression findings establish the presence of a negative and significant effect of elderly spending on economic growth and does not reveal a direct effect of population ageing and productive expenditure on economic growth.

Notes: (i) The support ratio is the share of the working-age population (aged between 15 and 65) relative to the total adult population (aged 15 and above). (ii) For POLS estimation, the standard errors are clustered at the country and year levels; robust standard errors are reported in parentheses. (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests. (iv) Year dummies are treated as strictly exogenous under both the difference and the system GMM. (v) Under the difference and system GMM specifications, the first and second lags of the endogenous variables were used as instruments for the endogenous variables. (vi) The null hypothesis under the Hansen test establishes that the instruments are uncorrelated with the residuals. (viii) The null hypothesis under the Arellano-Bond test for AR(2) posits that in first differences, the errors are not serially correlated of order 2.

2.5 Conclusion

This paper develops a political-economic model with endogenous economic growth and households that are heterogeneous in their age composition. This framework is used to analyse how population ageing via a democratic voting process endogenously affects the composition of government spending and economic growth. The model predicts that population ageing (i) induces a higher level of elderly spending, (ii) leaves productive spending unaffected, and (iii) slows down economic growth.

Applying regression analysis on a sample of 30 OECD countries over the 2007-2018 period delivers supporting evidence for predictions (i) and (ii). To evaluate the tenets of prediction (iii), we use dynamic regression analysis on a baseline sample of 178 countries from 2000 to 2018. The obtained results considerably support this prediction. Hence, this paper provides a theoretical rationale and empirical evidence for the conjecture that population ageing reduces economic growth through its effect on the composition of government expenditure.

Appendix

2.A Proofs

2.A.1 Proof of Proposition 1

Claim 1 Household-producer i's intertemporal optimization problem gives rise to the following present-value Hamiltonian

$$\mathcal{H}^i \equiv N^i \left[\ln c^i + (1-\phi^i) b \ln H\right] e^{-\rho t} + \lambda^i \left[(1-\tau) A^{\frac{1}{\alpha}} \left(\frac{G}{y}\right)^{\frac{1-\alpha}{\alpha}} k^i - \frac{c^i}{\phi^i}\right], \quad (2.A.1)$$

where λ^i denotes the present-value shadow price of household-producer i's capital stock. In performing the optimization, the individual household-producer takes τ, y, G, and H as given. Then, the necessary and sufficient optimality conditions are[20]

$$\frac{e^{-\rho t}}{c^i} = \frac{\lambda^i}{L^i} \quad (2.A.2)$$

$$\dot{\lambda}^i = -\lambda^i (1-\tau) A^{\frac{1}{\alpha}} \left(\frac{G}{y}\right)^{\frac{1-\alpha}{\alpha}} \quad (2.A.3)$$

$$0 = \lim_{t\to\infty} \left[\lambda^i k^i\right]. \quad (2.A.4)$$

Since L^i is constant, $G/y = \tau_G L$, and $\tau = \tau_G + \tau_H$ we may combine (2.A.2) and (2.A.3) to obtain (2.3.8).

From the flow budget constraint (2.3.6) we know that

$$\frac{c^i}{\phi^i k^i} = (1-\tau) A^{\frac{1}{\alpha}} (\tau_G L)^{\frac{1-\alpha}{\alpha}} - \frac{\dot{k}^i}{k^i}. \quad (2.A.5)$$

In a steady state the growth rate of the household-producer's capital stock per worker has to be constant. Therefore, for constant tax rates, τ_G and τ_H, the right-hand side of (2.A.5) is constant. Consequently, $c^i/(\phi^i k^i)$ is constant. Moreover, for a constant ϕ^i, the

[20] The Hamiltonian H^i is the sum of a concave function of c^i and a linear function of (k^i, c^i). Therefore, it is concave in (k^i, c^i). Moreover, it is strictly concave in c^i. Thus, the paths of c^i and k^i implied by (2.A.2)-(2.A.4) deliver a unique global maximum.

growth rate of the household-producer's capital stock per worker equals the growth rate of consumption per household member. Hence, in the steady state output per worker grows at the same rate as k^i and c^i.

Since all households have the same initial capital-labor share $k^i(0) = k_0$ and $y^i(t) = A^{\frac{1}{\alpha}} (\tau_G L)^{\frac{1-\alpha}{\alpha}} k^i(t)$ it is the case that all household-producers at all t have the same output and the same capital per worker. Accordingly, in equilibrium individual and economy-wide variables per worker coincide, i. e., $k = \int_0^1 k^i di = k^i$ and $y = \int_0^1 y^i di = y^i$. Each household-producer's instantaneous level of aggregate capital, output, and consumption depends on her respective (constant) labor supply and is proportional to k^i:

$$K^i(t) = k^i(t)L^i \tag{2.A.6}$$
$$Y^i(t) = A^{\frac{1}{\alpha}} (\tau_G L)^{\frac{1-\alpha}{\alpha}} k^i(t)L^i \tag{2.A.7}$$
$$C^i(t) = \rho k^i(t)L^i. \tag{2.A.8}$$

Thus, these three variables grow at the same rate as k^i. Finally, the economy-wide aggregate variables are given by

$$K(t) = \int_0^1 K^i(t)di = k^i(t) \int_0^1 L^i di = k^i(t)L \tag{2.A.9}$$
$$Y(t) = \int_0^1 Y^i(t)di = A^{\frac{1}{\alpha}} (\tau_G L)^{\frac{1-\alpha}{\alpha}} k^i(t)L \tag{2.A.10}$$
$$C(t) = \int_0^1 C^i(t)di = \rho k^i(t)L. \tag{2.A.11}$$

Hence, for a constant aggregate labor supply (L), K, Y, and C have to grow at the same rate as k^i. Finally, as G and H are proportional to aggregate output, these variables also have to grow at this rate. Thus, we have indeed established the existence of a steady-state growth path along which all variables, including the respective levels of public services, grow the same constant rate

$$\gamma(\tau_G, \tau_H) = \frac{\dot{c}^i}{c^i} = \frac{\dot{k}^i}{k^i}. \tag{2.A.12}$$

Moreover, using (2.A.2) and (2.A.3) to evaluate (2.A.4) one readily verifies that the transversality condition holds for any parameter constellation.

Claim 2 It is straightforward to show that the economy immediately jumps onto the steady-state path. The proof of this mirrors the one of a standard AK model.

2.A.2 Proof of Proposition 2

Substituting for $c^i(t)$ and $H(t)$ in household-producer i's utility function (2.3.5) and solving the integral gives

$$U^i(0) = \frac{N^i}{\rho}\left[\ln(\phi^i\rho k_0) + (1-\phi^i)b\ln\left(\tau_H\left(\tau_G\right)^{\frac{1-\alpha}{\alpha}}k_0\left(AL\right)^{\frac{1}{\alpha}}\right) + \frac{(1+(1-\phi^i)b)\gamma(\cdot)}{\rho}\right] \quad (2.A.13)$$
$$\equiv U^i\left(\tau_G^i, \tau_H^i\right).$$

Then, the optimization problem of household i reduces to choosing $\tau_G \in [0,1]$ and $\tau_H \in [0,1]$ to maximize (2.A.13) with γ given by (2.3.8). To determine the global maximum of U^i in the square $0 \leq \tau_G \leq 1$ and $0 \leq \tau_H \leq 1$ we proceed in two steps. First, we show that there exists a unique local maximum in the interior of the square. Second, we verify that this policy mix represents the global maximum in the square by comparing its implied utility level with the utility obtained at the local extrema on the boundary of the square and at corner points.

1. Derivation of the unique local maximum in the interior of the square:
   The above optimization problem delivers the following pair of necessary first-order conditions for an interior optimum

$$\frac{\partial U^i}{\partial \tau_G} = \frac{(1-\phi^i)b(1-\alpha)}{\alpha\tau_G} + \frac{1+(1-\phi^i)b}{\rho}\frac{\partial\gamma(\cdot)}{\partial\tau_G} = 0 \quad (2.A.14)$$

$$\frac{\partial U^i}{\partial \tau_H} = \frac{(1-\phi^i)b}{\tau_H} + \frac{1+(1-\phi^i)b}{\rho}\frac{\partial\gamma(\cdot)}{\partial\tau_H} = 0, \quad (2.A.15)$$

   where

$$\frac{\partial\gamma}{\partial\tau_G} = \frac{A^{\frac{1}{\alpha}}\left(\tau_G L\right)^{\frac{1-\alpha}{\alpha}}}{\alpha\tau_G}\left[(1-\alpha)(1-\tau_H) - \tau_G\right] \quad (2.A.16)$$

$$\frac{\partial\gamma}{\partial\tau_H} = -A^{\frac{1}{\alpha}}\left(\tau_G L\right)^{\frac{1-\alpha}{\alpha}} < 0. \quad (2.A.17)$$

   Rewriting conditions (2.A.14) and (2.A.15), household i's most preferred expenditure shares τ_G^i and τ_H^i are implicitly determined by

$$\frac{1+(1-\phi^i)b}{(1-\phi^i)b\rho} = -\frac{(1-\alpha)}{\alpha\tau_G^i\left(\frac{\partial\gamma(\cdot)}{\partial\tau_G}\right)\Big|_{\tau_G^i,\tau_H^i}} \tag{2.A.18}$$

$$\frac{1+(1-\phi^i)b}{(1-\phi^i)b\rho} = -\frac{1}{\tau_H^i\left(\frac{\partial\gamma(\cdot)}{\partial\tau_H}\right)\Big|_{\tau_G^i,\tau_H^i}}, \tag{2.A.19}$$

respectively. Then, combining (2.A.18) and (2.A.19) and taking (2.A.16) and (2.A.17) into account yields

$$-\frac{1-\alpha}{(1-\tau_H^i)(1-\alpha)-\tau_G^i} = \frac{1}{\tau_H^i}$$

and thus $\tau_G^i = 1-\alpha$.

Then, substituting $\tau_G^i = 1-\alpha$ and (2.A.17) in (2.A.15) and rearranging yields

$$\tau_H^i = \frac{(1-\phi^i)b\rho}{\left[1+(1-\phi^i)b\right]A^{\frac{1}{\alpha}}\left[(1-\alpha)L\right]^{\frac{1-\alpha}{\alpha}}}, \tag{2.A.20}$$

which is equation (2.3.14).

The sufficient condition for (τ_G^i, τ_H^i) to be a local maximum is

$$D\left(\tau_G^i,\tau_H^i\right) \equiv \frac{\partial^2 U^i}{\partial\tau_G^2}\bigg|_{\tau_G^i,\tau_H^i} \times \frac{\partial^2 U^i}{\partial\tau_H^2}\bigg|_{\tau_G^i,\tau_H^i} - \left(\frac{\partial^2 U^i}{\partial\tau_G\partial\tau_H}\bigg|_{\tau_G^i,\tau_H^i}\right)^2 > 0, \tag{2.A.21}$$

where

$$\frac{\partial^2 U^i}{\partial\tau_H^2} = -\frac{N^i}{\rho}\frac{(1-\phi^i)b}{(\tau_H)^2}, \tag{2.A.22}$$

$$\frac{\partial^2 U^i}{\partial\tau_G\partial\tau_H} = -\frac{N^i}{\rho}\frac{1-\alpha}{\alpha}\frac{1+(1-\phi^i)b}{\rho}\left(AL^{1-\alpha}\right)^{\frac{1}{\alpha}}(\tau_G)^{\frac{1-\alpha}{\alpha}-1}, \tag{2.A.23}$$

$$\frac{\partial^2 U^i}{\partial\tau_G^2} = \frac{N^i}{\rho}\left[-\frac{(1-\phi^i)b\,(1-\alpha)}{\alpha\,(\tau_G)^2} + \frac{1+(1-\phi^i)b}{\rho}\frac{\partial^2\gamma}{\partial\tau_G^2}\right] \quad \text{with} \tag{2.A.24}$$

$$\frac{\partial^2\gamma}{\partial\tau_G^2} = -\frac{1-\alpha}{\alpha}\left(AL^{1-\alpha}\right)^{\frac{1}{\alpha}}(\tau_G)^{\frac{1-\alpha}{\alpha}-2}\left[\frac{\tau_G}{\alpha}+\left(1-\frac{1-\alpha}{\alpha}\right)(1-\tau_H)\right].$$

Evaluating equations (2.A.22)-(2.A.24) at $\tau_G^i = 1 - \alpha$ and at τ_H^i as given by (2.A.20), substituting the resulting expressions in (2.A.21) and rearranging yields

$$D\left(\tau_G^i, \tau_H^i\right) = \frac{\left[1 + (1 - \phi^i)b\right]\left(AL^{1-\alpha}\right)^{\frac{3}{\alpha}}(1-\alpha)^{\frac{3(1-\alpha)}{\alpha}}}{(1-\phi^i)b\rho^3} > 0.$$

Thus, the policy mix $\left(\tau_G^i, \tau_H^i\right)$ is a local maximum in the interior of the square. The utility level associated with this policy mix is

$$\begin{aligned} U^i\left(\tau_G^i, \tau_H^i\right) &= \frac{N^i}{\rho}\left[\ln(\phi^i \rho k_0) + (1-\phi^i)b \ln\left(\frac{(1-\phi^i)b\rho}{1+(1-\phi^i)b} k_0 L\right)\right] \\ &+ \frac{N^i(1+(1-\phi^i)b)}{\rho^2}\alpha\left(A(1-\alpha)^{1-\alpha}L^{1-\alpha}\right)^{\frac{1}{\alpha}} \\ &- \frac{N^i}{\rho}\left[(1-\phi^i)b + (1+(1-\phi^i)b)\right]. \end{aligned} \quad (2.A.25)$$

2. Comparison to local maxima on the boundary of the square and to corner points: The boundary of the square consists of 4 parts. On the first two sides with either $\tau_G = 0$ or $\tau_H = 0$ no relative maximum exists as U^i tends to $-\infty$ if one of the tax rates approaches zero. Side 3 is $\tau_G = 1$ and $\tau_H \in [0, 1]$. On this side, we have

$$\begin{aligned} U^i(1, \tau_H) = \frac{N^i}{\rho}\Bigg[&\ln(\phi^i \rho k_0) + (1-\phi^i)b \ln\left(\tau_H k_0 (AL)^{\frac{1}{\alpha}}\right) \\ &+ \frac{(1+(1-\phi^i)b)}{\rho}\left(-\tau_H\left(AL^{1-\alpha}\right)^{\frac{1}{\alpha}} - \rho\right) \end{aligned} \quad (2.A.26)$$

and $\frac{\partial U^i(1,\tau_H)}{\partial \tau_H} = 0$ delivers the relative extremum

$$\hat{\tau}_H = \frac{(1-\phi^i)b\rho}{[1+(1-\phi^i)b]\left(AL^{1-\alpha}\right)^{\frac{1}{\alpha}}}.$$

Evaluating U^i at this critical point gives

$$\begin{aligned} U^i(1, \hat{\tau}_H) &= \frac{N^i}{\rho}\left[\ln(\phi^i \rho k_0) + (1-\phi^i)b \ln\left(\frac{(1-\phi^i)b\rho}{1+(1-\phi^i)b} k_0 L\right)\right] \\ &- \frac{N^i}{\rho}\left[(1-\phi^i)b + (1+(1-\phi^i)b)\right], \end{aligned}$$

which is strictly smaller than $U^i\left(\tau_G^i, \tau_H^i\right)$ given by (2.A.25).

Side 4 is $\tau_H = 1$ and $\tau_G \in [0,1]$. On this side, we have

$$U^i(\tau_G, 1) = \frac{N^i}{\rho}\Big[\ln(\phi^i\rho k_0) + (1-\phi^i)b\ln\big(\tau_G^{\frac{1-\alpha}{\alpha}}k_0(AL)^{\frac{1}{\alpha}}\big) - \frac{(1+(1-\phi^i)b)\,(\tau_G AL^{1-\alpha})^{\frac{1}{\alpha}}}{\rho}\Big] \quad (2.A.27)$$

and $\frac{\partial U^i(1,\tau_H)}{\partial \tau_G} = 0$ delivers the relative extremum

$$\bar{\tau}_G = \left[\frac{(1-\phi^i)\rho b\,(1-\alpha)}{[1+(1-\phi^i)b]\,(AL^{1-\alpha})^{\frac{1}{\alpha}}}\right]^{\alpha}.$$

Evaluating U^i at this critical point then gives

$$\begin{aligned} U^i(\bar{\tau}_G, 1) &= \frac{N^i}{\rho}\left[\ln(\phi^i\rho k_0) + (1-\phi^i)b\ln\left(\left[\frac{(1-\phi^i)\rho b\,(1-\alpha)}{[1+(1-\phi^i)b]\,(AL^{1-\alpha})^{\frac{1}{\alpha}}}\right]^{1-\alpha} k_0\,(AL)^{\frac{1}{\alpha}}\right)\right] \\ &- \frac{N^i}{\rho}\Big[(1-\phi^i)b\,(1-\alpha) + (1+(1-\phi^i)b)\Big], \end{aligned}$$

which under Assumption 1 can be shown to be strictly smaller than (2.A.25).

The only candidate for a corner solution is $\tau_G = \tau_H = 1$. In this case we obtain

$$U^i(1,1) = \frac{N^i}{\rho}\Big[\ln(\phi^i\rho k_0) + (1-\phi^i)b\ln\big(k_0(AL)^{\frac{1}{\alpha}}\big) - \frac{(1+(1-\phi^i)b)\,(AL^{1-\alpha})^{\frac{1}{\alpha}}}{\rho} - (1+(1-\phi^i)b)\Big] \quad (2.A.28)$$

which is strictly smaller than (2.A.25) because

$$\left[1+\ln\left(\frac{[1+(1-\phi^i)b]\,\big(AL^{1-\alpha}\big)^{\frac{1}{\alpha}}}{(1-\phi^i)b\rho}\right)\right] < \frac{(1+(1-\phi^i)b)\,\big(AL^{1-\alpha}\big)^{\frac{1}{\alpha}}}{(1-\phi^i)b\rho}\Big[1+\alpha\,(1-\alpha)^{\frac{1-\alpha}{\alpha}}\Big].$$

Thus, we have shown that all corner points and local extrema on the boundary of the square yield a lower utility than the interior local maximum at (τ_G^i, τ_H^i). Thus, this policy mix is the global maximum in the square.

2.A.3 Proof of Proposition 3

Follows with Proposition 2 and the arguments given in the main text.

2.A.4 Proof of Corollary 1

Follows immediately from Proposition 3 and and (2.3.15).

2.B Extensions

2.B.1 Non-Separable Preferences

To gauge the sensitivity of our results this section considers an alternative specification of the utility function with non-separable preferences between private and public consumption.

In particular, we assume that household i's intertemporal utility is given by

$$U^i(0) = \int_0^\infty \frac{\left(\left(C^i(t)\right)^{\phi^i} H(t)^{1-\phi^i}\right)^{1-\sigma} - 1}{1-\sigma} e^{-\rho t} dt, \tag{2.B.1}$$

where $C^i(t) = c^i(t)N^i$ denotes household i's aggregate private consumption and σ is the reciprocal of the intertemporal elasticity of substitution for consumption. We assume $1 - \sigma < 1$ such that the instantaneous utility function is strictly concave in its arguments. The share of private consumption in household i's utility relative to public consumption is given by the support ratio ϕ^i. The greater the share of elderly members, i. e., the smaller ϕ^i, the more important is the public consumption good for overall household utility. For simplicity, we normalize each households labor supply to unity, i. e., $L^i = 1$, such that in equilibrium $L = 1$. As the size of the household and her labor supply are assumed to be constant, this assumption does not affect our qualitative results, but simply eliminates the scale effect in the steady-state growth rate.

Economic Equilibrium

In this case, the optimization problem for each household i is to choose $c^i(t)$ and $k^i(t)$ to maximize (2.B.1), subject to (2.3.4), (2.3.6), and an initial capital stock per worker

$k^i(0) = k_0 > 0$, taking G, H, and $\tau = \tau_G + \tau_H$ as given. The corresponding present-value Hamiltonian is

$$\mathcal{H}^i \equiv \frac{\left(\left(c^i/\phi^i\right)^{\phi^i} H^{1-\phi^i} \right)^{1-\sigma} - 1}{1-\sigma} e^{-\rho t} + \lambda^i \left[(1-\tau_G-\tau_H) A^{\frac{1}{\alpha}} \left(\frac{G}{y}\right)^{\frac{1-\alpha}{\alpha}} k^i - \frac{c^i}{\phi^i}. \right] \quad (2.B.2)$$

where λ^i denotes the present-value shadow price of household-producer i's capital stock. The necessary and sufficient first-order conditions of this optimization problem yield

$$\left[(1-\sigma)\phi^i - 1\right] \frac{\dot{c}^i}{c^i} + (1-\phi^i)(1-\sigma)\frac{\dot{H}}{H} - \rho = \frac{\dot{\lambda}^i}{\lambda^i}, \quad (2.B.3)$$

$$\left[(1-\tau_G-\tau_H) A^{\frac{1}{\alpha}} \left(\frac{G}{y}\right)^{\frac{1-\alpha}{\alpha}}\right] = -\frac{\dot{\lambda}^i}{\lambda^i}, \quad (2.B.4)$$

$$\lim_{t\to\infty} \left[\lambda^i k^i\right] = 0. \quad (2.B.5)$$

Equation (2.3.7) implies for a time-invariant τ_H that $\dot{H}/H = \dot{Y}/Y$. Moreover, on a balanced growth path with a stationary population all variables have to grow at the same rate, i. e., $\gamma \equiv \dot{c}^i/c^i = \dot{H}/H$. Taking this into account and combining (2.B.3) and (2.B.4) with (2.3.10) for $L = 1$ yields the steady-state growth rate as

$$\gamma(\tau_G, \tau_H) = \frac{\dot{\tilde{c}}^i}{\tilde{c}^i} = \frac{1}{\sigma}\left[(1-\tau_G-\tau_H) A^{\frac{1}{\alpha}} (\tau_G)^{\frac{1-\alpha}{\alpha}} - \rho\right], \quad (2.B.6)$$

which generalizes equation (2.3.8) to $\sigma \neq 1$. As before, the economy has no transitional dynamics and is always in a position at which all variables at the household and the economy-wide level as well as government expenditure grow at the rate γ. For utility to be bounded $\rho > \gamma(1-\sigma)$ has to hold.

Given a starting amount of capital, $k^i(0)$, the levels of all variables are again determined. In particular, the initial quantity of consumption is

$$c^i(0) = \phi^i \left[(1-\tau_G-\tau_H) A^{\frac{1}{\alpha}} (\tau_G)^{\frac{1-\alpha}{\alpha}} - \gamma\right] k^i(0) \quad (2.B.7)$$

and the initial level of the public consumption good is

$$H(0) = \tau_H A^{\frac{1}{\alpha}} (\tau_G)^{\frac{1-\alpha}{\alpha}} k^i(0). \tag{2.B.8}$$

Also note that equations (2.B.6) and (2.B.7) imply that $c^i(0)$ can be written as

$$c^i(0) \quad = \quad \phi^i [\rho - \gamma(1-\sigma)] k^i(0). \tag{2.B.9}$$

Political-Economic Equilibrium

In the following we use the above results to determine household i's most preferred policy mix. The relevant optimization problem is

$$\max_{\tau_G,\tau_H} \int_0^\infty \frac{\left(\left(c^i(t)/\phi^i\right)^{\phi^i} H(t)^{1-\phi^i}\right)^{1-\sigma} - 1}{1-\sigma} e^{-\rho t}\, dt \quad \text{s.t.}$$
$$c^i(t) = c^i(0)e^{\gamma(\tau_G,\tau_H)t} \quad \text{and} \quad H(t) = H(0)e^{\gamma(\tau_G,\tau_H)t}.$$

For a constant γ the integral in the above equation can be simplified to yield (aside from a constant)

$$U^i(\tau_G, \tau_H) \quad = \quad \frac{\left(c^i(0)/\phi^i\right)^{\phi^i(1-\sigma)} H(0)^{\left(1-\phi^i\right)(1-\sigma)}}{(1-\sigma)[\rho - \gamma(1-\sigma)]}. \tag{2.B.10}$$

Then, using equations (2.B.8)-(2.B.9) in (2.B.10) gives i's indirect utility function as

$$U^i \quad = \quad \frac{k^i(0)^{1-\sigma}}{1-\sigma} (\rho - \gamma(\cdot)(1-\sigma))^{\phi^i(1-\sigma)-1} \left(\tau_H A^{\frac{1}{\alpha}} (\tau_G)^{\frac{1-\alpha}{\alpha}}\right)^{\left(1-\phi^i\right)(1-\sigma)}. \tag{2.B.11}$$

Maximizing (2.B.11) with respect to τ_G and τ_H yields the following pair of first-order conditions

$$
\begin{aligned}
& \frac{(1-\alpha)\left(1-\phi^i\right)}{\alpha\frac{\partial\gamma}{\partial\tau_G}}\left([\rho-\gamma(1-\sigma)]\right)^{\phi^i(1-\sigma)-1}\left(\tau_H A^{\frac{1}{\alpha}}\right)^{\left(1-\phi^i\right)(1-\sigma)}\left(\tau_G\right)^{\frac{(1-\alpha)(1-\sigma)\left(1-\phi^i\right)}{\alpha}-1} \\
= & -\left(1-\phi^i(1-\sigma)\right)\left([\rho-\gamma(1-\sigma)]\right)^{\phi^i(1-\sigma)-2}\left(\tau_H A^{\frac{1}{\alpha}}\left(\tau_G\right)^{\frac{1-\alpha}{\alpha}}\right)^{\left(1-\phi^i\right)(1-\sigma)}, \quad \text{(2.B.12)}
\end{aligned}
$$

$$
\begin{aligned}
& \frac{1-\phi^i}{\frac{\partial\gamma}{\partial\tau_H}}\left([\rho-\gamma(1-\sigma)]\right)^{\phi^i(1-\sigma)-1}\left(\tau_H\right)^{\left(1-\phi^i\right)(1-\sigma)-1}\left(A\left(\tau_G\right)^{1-\alpha}\right)^{\frac{(1-\sigma)\left(1-\phi^i\right)}{\alpha}} \\
= & -\left(1-\phi^i(1-\sigma)\right)\left([\rho-\gamma(1-\sigma)]\right)^{\phi^i(1-\sigma)-2}\left(\tau_H A^{\frac{1}{\alpha}}\left(\tau_G\right)^{\frac{1-\alpha}{\alpha}}\right)^{\left(1-\phi^i\right)(1-\sigma)}, \quad \text{(2.B.13)}
\end{aligned}
$$

where

$$
\begin{aligned}
\frac{\partial\gamma}{\partial\tau_G} &= \frac{A^{\frac{1}{\alpha}}\left(\tau_G\right)^{\frac{1-\alpha}{\alpha}}}{\sigma\alpha\tau_G}\left[(1-\alpha)(1-\tau_H)-\tau_G\right], & \text{(2.B.14)} \\
\frac{\partial\gamma}{\partial\tau_H} &= -\frac{1}{\sigma}A^{\frac{1}{\alpha}}\left(\tau_G\right)^{\frac{1-\alpha}{\alpha}} < 0. & \text{(2.B.15)}
\end{aligned}
$$

Combining conditions (2.B.12) and (2.B.13) and taking into account equations (2.B.14) and (2.B.15) yields

$$
-\frac{1-\alpha}{(1-\tau_H^i)(1-\alpha)-\tau_G^i} = \frac{1}{\tau_H^i}
$$

and thus $\tau_G^i = 1-\alpha$.

Then, substituting $\tau_G^i = 1-\alpha$ and (2.B.15) in (2.B.13) and rearranging delivers

$$
\left(1-\phi^i\right)[\rho-\gamma(1-\sigma)] = \frac{1}{\sigma}A^{\frac{1}{\alpha}}(1-\alpha)^{\frac{1-\alpha}{\alpha}}\left(1-\phi^i(1-\sigma)\right)\tau_H^i. \quad \text{(2.B.16)}
$$

Then, using (2.B.6) in (2.B.16) yields

$$
\tau_H^i = \frac{\left(1-\phi^i\right)\left[\rho-\alpha A^{\frac{1}{\alpha}}(1-\alpha)^{\frac{1-\alpha}{\alpha}}\right]}{A^{\frac{1}{\alpha}}(1-\alpha)^{\frac{1-\alpha}{\alpha}}\phi^i\sigma}.
$$

As τ_H^i cannot be negative, household i's most preferred spending share is given by

$$\tau_H^i \quad = \quad \max \left\{ 0, \frac{\left(1-\phi^i\right)\left[\rho - \alpha A^{\frac{1}{\alpha}}\left(1-\alpha\right)^{\frac{1-\alpha}{\alpha}}\right]}{A^{\frac{1}{\alpha}}\left(1-\alpha\right)^{\frac{1-\alpha}{\alpha}}\phi^i \sigma} \right\}. \tag{2.B.17}$$

Intuitively, if ρ is sufficiently small, i. e., if households care a lot about the future, then i prefers a high growth rate and thus $\tau_H^i = 0$. Henceforth, we assume that $\rho > \alpha A^{\frac{1}{\alpha}}\left(1-\alpha\right)^{\frac{1-\alpha}{\alpha}}$.

Equivalently to the main text, the voting problem has become one-dimensional. Moreover, preferences are single-peaked as U^i is strictly concave in τ_H^i for $\tau_G = 1-\alpha$.[21] Thus, the median voter theorem can be applied and the actual policy mix involves

$$\tau_G^* = 1-\alpha \quad \text{and} \quad \tau_H^* = \frac{\left(1-\phi^m\right)\left[\rho - \alpha A^{\frac{1}{\alpha}}\left(1-\alpha\right)^{\frac{1-\alpha}{\alpha}}\right]}{A^{\frac{1}{\alpha}}\left(1-\alpha\right)^{\frac{1-\alpha}{\alpha}}\phi^m \sigma}, \tag{2.B.18}$$

where ϕ^m denotes the support ratio of the median household. The corresponding steady-state growth rate of household and economy-wide variables is $\gamma^* \equiv \gamma(\tau_G^*, \tau_H^*)$.

Finally, it is straightforward to verify that population ageing, i. e., a decline in the median voter's support ratio has the following steady-state effects

$$\frac{d\tau_H^*}{d\phi^m} < 0, \quad \frac{d\tau_G^*}{d\phi^m} = 0, \quad \text{and} \quad \frac{d\gamma^*}{d\phi^m} > 0,$$

thereby confirming the results of Corollary 1.

2.B.2 Economic Equilibrium with an Equal Initial Capital Distribution

The optimization problem for each household-producer i is

$$\max_{\{c^i(t),k^i(t)\}_{t=0}^{\infty}} \quad U^i(0) \qquad \text{s.t. (2.3.4), (2.3.6), and } K^i(0) = K_0 > 0,$$
$$\text{taking } \tau, G, H, \text{and } y \text{ as given.} \tag{2.B.19}$$

[21] A proof of this is available upon request.

This gives rise to the same necessary and sufficient optimality conditions as in Appendix 2.A.3, namely equations (2.A.2)-(2.A.4). Thus, it is straightforward to show that (equivalent to Proposition 1) along the steady-state growth path for given time-invariant expenditure ratios τ_G and τ_H all variables will grow at the same constant rate $\gamma(\tau_G, \tau_H)$ given by (2.3.8).

The main difference to an equal initial capital distribution occurs at the level of per-period household variables. With the same initial capital stock all households have the same initial income and produce the same output at all t. To see this, note that

$$\begin{aligned} Y^i(t) &= Y^i(0)e^{\gamma t}, && (2.B.20)\\ \text{where} \quad Y^i(0) &= A^{\frac{1}{\alpha}} (\tau_G L)^{\frac{1-\alpha}{\alpha}} K_0. && (2.B.21) \end{aligned}$$

The argument of γ is (τ_G, τ_H). Thus, all households independent of the size of their labor force produce the same output but differ in their output per worker

$$y^i(t) = \frac{Y^i(t)}{L^i} = A^{\frac{1}{\alpha}} (\tau_G L)^{\frac{1-\alpha}{\alpha}} \frac{K_0}{L^i} e^{\gamma t}. \tag{2.B.22}$$

This is possible because firms in this setting asymmetrically benefit from productive expenditure at each t

$$G^i = G\frac{y^i}{y} = G\frac{L}{L^i}, \tag{2.B.23}$$

where we have used that in equilibrium at each t

$$y = \int_0^1 y^i di = \int_0^1 \frac{Y^i}{L^i} di = Y^i \int_0^1 \frac{1}{L^i} di = \frac{Y^i}{L}. \tag{2.B.24}$$

Intuitively, equation (2.B.23) implies that the government via the provision of public productive services subsidizes the production of firms with a smaller labor force. By contrast, when households have the same initial capital stock per worker as assumed in the main text they all produce the same output per worker at each t but differ in their aggregate output according to the size of their labor force.

2.C Supplementary Tables

Table 2.C.1: Countries in the expenditure sample

Austria	Belgium	Bulgaria	Croatia	Cyprus
Czechia	Denmark	Estonia	Finland	France
Germany	Greece	Hungary	Iceland	Ireland
Italy	Latvia	Lithuania	Luxembourg	Malta
Netherlands	Norway	Poland	Portugal	Romania
Slovakia	Slovenia	Spain	Sweden	Switzerland

Table 2.C.2: Countries in the growth sample

Afghanistan	Albania	Algeria	Angola	Antigua and Barbuda
Argentina	Armenia	Australia	Austria	Azerbaijan
Bahamas, The	Bahrain	Bangladesh	Barbados	Belarus
Belgium	Belize	Benin	Bhutan	Botswana
Brazil	Brunei Darussalam	Bulgaria	Burkina Faso	Burundi
Cabo Verde	Cambodia	Cameroon	Canada	Central African Republic
Chad	Chile	Colombia	Comoros	Congo, Dem Rep
Congo, Rep	Costa Rica	Cote d'Ivoire	Croatia	Cyprus
Czech Republic	Denmark	Djibouti	Dominican Republic	Ecuador
Egypt, Arab Rep	El Salvador	Estonia	Eswatini	Ethiopia
Fiji	Finland	France	Gabon	Gambia, The
Georgia	Germany	Ghana	Greece	Grenada
Guatemala	Guinea	Guinea-Bissau	Guyana	Haiti
Honduras	Hungary	Iceland	India	Indonesia
Iran, Islamic Rep	Ireland	Israel	Italy	Jamaica
Japan	Jordan	Kazakhstan	Kenya	Kiribati
Korea, Rep	Kuwait	Kyrgyz Republic	Lao PDR	Latvia
Lebanon	Lesotho	Liberia	Lithuania	Luxembourg
Madagascar	Malawi	Malaysia	Maldives	Mali
Malta	Mauritania	Mauritius	Mexico	Micronesia, Fed Sts
Moldova	Mongolia	Morocco	Mozambique	Myanmar
Namibia	Nepal	Netherlands	New Zealand	Nicaragua
Niger	North Macedonia	Norway	Oman	Pakistan
Panama	Papua New Guinea	Paraguay	Peru	Philippines
Poland	Portugal	Qatar	Romania	Russian Federation
Rwanda	Samoa	Sao Tome and Principe	Saudi Arabia	Senegal
Serbia	Seychelles	Sierra Leone	Singapore	Slovak Republic
Slovenia	Solomon Islands	South Africa	Spain	Sri Lanka
St Lucia	St Vincent and the Grenadines	Sudan	Sweden	Switzerland
Tajikistan	Tanzania	Thailand	Timor-Leste	Togo
Tonga	Trinidad and Tobago	Tunisia	Turkey	Turkmenistan
Uganda	Ukraine	United Kingdom	United States	Uruguay
Uzbekistan	Vanuatu	Vietnam	Zambia	Zimbabwe

Table 2.C.3: Descriptive statistics – Growth sample

Variable	Description	Mean	SD	Min	Max	Count
Dependent variable						
Log of GDP per capita	Natural logarithm of GDP per capita, PPP (constant 2017 international $)	9.20	1.17	6.59	11.63	2213
Control variables						
Support ratio	Working population aged 15-64 (% of adult population aged 15 and above)	87.72	6.27	74.00	99.18	1349
Healthcare expenditure	Current health expenditure (% of GDP) 2017 international $)	6.18	2.40	1.03	24.26	2268
Education expenditure	Government expenditure on education, total (% of GDP)	4.41	1.70	0.62	14.06	2268
Government effectiveness	Government effectiveness	0.09	0.99	-2.08	2.44	1818
School enrollment	School enrollment, secondary (% gross)	79.93	29.30	6.49	163.93	1827
Gross capital formation	Gross capital formation (% of GDP)	23.98	7.90	-0.10	77.89	2111
Infant mortality rate	Mortality rate, infant (per 1,000 live births)	27.71	25.90	1.60	139.50	2268
Trade	Trade (% of GDP)	84.17	49.87	0.20	437.33	2136
Population density	Population density (people per sq. km of land area)	258.35	1307.41	1.54	19196.00	2261

Summary: This table presents summary statistics for the variables used in the analysis examining the effect of population ageing, elderly spending and productive expenditure on economic growth. For each variable, we show the mean, standard deviation, minimum and maximum values as well as the number of observations.

Table 2.C.4: Population ageing, elderly spending and productive expenditure (First stage IV approach) – Expenditure sample

	(1) Sample A	(2) Sample B
Support ratio forecasts	0.620***	0.634***
	(0.067)	(0.069)
Population density	0.000	0.001
	(0.003)	(0.003)
Unemployment	0.035***	0.035***
	(0.012)	(0.013)
Inflation	-0.025**	-0.026**
	(0.012)	(0.013)
Government effectiveness	-0.737***	-0.769***
	(0.231)	(0.242)
Expenses	0.005	0.006
	(0.009)	(0.009)
CAP	-0.060***	-0.063***
	(0.010)	(0.012)
Expenses	0.005	0.006
	(0.009)	(0.009)
Year fixed effects	Yes	Yes
Country fixed effects	Yes	Yes
Observations	312	291
Adjusted R-squared	0.978	0.978

Summary: The table presents the results for the first stage of the instrumental variable regression for samples A and B, with the latter being delimited by observations available for R&D spending and the former by all other expenditure categories.

Notes: (i) Support ratio forecasts are produced by the United Nations in 1992 (ii) standard errors are clustered at country and year level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Chapter 3

Artefacts: Exploring the Emergence and Diffusion of Production Techniques

3.1 Introduction

Artefacts are material objects created or modified by humans for functional, aesthetic or symbolic purposes, examples include sculptures, tools and jewellery. These objects carry visible physical traces, such as surface treatments and tool marks, from which production practices can be inferred. Since artefacts are attributable to specific locations and datable in time, they provide direct evidence of the spatial and temporal distribution of manufacturing processes. This, in turn, enables the reconstruction of the emergence and diffusion of ancestral production techniques.

A large number of artefacts are preserved by museums and cultural institutions that record their provenance, material composition and estimated production dates. Advances in information and communication technologies have enabled many of these institutions to digitise their catalogues and make them publicly accessible. The resulting online collections create a unified source of information of these archaeological objects and provides a foundation for the systematic analysis of artefacts.

The development of large language and vision–language models offers new approaches for the large-scale analysis of artefactual records. By jointly processing textual descriptions and visual representations, these models are able to extract, interpret and organise complex information into structured form. Their ability to recognise semantic and visual information makes them particularly suitable for identifying production techniques from museum catalogues that combine descriptive language and imagery.

In this paper, I leverage information from the digital collection of the British Museum to analyse the emergence and diffusion of production techniques across time and space. Production techniques refer to the specific methods and processes applied in the transformation of materials into finished artefacts. Using a multimodal framework that combines textual and visual data, large language and vision–language models are employed to classify each artefact according to the production techniques applied in its manufacture. The resulting dataset comprises more than 800,000 artefacts with associated geographic and date information.

The analysis consists of three main components. The first generates information on production techniques by applying a multimodal large language model, namely GPT-4o, that jointly analyses image and textual information from artefacts. To validate this methodological approach, I compare the classifications generated by the model against curator-assigned information, revealing a strong overlap between the two sources. Then, I identify pioneering sites, defined as the earliest adopters of each production technique, and associate the respective emergence dates. The analysis shows strong regional clustering for these pioneering sites around the Mediterranean basin and in the Near East. Finally, I examine the relationship between distance to these pioneering sites and the timing of adoption of production techniques in other locations using regression analysis. The findings show that greater distance from pioneering sites are associated with delayed adoption.

The remainder of this paper is organised as follows. Section 3.2 summarises the related literature, Section 3.3 describes the collection of the British Museum from which the data is extracted. Sections 3.4 and 3.5 explain the methodology applied and present the results of the empirical analysis. Finally, Section 3.6 and Section 3.7 provide a discussion of the results and conclude.

3.2 Related Literature

This paper lies at the intersection of four strands of literature. The first concerns the study of archaeological artefacts to derive information on the production techniques of ancestral societies. The second examines the emergence and diffusion of production techniques over time and space. The third focuses on the geographical factors that shape the adoption of such techniques. Finally, the fourth involves the application of machine learning methods to analyse artefactual records.

Uncovering the emergence and diffusion of production techniques and craftsmanship has been a long-standing question for archaeologists and historical economists. Artefacts represent a valuable resource to trace human ingenuity. The idea of using human-made tools to infer technological practices dates back to early anthropologists such as Oakley (1961) and Sollas (1924). This perspective was later formalised under the *châıne opératoire* (operational chain) framework (Leroi-Gourhan, 1964). The latter provides a methodology to understand the production of artefacts by reconstructing the sequence of actions involved in their manufacture. The framework postulates that artefacts embody physical traces that reflect the technical knowledge and production practices of a group or a society.

Building on the châıne opératoire, Dobres and Hoffman (1994) and Dobres (2010) argued that artefacts also embody information on the cultural practices of the people that manufactured them. In that sense, they not only reflect material efficiency and technical performance; they carry information on social identity and structure.

Studies analysing the adoption of production techniques using archaeological artefacts have sought to answer a wide range of questions. These include the effect of the availability of raw materials (e.g., Andrefsky Jr, 1994; Geselowitz, 1993), the role of cultural transmission (e.g., Sillar and Tite, 2000; Vanhaeren and d'Errico, 2006; Zwyns, 2021) as well as that of imitation and social learning (e.g., Carrignon et al., 2020).

Archaeological artefacts have also been studied through the lens of *diffusionism*. This theory assumes that technical innovation is concentrated in certain locations from which it spreads. These studies were primarily conducted within the discipline of archaeology (e.g., Daems and Kafetzaki, 2025; Östborn and Gerding, 2015), but diffusionism has also been investigated by economists. For instance, D. A. Comin et al. (2012) studied how technologies diffuse across countries. Their findings suggested that geographical distance from adoption leaders delays a country's own adoption, but that this effect decreases over time and eventually disappears. Evaluating the role of distance to pre-industrial centres of innovation, Özak (2018) uncovered a U-shaped relationship between distance to innovation centres and pre-industrial economic development. Ashraf et al. (2010) found that, respectively, distance from the technological frontier and isolation were negatively and positively correlated with economic development.

With the advent of machine learning, an increasing number of studies have applied tools such as large language models (LLMs) and vision-language models (VLMs) to the analysis of archaeological artefacts. For instance, using generative adversarial networks, Zachariou et al. (2020) digitally restored ancient Roman coins, thereby recovering physical features such as inscriptions.[22] Yalov-Handzel et al. (2024) applied deep neural networks to date historical artefacts from the Levant region. Closely aligned with the present study, Cadavid-Sanchez et al. (2023) used a language model to extract structured information on artefacts exclusively from textual descriptions. Their objective was to categorise artefacts by material, technique and object type and to trace how these categories appear and spread across time and space.

I contribute to this literature by developing a novel method for inferring production

[22] A Generative Adversarial Network (GAN) is a type of machine learning model where one network generates data and another assesses how realistic it is. Through this competition, the model learns to produce outputs that closely resemble real examples.

techniques from archaeological artefacts through the combined use of large language and vision–language processing. By jointly analysing textual information and images, I produce classifications of production techniques across a large number of artefacts. This methodological contribution demonstrates how recent advances in multimodal learning can be applied to extract structured information from museum records, thereby enabling large-scale analysis. Using this approach, I identify early adopters of production techniques and reconstruct their spatial and temporal distribution. Finally, I examine the relationship between distance to the identified pioneering sites and the timing of adoption of production techniques in other locations.

3.3 The British Museum Collection

This study uses data from the online collection of the British Museum, a digital repository of 2,213,680 archaeological artefacts. These artefacts originate from various locations from all continents and cover a wide period starting from 850,000 years BCE. Records include structured metadata such as object type, materials, techniques, production place, findspot, production dates, images and textual descriptions.

On the one hand, the inclusion of textual descriptions and images allows for the use of both large language and vision language models to identify production techniques used to manufacture each artefact. On the other hand. information on production places, findspots and dates of production enable to tracing of these production techniques across different geographical regions and over time.

The collection has been assembled over more than two and a half centuries through a variety of channels. Donations and bequests account for a large portion of the records. For instance, Baron Ferdinand Rothschield donated nearly 300 medieval and Renaissance artefacts. Other objects were acquired following organised excavations, especially in Egypt and Mesopotamia. A number of the artefacts in the collection are the result of colonial activities. For instance, the British Museum concedes that some of the artefacts associated with Benin were acquired through looting during 1897 British military expedition in the West African Kingdom of Benin. This latter example may raise concern over uneven geographical representation in the collection in favour of regions that had closer historical contact with the British Empire.

Despite its large coverage, the metadata is not complete. Only 1,843,603 artefacts, representing 83.28 percent of the collection, are associated with either a findspot or a production place, of which 260,995 feature both location categories. Information on date of production is available for 1,452,716 artefacts, representing 65.62 percent of the aggregate records. Images are associated with 1,117,535 artefacts, corresponding to 50.48 percent of the entire catalogue. Almost all objects feature a textual description. Finally, 1,034,634 artefacts, representing 46.74 percent of the collection, are associated with curator-assigned production techniques in the metadata.

Figure 3.3.1: Image of an artefact record from the British Museum

Figure 3.3.1 depicts an example of a record from the online collection of the British Museum. It shows a brass sculpture produced by the Yoruba people in the region of Ife, Nigeria, around the 14^{th} or the 15^{th} century. The associated metadata is listed in Table 3.3.1.

Table 3.3.1: Metadata of an artefact record from the British Museum

Category	Information
Object Type	Sculpture
Title	Object: The Ife Head
Materials	Brass
Production Ethnic Group	Yoruba
Techniques	Lost-wax cast, incised, painted
Production Place	Made in: Ife; Africa: sub-Saharan Africa: Nigeria: Osun State: Ife
Findspot	Excavated at Ife; Africa: sub-Saharan Africa: Nigeria: Osun State: Ife
Production Date	14^{th}–15^{th} century
Description	Brass (heavily leaded zinc-brass) head cast using the lost wax (cire perdue) technique. The head is a little under life size and is made in a naturalistic style. It has a headdress, suggesting a crown, of complex construction. The main tubular section of the crown runs around the head in a three-layer composition. The upper layer has a band of four horizontal rectangles representing flat, discoidal beads surmounted by a red-painted tubular bead and a tassel. The central layer has a row of vertical rectangles representing tubular beads with tassels. The lower layer has a row of rosettes painted in red. The main tubular section of the crown also has a projecting arc around the forehead comprising small tubular beads edged with a row of red-painted feathers. At the back of the crown is a neck cover. The central part of the cover has eighteen vertical elements incised to indicate plaitwork with traces of black paint. The bottom and sides have a row of red-painted rosettes. A crest rises above the central crown at the front. It comprises a conical roundel with central boss surrounded by seven concentric rings, probably representing beads. A plaitwork element rises behind the roundel and terminates in a pointed ovoid tip; both elements bear traces of black paint. The face is slightly elongated and has vertical incised markings (striations). Two lines of holes run between the lobes of the ears, one going through the angle of the neck and the jaw, the second crossing the jaw below the lower lip. A double line of holes runs across the upper lip. The almond-shaped eyes are small in proportion to the head and the eyebrow ridge is sharply defined. The lips are not striated. There are grooves around the neck representing skin creases. Additional holes are pierced through the front and sides of the neck. A large irregular hole is visible on the right side of the jaw.

Note: Additional metadata fields (not shown here) include museum number, registration number, department, acquisition notes, acquisition date, previous owner, funder name, acquisition name, subjects, exhibition history, location, bibliographic references, curator's comments and dimensions.

3.4 Methodology

This section outlines the adopted definition of production techniques and describes the filtering procedure used to construct the analytical dataset from the online collection of the British Museum. It also explains the implementation of a large language and vision–language model, namely GPT-4o, to infer production techniques from the textual and visual information associated with each artefact.

3.4.1 Production Techniques

In this paper, I define *production techniques* as the processes used in the manufacture, decoration or modification of artefacts. "production techniques" may be also referred to as "techniques" for concision.

The set of techniques employed in the analysis was derived from the production techniques already reported in the curator-assigned metadata of the British Museum Collection; the latter was minimally refined. First, terminology with clear overlap was harmonised. For instance, *wheel-thrown* and *wheel-made* were merged into a single category, as both refer to the same process of shaping clay on a rotating wheel. Similarly, *calcite-tempered*, *flint-tempered* and *quartz-tempered* were collapsed into a single category named *tempered*. The latter captures the broader process of strengthening clay with added inclusions. Second, modern image production processes such as *gelatin silver printing*, *photogravure* and *lithography* were excluded. Since artefacts are observed through digital images, it is difficult to separate the underlying production process of the object from the secondary process by which its image was produced, thus resulting in inaccurate classifications for these techniques. Third, casts and other explicit replicas were omitted as they may exhibit more modern techniques that were not applied in the manufacture of the original object.

Nonetheless, not all categories were collapsed, even when they might appear superficially similar. For example, *tin-glazed* and *underglazed* pottery were retained as separate categories because they reflect distinct technological knowledge; tin glazing produces an opaque white surface using a tin oxide coating, while underglazing refers to decoration applied beneath a transparent glaze.

After these refinements, the dataset comprises 64 distinct techniques covering a wide range of domains. Ceramics include, for example, *slipped*, where liquid clay is applied to the surface before firing and *terra sigillata*, a fine pottery process with glossy red slip. Metalworking is represented by practices such as *repoussé*, in which designs are hammered from the reverse to create raised relief and *filigree*, a technique that uses twisted wires to form delicate openwork. Glassworking techniques include *blown*, the inflation of molten glass through a pipe and *enamelled*, the fusion of coloured powdered glass to a surface under heat. Textile processes include *woven*, *embroidered* and *dyed*, while surface treatments range from *burnished*, a technique that produces a glossy sheen by polishing, to *painted* and *gilded*.

Broader categories such as *metal technique*, *textile technique* and *ceramic technique* are also retained to capture cases where only the general material process is recorded.

A full list of definitions is provided in Table 3.A.1 in the Appendix.

3.4.2 Filtering Procedure

The aim of this paper is to identify the spatial and temporal emergence and diffusion of production techniques. Thus, the filtering process excluded all records missing geographic or chronological information. In practice, this implies that only artefacts with at least one of the fields *production place* or *findspot* and with production date information were retained.

Production place refers to the location where the artefact was produced, while the *findspot* records where it was recovered. Whenever both fields are available, the production place was retained as the geographic reference, as it most directly reflects where the production technique was originally applied. In cases where the production place was missing, the findspot was used as a proxy.[23]

The location fields were then matched to geographic coordinates. For locations corresponding to modern place names, such as “Rome, Italy” or “Papua New Guinea,” latitude and longitude coordinates were obtained through the Google Maps API. Historical place names, including entries such as “Thebes” “Byzantine Empire” or “Carthage” required manual matching. Each historical reference was researched in secondary sources and linked to a modern analogue. For example, “Constantinople” was matched

[23] In the British Museum collection, *production place* and *findspot* locations coincide in 93.6 percent of records.

to present-day Istanbul in Turkey. Since the analysis requires the computation of precise distances, point coordinates were adopted instead of polygon analogues.

Similar to locations, information on production dates varies considerably in degree of precision. Some artefacts are associated with specific years or narrow ranges, while others are assigned broader periods such as "Third century" or "500 BCE–100 AD." In some cases, production dates were not reported using the Gregorian calendar but instead relied on alternative systems, such as the Hijri or regnal calendars. These instances were identified during the cleaning process and converted into Gregorian equivalents using secondary sources.

Date entries were standardised into numeric lower and upper bounds, expressed as calendar years. For example, "300 BCE–500 AD" was coded as $[-300, 500]$. A detailed overview of the standardization rules applied to production dates is reported in Table 3.A.2 in the Appendix. Therefore, each artefact in the dataset is associated with an earliest estimated date of production and a latest one. In cases where and artefact has a precise year of production, these two values are the same.

Furthermore, artefacts were retained only if they included images as well as textual descriptions and material information. Images depict details of shape, decoration or surface treatment that can reveal the production techniques, while the information on materials and descriptions provides relevant context. The combination of visual and textual information offers a foundation for the methodological approach outlined in Section 3.4.3, where large language and vision-language models are employed to infer production techniques in a systematic manner.

Artefacts with missing images were retained only when production techniques had been recorded in the metadata by curators. In such cases, the information provides a direct account of the manufacturing methods involved and can be used without further inference.

In sum, the collection was restricted to artefacts that contained at least one geographic reference (production place or findspot), a valid production date and either (i) an image accompanied by textual description and material information or (ii) curator-assigned production techniques. The application of these filtering criteria resulted in a substantial reduction of the initial collection, yielding a final cohort of 823,417 artefacts suitable for the analysis of the spatial and temporal diffusion of production techniques.

3.4.3 GPT-4o

GPT is a multimodal large language model (LLM) developed by OpenAI. This model has witnessed increasing adoption in economics and social sciences to classify and annotate unstructured information. For instance, Lagakos et al. (2025) employed GPT to extract systematic information on critical junctures, sources of meaning and life satisfaction from life narratives.

Unlike earlier text-only models, GPT-4o processes both images and text analysis. This multimodal property is particularly suitable for examining the obtained artefacts which combine images, textual descriptions and material information. A fixed prompt was applied to analyse all artefact records against a pre-defined list of 64 techniques; the latter is reported in Section 3.B of the Appendix. The input encompassed artefact images, textual descriptions and material information. The model returned a binary vector, where the value of "1" indicated the presence of a given technique whereas "0" was assigned if the technique was absent.

All queries were executed via API calls to OpenAI to allow for the large-scale processing of inputs. The temperature parameter was set to zero throughout the analysis. This parameter controls the randomness of the responses of the model. Lower values yield more deterministic outputs, whereas higher values result in greater variability and creativity. Setting the temperature to zero minimises randomness and produces stable results across repeated runs on the same input, thereby improving reproducibility (Rosoł et al., 2023).

Before applying the procedure to the full dataset, a subset of 10,000 artefacts was analysed to evaluate the performance of the prompt and assess the reliability of GPT-4o in identifying production techniques. For this validation test, GPT-4o outputs were compared against the curator-assigned metadata for artefacts that already had a reported technique in the metadata from the collection of the British Museum . The comparison aimed to determine the extent to which the model could accurately reproduce curator-labelled information based solely on the textual descriptions, material information and images. The results show substantial overlap between the techniques identified by GPT-4o and those recorded in the metadata. Specifically, for 86.3 percent of the artefacts sampled, all techniques reported in the metadata were also identified by the model.

3.5 Empirical Analysis

This section first describes the dataset obtained following the GPT-based analysis. It then identifies pioneering sites (also referred to as *pioneers*), defined as the earliest known adopters of each production technique, and records their corresponding emergence dates. Finally, it outlines the methodology and presents the results of the regression framework used to examine the relationship between distance from pioneering sites and adoption delay for each technique.

3.5.1 The Dataset

From the 823,417 artefacts retained after filtering, 631,835 included images and were analysed using GPT-4o, while artefacts without images were retained only when production techniques were recorded in the metadata. This process identified 493,148 unique artefacts as exhibiting at least one of the 64 production techniques considered, yielding 1,099,523 artefact–technique pairs. Within this dataset, 47.39 percent of records were identified exclusively through GPT-4o. Among those already associated with at least one curator-assigned technique, the model added further techniques for 2.83 percent of artefacts.

In total, 10,885 unique locations are represented in the dataset: 83.7 percent correspond to sub-national units such as cities, towns or ancient settlements, 14.2 percent are reported at the country level and the remainder are broader regional references.

Although the dataset covers a wide geographic range, this distribution is largely uneven. The highest concentration of artefacts is in Europe and around the Mediterranean basin, with further clusters in the Middle East, the Nile Valley and Papua New Guinea. In contrast, representation is sparser in sub-Saharan Africa, the Americas and some parts of Asia. Figure 3.5.1 shows the distribution of artefacts.

London is the location that is most represented with a total of 84,192 associated artefacts, followed by Rome with 79,140 artefacts. Paris and Begram, the historical capital of the Kushan Empire, have considerable representation with a total of 16,187 and 11,272 records, respectively. The five countries that are most represented are Greece, Japan, the United Kingdom, Iraq and Italy, amounting to a total of 72,770 artefacts.

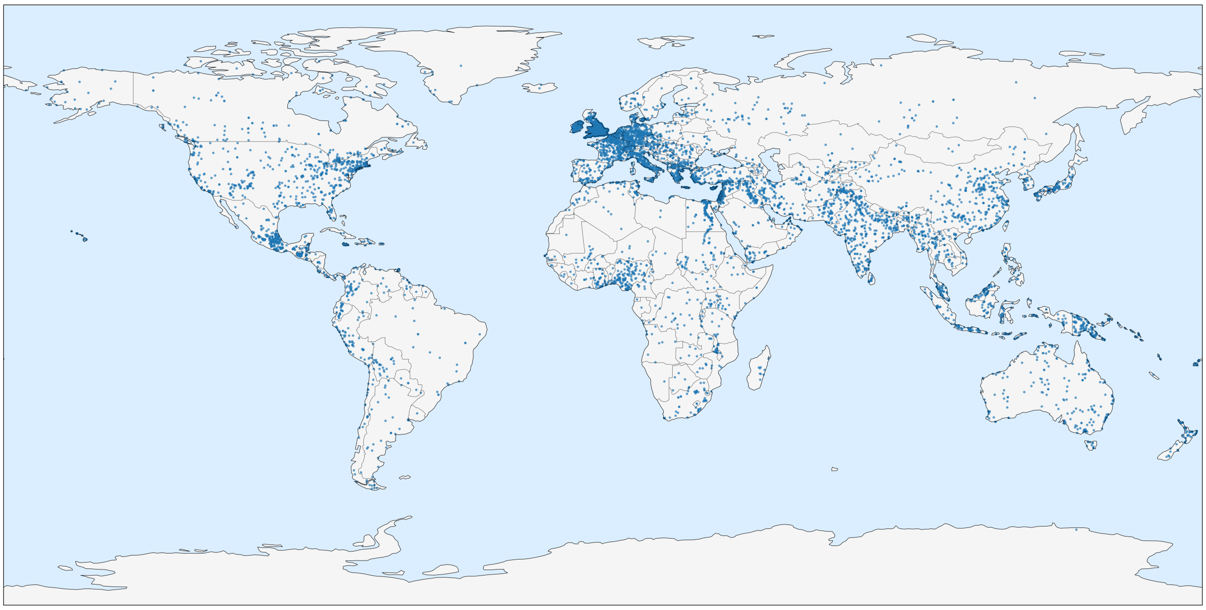


Figure 3.5.1: Spatial distribution of artefacts

Table 3.5.1 reports the distribution of the artefacts in the dataset over time. Prehistoric periods are largely under-represented, with 2.2 percent of artefacts dated to the Stone Age, 4.25 percent to the Bronze Age and 1.19 percent to the Iron Age. Coverage increases substantially with the onset of Classical Antiquity, which accounts for 30.27 percent of the records. Additionally, 21.66 percent of artefacts are dated to the Middle Ages, while 35.64 percent fall within the Industrial period. The most recent era, namely the Contemporary period, contributes only 4.79 percent of artefacts.

Table 3.5.1: Distribution of artefacts by era

Era	Count	Percent
Stone Age ($\leq$ 3000 BC)	10,840	2.20
Bronze Age (3000–1200 BC)	20,960	4.25
Iron Age (1200–1 BC)	5,858	1.19
Classical Antiquity (800 BC–500 AD)	149,253	30.27
Middle Ages (500–1700 AD)	106,831	21.66
Industrial Age (1700–1950 AD)	175,774	35.64
Contemporary (1950–present)	23,632	4.79
Total	493,148	100.00

3.5.2 Origins of Production Techniques

I define the origin of a production technique as the site of first occurrence, referred to as *pioneering site* or *pioneer*, and the earliest year of recording, referred to as *emergence date*. Formally, for technique j, the set of pioneering sites is:

$$P_j = \{ s \in \mathcal{S} : \exists i \in \mathcal{I}_j \text{ with } site(i) = s \text{ and } T_{ij} = F_j \},$$

where $\mathcal{S}$ denotes the set of all sites in the dataset, $\mathcal{I}_j$ the set of artefacts associated with technique j and T_{ij} the production year of artefact i. Hence, a site belongs to P_j if at least one artefact produced in that location is associated with technique j and is dated earlier than all other artefacts that are also associated with technique j.

The corresponding *emergence date* of a production technique is given by the earliest production year among all artefacts for which the technique is identified:[24]

$$F_j = \min_{i \in \mathcal{I}_j} T_{ij}.$$

Pioneering Sites

Figure 3.5.2 presents the geographic distribution of pioneering sites, corresponding to locations where a technique was first identified.

The Near East has the highest concentration of pioneering sites. In Mesopotamia, Arpachiyah and Chagar Bazar provide the earliest evidence of stamping and applied production techniques, while Ur is identified as the pioneering site for multiple techniques including chasing, embossing and intaglio. Additionally, Tell Atchana records the earliest artefacts associated with glazing. In the Levant, Jericho is found to be the pioneer of multiple techniques, including inlay and moulding.

Similarly, the Balkan Peninsula is associated with several pioneering sites, including burnished ceramics in Macedonia and impressing in Thessaly. In Western Europe, pioneering sites include Les Eyzies in France for engraving and other surface-treatment techniques and Kendrick's Cave in Wales for early pigmenting.

[24] When artefacts are dated by an interval $[t^{\text{earlier}}, t^{\text{latest}}]$, the baseline measure takes the lower bound t^{earlier}

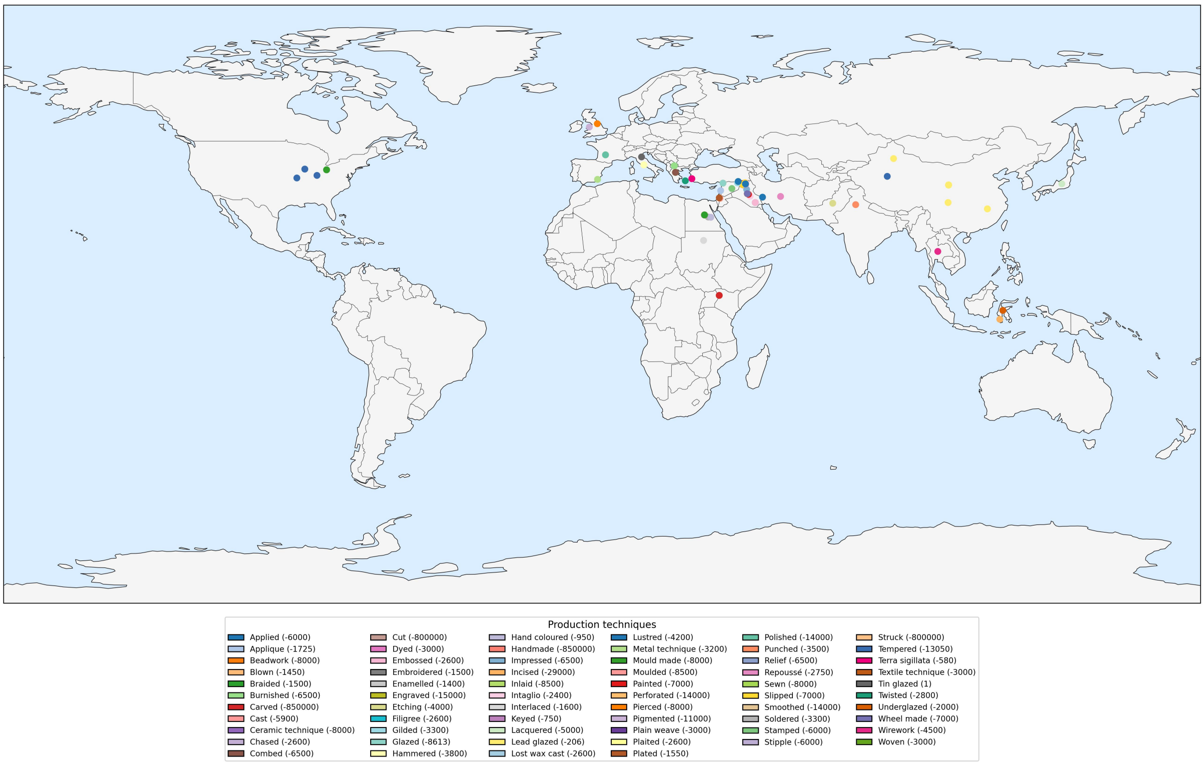


Figure 3.5.2: Spatial distribution of pioneering sites

In Africa, the Olduvai Gorge in Tanzania provides the earliest examples of carving, cutting and handmade stone tools, while Egypt is identified as an early centre for textile techniques such as braiding, weaving and dyeing.

In Southeast Asia, Ulu Leang in Sulawesi is identified as a pioneering site for techniques such as beadwork and sewing. In East Asia, China records the earliest lead-glazed ceramics. Finally, North America records the earliest evidence of the techniques tempering and mould-making production from sites corresponding to modern-day Illinois and Ohio.

For several techniques, multiple artefacts identify the pioneering sites. For instance, the metadata uncovered 185 artefacts associated with the technique *painted* linked to five different locations, all located in modern-day Iraq. Similarly, the technique *relief* is associated with two pioneering sites, Macedonia and Thessaly, where GPT identified a total of 16 artefacts. The two locations are approximately 223 kilometres apart.

Within the 64 techniques analysed, 10 have more than one pioneering site. Overall, these pioneering sites are geographically proximate. For eight of these techniques, the average distance between the pioneering sites for the same technique is below

1,000 kilometres. Conversely, two techniques show considerably greater distances between their respective pioneering sites. The technique *impressed* has two pioneering sites, Thessaly in Greece and Central Mesopotamia with an absolute distance of 1,978 kilometres. Similarly, *lead-glazed* is associated with four pioneering sites: Yonghe, Chengdu, Xinjiang, all located in China, as well as the broader national region of China, resulting in an average pairwise distance of 1,642 kilometres. Table 3.C.1 in the Appendix reports the list of techniques with multiple pioneering sites as well as their respective distances.

Pioneering sites were identified through GPT-based image analysis for 39 techniques; and through the metadata, i. e., curator-assigned techniques from the collection, for 18 techniques. For the remaining 7 techniques, pioneering sites were identified by both methods, resulting in eleven GPT–metadata pairs. In six of the eleven pairs, the pioneering sites identified by GPT and those identified by the metadata were located at the same site. Conversely, for *applied*, GPT identified Arpachiyah as the pioneering site, while the metadata identified Chagar Bazar, located approximately 210 kilometres away. For *burnished*, the metadata placed the pioneering site in Lete, Greece, whereas GPT identified two artefacts from the same period, in Lete and Macedonia, 223 kilometres apart. Finally, for *stamped*, GPT identified Chagar Bazar and Arpachiyah, while the metadata pointed to Arpachiyah and the broader region of Syria. Table 3.C.2 in the Appendix reports the source used to identify pioneering sites for each production technique and the corresponding number of artefacts attributed to each source.

Emergence Dates

Emergence dates, corresponding to the first occurrence of each production technique in the dataset, range from the Lower Palaeolithic to the beginning of the Common Era. The earliest techniques, *carved*, *handmade*, *cut* and *struck*, are recorded around 850,000–800,000 BCE, predating the appearance of modern humans. The period spanning approximately 800,000–50,000 BCE is characterised by the absence of newly emerging production techniques. By contrast, several techniques appeared during the Upper Palaeolithic (50,000–12,000 BCE), including pigmenting, painting and tempering.

During the 10,000–2,200 BCE period, roughly corresponding to the Neolithic era, many production techniques emerged. This is especially the case for ceramic techniques such as *inlaid* and *glazed*, first recorded around 8,500 BCE and *slipped* and *wheel-made*, which appear near 7,000 BCE. Metal-related techniques also appear during this period, such as *wirework*, dated to about 4,500 BCE and *gilded* in 3,300 BCE. Textile-related techniques also developed during this period with the earliest production of *dyed* and *woven* artefacts dating to around 3,000 BCE. Other surface treatment techniques appeared during this time, including *burnished*, *impressed*, *stamped* and *relief*. After the Neolithic period, only a small number of techniques emerge, including different glazing techniques. Table 3.C.3 in the Appendix reports the emergence dates of the production techniques studied.

Many of the pioneering sites and corresponding emergence dates align, to some extent, with established archaeological evidence. The earliest occurrences of carving, cutting and striking are located in Olduvai Gorge, a site recognised as one of the earliest centres of tool production (Leakey, 1971; Potts and Shipman, 1981). The associated production date of 850,000 BCE, however, is later than the earliest known evidence of tool-making. Textile techniques such as dyeing and weaving are correctly matched with Egypt around 3,000 BCE, consistent with previous studies (Mohamed, 2023; Vogler, 1982). Abydos in Egypt is identified as the earliest site of soldering around 3,300 BCE, broadly in agreement with the literature (Humpston and Jacobson, 2004). Several techniques are associated with pioneering sites in modern-day Iraq, including filigree and lost-wax casting in Ur, both dated to 2,600 BCE, which accords with existing research (De Lapérouse et al., 2024; Oliveira, 2021). The Levant is identified as the pioneering region for stamping and gilding, dated to around 6,000 BCE and 3,300 BCE, respectively, in line with archaeological findings (Darque-Ceretti et al., 2011; Duistermaat, 2013). Finally, Macedonia appears as the earliest site for burnishing around 6,500 BCE, in line with the statements of Bonga (2013), while the early appearance of repoussé in the same region is supported by Allan (1976).

3.5.3 Adoption Delay

This subsection examines the relationship between geographic proximity to pioneering sites and the timing of subsequent adoption of production techniques.

Data

The dependent variable is the adoption delay, defined as the number of years between the emergence of a production technique and its first recorded occurrence at a non-pioneering site. For each technique, the first local appearance is determined using the earliest dated artefact associated with a technique at each site. Using the earliest artefact as reference provides a consistent measure of the timing of initial adoption.

The explanatory variable of interest is distance from pioneering sites (shortened to *Distance from pioneer* in the regression tables), defined as the absolute distance between each site and the identified pioneering site of the corresponding technique. Distances are computed from latitude and longitude coordinates. This measure does not account for geographic barriers nor for advancements in transportation. To address this shortcoming, the analysis is conducted separately for three samples: artefacts dated before 1500, artefacts dated before 1800 and the full dataset.

The 1500 AD boundary corresponds to the pre-colonial era and follows the approach of D. Comin et al. (2010). Colonisation presents a potential source of bias, particularly when locations are defined by the *findspot* rather than the *production place*. In such cases, foreign-produced artefacts introduced through colonial trade will not reflect local adoption of the underlying technique. Conversely, the transfer of objects from colonised regions to colonial territories may also distort the inferred spatial distribution of adoption.

Similarly, the 1800 AD cutoff corresponds, approximately, to the onset of the industrial era, which resulted in significant improvements in transportation and communication. These developments substantially reduced the cost of mobility and increased the speed of information exchange across regions. As a result, geographic distance no longer provides an accurate measure of the barriers to interaction or the potential for diffusion. Including this cutoff therefore, serves two purposes. First, it limits the main analysis to a period in which distance remains a meaningful proxy for spatial separation. Second, it allows an assessment of whether the role of geographic proximity in shaping adoption weakened following the expansion of transport and communication networks.

The regression analyses include a set of geographic covariates that capture features of the physical environment that may influence the spatial diffusion of production techniques. These are distance to the coast, distance to rivers, terrain ruggedness, elevation and land suitability. All distances are expressed in thousands of kilometres.

Distances to coasts and rivers capture the accessibility of a given location and its potential for interaction with other regions through trade or migration. Such interactions may have facilitated the exchange of technological knowledge and contributed to the diffusion of production techniques. Conversely, ruggedness and elevation capture physical constraints on transport and mobility that could limit such diffusion. Land suitability represents the agricultural potential of different regions and may be associated with settlement size and the concentration of productive activity.

Specification

The relationship between distance from pioneering sites and delay in adoption is estimated using the following specification:

$$Delay_{sj} = \alpha_j + \beta_j \, Distance_{sj} + \mathbf{X}_s \gamma_j + \varepsilon_{sj},$$

$Delay_{sj}$ denotes the adoption delay for technique j at site s. It is defined as:

$$Delay_{sj} = T_{sj} - F_j,$$

where T_{sj} is the production date of the earliest artefact at site s using technique j and F_j is the emergence date of that technique.

$Distance_{sj}$ measures the absolute distance between site s and the pioneering site (also referred to as "pioneer") for technique j. For techniques with multiple pioneering sites, the pioneer closest to a given location is considered as the reference point. It is defined as:

$$Distance_{sj} = \min_{p \in P_j} d(s, p),$$

where P_j is the set of pioneering sites for technique j and $d(s, p)$ is the absolute distance in kilometres between site s and pioneer p.

The coefficient of interest, β_j, captures the association between distance from pioneering sites and adoption delay for each production technique j. A positive value for this coefficient would indicate that sites located further from pioneering sites adopt production techniques later than sites that are closer to these points of origin.

The vector $\mathbf{X}_s$ includes the set of geographic covariates described in Section 3.5.3: *Distance to coast*, *Distance to river*, *Elevation*, *Land suitability* and *Ruggedness*. Furthermore, the regressions also control for relative date uncertainty and the number of objects per site.[25] ε_{sj} is the site- and technique-specific error term.

The regressions are estimated separately for each production technique using ordinary least squares (OLS) and results are reported for the three samples defined in Section 3.5.3: pre-1500, pre-1800 and the full dataset, named "All".

The number of usable observations for each technique is presented in Table 3.C.4 in the Appendix. Some techniques, such as *engraved*, *stamped* and *cast*, are associated with a particularly large number of artefacts, while others, such as *interlaced* or *embroidered*, are represented by fewer observations. Descriptive statistics for the regression samples, which only consider the earliest artefact associated with each technique at the site level, are reported in Tables 3.C.5, 3.C.6 and 3.C.7 in the Appendix.

Results

Table 3.5.2 reports the estimated coefficients on *Distance from pioneer*, for each production technique and sample, namely *Pre-1500*, *Pre-1800* and *All*. Each coefficient corresponds to the OLS estimate from a technique-specific regression where the dependent variable is the delay in adoption of each respective technique, measured in years. All specifications include the same set of controls, namely proximity to rivers, distance to coast, terrain ruggedness, elevation and land suitability. The regression results showing the coefficients on all independent variables are reported in the Appendix.

The regression results reveal a clear positive association between distance from pioneering sites and adoption delay. In the pre-1500 sample, among the 63 techniques for which regressions could be estimated, 21 display a positive and statistically significant coefficient at the 1 percent significance level. The average coefficient estimate across all techniques in this sample that are significant at the 1 percent significance level is 84.66. This suggests that, approximately, a 1,000 kilometre distance from a pioneering site is associated with an 85-year delay in the adoption of a production technique. The number

[25] $\textit{Relative Date Uncertainty} = \frac{latest\_date - earlier\_date}{|earlier\_date| + 1}$.

of positive and significant coefficient estimates regarding distance from pioneering sites rises to 29 and 35 when considering significance at the 5 and 10 percent significance levels, respectively.

The results for the pre-1800 sample are qualitatively similar. Specifically, 43 of the 64 estimated coefficients are positive and statistically significant at the 5 percent significance level, with an average coefficient of approximately 125.33 years. In parallel, 43 of the coefficient estimates of interest are positive and significant at the 5 percent significance level when considering the entire sample, with an average estimate of 119.61. These findings suggest that distance from pioneering sites remained strongly associated with adoption delay of production techniques even after the emergence of global trade networks and transport improvements.

The magnitude of the coefficients on distance from pioneering sites varies considerably across the different techniques. For instance, the technique *wheel-made* exhibits coefficient estimates ranging from 188 to 205 across the three samples, all significant at the 1 percent level. This implies that, *ceteris paribus*, an increase of 1,000 kilometres in distance from the pioneering site is associated with roughly 200 years of delay in adoption. Similarly, techniques such as *slipped*, *painted*, *inlaid* and *glazed* display highly significant coefficients ranging from 100 to 200 years per 1,000 kilometres. The technique *tempered* shows some of the largest estimates, with coefficients between 231 and 361, suggesting particularly slow diffusion from the pioneering site.

By contrast, there are very few negative and statistically significant coefficient estimates on the Distance from pioneer variable. All samples considered, only the coefficient estimate for the technique *sewn* in the pre-1800 sample is negative and significant at the 1 percent significance level, however, the latter is only estimated at -35.60. Two coefficients are negative and significant at the 5 percent significance level; both concern the pre-1500 sample and are reported for similar techniques, namely *tin-glazed* and *underglazed*, with coefficients estimated at -118.47 and -13.40, respectively. Another three coefficient estimates are negative and significant when considering the 10 percent significance level; these relate to the techniques *pierced* and *cut* in the pre-1500 sample and *mould-made* for the pre-1800 sample.

Overall, the regression results show a strong association between distance from pioneering sites and delay in adoption in non-pioneering sites. The analyses do not indicate that this relationship weakens over time.

Table 3.5.2: Distance from pioneer (per 1,000 km) and adoption delay (OLS)

Technique	Pre-1500	Pre-1800	All
Applied	180.315***	208.481***	136.447***
Appliqué	71.460***	91.789***	48.316***
Beadwork	74.228	-2.660	-7.981
Blown	30.033	119.815***	142.215***
Braided	49.214	127.240***	11.186
Burnished	123.502*	147.272**	186.936***
Carved	584.239	503.890	232.078
Cast	85.575***	160.331***	170.541***
Ceramic technique	44.963	37.111	51.570**
Chased	144.750***	208.371***	164.621***
Combed	168.533***	162.939***	154.233***
Cut	-321.903*	-194.568	-62.983
Dyed	23.906	76.158***	3.422
Embossed	42.295*	108.974***	73.898**
Embroidered	1.464	38.844	3.778
Enamelled	64.113**	109.678***	79.158***
Engraved	-14.410	29.055	55.457***
Etching	–	80.699	22.872
Filigree	93.028*	99.045*	77.365
Gilded	82.203***	119.739***	103.418***
Glazed	112.366***	103.925***	104.953***
Hammered	65.151**	125.765***	167.747***
Hand coloured	34.065	68.199	26.035**
Handmade	102.254***	156.177***	116.411***
Impressed	123.803***	119.486***	145.307***
Incised	62.972*	24.663	-6.511
Inlaid	103.755***	146.543***	138.234***
Intaglio	106.348	195.813***	118.793***
Interlaced	77.913	49.569	-9.994

Continued on next page

Table 3.5.2: Distance from pioneer (per 1,000 km) and adoption delay (OLS) (continued).

Technique	Pre-1500	Pre-1800	All
Keyed	67.564**	68.504**	63.957*
Lacquered	20.666	45.717**	26.341**
Lead-glazed	39.775**	53.530***	36.679***
Lost-wax cast	111.887***	110.656**	131.096**
Lustred	68.594	100.379***	95.961***
Metal technique	31.645*	96.927***	96.738***
Mould-made	-28.565	-67.354*	-44.883
Moulded	145.827***	151.394***	148.077***
Painted	163.139***	196.745***	171.755***
Perforated	-38.348	79.961*	176.058***
Pierced	-88.508*	-38.203	79.265***
Pigmented	45.909	125.296***	108.905***
Plain weave	13.333	18.584	-1.933
Plaited	65.606	121.688***	24.205***
Plated	38.746	73.500	79.901***
Polished	-38.849	74.635*	133.922***
Punched	64.775**	87.003**	54.018
Relief	82.755***	106.309***	130.490***
Repoussé	121.402***	139.728***	116.008***
Sewn	69.840*	-35.603***	-0.148
Slipped	176.533***	187.801***	198.377***
Smoothed	-35.311	113.132**	167.501***
Soldered	67.579**	125.047***	112.488***
Stamped	100.337***	150.080***	131.147***
Stipple	132.206***	150.543**	100.593*
Struck	43.061	120.969***	116.258***
Tempered	360.629***	230.581**	344.621***
Terra sigillata	8.448	8.448	8.448
Textile technique	26.856	88.938**	12.520

Continued on next page

Table 3.5.2: Distance from pioneer (per 1,000 km) and adoption delay (OLS) (continued).

Technique	Pre-1500	Pre-1800	All
Tin-glazed	-118.477**	10.162	10.040
Twisted	119.076***	168.751***	125.953***
Underglazed	-13.399**	16.803***	19.026***
Wheel made	196.721***	204.932***	188.177***
Wirework	80.003**	30.001	24.479
Woven	86.198**	100.440***	9.302

Summary: OLS estimates of the relationship between distance from pioneer and technique adoption delay. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors clustered at country level; (iii) *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$, two-sided tests.

3.6 Discussion

Although the regression analyses show a clear positive association between distance from pioneering sites and delay in the adoption of production techniques, it is not possible to assert that this relationship is causal. Unobserved factors such as linguistic similarity, cultural proximity or institutional resemblance may be correlated with both distance from pioneering sites and adoption delay. In this study, I focus on diffusion from pioneering sites to all other locations, a possible alternative to this approach would be to model the gradual diffusion process instead. This would involve ordering sites according to their adoption time to determine whether production techniques spread sequentially from one site to another.

The framework developed by Ashraf et al. (2010) offers a relevant comparison. Their study examines how distance to technological frontiers and geographic isolation influenced long-run development, identifying frontier regions from historical urbanisation patterns. While the present paper does not construct a direct measure of technological frontiers, the identification of pioneering sites provides a basis for approximation through early adoption patterns. With further refinement, such artefact-based measures could complement existing frontier definitions. Furthermore, their results also highlight the broader role of isolation in shaping development, a dimension that could be explored using the data assembled in this study.

The analysis adopted in this paper relies on the absolute distance in kilometres between pioneering sites and other locations which fails to account for natural barriers to mobility such as water bodies or mountain ranges and does not capture transportation technology advancements. A more appropriate alternative would be the Human Mobility Index with Seafaring (HMISea) (Özak, 2010) which measures the time needed to travel through each square kilometre of land and selected sea routes.

Lastly, although the dataset uses a large number of artefactual records, it remains incomplete. The British Museum collection offers extensive coverage but does not encompass the global archaeological record. Expanding the dataset to include digitised collections from other major institutions, such as the Louvre, the Smithsonian or the Metropolitan Museum of Art, could significantly enhance geographic and chronological representativeness.

3.7 Conclusion

The contribution of this paper is threefold. First, I demonstrate the potential of large language and vision–language models for the systematic extraction of structured information from artefactual data. By jointly analysing images and textual descriptions, the approach produces consistent and scalable classifications of production techniques across a large number of artefacts. This methodological contribution illustrates how recent advances in artificial intelligence can convert qualitative museum records into quantitative datasets suitable for large-scale empirical analysis. Second, I reconstruct the spatial and temporal distribution of pioneering sites, defined as the earliest identified adopters of specific production techniques. Third, I examine how spatial separation from these pioneering sites influenced the timing of adoption. The findings reveal a clear positive association between distance and adoption delay.

Appendix

3.A Definitions

Table 3.A.1: List of production techniques

Technique	Definition
Applied	General term for techniques where material is added or affixed onto a surface.
Appliqué	Decorative technique of attaching one material onto another, often by sewing, gluing or pressing.
Beadwork	Decoration created by stringing, stitching or attaching beads onto a surface.
Blown	Forming hollow glass objects by inflating molten glass through a blowpipe.
Braided	Technique of interweaving three or more strands of material, such as fibres or wires.
Burnished	Surface polished by rubbing with a hard tool to produce gloss or sheen.
Carved	Shaping or decorating by cutting into wood, stone, bone or ivory with tools.
Cast	Forming objects by pouring molten metal, glass or slip into a mould and allowing it to solidify.
Ceramic technique	Broad term covering ceramic manufacturing or finishing processes not otherwise specified.
Chased	Metal surface decoration achieved by hammering from the front to create lines or textures.
Combed	Decoration created by dragging a comb-like tool across a soft surface, often clay or slip.
Cut	Material removed from a solid block (stone, bone, ivory, metal) using sharp tools.
Dyed	Textile fibres or fabrics coloured by immersion in dye solutions.

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Technique	Definition
Embossed	Decoration raised above the surface of metal, leather or paper by pressing or hammering from the reverse.
Embroidered	Decorative stitching applied to textiles with needle and thread.
Enamelled	Glassy coating fused to metal, glass or ceramic surfaces under high heat.
Engraved	Cutting fine lines or designs into metal, glass or stone with a sharp tool.
Etching	Printmaking method using acid to incise designs into a prepared metal plate.
Filigree	Metalworking technique using fine wires twisted or soldered to create delicate openwork patterns.
Gilded	Thin coating of gold applied to a surface by mechanical or chemical means.
Glazed	Ceramic surface coated with vitreous glaze, fused during firing to produce gloss and impermeability.
Hammered	Metal surface shaped or decorated by repeated blows of a hammer.
Hand coloured	Prints or surfaces coloured manually with pigment after initial production.
Handmade	General designation for objects shaped or finished entirely by hand.
Impressed	Decoration created by pressing tools or objects into a soft surface to leave impressions.
Incised	Designs cut into the surface of a material with a sharp tool.
Inlaid	Decoration created by embedding contrasting materials into a base surface.
Intaglio	Printmaking technique where the design is incised into a plate and filled with ink.
Interlaced	Decoration or structure formed by crossing or looping strands over and under each other.

Continued on next page

Technique	Definition
Keyed	Surface prepared with cross-hatching or roughening to allow another material to adhere.
Lacquered	Surface coated with layers of resin-based lacquer for gloss and protection.
Lead-glazed	Pottery covered with a lead-based glaze to produce a glossy, impermeable surface.
Lost-wax cast	Casting method using a wax model that is melted away to create a mould cavity.
Lustred	Ceramic decoration using metallic oxides to produce an iridescent sheen.
Metal technique	General term for metalworking processes not otherwise specified.
Mould-made	Objects produced by pressing material into a mould.
Moulded	Objects shaped by hand-pressing material into a form or matrix.
Painted	Surfaces decorated with applied paint or pigment.
Perforated	Surfaces or objects intentionally pierced with holes.
Pierced	Decoration produced by cutting or drilling openwork patterns into a solid material.
Pigmented	Surface coloured with pigment applied directly rather than through glazing.
Plain weave	Basic textile weave in which warp and weft threads cross alternately.
Plaited	Interlacing three or more strands of material in a flat braid.
Plated	Covering one metal with a thin layer of another, often precious, metal.
Polished	Surface smoothed and brightened by abrasion or rubbing.
Punched	Decoration created by striking a surface with punches to form repeated impressions.
Relief	Printmaking or sculpture method where the design projects above the background.

Continued on next page

Technique	Definition
Repoussé	Metalworking technique where designs are hammered from the reverse to create raised relief.
Sewn	Joining or decorating materials using stitching with thread or fibre.
Slipped	Pottery coated with liquid clay (slip), sometimes coloured, before firing.
Smoothed	Surface made even by rubbing, scraping or levelling.
Soldered	Joining metal components using a filler metal melted at a lower temperature.
Stamped	Decoration or marks made by pressing a stamp into a surface.
Stipple	Printmaking technique using dots incised or punched to create tone.
Struck	Objects, often coins or medals, made by striking a blank with engraved dies.
Tempered	Clay strengthened with added materials (temper) such as sand, shell or grit.
Terra sigillata	Fine pottery with glossy red slip, often decorated with stamped motifs.
Textile technique	General term for processes of weaving, spinning or fabric finishing not otherwise specified.
Tin glazed	Pottery covered with an opaque white tin-based glaze.
Twisted	Fibres, wires or strands wound together to form cord or decoration.
Underglazed	Decoration applied beneath a transparent glaze.
Wheel made	Pottery formed on a rotating wheel.
Wirework	Objects or decoration formed by shaping and joining wire.
Woven	Textile created by interlacing warp and weft threads.

Table 3.A.2: Standardisation rules of production dates

Original form	Standardisation
Single year	Coded as identical lower and upper bounds.
Year BCE	Converted to negative year values.
Explicit range	Converted directly to numeric lower and upper bounds.
Century AD	Expanded to the corresponding 100-year span.
Century BCE	Expanded to the corresponding negative-year span.
Early / mid / late century	Divided into thirds of the century (early, middle, late).
Millennium	Expanded to the corresponding 1000-year span.
Named archaeological periods	Converted to conventional chronological ranges for the relevant region.
Non-Gregorian systems (Hijri, regnal, dynastic)	Converted into Gregorian equivalents using secondary sources.
Open-ended expressions	One bound fixed, the other left open.
Circa or "c."	Treated as equivalent to precise years or ranges.
Multiple attributions (e.g. cast vs. original)	Original production date retained.

3.B GPT-4o Prompt

You are an artefacts specialist and you are interested in identifying the techniques and know-hows used to create ancient objects.

Based on the image, infer the techniques that were likely used to create the object.

Always consider the artefact's description and materials information together with the image when making your assessment.

You can make reasonable guesses and assumptions taking into consideration the textures, joins, shapes, forms, colours, materials, composition and overall construction.

Do not assign any technique if the object appears to be an unmodified stone or natural fossil.

If the technique cannot be identified based on the image and materials, leave all values as 0.

Only choose from the techniques in the list below.

List of techniques: Applied, Appliqué, Beadwork, Blown, Braided, Burnished, Carved, Cast, Ceramic technique, Chased, Combed, Cut, Dyed, Embossed, Embroidered, Enamelled, Engraved, Etching, Filigree, Gilded, Glazed, Hammered, Hand coloured, Handmade, Impressed, Incised, Inlaid, Intaglio, Interlaced, Keyed, Lacquered, Lead-glazed, Lost-wax cast, Lustred, Metal technique, Mouldmade, Moulded, Painted, Perforated, Pierced, Pigmented, Plain weave, Plaited, Plated, Polished, Punched, Relief, Repoussé, Sewn, Slipped, Smoothed, Soldered, Stamped, Stipple, Struck, Tempered, Terra sigillata, Textile technique, Tin glazed, Twisted, Underglazed, Wheel made, Wirework, Woven.

3.C Supplementary Tables

Table 3.C.1: Distance between pioneering sites

Technique	Sites	Min (km)	Max (km)
Applied	2	210.2	210.2
Burnished	2	223.7	223.7
Impressed	2	1978.7	1978.7
Intaglio	4	116.2	710.1
Lead-glazed	4	588.3	3019.4
Painted	5	25.9	396.6
Relief	2	223.7	223.7
Slipped	3	80.16	366.2
Stamped	3	210.9	404.7
Tempered	4	343.2	481.0

Note: Distances refer to the minimum and maximum pairwise distances between pioneering sites for each technique. Values are expressed in kilometres.

Table 3.C.2: Production techniques by identification source

Technique	GPT	Artefacts (GPT)	Metadata	Artefacts (Metadata)
Applied	Yes	1	Yes	1
Appliqué	Yes	1	No	0
Beadwork	Yes	1	No	0
Blown	Yes	2	No	0
Braided	No	0	Yes	1
Burnished	Yes	2	Yes	75
Carved	Yes	1	No	0
Cast	No	0	Yes	1
Ceramic technique	Yes	3	No	0
Chased	Yes	7	No	0
Combed	No	0	Yes	2
Cut	Yes	2	No	0
Dyed	No	0	Yes	3
Embossed	Yes	1	Yes	1
Embroidered	No	0	Yes	1
Enamelled	Yes	1	No	0
Engraved	Yes	1	No	0
Etching	Yes	1	No	0
Filigree	No	0	Yes	1
Gilded	Yes	1	No	0
Glazed	No	0	Yes	1
Hammered	Yes	14	Yes	1
Hand coloured	Yes	1	No	0
Handmade	Yes	1	No	0
Impressed	No	0	Yes	5
Incised	Yes	1	No	0
Inlaid	Yes	1	No	0
Intaglio	Yes	5	No	0

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Table 3.C.2: Identification of techniques across GPT and metadata sources (continued).

Technique	GPT	Artefacts (GPT)	Metadata	Artefacts (Metadata)
Interlaced	Yes	1	No	0
Keyed	Yes	1	No	0
Lacquered	No	0	Yes	1
Lead-glazed	No	0	Yes	39
Lost-wax cast	Yes	1	No	0
Lustred	Yes	1	No	0
Metal technique	Yes	2	No	0
Mould-made	Yes	3	No	0
Moulded	Yes	1	No	0
Painted	No	0	Yes	185
Perforated	Yes	1	No	0
Pierced	Yes	1	No	0
Pigmented	Yes	1	No	0
Plain weave	Yes	1	Yes	4
Plaited	No	0	Yes	1
Plated	No	0	Yes	1
Polished	Yes	1	No	0
Punched	No	0	Yes	1
Relief	Yes	16	No	0
Repoussé	Yes	1	No	0
Sewn	Yes	1	No	0
Slipped	No	0	Yes	9
Smoothed	Yes	3	No	0
Soldered	No	0	Yes	1
Stamped	Yes	2	Yes	3
Stipple	Yes	1	No	0
Struck	Yes	1	No	0
Tempered	Yes	5	No	0

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Table 3.C.2: Identification of techniques across GPT and metadata sources (continued).

Technique	GPT	Artefacts (GPT)	Metadata	Artefacts (Metadata)
Terra sigillata	Yes	2	No	0
Textile technique	Yes	3	No	0
Tin-glazed	No	0	Yes	1
Twisted	Yes	1	No	0
Underglazed	Yes	1	No	0
Wheel-made	No	0	Yes	1
Wirework	Yes	1	No	0
Woven	Yes	1	Yes	4

Note: "Yes" indicates that at least one artefact for the corresponding technique was identified through the respective source (GPT or metadata). The "Artefacts" columns report the number of artefacts associated with the pioneering site(s) for each technique.

Table 3.C.3: Emergence dates of production techniques

Technique	Year
Carved	850,000 BCE
Handmade	850,000 BCE
Cut	800,000 BCE
Struck	800,000 BCE
Painted	31,000 BCE
Engraved	29,000 BCE
Incised	29,000 BCE
Pigmented	29,000 BCE
Perforated	14,000 BCE
Polished	14,000 BCE
Smoothed	14,000 BCE
Tempered	13,050 BCE
Cast	11,500 BCE
Mould-made	11,500 BCE

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Table 3.C.3: Emergence dates of production techniques (continued).

Technique	Year
Glazed	8,613 BCE
Inlaid	8,500 BCE
Moulded	8,500 BCE
Beadwork	8,000 BCE
Ceramic technique	8,000 BCE
Metal technique	8,000 BCE
Pierced	8,000 BCE
Sewn	8,000 BCE
Slipped	7,000 BCE
Wheel made	7,000 BCE
Burnished	6,500 BCE
Combed	6,500 BCE
Impressed	6,500 BCE
Relief	6,500 BCE
Applied	6,000 BCE
Stamped	6,000 BCE
Stipple	6,000 BCE
Lacquered	5,000 BCE
Wirework	4,500 BCE
Lustred	4,200 BCE
Etching	4,000 BCE
Hammered	3,800 BCE
Punched	3,500 BCE
Gilded	3,300 BCE
Soldered	3,300 BCE
Dyed	3,000 BCE
Plain weave	3,000 BCE
Textile technique	3,000 BCE
Woven	3,000 BCE

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Table 3.C.3: Emergence dates of production techniques (continued).

Technique	Year
Twisted	2,800 BCE
Repoussé	2,750 BCE
Chased	2,600 BCE
Embossed	2,600 BCE
Filigree	2,600 BCE
Lost-wax cast	2,600 BCE
Plaited	2,600 BCE
Intaglio	2,400 BCE
Blown	2,050 BCE
Braided	2,000 BCE
Underglazed	2,000 BCE
Hand coloured	1,850 BCE
Appliqué	1,725 BCE
Interlaced	1,600 BCE
Plated	1,550 BCE
Embroidered	1,500 BCE
Enamelled	1,400 BCE
Keyed	750 BCE
Terra sigillata	580 BCE
Lead-glazed	206 BCE
Tin-glazed	1 CE

Note: Each year corresponds to the lower bound of the estimated production date range for the earliest artefact associated with that technique.

Table 3.C.4: Number of observations by production technique

Technique	<1500	<1800	All
Applied	2312	3751	6776
Appliqué	398	425	1182
Beadwork	627	805	5779
Blown	2114	2497	2947
Braided	90	291	3122
Burnished	4206	4271	4690
Carved	20255	25268	56110
Cast	30328	47407	55578
Ceramic technique	25367	27493	32101
Chased	592	1417	2442
Combed	783	799	828
Cut	4588	5152	9679
Dyed	747	874	6087
Embossed	557	1202	1860
Embroidered	188	287	4300
Enamelled	678	2273	4292
Engraved	75560	119933	148270
Etching	6	27200	51953
Filigree	766	893	1209
Gilded	3287	8616	11010
Glazed	25434	33323	36924
Hammered	7581	7995	11022
Hand coloured	144	3712	12890
Handmade	29210	33289	65014
Impressed	3313	3591	4090
Incised	19627	20967	27042
Inlaid	2297	3008	4897
Intaglio	890	3701	5753
Interlaced	74	103	180

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Table 3.C.4: Number of observations by production technique (continued).

Technique	<1500	<1800	All
Keyed	1257	1276	1282
Lacquered	157	793	1867
Lead-glazed	10608	11406	11488
Lost-wax cast	1126	4003	4475
Lustred	840	1035	1084
Metal technique	11135	13743	22207
Mould-made	14041	15676	17341
Moulded	2280	3715	4231
Painted	40168	50081	65452
Perforated	2358	2466	3380
Pierced	5788	7766	10108
Pigmented	733	1427	3811
Plain weave	815	827	3549
Plaited	173	648	9778
Plated	752	783	1304
Polished	4691	5947	10747
Punched	2009	2176	2527
Relief	5367	9035	10944
Repoussé	757	921	1345
Sewn	816	1299	14368
Slipped	20419	20928	21587
Smoothed	1246	1293	2128
Soldered	1742	2237	3722
Stamped	77394	94538	105397
Stipple	199	4144	11189
Struck	75009	84859	93017
Tempered	3153	3243	3365
Terra sigillata	955	955	955
Textile technique	1150	1372	6088

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Table 3.C.4: Number of observations by production technique (continued).

Technique	<1500	<1800	All
Tin glazed	378	1040	1071
Twisted	2012	2291	5689
Underglazed	1013	3170	3814
Wheel made	36014	37948	39896
Wirework	1182	1247	2917
Woven	1829	2614	19819

Note: The figures report the total number of artefacts associated with each production technique across all sites across the three samples; *pre-1500*, *pre-1800* and *All*.

Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample

Variable	Mean	SD	Min	Max	Count
Applied					
Adoption delay (years)	5975.73	1154.72	100.00	7500.00	486
Distance to coast (000s km)	0.17	0.31	0.00	2.07	486
Distance from pioneer (000s km)	2.93	2.18	0.00	13.20	486
Distance to river (000s km)	0.39	0.32	0.00	2.30	486
Elevation (m)	0.29	0.45	0.00	4.15	486
Land suitability	0.60	0.34	0.00	1.00	486
Ruggedness	2.88	4.95	0.00	25.90	486
Appliqué					
Adoption delay (years)	1970.56	621.31	725.00	3093.00	77
Distance to coast (000s km)	0.38	0.49	0.00	2.07	77
Distance from pioneer (000s km)	4.33	3.77	0.23	12.48	77
Distance to river (000s km)	0.49	0.35	0.01	1.42	77
Elevation (m)	0.55	0.69	0.00	3.09	77
Land suitability	0.54	0.37	0.00	1.00	77
Ruggedness	4.00	6.12	0.00	25.90	77
Beadwork					
Adoption delay (years)	7687.18	1128.68	2100.00	9450.00	152
Distance to coast (000s km)	0.19	0.31	0.00	1.76	152
Distance from pioneer (000s km)	10.44	2.63	0.00	18.38	152
Distance to river (000s km)	0.48	0.40	0.00	2.13	152
Elevation (m)	0.33	0.46	0.00	3.09	152
Land suitability	0.56	0.36	0.00	0.99	152
Ruggedness	2.77	5.15	0.00	30.88	152
Blown					
Adoption delay (years)	1630.01	453.56	50.00	2950.00	237
Distance to coast (000s km)	0.20	0.33	0.00	2.07	237

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	2.03	1.51	0.02	10.66	237
Distance to river (000s km)	0.36	0.34	0.00	2.33	237
Elevation (m)	0.30	0.49	-0.06	4.15	237
Land suitability	0.57	0.37	0.00	1.00	237
Ruggedness	3.12	5.21	0.00	29.87	237
Braided					
Adoption delay (years)	1838.46	644.28	750.00	2950.00	37
Distance to coast (000s km)	0.34	0.54	0.00	1.97	37
Distance from pioneer (000s km)	4.77	3.69	0.00	12.38	37
Distance to river (000s km)	0.42	0.39	0.01	1.42	37
Elevation (m)	0.49	0.76	0.00	3.09	37
Land suitability	0.42	0.37	0.00	0.99	37
Ruggedness	2.65	4.90	0.00	24.92	37
Burnished					
Adoption delay (years)	5815.34	1541.63	300.00	8000.00	278
Distance to coast (000s km)	0.23	0.34	0.00	2.07	278
Distance from pioneer (000s km)	2.74	2.41	0.00	11.64	278
Distance to river (000s km)	0.38	0.31	0.00	1.48	278
Elevation (m)	0.38	0.58	-0.06	3.41	278
Land suitability	0.61	0.32	0.00	1.00	278
Ruggedness	2.65	5.20	0.00	40.94	278
Carved					
Adoption delay (years)	848395.72	23645.08	50000.00	851500.00	1407
Distance to coast (000s km)	0.20	0.33	0.00	2.07	1407
Distance from pioneer (000s km)	5.88	2.77	0.00	15.76	1407
Distance to river (000s km)	0.48	0.44	0.00	8.18	1407
Elevation (m)	0.37	0.58	-0.06	4.91	1407
Land suitability	0.58	0.34	0.00	1.00	1407

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	3.37	5.43	0.00	37.23	1407
Cast					
Adoption delay (years)	5734.83	885.54	2100.00	7400.00	1925
Distance to coast (000s km)	0.15	0.29	0.00	2.07	1925
Distance from pioneer (000s km)	3.38	2.01	0.01	15.76	1925
Distance to river (000s km)	0.41	0.34	0.00	4.86	1925
Elevation (m)	0.32	0.54	-0.02	5.60	1925
Land suitability	0.64	0.30	0.00	1.00	1925
Ruggedness	2.76	5.31	0.00	43.03	1925
Ceramic technique					
Adoption delay (years)	7741.68	1523.85	1000.00	9500.00	1068
Distance to coast (000s km)	0.22	0.35	0.00	2.07	1068
Distance from pioneer (000s km)	10.04	3.48	0.00	19.07	1068
Distance to river (000s km)	0.43	0.35	0.00	2.33	1068
Elevation (m)	0.40	0.60	-0.06	4.22	1068
Land suitability	0.60	0.34	0.00	1.00	1068
Ruggedness	3.20	5.32	0.00	40.04	1068
Chased					
Adoption delay (years)	2629.02	838.73	200.00	4100.00	202
Distance to coast (000s km)	0.16	0.29	0.00	1.74	202
Distance from pioneer (000s km)	3.30	2.09	0.19	13.04	202
Distance to river (000s km)	0.46	0.34	0.00	2.43	202
Elevation (m)	0.42	0.72	0.00	5.60	202
Land suitability	0.65	0.31	0.00	1.00	202
Ruggedness	3.76	5.74	0.00	36.02	202
Combed					
Adoption delay (years)	6627.35	1112.46	2000.00	7950.00	132
Distance to coast (000s km)	0.20	0.33	0.00	2.07	132

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	2.61	2.43	0.06	10.72	132
Distance to river (000s km)	0.39	0.32	0.00	2.30	132
Elevation (m)	0.33	0.51	0.00	3.09	132
Land suitability	0.59	0.34	0.00	1.00	132
Ruggedness	3.18	5.44	0.00	32.56	132
Cut					
Adoption delay (years)	798268.93	16329.42	450000.00	801500.00	544
Distance to coast (000s km)	0.20	0.34	0.00	2.07	544
Distance from pioneer (000s km)	5.87	2.53	1.27	14.60	544
Distance to river (000s km)	0.41	0.34	0.00	2.03	544
Elevation (m)	0.33	0.51	0.00	4.15	544
Land suitability	0.56	0.34	0.00	1.00	544
Ruggedness	2.46	4.38	0.00	24.70	544
Dyed					
Adoption delay (years)	3365.26	879.35	200.00	4500.00	46
Distance to coast (000s km)	0.42	0.54	0.00	2.07	46
Distance from pioneer (000s km)	3.88	3.77	0.00	12.38	46
Distance to river (000s km)	0.42	0.43	0.00	2.10	46
Elevation (m)	0.75	1.01	0.00	4.35	46
Land suitability	0.25	0.31	0.00	0.89	46
Ruggedness	3.13	4.03	0.00	15.33	46
Embossed					
Adoption delay (years)	2547.22	902.29	100.00	4100.00	162
Distance to coast (000s km)	0.14	0.25	0.00	1.59	162
Distance from pioneer (000s km)	3.72	2.86	0.16	15.73	162
Distance to river (000s km)	0.45	0.62	0.01	7.40	162
Elevation (m)	0.37	0.53	-0.01	3.09	162
Land suitability	0.64	0.32	0.00	1.00	162

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	3.08	5.09	0.00	25.90	162
Embroidered					
Adoption delay (years)	2102.85	581.04	900.00	3000.00	33
Distance to coast (000s km)	0.52	0.67	0.00	1.97	33
Distance from pioneer (000s km)	4.26	3.52	0.00	12.38	33
Distance to river (000s km)	0.44	0.32	0.01	1.14	33
Elevation (m)	0.63	0.76	0.00	3.75	33
Land suitability	0.40	0.38	0.00	0.91	33
Ruggedness	4.76	6.33	0.00	24.92	33
Enamelled					
Adoption delay (years)	1942.35	682.42	30.00	2900.00	188
Distance to coast (000s km)	0.09	0.17	0.00	1.21	188
Distance from pioneer (000s km)	3.39	1.72	0.00	16.47	188
Distance to river (000s km)	0.36	0.27	0.00	2.11	188
Elevation (m)	0.21	0.31	-0.00	2.10	188
Land suitability	0.62	0.29	0.00	1.00	188
Ruggedness	1.89	3.61	0.00	25.13	188
Engraved					
Adoption delay (years)	14999.17	1156.05	1000.00	16500.00	1927
Distance to coast (000s km)	0.15	0.27	0.00	2.07	1927
Distance from pioneer (000s km)	2.49	2.66	0.00	19.10	1927
Distance to river (000s km)	0.41	0.34	0.00	4.86	1927
Elevation (m)	0.32	0.54	-0.02	4.91	1927
Land suitability	0.64	0.30	0.00	1.00	1927
Ruggedness	2.74	5.11	0.00	43.03	1927
Etching					
Adoption delay (years)	3212.00	1599.37	1500.00	4960.00	5
Distance to coast (000s km)	0.65	0.72	0.03	1.63	5

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	2.82	1.50	1.21	5.16	5
Distance to river (000s km)	0.40	0.34	0.04	0.71	5
Elevation (m)	0.71	0.93	0.02	2.07	5
Land suitability	0.26	0.39	0.01	0.90	5
Ruggedness	1.45	2.82	0.08	6.49	5
Filigree					
Adoption delay (years)	2863.91	680.87	100.00	4100.00	182
Distance to coast (000s km)	0.12	0.24	0.00	1.59	182
Distance from pioneer (000s km)	3.61	1.74	0.00	12.58	182
Distance to river (000s km)	0.39	0.29	0.00	1.75	182
Elevation (m)	0.27	0.44	-0.00	3.09	182
Land suitability	0.69	0.29	0.00	1.00	182
Ruggedness	2.76	5.07	0.00	36.02	182
Gilded					
Adoption delay (years)	3560.99	763.57	687.00	4800.00	493
Distance to coast (000s km)	0.18	0.35	0.00	2.07	493
Distance from pioneer (000s km)	3.27	2.06	0.14	13.55	493
Distance to river (000s km)	0.39	0.31	0.00	2.22	493
Elevation (m)	0.36	0.67	0.00	4.91	493
Land suitability	0.63	0.31	0.00	1.00	493
Ruggedness	2.99	5.10	0.00	30.88	493
Glazed					
Adoption delay (years)	9254.44	994.57	2613.00	10113.00	863
Distance to coast (000s km)	0.20	0.33	0.00	2.07	863
Distance from pioneer (000s km)	3.43	2.30	0.00	14.19	863
Distance to river (000s km)	0.39	0.33	0.00	2.33	863
Elevation (m)	0.31	0.49	-0.00	4.46	863
Land suitability	0.60	0.32	0.00	1.00	863

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.76	4.88	0.00	32.56	863
Hammered					
Adoption delay (years)	3428.83	957.18	800.00	5300.00	736
Distance to coast (000s km)	0.16	0.28	0.00	1.97	736
Distance from pioneer (000s km)	2.38	2.40	0.00	16.87	736
Distance to river (000s km)	0.41	0.44	0.00	7.40	736
Elevation (m)	0.30	0.47	-0.01	4.66	736
Land suitability	0.62	0.30	0.00	1.00	736
Ruggedness	2.68	5.16	0.00	40.94	736
Hand coloured					
Adoption delay (years)	1341.60	840.32	390.00	2450.00	35
Distance to coast (000s km)	0.21	0.33	0.00	1.79	35
Distance from pioneer (000s km)	3.13	2.90	0.20	12.42	35
Distance to river (000s km)	0.36	0.30	0.00	1.05	35
Elevation (m)	0.34	0.33	0.00	1.73	35
Land suitability	0.64	0.33	0.00	0.97	35
Ruggedness	3.60	4.66	0.00	15.21	35
Handmade					
Adoption delay (years)	849457.59	2345.38	790000.00	851500.00	1566
Distance to coast (000s km)	0.20	0.33	0.00	2.07	1566
Distance from pioneer (000s km)	5.95	2.71	0.24	15.76	1566
Distance to river (000s km)	0.45	0.42	0.00	8.18	1566
Elevation (m)	0.40	0.61	-0.06	4.72	1566
Land suitability	0.60	0.33	0.00	1.00	1566
Ruggedness	3.34	5.82	0.00	47.35	1566
Impressed					
Adoption delay (years)	5981.34	1435.20	300.00	8000.00	382
Distance to coast (000s km)	0.24	0.35	0.00	2.07	382

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	2.64	2.54	0.00	11.66	382
Distance to river (000s km)	0.38	0.35	0.00	2.03	382
Elevation (m)	0.36	0.59	0.00	4.22	382
Land suitability	0.54	0.35	0.00	1.00	382
Ruggedness	2.86	5.25	0.00	29.87	382
Incised					
Adoption delay (years)	28647.18	1544.81	14000.00	30500.00	1586
Distance to coast (000s km)	0.19	0.31	0.00	2.07	1586
Distance from pioneer (000s km)	10.67	2.84	0.10	19.33	1586
Distance to river (000s km)	0.41	0.32	0.00	2.49	1586
Elevation (m)	0.34	0.56	-0.06	4.69	1586
Land suitability	0.59	0.33	0.00	1.00	1586
Ruggedness	2.82	5.14	0.00	40.94	1586
Inlaid					
Adoption delay (years)	8584.74	918.70	2600.00	10000.00	482
Distance to coast (000s km)	0.16	0.26	0.00	1.63	482
Distance from pioneer (000s km)	3.21	2.26	0.02	16.59	482
Distance to river (000s km)	0.38	0.33	0.00	2.18	482
Elevation (m)	0.34	0.66	0.00	5.60	482
Land suitability	0.62	0.32	0.00	1.00	482
Ruggedness	2.70	4.81	0.00	36.02	482
Intaglio					
Adoption delay (years)	2338.73	689.27	300.00	3850.00	115
Distance to coast (000s km)	0.20	0.35	0.00	1.63	115
Distance from pioneer (000s km)	2.55	1.69	0.00	10.44	115
Distance to river (000s km)	0.39	0.29	0.00	1.44	115
Elevation (m)	0.36	0.62	0.00	4.15	115
Land suitability	0.61	0.35	0.00	1.00	115

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	3.38	4.98	0.00	19.52	115
Interlaced					
Adoption delay (years)	2325.07	419.07	950.00	3000.00	46
Distance to coast (000s km)	0.15	0.32	0.00	1.76	46
Distance from pioneer (000s km)	4.54	2.59	0.21	13.25	46
Distance to river (000s km)	0.46	0.32	0.01	1.35	46
Elevation (m)	0.25	0.41	0.01	2.07	46
Land suitability	0.45	0.32	0.00	0.96	46
Ruggedness	2.00	3.54	0.00	14.53	46
Keyed					
Adoption delay (years)	1912.46	374.21	200.00	2200.00	93
Distance to coast (000s km)	0.06	0.08	0.00	0.54	93
Distance from pioneer (000s km)	3.95	1.24	0.35	10.44	93
Distance to river (000s km)	0.24	0.08	0.00	0.41	93
Elevation (m)	0.11	0.08	0.00	0.47	93
Land suitability	0.70	0.22	0.00	0.96	93
Ruggedness	1.14	3.71	0.00	31.91	93
Lacquered					
Adoption delay (years)	5614.84	723.03	3950.00	6489.00	25
Distance to coast (000s km)	0.80	0.71	0.01	2.07	25
Distance from pioneer (000s km)	3.63	1.84	0.00	8.25	25
Distance to river (000s km)	0.62	0.55	0.01	1.98	25
Elevation (m)	0.65	0.60	0.02	2.07	25
Land suitability	0.51	0.38	0.00	0.98	25
Ruggedness	3.58	6.87	0.00	30.88	25
Lead-glazed					
Adoption delay (years)	1429.99	282.83	156.00	1706.00	258
Distance to coast (000s km)	0.07	0.13	0.00	1.21	258

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	6.05	1.28	0.00	10.55	258
Distance to river (000s km)	0.30	0.15	0.00	1.05	258
Elevation (m)	0.14	0.23	-0.00	2.13	258
Land suitability	0.67	0.23	0.00	1.00	258
Ruggedness	1.29	3.28	0.00	31.91	258
Lost-wax cast					
Adoption delay (years)	2557.22	851.72	100.00	4100.00	202
Distance to coast (000s km)	0.18	0.27	0.00	1.76	202
Distance from pioneer (000s km)	3.94	3.04	0.00	14.21	202
Distance to river (000s km)	0.48	0.41	0.00	1.95	202
Elevation (m)	0.53	0.72	-0.00	4.35	202
Land suitability	0.63	0.33	0.00	1.00	202
Ruggedness	4.34	6.33	0.00	34.62	202
Lustred					
Adoption delay (years)	5270.88	500.17	2600.00	5700.00	42
Distance to coast (000s km)	0.31	0.27	0.01	1.03	42
Distance from pioneer (000s km)	2.59	3.02	0.19	13.67	42
Distance to river (000s km)	0.54	0.42	0.01	1.41	42
Elevation (m)	0.60	0.58	0.01	2.47	42
Land suitability	0.43	0.41	0.00	0.99	42
Ruggedness	4.41	5.46	0.00	20.46	42
Metal-technique					
Adoption delay (years)	3192.31	813.25	200.00	4700.00	980
Distance to coast (000s km)	0.15	0.28	0.00	1.97	980
Distance from pioneer (000s km)	2.69	2.26	0.17	18.67	980
Distance to river (000s km)	0.40	0.31	0.00	2.13	980
Elevation (m)	0.32	0.50	-0.02	4.69	980
Land suitability	0.63	0.30	0.00	1.00	980

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.81	5.28	0.00	43.03	980
Mould-made					
Adoption delay (years)	7885.63	866.72	2100.00	9500.00	765
Distance to coast (000s km)	0.21	0.35	0.00	2.07	765
Distance from pioneer (000s km)	8.42	2.44	0.23	16.14	765
Distance to river (000s km)	0.43	0.43	0.00	8.30	765
Elevation (m)	0.37	0.53	-0.00	4.15	765
Land suitability	0.60	0.35	0.00	1.00	765
Ruggedness	3.38	5.30	0.00	40.94	765
Moulded					
Adoption delay (years)	8652.34	976.31	2600.00	10000.00	386
Distance to coast (000s km)	0.24	0.37	0.00	2.07	386
Distance from pioneer (000s km)	3.56	2.61	0.09	12.80	386
Distance to river (000s km)	0.41	0.31	0.00	1.91	386
Elevation (m)	0.36	0.50	0.00	3.22	386
Land suitability	0.62	0.34	0.00	1.00	386
Ruggedness	3.27	5.38	0.00	34.62	386
Painted					
Adoption delay (years)	6408.60	1799.31	500.00	8500.00	806
Distance to coast (000s km)	0.27	0.37	0.00	2.07	806
Distance from pioneer (000s km)	3.18	3.22	0.00	17.17	806
Distance to river (000s km)	0.46	0.36	0.00	2.33	806
Elevation (m)	0.54	0.70	-0.06	4.69	806
Land suitability	0.52	0.38	0.00	1.00	806
Ruggedness	4.26	6.34	0.00	47.35	806
Perforated					
Adoption delay (years)	12977.48	1805.27	6000.00	15500.00	446
Distance to coast (000s km)	0.18	0.30	0.00	1.59	446

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	2.91	2.60	0.11	12.43	446
Distance to river (000s km)	0.42	0.32	0.00	1.87	446
Elevation (m)	0.32	0.55	-0.00	4.15	446
Land suitability	0.57	0.32	0.00	1.00	446
Ruggedness	2.29	4.55	0.00	34.62	446
Pierced					
Adoption delay (years)	7706.92	1506.84	1000.00	9500.00	776
Distance to coast (000s km)	0.19	0.32	0.00	2.07	776
Distance from pioneer (000s km)	2.88	2.76	0.01	15.45	776
Distance to river (000s km)	0.40	0.31	0.00	2.30	776
Elevation (m)	0.37	0.60	-0.06	4.91	776
Land suitability	0.60	0.33	0.00	1.00	776
Ruggedness	2.93	5.27	0.00	36.02	776
Pigmented					
Adoption delay (years)	10741.82	1229.43	4500.00	12500.00	184
Distance to coast (000s km)	0.24	0.38	0.00	2.07	184
Distance from pioneer (000s km)	4.60	2.71	0.19	11.09	184
Distance to river (000s km)	0.50	0.33	0.00	1.68	184
Elevation (m)	0.44	0.57	0.00	3.09	184
Land suitability	0.57	0.37	0.00	0.99	184
Ruggedness	3.73	5.33	0.00	24.70	184
Plain weave					
Adoption delay (years)	3214.36	884.96	500.00	4500.00	39
Distance to coast (000s km)	0.40	0.58	0.00	2.07	39
Distance from pioneer (000s km)	4.34	4.23	0.00	12.38	39
Distance to river (000s km)	0.43	0.40	0.00	1.75	39
Elevation (m)	0.65	0.85	0.01	4.26	39
Land suitability	0.28	0.35	0.00	0.99	39

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	4.17	6.18	0.00	29.14	39
Plaited					
Adoption delay (years)	2945.69	717.28	1050.00	4050.00	90
Distance to coast (000s km)	0.26	0.47	0.00	2.07	90
Distance from pioneer (000s km)	4.26	2.54	0.00	14.16	90
Distance to river (000s km)	0.47	0.39	0.01	2.33	90
Elevation (m)	0.36	0.45	0.01	2.07	90
Land suitability	0.54	0.35	0.00	0.99	90
Ruggedness	2.91	4.31	0.00	17.91	90
Plated					
Adoption delay (years)	1292.19	479.93	150.00	2450.00	83
Distance to coast (000s km)	0.11	0.24	0.00	1.21	83
Distance from pioneer (000s km)	3.29	2.33	0.34	13.06	83
Distance to river (000s km)	0.42	0.27	0.02	1.19	83
Elevation (m)	0.30	0.51	0.00	3.09	83
Land suitability	0.68	0.29	0.00	1.00	83
Ruggedness	3.10	5.17	0.00	23.47	83
Polished					
Adoption delay (years)	13109.45	1644.39	950.00	15480.00	727
Distance to coast (000s km)	0.19	0.31	0.00	1.87	727
Distance from pioneer (000s km)	3.27	2.84	0.14	13.01	727
Distance to river (000s km)	0.45	0.37	0.00	4.86	727
Elevation (m)	0.37	0.56	-0.06	4.69	727
Land suitability	0.61	0.33	0.00	1.00	727
Ruggedness	3.33	5.53	0.00	40.94	727
Punched					
Adoption delay (years)	3566.87	791.85	300.00	5000.00	393
Distance to coast (000s km)	0.12	0.22	0.00	1.21	393

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	5.93	1.87	0.29	16.63	393
Distance to river (000s km)	0.36	0.27	0.00	1.68	393
Elevation (m)	0.22	0.39	0.00	3.09	393
Land suitability	0.64	0.28	0.00	1.00	393
Ruggedness	1.98	4.08	0.00	36.02	393
Relief					
Adoption delay (years)	6427.95	987.06	1200.00	8000.00	686
Distance to coast (000s km)	0.17	0.29	0.00	2.07	686
Distance from pioneer (000s km)	2.40	2.53	0.00	14.31	686
Distance to river (000s km)	0.43	0.32	0.00	1.91	686
Elevation (m)	0.37	0.51	-0.00	4.15	686
Land suitability	0.62	0.34	0.00	1.00	686
Ruggedness	3.62	5.68	0.00	38.00	686
Repoussé					
Adoption delay (years)	2654.14	766.62	150.00	4175.00	211
Distance to coast (000s km)	0.15	0.26	0.00	1.59	211
Distance from pioneer (000s km)	3.85	2.29	0.00	14.49	211
Distance to river (000s km)	0.42	0.28	0.00	1.47	211
Elevation (m)	0.35	0.48	0.00	3.09	211
Land suitability	0.67	0.29	0.00	1.00	211
Ruggedness	3.43	5.64	0.00	36.02	211
Sewn					
Adoption delay (years)	8339.88	811.00	5800.00	9500.00	76
Distance to coast (000s km)	0.41	0.54	0.00	2.07	76
Distance from pioneer (000s km)	10.93	3.03	4.52	18.42	76
Distance to river (000s km)	0.46	0.41	0.00	2.10	76
Elevation (m)	0.51	0.73	-0.06	4.26	76
Land suitability	0.31	0.35	0.00	0.98	76

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	3.29	5.29	0.00	24.92	76
Slipped					
Adoption delay (years)	6570.35	1515.56	500.00	8500.00	641
Distance to coast (000s km)	0.26	0.37	0.00	2.07	641
Distance from pioneer (000s km)	3.18	2.64	0.00	13.40	641
Distance to river (000s km)	0.45	0.34	0.00	1.99	641
Elevation (m)	0.45	0.58	-0.06	3.41	641
Land suitability	0.57	0.36	0.00	1.00	641
Ruggedness	3.68	5.54	0.00	29.87	641
Smoothed					
Adoption delay (years)	13241.84	1642.72	6000.00	15450.00	226
Distance to coast (000s km)	0.17	0.30	0.00	2.07	226
Distance from pioneer (000s km)	2.94	2.54	0.17	12.43	226
Distance to river (000s km)	0.46	0.35	0.00	1.87	226
Elevation (m)	0.34	0.54	0.00	3.49	226
Land suitability	0.55	0.35	0.00	0.99	226
Ruggedness	3.29	5.24	0.00	29.87	226
Soldered					
Adoption delay (years)	3249.26	803.04	300.00	4750.00	352
Distance to coast (000s km)	0.11	0.21	0.00	1.59	352
Distance from pioneer (000s km)	3.36	2.03	0.07	13.26	352
Distance to river (000s km)	0.39	0.31	0.00	1.91	352
Elevation (m)	0.26	0.44	0.00	4.35	352
Land suitability	0.65	0.30	0.00	0.99	352
Ruggedness	2.53	4.65	0.00	34.62	352
Stamped					
Adoption delay (years)	6180.59	807.22	1000.00	7497.00	1308
Distance to coast (000s km)	0.16	0.29	0.00	2.07	1308

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	3.14	2.15	0.00	15.46	1308
Distance to river (000s km)	0.41	0.33	0.00	2.30	1308
Elevation (m)	0.33	0.53	-0.02	4.69	1308
Land suitability	0.65	0.30	0.00	1.00	1308
Ruggedness	2.94	5.31	0.00	43.03	1308
Stipple					
Adoption delay (years)	5889.11	750.78	4300.00	7500.00	35
Distance to coast (000s km)	0.13	0.27	0.00	1.03	35
Distance from pioneer (000s km)	2.85	2.76	0.44	13.38	35
Distance to river (000s km)	0.45	0.25	0.01	0.85	35
Elevation (m)	0.33	0.56	-0.00	3.09	35
Land suitability	0.68	0.32	0.00	0.98	35
Ruggedness	3.73	5.51	0.00	17.91	35
Struck					
Adoption delay (years)	800130.86	1909.41	755000.00	801493.00	1023
Distance to coast (000s km)	0.15	0.28	0.00	2.07	1023
Distance from pioneer (000s km)	5.68	1.90	1.04	15.08	1023
Distance to river (000s km)	0.43	0.34	0.00	2.19	1023
Elevation (m)	0.33	0.50	-0.02	4.69	1023
Land suitability	0.67	0.29	0.00	1.00	1023
Ruggedness	2.97	5.35	0.00	43.03	1023
Tempered					
Adoption delay (years)	12601.04	1609.82	2050.00	14451.00	177
Distance to coast (000s km)	0.16	0.28	0.00	2.07	177
Distance from pioneer (000s km)	5.49	1.48	0.48	8.73	177
Distance to river (000s km)	0.39	0.40	0.00	2.03	177
Elevation (m)	0.25	0.40	0.00	2.49	177
Land suitability	0.61	0.33	0.00	0.99	177

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.17	4.53	0.00	29.87	177
Terra sigillata					
Adoption delay (years)	663.86	117.92	280.00	1130.00	71
Distance to coast (000s km)	0.15	0.17	0.00	0.92	71
Distance from pioneer (000s km)	2.21	1.49	0.62	9.69	71
Distance to river (000s km)	0.40	0.36	0.00	1.42	71
Elevation (m)	0.30	0.32	0.00	1.30	71
Land suitability	0.72	0.27	0.00	1.00	71
Ruggedness	2.83	3.78	0.00	17.44	71
Textile technique					
Adoption delay (years)	3323.68	840.91	500.00	4500.00	76
Distance to coast (000s km)	0.36	0.55	0.00	2.07	76
Distance from pioneer (000s km)	4.30	3.64	0.00	12.38	76
Distance to river (000s km)	0.46	0.40	0.00	1.75	76
Elevation (m)	0.72	1.06	-0.06	4.69	76
Land suitability	0.38	0.39	0.00	0.99	76
Ruggedness	3.89	5.96	0.00	29.14	76
Tin-glazed					
Adoption delay (years)	1322.55	194.57	849.00	1499.00	38
Distance to coast (000s km)	0.09	0.13	0.00	0.59	38
Distance from pioneer (000s km)	0.85	0.93	0.00	3.48	38
Distance to river (000s km)	0.65	0.33	0.01	1.41	38
Elevation (m)	0.32	0.27	0.01	1.16	38
Land suitability	0.80	0.27	0.01	1.00	38
Ruggedness	4.56	5.27	0.00	23.47	38
Twisted					
Adoption delay (years)	2661.31	945.78	100.00	4300.00	358
Distance to coast (000s km)	0.17	0.33	0.00	2.07	358

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	2.45	1.85	0.04	14.05	358
Distance to river (000s km)	0.36	0.28	0.00	1.69	358
Elevation (m)	0.30	0.47	0.00	4.15	358
Land suitability	0.61	0.32	0.00	1.00	358
Ruggedness	2.72	5.23	0.00	34.62	358
Underglazed					
Adoption delay (years)	3206.67	261.76	2050.00	3500.00	55
Distance to coast (000s km)	0.35	0.31	0.00	1.25	55
Distance from pioneer (000s km)	6.31	3.13	1.32	12.75	55
Distance to river (000s km)	0.42	0.38	0.01	1.91	55
Elevation (m)	0.45	0.51	0.01	2.47	55
Land suitability	0.49	0.33	0.00	1.00	55
Ruggedness	3.62	5.98	0.00	30.88	55
Wheel-made					
Adoption delay (years)	6939.89	1412.02	500.00	8500.00	896
Distance to coast (000s km)	0.19	0.31	0.00	2.07	896
Distance from pioneer (000s km)	3.64	2.67	0.00	13.95	896
Distance to river (000s km)	0.41	0.34	0.00	2.30	896
Elevation (m)	0.33	0.49	-0.06	4.08	896
Land suitability	0.63	0.33	0.00	1.00	896
Ruggedness	3.11	5.51	0.00	40.94	896
Wirework					
Adoption delay (years)	4489.12	837.83	1900.00	6000.00	222
Distance to coast (000s km)	0.11	0.20	0.00	1.36	222
Distance from pioneer (000s km)	8.36	1.84	1.83	17.85	222
Distance to river (000s km)	0.39	0.26	0.01	1.33	222
Elevation (m)	0.32	0.60	0.00	4.35	222
Land suitability	0.65	0.30	0.00	0.99	222

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Table 3.C.5: Descriptive statistics by production technique — Pre-1500 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.87	5.08	0.00	28.45	222
Woven					
Adoption delay (years)	3326.80	868.24	500.00	4500.00	89
Distance to coast (000s km)	0.35	0.56	0.00	2.07	89
Distance from pioneer (000s km)	4.43	3.74	0.00	12.38	89
Distance to river (000s km)	0.46	0.40	0.00	1.75	89
Elevation (m)	0.57	0.80	0.00	4.26	89
Land suitability	0.34	0.36	0.00	0.99	89
Ruggedness	3.86	5.47	0.00	29.14	89

Note: The table reports descriptive statistics for the regression sample restricted to artefacts dated before 1500. Each observation corresponds to the earliest artefact associated with a given production technique at each site.

Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample

Variable	Mean	SD	Min	Max	Count
Applied					
Adoption delay (years)	6502.69	1248.58	100.00	7800.00	700
Distance to coast (000s km)	0.15	0.27	0.00	2.07	700
Distance from pioneer (000s km)	3.70	2.99	0.00	18.21	700
Distance to river (000s km)	0.51	0.83	0.00	7.46	700
Elevation (m)	0.29	0.47	-0.00	4.69	700
Land suitability	0.59	0.32	0.00	1.00	700
Ruggedness	2.79	5.13	0.00	34.62	700
Appliqué					
Adoption delay (years)	2198.10	783.89	725.00	3525.00	91
Distance to coast (000s km)	0.35	0.46	0.00	2.07	91
Distance from pioneer (000s km)	4.94	4.12	0.23	17.96	91
Distance to river (000s km)	0.61	0.88	0.01	7.42	91
Elevation (m)	0.57	0.71	0.00	3.45	91
Land suitability	0.53	0.36	0.00	1.00	91
Ruggedness	3.96	5.92	0.00	25.90	91
Beadwork					
Adoption delay (years)	8187.20	1320.09	2100.00	9800.00	201
Distance to coast (000s km)	0.19	0.30	0.00	1.76	201
Distance from pioneer (000s km)	9.98	3.59	0.00	19.57	201
Distance to river (000s km)	0.73	1.12	0.00	7.46	201
Elevation (m)	0.37	0.58	0.00	4.35	201
Land suitability	0.51	0.36	0.00	0.99	201
Ruggedness	2.67	4.88	0.00	30.88	201
Blown					
Adoption delay (years)	1851.09	678.22	50.00	3250.00	278
Distance to coast (000s km)	0.19	0.31	0.00	2.07	278

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	2.39	2.10	0.02	17.90	278
Distance to river (000s km)	0.40	0.55	0.00	7.42	278
Elevation (m)	0.32	0.52	-0.06	4.15	278
Land suitability	0.56	0.36	0.00	1.00	278
Ruggedness	3.30	5.55	0.00	29.87	278
Braided					
Adoption delay (years)	2751.30	782.23	750.00	3300.00	104
Distance to coast (000s km)	0.19	0.39	0.00	1.97	104
Distance from pioneer (000s km)	9.13	5.33	0.00	19.53	104
Distance to river (000s km)	1.76	2.28	0.01	7.46	104
Elevation (m)	0.38	0.62	-0.00	3.49	104
Land suitability	0.41	0.34	0.00	0.99	104
Ruggedness	2.39	4.93	0.00	30.88	104
Burnished					
Adoption delay (years)	6008.87	1611.95	300.00	8300.00	303
Distance to coast (000s km)	0.23	0.33	0.00	2.07	303
Distance from pioneer (000s km)	2.85	2.60	0.00	13.57	303
Distance to river (000s km)	0.39	0.34	0.00	2.86	303
Elevation (m)	0.38	0.57	-0.06	3.41	303
Land suitability	0.61	0.32	0.00	1.00	303
Ruggedness	2.56	5.03	0.00	40.94	303
Carved					
Adoption delay (years)	849047.19	21253.55	50000.00	851800.00	1748
Distance to coast (000s km)	0.18	0.31	0.00	2.07	1748
Distance from pioneer (000s km)	6.65	3.42	0.00	19.00	1748
Distance to river (000s km)	0.68	1.01	0.00	8.31	1748
Elevation (m)	0.37	0.59	-0.06	4.91	1748
Land suitability	0.56	0.34	0.00	1.00	1748

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	3.22	5.35	0.00	37.23	1748
Cast					
Adoption delay (years)	6215.64	1107.51	2100.00	7700.00	2612
Distance to coast (000s km)	0.14	0.27	0.00	2.07	2612
Distance from pioneer (000s km)	3.72	2.14	0.01	18.46	2612
Distance to river (000s km)	0.40	0.36	0.00	7.42	2612
Elevation (m)	0.29	0.54	-0.02	5.60	2612
Land suitability	0.64	0.28	0.00	1.00	2612
Ruggedness	2.37	4.82	0.00	43.03	2612
Ceramic technique					
Adoption delay (years)	7993.77	1564.99	1000.00	9800.00	1227
Distance to coast (000s km)	0.21	0.33	0.00	2.07	1227
Distance from pioneer (000s km)	10.07	3.51	0.00	19.67	1227
Distance to river (000s km)	0.45	0.44	0.00	8.28	1227
Elevation (m)	0.39	0.59	-0.06	4.35	1227
Land suitability	0.61	0.33	0.00	1.00	1227
Ruggedness	3.13	5.24	0.00	40.04	1227
Chased					
Adoption delay (years)	3111.07	1025.15	200.00	4400.00	287
Distance to coast (000s km)	0.16	0.27	0.00	1.74	287
Distance from pioneer (000s km)	3.67	2.16	0.19	15.68	287
Distance to river (000s km)	0.45	0.37	0.00	2.43	287
Elevation (m)	0.42	0.76	-0.00	5.60	287
Land suitability	0.64	0.30	0.00	1.00	287
Ruggedness	3.51	5.84	0.00	36.02	287
Combed					
Adoption delay (years)	6672.51	1126.37	2000.00	8201.00	136
Distance to coast (000s km)	0.20	0.32	0.00	2.07	136

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	2.59	2.40	0.06	10.72	136
Distance to river (000s km)	0.39	0.32	0.00	2.30	136
Elevation (m)	0.33	0.51	0.00	3.09	136
Land suitability	0.59	0.34	0.00	1.00	136
Ruggedness	3.13	5.38	0.00	32.56	136
Cut					
Adoption delay (years)	798892.86	14837.67	450000.00	801800.00	664
Distance to coast (000s km)	0.19	0.32	0.00	2.07	664
Distance from pioneer (000s km)	6.37	2.97	0.93	18.38	664
Distance to river (000s km)	0.55	0.87	0.00	8.31	664
Elevation (m)	0.34	0.52	-0.00	4.35	664
Land suitability	0.56	0.34	0.00	1.00	664
Ruggedness	2.56	4.63	0.00	34.36	664
Dyed					
Adoption delay (years)	4046.46	939.74	200.00	4800.00	90
Distance to coast (000s km)	0.33	0.47	0.00	2.07	90
Distance from pioneer (000s km)	6.98	5.06	0.00	19.00	90
Distance to river (000s km)	1.15	1.64	0.00	8.31	90
Elevation (m)	0.63	0.87	0.00	4.35	90
Land suitability	0.35	0.34	0.00	0.98	90
Ruggedness	2.91	4.41	0.00	22.50	90
Embossed					
Adoption delay (years)	3244.47	1097.74	100.00	4400.00	272
Distance to coast (000s km)	0.15	0.23	0.00	1.59	272
Distance from pioneer (000s km)	4.18	2.68	0.16	15.73	272
Distance to river (000s km)	0.41	0.53	0.00	7.40	272
Elevation (m)	0.32	0.52	-0.01	4.35	272
Land suitability	0.64	0.29	0.00	1.00	272

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.48	4.76	0.00	34.62	272
Embroidered					
Adoption delay (years)	2618.21	708.02	900.00	3300.00	61
Distance to coast (000s km)	0.44	0.56	0.00	1.97	61
Distance from pioneer (000s km)	5.32	3.72	0.00	17.23	61
Distance to river (000s km)	0.61	0.97	0.01	7.42	61
Elevation (m)	0.75	0.96	-0.00	4.35	61
Land suitability	0.41	0.35	0.00	0.99	61
Ruggedness	3.82	5.78	0.00	24.92	61
Enamelled					
Adoption delay (years)	2403.34	776.00	30.00	3200.00	313
Distance to coast (000s km)	0.13	0.19	0.00	1.21	313
Distance from pioneer (000s km)	3.84	2.09	0.00	16.47	313
Distance to river (000s km)	0.35	0.30	0.00	2.13	313
Elevation (m)	0.26	0.43	-0.00	4.35	313
Land suitability	0.61	0.27	0.00	1.00	313
Ruggedness	2.08	4.44	0.00	34.62	313
Engraved					
Adoption delay (years)	15609.57	1224.70	1000.00	16800.00	3033
Distance to coast (000s km)	0.14	0.25	0.00	2.07	3033
Distance from pioneer (000s km)	2.66	3.13	0.00	19.37	3033
Distance to river (000s km)	0.41	0.43	0.00	8.31	3033
Elevation (m)	0.29	0.51	-0.02	4.91	3033
Land suitability	0.64	0.28	0.00	1.00	3033
Ruggedness	2.32	4.58	0.00	43.03	3033
Etching					
Adoption delay (years)	5639.66	455.18	1500.00	5800.00	203
Distance to coast (000s km)	0.16	0.21	0.00	1.63	203

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	5.78	1.47	1.21	12.75	203
Distance to river (000s km)	0.26	0.27	0.00	2.13	203
Elevation (m)	0.20	0.29	-0.00	2.43	203
Land suitability	0.68	0.23	0.01	1.00	203
Ruggedness	1.51	2.96	0.00	20.33	203
Filigree					
Adoption delay (years)	2977.67	758.14	100.00	4400.00	198
Distance to coast (000s km)	0.13	0.25	0.00	1.59	198
Distance from pioneer (000s km)	3.65	1.71	0.00	12.58	198
Distance to river (000s km)	0.41	0.32	0.00	1.75	198
Elevation (m)	0.29	0.54	-0.00	4.69	198
Land suitability	0.68	0.29	0.00	1.00	198
Ruggedness	2.71	5.13	0.00	36.02	198
Gilded					
Adoption delay (years)	4136.24	918.13	687.00	5100.00	825
Distance to coast (000s km)	0.18	0.32	0.00	2.07	825
Distance from pioneer (000s km)	3.61	2.11	0.14	16.05	825
Distance to river (000s km)	0.38	0.35	0.00	2.22	825
Elevation (m)	0.35	0.64	-0.00	4.91	825
Land suitability	0.63	0.29	0.00	1.00	825
Ruggedness	2.74	4.94	0.00	34.62	825
Glazed					
Adoption delay (years)	9506.27	977.29	2613.00	10413.00	1135
Distance to coast (000s km)	0.18	0.30	0.00	2.07	1135
Distance from pioneer (000s km)	3.67	2.48	0.00	16.53	1135
Distance to river (000s km)	0.42	0.43	0.00	7.46	1135
Elevation (m)	0.29	0.45	-0.00	4.46	1135
Land suitability	0.62	0.31	0.00	1.00	1135

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.63	4.64	0.00	34.62	1135
Hammered					
Adoption delay (years)	3614.03	1089.15	800.00	5600.00	808
Distance to coast (000s km)	0.16	0.28	0.00	1.97	808
Distance from pioneer (000s km)	2.72	2.84	0.00	17.63	808
Distance to river (000s km)	0.45	0.52	0.00	7.42	808
Elevation (m)	0.31	0.50	-0.01	4.66	808
Land suitability	0.61	0.30	0.00	1.00	808
Ruggedness	2.61	5.01	0.00	40.94	808
Hand coloured					
Adoption delay (years)	2384.23	663.86	390.00	2750.00	167
Distance to coast (000s km)	0.21	0.25	0.00	1.79	167
Distance from pioneer (000s km)	3.99	2.37	0.20	13.62	167
Distance to river (000s km)	0.35	0.31	0.00	1.48	167
Elevation (m)	0.37	0.44	0.00	3.49	167
Land suitability	0.64	0.28	0.00	1.00	167
Ruggedness	3.00	5.19	0.00	34.62	167
Handmade					
Adoption delay (years)	849884.93	2292.28	790000.00	851800.00	1929
Distance to coast (000s km)	0.19	0.32	0.00	2.07	1929
Distance from pioneer (000s km)	6.50	3.14	0.24	18.54	1929
Distance to river (000s km)	0.59	0.88	0.00	8.31	1929
Elevation (m)	0.38	0.60	-0.06	4.78	1929
Land suitability	0.58	0.33	0.00	1.00	1929
Ruggedness	3.18	5.64	0.00	47.35	1929
Impressed					
Adoption delay (years)	6190.27	1510.85	300.00	8300.00	422
Distance to coast (000s km)	0.23	0.34	0.00	2.07	422

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	2.74	2.65	0.00	15.14	422
Distance to river (000s km)	0.40	0.54	0.00	8.28	422
Elevation (m)	0.37	0.64	0.00	4.67	422
Land suitability	0.55	0.35	0.00	1.00	422
Ruggedness	2.84	5.12	0.00	29.87	422
Incised					
Adoption delay (years)	28842.26	1587.88	14000.00	30800.00	1753
Distance to coast (000s km)	0.18	0.30	0.00	2.07	1753
Distance from pioneer (000s km)	10.53	3.07	0.10	19.33	1753
Distance to river (000s km)	0.46	0.54	0.00	8.31	1753
Elevation (m)	0.34	0.56	-0.06	4.69	1753
Land suitability	0.59	0.33	0.00	1.00	1753
Ruggedness	2.79	5.11	0.00	40.94	1753
Inlaid					
Adoption delay (years)	8848.27	1033.80	2600.00	10300.00	575
Distance to coast (000s km)	0.17	0.27	0.00	2.07	575
Distance from pioneer (000s km)	3.80	2.98	0.02	16.76	575
Distance to river (000s km)	0.47	0.57	0.00	7.46	575
Elevation (m)	0.36	0.69	0.00	5.60	575
Land suitability	0.59	0.32	0.00	1.00	575
Ruggedness	2.87	5.04	0.00	36.02	575
Intaglio					
Adoption delay (years)	3179.18	1018.22	300.00	4200.00	219
Distance to coast (000s km)	0.17	0.29	0.00	1.63	219
Distance from pioneer (000s km)	3.43	2.27	0.00	13.13	219
Distance to river (000s km)	0.36	0.30	0.00	1.58	219
Elevation (m)	0.28	0.49	-0.00	4.15	219
Land suitability	0.62	0.31	0.00	1.00	219

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.70	4.82	0.00	34.62	219
Interlaced					
Adoption delay (years)	2499.41	535.78	950.00	3400.00	56
Distance to coast (000s km)	0.16	0.29	0.00	1.76	56
Distance from pioneer (000s km)	4.40	2.38	0.21	13.25	56
Distance to river (000s km)	0.42	0.31	0.00	1.35	56
Elevation (m)	0.26	0.39	0.01	2.07	56
Land suitability	0.47	0.31	0.00	0.96	56
Ruggedness	1.82	3.24	0.00	14.53	56
Keyed					
Adoption delay (years)	1939.43	378.63	200.00	2545.00	99
Distance to coast (000s km)	0.06	0.08	0.00	0.54	99
Distance from pioneer (000s km)	3.95	1.20	0.35	10.44	99
Distance to river (000s km)	0.24	0.08	0.00	0.41	99
Elevation (m)	0.11	0.08	0.00	0.47	99
Land suitability	0.70	0.22	0.00	0.97	99
Ruggedness	1.15	3.60	0.00	31.91	99
Lacquered					
Adoption delay (years)	6351.51	648.04	3950.00	6800.00	79
Distance to coast (000s km)	0.38	0.53	0.00	2.07	79
Distance from pioneer (000s km)	4.20	2.87	0.00	10.10	79
Distance to river (000s km)	0.64	0.55	0.00	2.21	79
Elevation (m)	0.54	0.79	0.00	4.35	79
Land suitability	0.56	0.30	0.00	0.98	79
Ruggedness	3.03	5.11	0.00	30.88	79
Lead-glazed					
Adoption delay (years)	1518.74	312.14	156.00	2006.00	322
Distance to coast (000s km)	0.08	0.14	0.00	1.21	322

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	6.13	1.38	0.00	11.92	322
Distance to river (000s km)	0.30	0.18	0.00	1.22	322
Elevation (m)	0.14	0.22	-0.00	2.13	322
Land suitability	0.66	0.23	0.00	1.00	322
Ruggedness	1.31	3.12	0.00	31.91	322
Lost-wax cast					
Adoption delay (years)	2743.88	963.80	100.00	4400.00	227
Distance to coast (000s km)	0.19	0.29	0.00	1.76	227
Distance from pioneer (000s km)	3.99	2.93	0.00	14.21	227
Distance to river (000s km)	0.49	0.41	0.00	1.95	227
Elevation (m)	0.57	0.80	-0.00	4.69	227
Land suitability	0.63	0.33	0.00	1.00	227
Ruggedness	4.39	6.43	0.00	34.62	227
Lustred					
Adoption delay (years)	5424.79	503.41	2600.00	6000.00	57
Distance to coast (000s km)	0.29	0.30	0.00	1.21	57
Distance from pioneer (000s km)	3.30	3.52	0.19	17.61	57
Distance to river (000s km)	0.65	0.99	0.00	7.42	57
Elevation (m)	0.53	0.57	0.01	2.47	57
Land suitability	0.49	0.40	0.00	0.99	57
Ruggedness	4.29	5.30	0.00	20.46	57
Metal technique					
Adoption delay (years)	3666.86	1029.27	200.00	5000.00	1360
Distance to coast (000s km)	0.15	0.26	0.00	2.07	1360
Distance from pioneer (000s km)	3.22	3.06	0.17	18.67	1360
Distance to river (000s km)	0.44	0.47	0.00	7.42	1360
Elevation (m)	0.30	0.48	-0.02	4.69	1360
Land suitability	0.63	0.29	0.00	1.00	1360

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.51	4.89	0.00	43.03	1360
Mixed method					
Adoption delay (years)	2.00	nan	2.00	2.00	1
Distance to coast (000s km)	0.03	nan	0.03	0.03	1
Distance from pioneer (000s km)	0.00	nan	0.00	0.00	1
Distance to river (000s km)	0.23	nan	0.23	0.23	1
Elevation (m)	0.05	nan	0.05	0.05	1
Land suitability	0.86	nan	0.86	0.86	1
Ruggedness	0.52	nan	0.52	0.52	1
Mould-made					
Adoption delay (years)	8207.91	1045.94	2100.00	9800.00	932
Distance to coast (000s km)	0.20	0.33	0.00	2.07	932
Distance from pioneer (000s km)	8.19	2.58	0.23	16.14	932
Distance to river (000s km)	0.42	0.42	0.00	8.30	932
Elevation (m)	0.35	0.53	-0.00	4.35	932
Land suitability	0.61	0.33	0.00	1.00	932
Ruggedness	3.09	5.04	0.00	40.94	932
Moulded					
Adoption delay (years)	9046.74	1078.30	2600.00	10300.00	519
Distance to coast (000s km)	0.21	0.34	0.00	2.07	519
Distance from pioneer (000s km)	3.76	2.60	0.09	16.27	519
Distance to river (000s km)	0.40	0.33	0.00	2.70	519
Elevation (m)	0.35	0.54	-0.00	4.69	519
Land suitability	0.63	0.32	0.00	1.00	519
Ruggedness	3.02	5.09	0.00	34.62	519
Painted					
Adoption delay (years)	7172.48	1829.31	500.00	8800.00	1205
Distance to coast (000s km)	0.24	0.34	0.00	2.07	1205

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	3.90	3.53	0.00	17.67	1205
Distance to river (000s km)	0.58	0.89	0.00	8.31	1205
Elevation (m)	0.47	0.67	-0.06	4.69	1205
Land suitability	0.54	0.35	0.00	1.00	1205
Ruggedness	3.66	5.78	0.00	47.35	1205
Perforated					
Adoption delay (years)	13186.69	1881.01	6000.00	15800.00	483
Distance to coast (000s km)	0.18	0.29	0.00	1.59	483
Distance from pioneer (000s km)	3.32	3.27	0.11	19.37	483
Distance to river (000s km)	0.48	0.67	0.00	7.46	483
Elevation (m)	0.33	0.55	-0.00	4.15	483
Land suitability	0.57	0.32	0.00	1.00	483
Ruggedness	2.33	4.48	0.00	34.62	483
Pierced					
Adoption delay (years)	8113.56	1563.21	1000.00	9800.00	977
Distance to coast (000s km)	0.18	0.31	0.00	2.07	977
Distance from pioneer (000s km)	3.05	3.24	0.01	18.33	977
Distance to river (000s km)	0.48	0.76	0.00	7.46	977
Elevation (m)	0.35	0.57	-0.06	4.91	977
Land suitability	0.59	0.32	0.00	1.00	977
Ruggedness	2.70	4.97	0.00	36.02	977
Pigmented					
Adoption delay (years)	11279.33	1374.15	4500.00	12800.00	252
Distance to coast (000s km)	0.25	0.38	0.00	2.07	252
Distance from pioneer (000s km)	5.79	3.84	0.11	18.63	252
Distance to river (000s km)	0.70	0.87	0.00	7.46	252
Elevation (m)	0.49	0.71	0.00	4.69	252
Land suitability	0.55	0.35	0.00	0.99	252

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	3.59	5.37	0.00	24.70	252
Plain weave					
Adoption delay (years)	3450.87	990.04	500.00	4800.00	46
Distance to coast (000s km)	0.38	0.55	0.00	2.07	46
Distance from pioneer (000s km)	4.50	4.05	0.00	12.38	46
Distance to river (000s km)	0.49	0.47	0.00	1.91	46
Elevation (m)	0.62	0.80	0.01	4.26	46
Land suitability	0.31	0.36	0.00	0.99	46
Ruggedness	4.26	7.07	0.00	30.88	46
Plaited					
Adoption delay (years)	3728.39	857.56	1050.00	4400.00	200
Distance to coast (000s km)	0.17	0.36	0.00	2.07	200
Distance from pioneer (000s km)	7.36	4.43	0.00	18.20	200
Distance to river (000s km)	1.49	1.95	0.01	7.46	200
Elevation (m)	0.35	0.47	0.00	3.49	200
Land suitability	0.45	0.34	0.00	0.99	200
Ruggedness	2.98	5.29	0.00	34.62	200
Plated					
Adoption delay (years)	1590.89	833.53	150.00	3350.00	98
Distance to coast (000s km)	0.13	0.24	0.00	1.21	98
Distance from pioneer (000s km)	3.48	2.37	0.34	13.06	98
Distance to river (000s km)	0.43	0.38	0.00	2.70	98
Elevation (m)	0.31	0.52	-0.00	3.09	98
Land suitability	0.68	0.28	0.00	1.00	98
Ruggedness	2.78	4.84	0.00	23.47	98
Polished					
Adoption delay (years)	13602.07	1802.28	950.00	15800.00	895
Distance to coast (000s km)	0.17	0.29	0.00	1.87	895

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	4.12	3.99	0.14	19.79	895
Distance to river (000s km)	0.62	0.91	0.00	8.31	895
Elevation (m)	0.36	0.58	-0.06	4.69	895
Land suitability	0.59	0.33	0.00	1.00	895
Ruggedness	3.09	5.33	0.00	40.94	895
Punched					
Adoption delay (years)	3739.07	895.98	300.00	5300.00	441
Distance to coast (000s km)	0.13	0.22	0.00	1.21	441
Distance from pioneer (000s km)	6.00	1.99	0.23	16.63	441
Distance to river (000s km)	0.36	0.28	0.00	1.68	441
Elevation (m)	0.24	0.42	-0.00	3.09	441
Land suitability	0.64	0.28	0.00	1.00	441
Ruggedness	1.91	3.97	0.00	36.02	441
Relief					
Adoption delay (years)	6761.68	1123.25	1200.00	8300.00	848
Distance to coast (000s km)	0.16	0.27	0.00	2.07	848
Distance from pioneer (000s km)	2.61	2.80	0.00	17.69	848
Distance to river (000s km)	0.43	0.47	0.00	7.42	848
Elevation (m)	0.35	0.52	-0.00	4.69	848
Land suitability	0.62	0.32	0.00	1.00	848
Ruggedness	3.33	5.46	0.00	38.00	848
Repoussé					
Adoption delay (years)	2939.91	962.86	150.00	4550.00	251
Distance to coast (000s km)	0.17	0.27	0.00	1.59	251
Distance from pioneer (000s km)	3.97	2.34	0.00	14.49	251
Distance to river (000s km)	0.43	0.32	0.00	1.68	251
Elevation (m)	0.43	0.70	-0.00	5.58	251
Land suitability	0.65	0.29	0.00	1.00	251

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	3.60	5.93	0.00	36.02	251
Sewn					
Adoption delay (years)	9192.35	859.74	5800.00	9800.00	192
Distance to coast (000s km)	0.25	0.40	0.00	2.07	192
Distance from pioneer (000s km)	8.82	4.71	0.00	19.57	192
Distance to river (000s km)	1.26	1.78	0.00	8.31	192
Elevation (m)	0.44	0.66	-0.06	4.35	192
Land suitability	0.35	0.33	0.00	0.99	192
Ruggedness	3.14	5.70	0.00	34.36	192
Slipped					
Adoption delay (years)	6767.19	1565.65	500.00	8800.00	708
Distance to coast (000s km)	0.24	0.36	0.00	2.07	708
Distance from pioneer (000s km)	3.26	2.59	0.00	13.40	708
Distance to river (000s km)	0.45	0.34	0.00	1.99	708
Elevation (m)	0.42	0.57	-0.06	3.41	708
Land suitability	0.58	0.35	0.00	1.00	708
Ruggedness	3.57	5.40	0.00	29.87	708
Smoothed					
Adoption delay (years)	13473.63	1725.93	6000.00	15800.00	249
Distance to coast (000s km)	0.17	0.30	0.00	2.07	249
Distance from pioneer (000s km)	3.70	3.72	0.17	19.79	249
Distance to river (000s km)	0.57	0.77	0.00	7.42	249
Elevation (m)	0.35	0.54	0.00	3.49	249
Land suitability	0.54	0.35	0.00	0.99	249
Ruggedness	3.16	5.08	0.00	29.87	249
Soldered					
Adoption delay (years)	3606.09	1003.68	300.00	5100.00	443
Distance to coast (000s km)	0.12	0.21	0.00	1.59	443

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	3.67	2.24	0.07	14.73	443
Distance to river (000s km)	0.40	0.33	0.00	1.91	443
Elevation (m)	0.27	0.44	-0.00	4.35	443
Land suitability	0.64	0.28	0.00	1.00	443
Ruggedness	2.30	4.29	0.00	34.62	443
Stamped					
Adoption delay (years)	6798.75	956.92	1000.00	7800.00	2243
Distance to coast (000s km)	0.14	0.25	0.00	2.07	2243
Distance from pioneer (000s km)	3.65	2.28	0.00	17.93	2243
Distance to river (000s km)	0.38	0.38	0.00	7.42	2243
Elevation (m)	0.28	0.50	-0.02	4.69	2243
Land suitability	0.65	0.28	0.00	1.00	2243
Ruggedness	2.32	4.63	0.00	43.03	2243
Stipple					
Adoption delay (years)	7162.71	965.14	4300.00	7800.00	111
Distance to coast (000s km)	0.14	0.19	0.00	1.03	111
Distance from pioneer (000s km)	3.37	1.86	0.44	13.38	111
Distance to river (000s km)	0.30	0.21	0.00	0.85	111
Elevation (m)	0.22	0.35	-0.00	3.09	111
Land suitability	0.65	0.25	0.00	1.00	111
Ruggedness	2.21	4.07	0.00	20.33	111
Struck					
Adoption delay (years)	800604.71	1740.42	755000.00	801800.00	1478
Distance to coast (000s km)	0.15	0.26	0.00	2.07	1478
Distance from pioneer (000s km)	6.04	2.02	0.93	17.44	1478
Distance to river (000s km)	0.40	0.38	0.00	7.42	1478
Elevation (m)	0.32	0.52	-0.02	4.69	1478
Land suitability	0.66	0.28	0.00	1.00	1478

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.67	5.05	0.00	43.03	1478
Tempered					
Adoption delay (years)	12914.73	1672.89	2050.00	14850.00	207
Distance to coast (000s km)	0.16	0.28	0.00	2.07	207
Distance from pioneer (000s km)	5.42	1.47	0.48	8.73	207
Distance to river (000s km)	0.42	0.43	0.00	2.03	207
Elevation (m)	0.25	0.38	0.00	2.49	207
Land suitability	0.59	0.33	0.00	1.00	207
Ruggedness	2.14	4.31	0.00	29.87	207
Terra sigillata					
Adoption delay (years)	663.86	117.92	280.00	1130.00	71
Distance to coast (000s km)	0.15	0.17	0.00	0.92	71
Distance from pioneer (000s km)	2.21	1.49	0.62	9.69	71
Distance to river (000s km)	0.40	0.36	0.00	1.42	71
Elevation (m)	0.30	0.32	0.00	1.30	71
Land suitability	0.72	0.27	0.00	1.00	71
Ruggedness	2.83	3.78	0.00	17.44	71
Textile technique					
Adoption delay (years)	3936.57	946.89	500.00	4800.00	134
Distance to coast (000s km)	0.30	0.47	0.00	2.07	134
Distance from pioneer (000s km)	6.25	4.84	0.00	19.53	134
Distance to river (000s km)	0.95	1.56	0.00	7.46	134
Elevation (m)	0.62	0.91	-0.06	4.69	134
Land suitability	0.40	0.36	0.00	0.99	134
Ruggedness	3.56	5.51	0.00	29.14	134
Tin-glazed					
Adoption delay (years)	1536.75	213.10	849.00	1777.00	102
Distance to coast (000s km)	0.10	0.14	0.00	0.61	102

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	1.31	2.27	0.00	16.09	102
Distance to river (000s km)	0.52	0.35	0.00	1.41	102
Elevation (m)	0.27	0.26	-0.00	1.16	102
Land suitability	0.77	0.25	0.01	1.00	102
Ruggedness	3.28	4.38	0.00	23.47	102
Twisted					
Adoption delay (years)	2950.31	1100.05	100.00	4600.00	424
Distance to coast (000s km)	0.16	0.31	0.00	2.07	424
Distance from pioneer (000s km)	3.17	3.15	0.04	18.56	424
Distance to river (000s km)	0.51	0.88	0.00	7.46	424
Elevation (m)	0.31	0.50	-0.00	4.35	424
Land suitability	0.58	0.32	0.00	1.00	424
Ruggedness	2.84	5.48	0.00	34.62	424
Underglazed					
Adoption delay (years)	3506.92	295.95	2050.00	3800.00	142
Distance to coast (000s km)	0.24	0.32	0.00	1.79	142
Distance from pioneer (000s km)	7.73	4.03	0.00	16.28	142
Distance to river (000s km)	0.54	0.55	0.00	3.74	142
Elevation (m)	0.36	0.46	-0.00	2.47	142
Land suitability	0.56	0.29	0.00	1.00	142
Ruggedness	3.02	4.92	0.00	30.88	142
Wheel-made					
Adoption delay (years)	7157.60	1439.85	500.00	8800.00	1025
Distance to coast (000s km)	0.18	0.30	0.00	2.07	1025
Distance from pioneer (000s km)	3.83	2.72	0.00	15.65	1025
Distance to river (000s km)	0.42	0.36	0.00	2.70	1025
Elevation (m)	0.32	0.48	-0.06	4.08	1025
Land suitability	0.63	0.32	0.00	1.00	1025

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Table 3.C.6: Descriptive statistics by production technique — Pre-1800 sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	3.01	5.31	0.00	40.94	1025
Wirework					
Adoption delay (years)	4658.58	949.01	1900.00	6300.00	246
Distance to coast (000s km)	0.12	0.20	0.00	1.36	246
Distance from pioneer (000s km)	8.19	2.34	0.75	18.37	246
Distance to river (000s km)	0.45	0.36	0.01	2.61	246
Elevation (m)	0.33	0.59	-0.00	4.35	246
Land suitability	0.63	0.30	0.00	0.99	246
Ruggedness	2.74	4.88	0.00	28.45	246
Woven					
Adoption delay (years)	4240.16	858.39	500.00	4800.00	249
Distance to coast (000s km)	0.23	0.42	0.00	2.07	249
Distance from pioneer (000s km)	7.61	4.93	0.00	19.63	249
Distance to river (000s km)	1.23	1.70	0.00	7.46	249
Elevation (m)	0.48	0.74	-0.00	4.35	249
Land suitability	0.42	0.34	0.00	0.99	249
Ruggedness	3.07	5.14	0.00	30.88	249

Note: The table reports descriptive statistics for the regression sample restricted to artefacts dated before 1800. Each observation corresponds to the earliest artefact associated with a given production technique at each site.

Table 3.C.7: Descriptive statistics by production technique — All sample

Variable	Mean	SD	Min	Max	Count
Applied					
Adoption delay (years)	7119.61	1160.38	100.00	8015.00	1258
Distance to coast (000s km)	0.18	0.30	0.00	2.07	1258
Distance from pioneer (000s km)	5.39	4.06	0.00	18.21	1258
Distance to river (000s km)	0.76	1.03	0.00	8.36	1258
Elevation (m)	0.38	0.57	-0.00	4.78	1258
Land suitability	0.55	0.31	0.00	1.00	1258
Ruggedness	2.85	5.04	0.00	38.25	1258
Appliqué					
Adoption delay (years)	3171.69	819.15	725.00	3735.00	276
Distance to coast (000s km)	0.36	0.48	0.00	2.19	276
Distance from pioneer (000s km)	5.92	4.30	0.09	18.11	276
Distance to river (000s km)	0.84	1.11	0.00	8.11	276
Elevation (m)	0.68	0.83	0.00	4.69	276
Land suitability	0.51	0.33	0.00	1.00	276
Ruggedness	3.95	5.88	0.00	31.32	276
Beadwork					
Adoption delay (years)	9426.20	1030.27	2100.00	10010.00	732
Distance to coast (000s km)	0.24	0.36	0.00	2.19	732
Distance from pioneer (000s km)	9.08	4.63	0.00	19.67	732
Distance to river (000s km)	1.03	1.17	0.00	8.31	732
Elevation (m)	0.52	0.69	0.00	4.78	732
Land suitability	0.48	0.32	0.00	1.00	732
Ruggedness	3.32	5.47	0.00	34.62	732
Blown					
Adoption delay (years)	2145.20	854.91	50.00	3465.00	345
Distance to coast (000s km)	0.20	0.31	0.00	2.07	345

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	2.81	2.48	0.02	17.90	345
Distance to river (000s km)	0.41	0.54	0.00	7.42	345
Elevation (m)	0.33	0.54	-0.06	4.35	345
Land suitability	0.56	0.35	0.00	1.00	345
Ruggedness	3.00	5.26	0.00	29.87	345
Braided					
Adoption delay (years)	3284.87	404.26	750.00	3511.00	617
Distance to coast (000s km)	0.24	0.39	0.00	1.97	617
Distance from pioneer (000s km)	8.25	4.85	0.00	19.63	617
Distance to river (000s km)	1.28	1.51	0.00	8.31	617
Elevation (m)	0.51	0.66	-0.00	5.28	617
Land suitability	0.47	0.32	0.00	1.00	617
Ruggedness	3.27	5.51	0.00	34.62	617
Burnished					
Adoption delay (years)	6671.61	1744.39	300.00	8523.00	418
Distance to coast (000s km)	0.24	0.33	0.00	2.07	418
Distance from pioneer (000s km)	3.98	3.63	0.00	18.05	418
Distance to river (000s km)	0.57	0.79	0.00	8.30	418
Elevation (m)	0.45	0.65	-0.06	4.35	418
Land suitability	0.57	0.33	0.00	1.00	418
Ruggedness	2.79	5.19	0.00	40.94	418
Carved					
Adoption delay (years)	850382.62	15531.19	50000.00	852020.00	3300
Distance to coast (000s km)	0.18	0.31	0.00	2.07	3300
Distance from pioneer (000s km)	8.06	4.11	0.00	19.36	3300
Distance to river (000s km)	0.95	1.24	0.00	8.33	3300
Elevation (m)	0.43	0.64	-0.06	4.91	3300
Land suitability	0.51	0.33	0.00	1.00	3300

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	3.09	5.30	0.00	42.21	3300
Cast					
Adoption delay (years)	6474.65	1168.03	2100.00	7923.00	3128
Distance to coast (000s km)	0.15	0.28	0.00	2.19	3128
Distance from pioneer (000s km)	4.13	2.60	0.01	18.46	3128
Distance to river (000s km)	0.43	0.39	0.00	7.42	3128
Elevation (m)	0.31	0.56	-0.02	5.60	3128
Land suitability	0.63	0.29	0.00	1.00	3128
Ruggedness	2.35	4.75	0.00	43.03	3128
Ceramic technique					
Adoption delay (years)	8486.90	1587.24	1000.00	10023.00	1653
Distance to coast (000s km)	0.21	0.32	0.00	2.07	1653
Distance from pioneer (000s km)	10.27	4.07	0.00	19.67	1653
Distance to river (000s km)	0.55	0.59	0.00	8.31	1653
Elevation (m)	0.46	0.69	-0.06	4.35	1653
Land suitability	0.59	0.32	0.00	1.00	1653
Ruggedness	3.19	5.20	0.00	40.04	1653
Chased					
Adoption delay (years)	3449.31	1068.46	200.00	4610.00	381
Distance to coast (000s km)	0.18	0.28	0.00	1.74	381
Distance from pioneer (000s km)	4.06	2.48	0.19	15.68	381
Distance to river (000s km)	0.51	0.44	0.00	2.43	381
Elevation (m)	0.46	0.76	-0.00	5.60	381
Land suitability	0.61	0.31	0.00	1.00	381
Ruggedness	3.48	5.73	0.00	36.02	381
Combed					
Adoption delay (years)	6781.12	1170.06	2000.00	8470.00	145
Distance to coast (000s km)	0.22	0.33	0.00	2.07	145

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	2.68	2.43	0.06	10.72	145
Distance to river (000s km)	0.43	0.39	0.00	2.33	145
Elevation (m)	0.35	0.50	0.00	3.09	145
Land suitability	0.58	0.34	0.00	1.00	145
Ruggedness	3.00	5.23	0.00	32.56	145
Cut					
Adoption delay (years)	800305.67	10892.41	450000.00	802017.00	1255
Distance to coast (000s km)	0.21	0.33	0.00	2.22	1255
Distance from pioneer (000s km)	7.66	3.94	0.24	19.36	1255
Distance to river (000s km)	0.81	1.10	0.00	8.31	1255
Elevation (m)	0.43	0.62	-0.00	4.78	1255
Land suitability	0.53	0.33	0.00	1.00	1255
Ruggedness	2.85	5.06	0.00	38.25	1255
Dyed					
Adoption delay (years)	4833.75	405.56	200.00	5022.00	876
Distance to coast (000s km)	0.25	0.37	0.00	2.19	876
Distance from pioneer (000s km)	7.91	4.97	0.00	19.63	876
Distance to river (000s km)	1.30	1.63	0.00	8.31	876
Elevation (m)	0.53	0.70	0.00	5.28	876
Land suitability	0.46	0.31	0.00	1.00	876
Ruggedness	3.23	5.36	0.00	40.15	876
Embossed					
Adoption delay (years)	3625.82	1082.38	100.00	4621.00	391
Distance to coast (000s km)	0.18	0.27	0.00	1.59	391
Distance from pioneer (000s km)	4.39	2.73	0.16	15.73	391
Distance to river (000s km)	0.50	0.56	0.00	7.40	391
Elevation (m)	0.40	0.62	-0.01	4.35	391
Land suitability	0.59	0.31	0.00	1.00	391

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.70	4.93	0.00	34.62	391
Embroidered					
Adoption delay (years)	3356.56	322.02	900.00	3523.00	659
Distance to coast (000s km)	0.33	0.43	0.00	2.19	659
Distance from pioneer (000s km)	6.19	4.22	0.00	18.83	659
Distance to river (000s km)	0.75	0.85	0.00	7.46	659
Elevation (m)	0.71	0.82	-0.06	5.28	659
Land suitability	0.50	0.34	0.00	1.00	659
Ruggedness	4.54	6.21	0.00	41.14	659
Enamelled					
Adoption delay (years)	2709.88	762.53	30.00	3414.00	474
Distance to coast (000s km)	0.16	0.25	0.00	1.59	474
Distance from pioneer (000s km)	4.37	2.58	0.00	16.47	474
Distance to river (000s km)	0.41	0.37	0.00	2.15	474
Elevation (m)	0.29	0.47	-0.00	4.35	474
Land suitability	0.59	0.28	0.00	1.00	474
Ruggedness	2.04	4.27	0.00	34.62	474
Engraved					
Adoption delay (years)	15951.49	1186.49	1000.00	17019.00	4162
Distance to coast (000s km)	0.15	0.27	0.00	2.07	4162
Distance from pioneer (000s km)	3.57	4.05	0.00	19.37	4162
Distance to river (000s km)	0.51	0.66	0.00	8.31	4162
Elevation (m)	0.30	0.53	-0.02	4.91	4162
Land suitability	0.61	0.29	0.00	1.00	4162
Ruggedness	2.23	4.40	0.00	43.03	4162
Etching					
Adoption delay (years)	5744.78	348.88	1500.00	6017.00	389
Distance to coast (000s km)	0.14	0.21	0.00	1.63	389

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	6.06	2.01	0.88	14.53	389
Distance to river (000s km)	0.32	0.33	0.00	2.80	389
Elevation (m)	0.22	0.36	-0.00	3.49	389
Land suitability	0.66	0.25	0.00	1.00	389
Ruggedness	1.73	3.75	0.00	31.91	389
Filigree					
Adoption delay (years)	3385.02	933.72	100.00	4610.00	271
Distance to coast (000s km)	0.17	0.31	0.00	1.94	271
Distance from pioneer (000s km)	3.71	1.85	0.00	12.58	271
Distance to river (000s km)	0.49	0.43	0.00	2.72	271
Elevation (m)	0.38	0.65	-0.00	4.78	271
Land suitability	0.62	0.32	0.00	1.00	271
Ruggedness	3.00	5.29	0.00	36.02	271
Gilded					
Adoption delay (years)	4371.22	921.60	687.00	5321.00	1061
Distance to coast (000s km)	0.18	0.31	0.00	2.19	1061
Distance from pioneer (000s km)	3.92	2.45	0.14	16.05	1061
Distance to river (000s km)	0.44	0.41	0.00	2.44	1061
Elevation (m)	0.37	0.66	-0.00	4.91	1061
Land suitability	0.61	0.30	0.00	1.00	1061
Ruggedness	2.75	4.99	0.00	41.14	1061
Glazed					
Adoption delay (years)	9721.35	962.67	2613.00	10629.00	1439
Distance to coast (000s km)	0.18	0.30	0.00	2.07	1439
Distance from pioneer (000s km)	4.22	2.95	0.00	16.53	1439
Distance to river (000s km)	0.50	0.59	0.00	8.36	1439
Elevation (m)	0.34	0.56	-0.01	4.66	1439
Land suitability	0.61	0.30	0.00	1.00	1439

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.76	4.69	0.00	34.62	1439
Hammered					
Adoption delay (years)	4132.77	1303.61	800.00	5810.00	1077
Distance to coast (000s km)	0.20	0.33	0.00	2.19	1077
Distance from pioneer (000s km)	3.80	3.59	0.00	18.54	1077
Distance to river (000s km)	0.55	0.61	0.00	7.42	1077
Elevation (m)	0.40	0.66	-0.01	4.78	1077
Land suitability	0.57	0.31	0.00	1.00	1077
Ruggedness	2.72	5.24	0.00	42.21	1077
Hand coloured					
Adoption delay (years)	2694.77	422.50	390.00	2971.00	546
Distance to coast (000s km)	0.19	0.26	0.00	1.79	546
Distance from pioneer (000s km)	5.38	3.35	0.20	19.03	546
Distance to river (000s km)	0.44	0.60	0.00	7.42	546
Elevation (m)	0.33	0.51	-0.00	4.69	546
Land suitability	0.62	0.28	0.00	1.00	546
Ruggedness	2.36	4.45	0.00	34.62	546
Handmade					
Adoption delay (years)	850815.06	1956.96	790000.00	852023.00	3590
Distance to coast (000s km)	0.20	0.33	0.00	2.19	3590
Distance from pioneer (000s km)	7.66	3.98	0.11	19.36	3590
Distance to river (000s km)	0.85	1.17	0.00	8.36	3590
Elevation (m)	0.45	0.67	-0.06	5.58	3590
Land suitability	0.54	0.32	0.00	1.00	3590
Ruggedness	3.11	5.48	0.00	47.35	3590
Impressed					
Adoption delay (years)	6631.51	1616.05	300.00	8508.00	527
Distance to coast (000s km)	0.23	0.33	0.00	2.07	527

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	3.23	3.09	0.00	17.44	527
Distance to river (000s km)	0.52	0.88	0.00	8.36	527
Elevation (m)	0.39	0.64	0.00	4.67	527
Land suitability	0.54	0.33	0.00	1.00	527
Ruggedness	2.72	4.87	0.00	29.87	527
Incised					
Adoption delay (years)	29392.48	1633.11	14000.00	31019.00	2398
Distance to coast (000s km)	0.19	0.31	0.00	2.07	2398
Distance from pioneer (000s km)	9.98	3.83	0.10	19.85	2398
Distance to river (000s km)	0.66	0.90	0.00	8.36	2398
Elevation (m)	0.38	0.61	-0.06	4.78	2398
Land suitability	0.56	0.32	0.00	1.00	2398
Ruggedness	2.81	5.12	0.00	40.94	2398
Inlaid					
Adoption delay (years)	9356.72	1114.86	2600.00	10517.00	858
Distance to coast (000s km)	0.20	0.32	0.00	2.19	858
Distance from pioneer (000s km)	5.09	3.95	0.02	17.09	858
Distance to river (000s km)	0.70	0.94	0.00	8.31	858
Elevation (m)	0.44	0.74	-0.00	5.60	858
Land suitability	0.56	0.32	0.00	1.00	858
Ruggedness	2.90	5.08	0.00	36.65	858
Intaglio					
Adoption delay (years)	3669.11	930.02	300.00	4417.00	398
Distance to coast (000s km)	0.16	0.27	0.00	1.87	398
Distance from pioneer (000s km)	4.74	3.21	0.00	15.15	398
Distance to river (000s km)	0.40	0.38	0.00	3.73	398
Elevation (m)	0.24	0.46	-0.00	4.15	398
Land suitability	0.59	0.29	0.00	1.00	398

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.02	3.93	0.00	34.62	398
Interlaced					
Adoption delay (years)	2923.49	643.28	950.00	3595.00	97
Distance to coast (000s km)	0.21	0.30	0.00	1.76	97
Distance from pioneer (000s km)	4.47	2.64	0.21	13.25	97
Distance to river (000s km)	0.56	0.47	0.00	2.33	97
Elevation (m)	0.43	0.60	0.00	4.35	97
Land suitability	0.45	0.31	0.00	1.00	97
Ruggedness	2.75	4.18	0.00	17.44	97
Keyed					
Adoption delay (years)	1967.40	396.65	200.00	2697.00	103
Distance to coast (000s km)	0.07	0.13	0.00	0.91	103
Distance from pioneer (000s km)	3.97	1.19	0.35	10.44	103
Distance to river (000s km)	0.25	0.13	0.00	1.25	103
Elevation (m)	0.13	0.19	0.00	1.62	103
Land suitability	0.69	0.22	0.00	0.97	103
Ruggedness	1.16	3.54	0.00	31.91	103
Lacquered					
Adoption delay (years)	6657.41	517.32	3950.00	7013.00	175
Distance to coast (000s km)	0.30	0.42	0.00	2.07	175
Distance from pioneer (000s km)	4.96	3.49	0.00	13.18	175
Distance to river (000s km)	0.63	0.56	0.00	2.41	175
Elevation (m)	0.58	0.88	0.00	4.78	175
Land suitability	0.58	0.29	0.00	1.00	175
Ruggedness	3.36	5.21	0.00	30.88	175
Lead-glazed					
Adoption delay (years)	1567.46	340.52	156.00	2167.00	351
Distance to coast (000s km)	0.08	0.14	0.00	1.21	351

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	6.08	1.35	0.00	11.92	351
Distance to river (000s km)	0.34	0.29	0.00	2.09	351
Elevation (m)	0.16	0.24	-0.00	2.13	351
Land suitability	0.65	0.25	0.00	1.00	351
Ruggedness	1.45	3.37	0.00	31.91	351
Lost-wax cast					
Adoption delay (years)	2898.13	1045.61	100.00	4611.00	249
Distance to coast (000s km)	0.21	0.30	0.00	1.76	249
Distance from pioneer (000s km)	4.19	3.05	0.00	14.21	249
Distance to river (000s km)	0.50	0.42	0.00	1.95	249
Elevation (m)	0.59	0.83	-0.00	4.69	249
Land suitability	0.61	0.33	0.00	1.00	249
Ruggedness	4.29	6.37	0.00	34.62	249
Lustred					
Adoption delay (years)	5627.57	520.39	2600.00	6205.00	82
Distance to coast (000s km)	0.25	0.29	0.00	1.21	82
Distance from pioneer (000s km)	3.85	3.28	0.19	17.61	82
Distance to river (000s km)	0.57	0.85	0.00	7.42	82
Elevation (m)	0.45	0.54	0.00	2.47	82
Land suitability	0.53	0.35	0.00	0.99	82
Ruggedness	3.49	4.68	0.00	20.46	82
Metal technique					
Adoption delay (years)	4123.48	1077.68	200.00	5219.00	2003
Distance to coast (000s km)	0.19	0.32	0.00	2.22	2003
Distance from pioneer (000s km)	4.26	3.79	0.17	19.42	2003
Distance to river (000s km)	0.55	0.64	0.00	8.31	2003
Elevation (m)	0.37	0.58	-0.02	4.78	2003
Land suitability	0.59	0.30	0.00	1.00	2003

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.68	5.04	0.00	43.03	2003
Mixed method					
Adoption delay (years)	57.39	45.95	2.00	204.00	36
Distance to coast (000s km)	0.13	0.22	0.00	0.91	36
Distance from pioneer (000s km)	1.94	2.88	0.00	8.77	36
Distance to river (000s km)	0.36	0.26	0.00	1.28	36
Elevation (m)	0.16	0.25	0.01	1.42	36
Land suitability	0.60	0.23	0.12	1.00	36
Ruggedness	0.77	0.87	0.00	3.51	36
Mould-made					
Adoption delay (years)	8521.49	1154.52	2100.00	10019.00	1141
Distance to coast (000s km)	0.20	0.32	0.00	2.07	1141
Distance from pioneer (000s km)	8.19	3.00	0.18	17.36	1141
Distance to river (000s km)	0.46	0.52	0.00	8.31	1141
Elevation (m)	0.40	0.63	-0.00	4.78	1141
Land suitability	0.60	0.33	0.00	1.00	1141
Ruggedness	3.05	5.07	0.00	40.94	1141
Moulded					
Adoption delay (years)	9289.71	1107.56	2600.00	10522.00	632
Distance to coast (000s km)	0.22	0.34	0.00	2.07	632
Distance from pioneer (000s km)	4.17	2.90	0.09	16.27	632
Distance to river (000s km)	0.43	0.48	0.00	8.31	632
Elevation (m)	0.40	0.65	-0.00	4.78	632
Land suitability	0.61	0.31	0.00	1.00	632
Ruggedness	3.02	5.02	0.00	34.62	632
Painted					
Adoption delay (years)	7962.97	1605.31	500.00	9019.00	2209
Distance to coast (000s km)	0.22	0.32	0.00	2.07	2209

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	5.88	4.35	0.00	18.89	2209
Distance to river (000s km)	0.80	1.05	0.00	8.31	2209
Elevation (m)	0.53	0.75	-0.06	5.80	2209
Land suitability	0.54	0.33	0.00	1.00	2209
Ruggedness	3.40	5.47	0.00	47.35	2209
Perforated					
Adoption delay (years)	14049.80	1993.22	6000.00	16015.00	712
Distance to coast (000s km)	0.17	0.28	0.00	1.59	712
Distance from pioneer (000s km)	5.57	4.96	0.11	19.37	712
Distance to river (000s km)	0.82	1.17	0.00	8.31	712
Elevation (m)	0.40	0.65	-0.00	4.35	712
Land suitability	0.54	0.31	0.00	1.00	712
Ruggedness	2.48	4.64	0.00	34.62	712
Pierced					
Adoption delay (years)	8591.31	1550.19	1000.00	10011.00	1338
Distance to coast (000s km)	0.18	0.30	0.00	2.08	1338
Distance from pioneer (000s km)	4.65	4.50	0.01	18.51	1338
Distance to river (000s km)	0.70	1.09	0.00	8.31	1338
Elevation (m)	0.38	0.60	-0.06	4.91	1338
Land suitability	0.57	0.32	0.00	1.00	1338
Ruggedness	2.64	4.83	0.00	36.02	1338
Pigmented					
Adoption delay (years)	12228.58	1176.07	4500.00	13018.00	621
Distance to coast (000s km)	0.20	0.32	0.00	2.07	621
Distance from pioneer (000s km)	9.03	4.96	0.11	18.71	621
Distance to river (000s km)	1.15	1.14	0.00	8.35	621
Elevation (m)	0.43	0.65	0.00	4.78	621
Land suitability	0.52	0.31	0.00	1.00	621

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.76	5.13	0.00	38.25	621
Plain weave					
Adoption delay (years)	4725.92	607.86	500.00	5020.00	355
Distance to coast (000s km)	0.29	0.39	0.00	2.07	355
Distance from pioneer (000s km)	4.88	3.66	0.00	16.46	355
Distance to river (000s km)	0.71	0.80	0.00	8.31	355
Elevation (m)	0.54	0.66	0.00	4.69	355
Land suitability	0.50	0.33	0.00	1.00	355
Ruggedness	3.15	4.87	0.00	30.88	355
Plaited					
Adoption delay (years)	4353.07	475.27	1050.00	4623.00	1090
Distance to coast (000s km)	0.20	0.35	0.00	2.07	1090
Distance from pioneer (000s km)	8.15	4.26	0.00	19.10	1090
Distance to river (000s km)	1.52	1.76	0.00	8.36	1090
Elevation (m)	0.46	0.65	0.00	4.78	1090
Land suitability	0.46	0.30	0.00	1.00	1090
Ruggedness	3.06	5.48	0.00	38.25	1090
Plated					
Adoption delay (years)	2520.81	1117.71	150.00	3569.00	193
Distance to coast (000s km)	0.21	0.30	0.00	1.80	193
Distance from pioneer (000s km)	4.21	3.05	0.18	16.31	193
Distance to river (000s km)	0.50	0.49	0.00	2.70	193
Elevation (m)	0.44	0.63	-0.00	4.35	193
Land suitability	0.58	0.31	0.00	1.00	193
Ruggedness	2.92	5.17	0.00	34.62	193
Polished					
Adoption delay (years)	14471.42	1795.83	950.00	16016.00	1450
Distance to coast (000s km)	0.18	0.30	0.00	1.87	1450

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	6.26	5.10	0.14	19.79	1450
Distance to river (000s km)	0.88	1.18	0.00	8.31	1450
Elevation (m)	0.41	0.63	-0.06	4.78	1450
Land suitability	0.55	0.32	0.00	1.00	1450
Ruggedness	2.82	5.00	0.00	40.94	1450
Punched					
Adoption delay (years)	4011.98	1026.97	300.00	5520.00	527
Distance to coast (000s km)	0.18	0.29	0.00	1.55	527
Distance from pioneer (000s km)	5.89	2.25	0.23	16.63	527
Distance to river (000s km)	0.40	0.34	0.00	2.33	527
Elevation (m)	0.30	0.54	-0.00	4.69	527
Land suitability	0.61	0.29	0.00	1.00	527
Ruggedness	2.07	4.44	0.00	36.65	527
Relief					
Adoption delay (years)	7023.45	1189.69	1200.00	8515.00	1011
Distance to coast (000s km)	0.17	0.27	0.00	2.07	1011
Distance from pioneer (000s km)	3.17	3.33	0.00	17.71	1011
Distance to river (000s km)	0.49	0.66	0.00	8.31	1011
Elevation (m)	0.36	0.55	-0.00	4.69	1011
Land suitability	0.61	0.32	0.00	1.00	1011
Ruggedness	3.15	5.26	0.00	38.00	1011
Repoussé					
Adoption delay (years)	3350.44	1110.55	150.00	4754.00	331
Distance to coast (000s km)	0.20	0.29	0.00	1.59	331
Distance from pioneer (000s km)	4.26	2.57	0.00	14.49	331
Distance to river (000s km)	0.49	0.38	0.00	1.97	331
Elevation (m)	0.50	0.73	-0.00	5.58	331
Land suitability	0.61	0.31	0.00	1.00	331

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	3.79	6.41	0.00	41.14	331
Sewn					
Adoption delay (years)	9814.81	405.02	5800.00	10020.00	1416
Distance to coast (000s km)	0.27	0.40	0.00	2.22	1416
Distance from pioneer (000s km)	9.24	4.82	0.00	19.89	1416
Distance to river (000s km)	1.08	1.34	0.00	8.33	1416
Elevation (m)	0.58	0.77	-0.06	5.28	1416
Land suitability	0.46	0.32	0.00	1.00	1416
Ruggedness	3.51	5.81	0.00	41.14	1416
Slipped					
Adoption delay (years)	7104.70	1638.53	500.00	9011.00	839
Distance to coast (000s km)	0.25	0.35	0.00	2.07	839
Distance from pioneer (000s km)	3.78	3.18	0.00	14.18	839
Distance to river (000s km)	0.49	0.39	0.00	2.33	839
Elevation (m)	0.49	0.66	-0.06	4.09	839
Land suitability	0.57	0.35	0.00	1.00	839
Ruggedness	3.56	5.35	0.00	29.87	839
Smoothed					
Adoption delay (years)	14636.10	1719.40	6000.00	16023.00	485
Distance to coast (000s km)	0.17	0.29	0.00	2.07	485
Distance from pioneer (000s km)	7.50	5.60	0.17	19.79	485
Distance to river (000s km)	1.05	1.32	0.00	8.31	485
Elevation (m)	0.39	0.55	0.00	3.49	485
Land suitability	0.50	0.33	0.00	1.00	485
Ruggedness	2.83	4.83	0.00	30.88	485
Soldered					
Adoption delay (years)	4184.20	1112.53	300.00	5315.00	693
Distance to coast (000s km)	0.19	0.30	0.00	2.22	693

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	4.53	3.03	0.04	16.29	693
Distance to river (000s km)	0.52	0.47	0.00	2.72	693
Elevation (m)	0.41	0.65	-0.00	4.78	693
Land suitability	0.58	0.31	0.00	1.00	693
Ruggedness	2.55	4.64	0.00	34.62	693
Stamped					
Adoption delay (years)	7062.39	953.27	1000.00	8019.00	2966
Distance to coast (000s km)	0.15	0.27	0.00	2.19	2966
Distance from pioneer (000s km)	4.32	2.93	0.00	17.93	2966
Distance to river (000s km)	0.42	0.44	0.00	7.42	2966
Elevation (m)	0.30	0.51	-0.02	4.78	2966
Land suitability	0.63	0.28	0.00	1.00	2966
Ruggedness	2.21	4.45	0.00	43.03	2966
Stipple					
Adoption delay (years)	7448.52	808.77	4300.00	7994.00	191
Distance to coast (000s km)	0.14	0.20	0.00	1.21	191
Distance from pioneer (000s km)	3.85	2.00	0.44	13.38	191
Distance to river (000s km)	0.35	0.33	0.00	2.33	191
Elevation (m)	0.21	0.35	-0.00	3.09	191
Land suitability	0.64	0.25	0.00	1.00	191
Ruggedness	1.94	3.98	0.00	31.91	191
Struck					
Adoption delay (years)	800788.01	1670.94	755000.00	802019.00	1727
Distance to coast (000s km)	0.16	0.27	0.00	2.19	1727
Distance from pioneer (000s km)	6.28	2.40	0.24	17.44	1727
Distance to river (000s km)	0.43	0.43	0.00	7.42	1727
Elevation (m)	0.33	0.52	-0.02	4.69	1727
Land suitability	0.64	0.29	0.00	1.00	1727

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	2.57	4.89	0.00	43.03	1727
Tempered					
Adoption delay (years)	13205.39	1701.24	2050.00	15022.00	242
Distance to coast (000s km)	0.20	0.30	0.00	2.07	242
Distance from pioneer (000s km)	5.59	1.63	0.48	9.00	242
Distance to river (000s km)	0.49	0.51	0.00	2.33	242
Elevation (m)	0.34	0.54	0.00	3.90	242
Land suitability	0.58	0.33	0.00	1.00	242
Ruggedness	2.29	4.46	0.00	29.87	242
Terra sigillata					
Adoption delay (years)	663.86	117.92	280.00	1130.00	71
Distance to coast (000s km)	0.15	0.17	0.00	0.92	71
Distance from pioneer (000s km)	2.21	1.49	0.62	9.69	71
Distance to river (000s km)	0.40	0.36	0.00	1.42	71
Elevation (m)	0.30	0.32	0.00	1.30	71
Land suitability	0.72	0.27	0.00	1.00	71
Ruggedness	2.83	3.78	0.00	17.44	71
Textile technique					
Adoption delay (years)	4759.81	524.58	500.00	5017.00	837
Distance to coast (000s km)	0.27	0.40	0.00	2.19	837
Distance from pioneer (000s km)	7.44	4.65	0.00	19.53	837
Distance to river (000s km)	1.02	1.18	0.00	8.33	837
Elevation (m)	0.64	0.82	-0.06	5.80	837
Land suitability	0.48	0.32	0.00	1.00	837
Ruggedness	3.73	5.97	0.00	34.62	837
Tin-glazed					
Adoption delay (years)	1569.84	226.43	849.00	1924.00	113
Distance to coast (000s km)	0.10	0.14	0.00	0.61	113

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Distance from pioneer (000s km)	1.32	2.18	0.00	16.09	113
Distance to river (000s km)	0.49	0.35	0.00	1.41	113
Elevation (m)	0.26	0.26	-0.00	1.16	113
Land suitability	0.75	0.25	0.00	1.00	113
Ruggedness	3.13	4.21	0.00	23.47	113
Twisted					
Adoption delay (years)	3915.25	1136.21	100.00	4817.00	951
Distance to coast (000s km)	0.20	0.34	0.00	2.07	951
Distance from pioneer (000s km)	6.05	4.85	0.04	18.56	951
Distance to river (000s km)	0.94	1.27	0.00	8.31	951
Elevation (m)	0.42	0.62	-0.00	4.69	951
Land suitability	0.53	0.31	0.00	1.00	951
Ruggedness	3.04	5.73	0.00	38.25	951
Underglazed					
Adoption delay (years)	3629.61	310.86	2050.00	4000.00	204
Distance to coast (000s km)	0.21	0.31	0.00	1.79	204
Distance from pioneer (000s km)	7.95	4.04	0.00	16.28	204
Distance to river (000s km)	0.59	0.57	0.00	3.74	204
Elevation (m)	0.36	0.51	-0.00	3.75	204
Land suitability	0.57	0.27	0.00	1.00	204
Ruggedness	3.28	5.08	0.00	30.88	204
Wheel-made					
Adoption delay (years)	7534.33	1465.83	500.00	9023.00	1305
Distance to coast (000s km)	0.19	0.29	0.00	2.07	1305
Distance from pioneer (000s km)	4.39	3.19	0.00	15.65	1305
Distance to river (000s km)	0.51	0.54	0.00	8.31	1305
Elevation (m)	0.37	0.56	-0.06	4.35	1305
Land suitability	0.60	0.32	0.00	1.00	1305

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Table 3.C.7: Descriptive statistics by production technique — All sample (continued).

Variable	Mean	SD	Min	Max	Count
Ruggedness	3.05	5.21	0.00	40.94	1305
Wirework					
Adoption delay (years)	5415.90	1123.93	1900.00	6513.00	434
Distance to coast (000s km)	0.20	0.30	0.00	1.66	434
Distance from pioneer (000s km)	8.30	3.44	0.00	19.05	434
Distance to river (000s km)	0.58	0.48	0.00	2.62	434
Elevation (m)	0.49	0.70	-0.06	4.35	434
Land suitability	0.56	0.31	0.00	0.99	434
Ruggedness	3.02	5.17	0.00	30.88	434
Woven					
Adoption delay (years)	4813.69	405.58	500.00	5022.00	1729
Distance to coast (000s km)	0.23	0.34	0.00	2.22	1729
Distance from pioneer (000s km)	7.84	4.59	0.00	19.63	1729
Distance to river (000s km)	1.09	1.29	0.00	8.31	1729
Elevation (m)	0.59	0.81	-0.00	5.80	1729
Land suitability	0.50	0.31	0.00	1.00	1729
Ruggedness	3.62	5.87	0.00	41.14	1729

Note: The table reports descriptive statistics for the regression sample with no restriction on artefact date. Each observation corresponds to the earliest artefact associated with a given production technique at each site.

Table 3.C.8: Distance from the pioneer of the *applied* technique and delay in the adoption of *applied* technique (OLS)

	Delay in adoption of *applied* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	180.315***	208.481***	136.447***
	(37.327)	(36.739)	(22.077)
Distance to coast (000s km)	109.313	-220.879	196.637
	(264.145)	(273.981)	(174.470)
Distance to river (000s km)	165.308	-173.846**	-59.989
	(206.711)	(88.548)	(58.087)
Elevation (m)	-427.848**	-102.670	65.118
	(207.160)	(176.252)	(89.230)
Land suitability	526.995*	467.888*	163.036
	(273.908)	(262.816)	(265.047)
Ruggedness	-11.234	-12.171	-9.396
	(14.699)	(14.502)	(11.386)
Observations	486	700	1258
Adjusted R-squared	0.212	0.252	0.262

Summary: OLS estimates of the relationship between distance from *applied* technique pioneer and delay in adopting the *applied* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.9: Distance from the pioneer of the *appliqué* technique and delay in the adoption of *appliqué* technique (OLS)

	Delay in adoption of *appliqué* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	71.460***	91.789***	48.316***
	(12.955)	(19.377)	(18.618)
Distance to coast (000s km)	-53.558	-195.702	78.502
	(159.504)	(145.809)	(161.562)
Distance to river (000s km)	-161.692	-48.788	5.137
	(210.233)	(60.077)	(43.147)
Elevation (m)	-50.495	57.913	77.516
	(92.521)	(135.189)	(48.725)
Land suitability	-299.432	-342.832*	-134.187
	(183.300)	(197.521)	(185.105)
Ruggedness	-1.297	-10.312	-7.340
	(16.894)	(19.398)	(10.244)
Observations	77	91	276
Adjusted R-squared	0.119	0.262	0.273

Summary: OLS estimates of the relationship between distance from *appliqué* technique pioneer and delay in adopting the *appliqué* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.10: Distance from the pioneer of the *beadwork* technique and delay in the adoption of *beadwork* technique (OLS)

	Delay in adoption of *beadwork* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	74.228	-2.660	-7.981
	(54.059)	(50.411)	(14.165)
Distance to coast (000s km)	40.650	-469.839*	151.263
	(271.235)	(259.552)	(116.873)
Distance to river (000s km)	390.816	326.800**	168.122**
	(455.500)	(134.142)	(77.380)
Elevation (m)	97.940	411.621**	199.191***
	(190.480)	(168.068)	(69.405)
Land suitability	320.972	12.718	-90.173
	(247.849)	(415.916)	(245.416)
Ruggedness	-40.622***	-57.499***	-6.720
	(14.557)	(19.209)	(9.036)
Observations	152	201	732
Adjusted R-squared	0.037	0.106	0.116

Summary: OLS estimates of the relationship between distance from *beadwork* technique pioneer and delay in adopting the *beadwork* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.11: Distance from the pioneer of the *blown* technique and delay in the adoption of *blown* technique (OLS)

	Delay in adoption of *blown* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	30.033	119.815***	142.215***
	(24.610)	(17.914)	(16.789)
Distance to coast (000s km)	-47.833	-244.450**	-80.410
	(94.275)	(100.174)	(259.945)
Distance to river (000s km)	69.242	-45.032	-76.689
	(115.653)	(94.619)	(110.054)
Elevation (m)	-93.351	-32.324	26.618
	(86.226)	(101.484)	(79.012)
Land suitability	-309.899***	-334.048**	-136.281
	(107.279)	(152.160)	(196.617)
Ruggedness	2.804	8.585	-2.028
	(5.870)	(9.454)	(9.528)
Observations	237	278	345
Adjusted R-squared	0.079	0.200	0.263

Summary: OLS estimates of the relationship between distance from *blown* technique pioneer and delay in adopting the *blown* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.12: Distance from the pioneer of the *braided* technique and delay in the adoption of *braided* technique (OLS)

	Delay in adoption of *braided* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	49.214	127.240***	11.186
	(37.238)	(23.636)	(8.438)
Distance to coast (000s km)	-441.780**	-190.903	14.819
	(174.579)	(147.317)	(106.131)
Distance to river (000s km)	322.520	-132.621***	-1.612
	(356.190)	(48.257)	(10.511)
Elevation (m)	-74.775	-128.790	34.612
	(107.915)	(127.474)	(27.839)
Land suitability	-705.162***	-159.969	21.242
	(272.986)	(339.254)	(106.769)
Ruggedness	36.984*	14.313	4.639
	(21.268)	(8.984)	(3.658)
Observations	37	104	617
Adjusted R-squared	0.112	0.501	0.229

Summary: OLS estimates of the relationship between distance from *braided* technique pioneer and delay in adopting the *braided* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.13: Distance from the pioneer of the *burnished* technique and delay in the adoption of *burnished* technique (OLS)

	Delay in adoption of *burnished* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	123.502*	147.272**	186.936***
	(74.374)	(66.742)	(43.654)
Distance to coast (000s km)	-321.167	-440.252	-343.321
	(420.002)	(405.883)	(407.541)
Distance to river (000s km)	-43.864	58.876	27.393
	(396.187)	(368.605)	(159.149)
Elevation (m)	-536.654*	-491.858	-197.656
	(323.947)	(324.922)	(302.727)
Land suitability	700.962	862.174*	168.439
	(494.284)	(506.569)	(496.899)
Ruggedness	-9.466	-17.662	-16.463
	(26.879)	(26.899)	(25.264)
Observations	278	303	418
Adjusted R-squared	0.135	0.111	0.153

Summary: OLS estimates of the relationship between distance from *burnished* technique pioneer and delay in adopting the *burnished* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.14: Distance from the pioneer of the *carved* technique and delay in the adoption of *carved* technique (OLS)

	Delay in adoption of *carved* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	584.239	503.890	232.078
	(697.604)	(524.689)	(177.786)
Distance to coast (000s km)	-1984.687	-2216.042	-817.672
	(2574.297)	(2364.072)	(1064.396)
Distance to river (000s km)	-5775.928	-1303.661	-367.826
	(5448.335)	(1616.152)	(464.551)
Elevation (m)	124.825	-11.085	116.475
	(565.676)	(500.008)	(205.634)
Land suitability	8.506	-545.524	-427.245
	(1266.176)	(931.671)	(494.167)
Ruggedness	144.039	75.558	20.763
	(141.390)	(82.911)	(30.623)
Observations	1407	1748	3300
Adjusted R-squared	0.079	0.073	0.076

Summary: OLS estimates of the relationship between distance from *carved* technique pioneer and delay in adopting the *carved* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.15: Distance from the pioneer of the *cast* technique and delay in the adoption of *cast* technique (OLS)

	Delay in adoption of *cast* technique		
	(1)	(2)	(3)
	Pre-1500	Pre-1800	All
Distance from pioneer (000s km)	85.575***	160.331***	170.541***
	(20.131)	(29.744)	(22.698)
Distance to coast (000s km)	44.929	-166.626	50.471
	(112.439)	(195.839)	(186.679)
Distance to river (000s km)	-67.519	-293.450	-163.427
	(165.031)	(179.249)	(152.327)
Elevation (m)	-39.643	-36.577	-66.710
	(73.533)	(110.873)	(88.078)
Land suitability	-88.647	-54.642	-216.038
	(160.739)	(194.966)	(196.250)
Ruggedness	-4.185	-16.520**	-14.904**
	(5.311)	(7.870)	(7.125)
Observations	1925	2612	3128
Adjusted R-squared	0.055	0.126	0.166

Summary: OLS estimates of the relationship between distance from *cast* technique pioneer and delay in adopting the *cast* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.16: Distance from the pioneer of the *ceramic technique* technique and delay in the adoption of *ceramic technique* technique (OLS)

	Delay in adoption of *ceramic technique* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	44.963	37.111	51.570**
	(36.420)	(31.256)	(23.329)
Distance to coast (000s km)	462.311*	249.164	-24.398
	(280.741)	(291.992)	(247.270)
Distance to river (000s km)	158.875	276.356	595.747***
	(285.023)	(209.621)	(192.335)
Elevation (m)	-271.636	-261.390	89.504
	(185.788)	(216.369)	(137.524)
Land suitability	804.338***	739.617**	405.684
	(293.410)	(304.818)	(322.309)
Ruggedness	-12.458	-15.745	-28.273***
	(10.415)	(9.972)	(10.466)
Observations	1068	1227	1653
Adjusted R-squared	0.068	0.066	0.086

Summary: OLS estimates of the relationship between distance from *ceramic technique* technique pioneer and delay in adopting the *ceramic technique* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.17: Distance from the pioneer of the *chased* technique and delay in the adoption of *chased* technique (OLS)

	Delay in adoption of *chased* technique		
	(1)	(2)	(3)
	Pre-1500	Pre-1800	All
Distance from pioneer (000s km)	144.750***	208.371***	164.621***
	(45.273)	(52.167)	(43.185)
Distance to coast (000s km)	155.356	161.951	247.431
	(232.200)	(174.837)	(205.719)
Distance to river (000s km)	22.498	-318.307	58.735
	(210.065)	(249.484)	(174.384)
Elevation (m)	99.003	102.611	93.648
	(73.909)	(69.079)	(72.378)
Land suitability	11.088	63.423	-272.199
	(212.187)	(209.229)	(251.667)
Ruggedness	-24.869*	-16.583	-17.154*
	(14.588)	(11.225)	(10.016)
Observations	202	287	381
Adjusted R-squared	0.145	0.183	0.198

Summary: OLS estimates of the relationship between distance from *chased* technique pioneer and delay in adopting the *chased* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.18: Distance from the pioneer of the *combed* technique and delay in the adoption of *combed* technique (OLS)

	Delay in adoption of *combed* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	168.533***	162.939***	154.233***
	(30.017)	(31.822)	(33.942)
Distance to coast (000s km)	-431.748	-445.758	-243.401
	(465.257)	(472.058)	(430.982)
Distance to river (000s km)	-138.809	-90.950	224.280
	(343.972)	(352.144)	(333.001)
Elevation (m)	-526.438**	-489.513*	-385.960
	(247.528)	(252.378)	(271.462)
Land suitability	-462.268	-426.251	-324.837
	(322.952)	(321.010)	(321.083)
Ruggedness	18.207	13.541	1.084
	(20.859)	(21.716)	(22.734)
Observations	132	136	145
Adjusted R-squared	0.134	0.119	0.099

Summary: OLS estimates of the relationship between distance from *combed* technique pioneer and delay in adopting the *combed* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.19: Distance from the pioneer of the *cut* technique and delay in the adoption of *cut* technique (OLS)

	Delay in adoption of *cut* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	-321.903*	-194.568	-62.983
	(166.622)	(154.170)	(90.058)
Distance to coast (000s km)	-10.683	-524.755	53.941
	(786.257)	(739.319)	(482.257)
Distance to river (000s km)	-3254.435	43.972	128.996
	(4325.974)	(627.566)	(208.183)
Elevation (m)	1629.767*	1199.150*	656.392**
	(984.568)	(685.562)	(285.869)
Land suitability	-2603.636	-2819.563*	-1644.278*
	(1616.049)	(1531.689)	(873.053)
Ruggedness	86.989	34.028	6.940
	(110.268)	(60.382)	(24.293)
Observations	544	664	1255
Adjusted R-squared	0.410	0.387	0.391

Summary: OLS estimates of the relationship between distance from *cut* technique pioneer and delay in adopting the *cut* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.20: Distance from the pioneer of the *dyed* technique and delay in the adoption of *dyed* technique (OLS)

	Delay in adoption of *dyed* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	23.906	76.158***	3.422
	(39.827)	(29.240)	(5.982)
Distance to coast (000s km)	-44.678	1.612	-15.906
	(128.440)	(237.209)	(100.704)
Distance to river (000s km)	91.263	6.847	11.809
	(223.734)	(59.053)	(9.317)
Elevation (m)	188.404***	87.217	-2.100
	(72.117)	(58.067)	(16.108)
Land suitability	879.667***	788.997***	180.138*
	(325.443)	(242.225)	(107.197)
Ruggedness	24.252	-3.318	2.337
	(21.397)	(10.955)	(1.446)
Observations	46	90	876
Adjusted R-squared	0.379	0.607	0.361

Summary: OLS estimates of the relationship between distance from *dyed* technique pioneer and delay in adopting the *dyed* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.21: Distance from the pioneer of the *embossed* technique and delay in the adoption of *embossed* technique (OLS)

	Delay in adoption of *embossed* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	42.295*	108.974***	73.898**
	(24.074)	(42.157)	(37.609)
Distance to coast (000s km)	157.898	231.046	368.579
	(302.505)	(373.582)	(320.283)
Distance to river (000s km)	42.543	-184.393	86.075
	(77.650)	(140.070)	(154.717)
Elevation (m)	-239.172	-305.339	-81.436
	(148.019)	(223.391)	(141.004)
Land suitability	211.587	51.505	-245.696
	(347.946)	(312.441)	(272.562)
Ruggedness	-23.744	-27.961	-19.192
	(18.790)	(22.326)	(15.841)
Observations	162	272	391
Adjusted R-squared	0.040	0.120	0.103

Summary: OLS estimates of the relationship between distance from *embossed* technique pioneer and delay in adopting the *embossed* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.22: Distance from the pioneer of the *embroidered* technique and delay in the adoption of *embroidered* technique (OLS)

	Delay in adoption of *embroidered* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	1.464	38.844	3.778
	(27.329)	(59.705)	(4.904)
Distance to coast (000s km)	72.582	-218.449	-71.818
	(112.798)	(200.026)	(65.375)
Distance to river (000s km)	-495.692	1.721	12.278
	(490.836)	(115.355)	(15.451)
Elevation (m)	-18.909	111.385	11.757
	(120.771)	(73.498)	(16.716)
Land suitability	174.572	122.563	66.801
	(295.824)	(350.131)	(56.346)
Ruggedness	-5.355	-22.376	-2.394
	(12.667)	(18.471)	(2.439)
Observations	33	61	659
Adjusted R-squared	-0.099	0.060	0.123

Summary: OLS estimates of the relationship between distance from *embroidered* technique pioneer and delay in adopting the *embroidered* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.23: Distance from the pioneer of the *enamelled* technique and delay in the adoption of *enamelled* technique (OLS)

	Delay in adoption of *enamelled* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	64.113**	109.678***	79.158***
	(32.102)	(21.843)	(15.276)
Distance to coast (000s km)	464.733	677.950*	573.525***
	(291.791)	(386.448)	(180.690)
Distance to river (000s km)	-577.408**	-546.397**	-103.390
	(292.059)	(230.345)	(134.532)
Elevation (m)	180.600	99.616	6.286
	(271.310)	(120.876)	(80.449)
Land suitability	-106.253	-82.417	-182.227
	(93.697)	(130.398)	(145.487)
Ruggedness	3.849	4.547	0.495
	(26.154)	(12.119)	(10.767)
Observations	188	313	474
Adjusted R-squared	0.066	0.160	0.159

Summary: OLS estimates of the relationship between distance from *enamelled* technique pioneer and delay in adopting the *enamelled* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.24: Distance from the pioneer of the *engraved* technique and delay in the adoption of *engraved* technique (OLS)

	Delay in adoption of *engraved* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	-14.410	29.055	55.457***
	(26.422)	(26.587)	(20.207)
Distance to coast (000s km)	-189.048	-407.371	-190.579
	(178.838)	(253.164)	(208.267)
Distance to river (000s km)	152.633	12.587	37.502
	(195.085)	(162.278)	(88.135)
Elevation (m)	-28.683	-80.943	-42.794
	(131.532)	(134.900)	(111.722)
Land suitability	58.017	-5.341	-113.768
	(266.027)	(330.133)	(289.707)
Ruggedness	-14.635	-27.917***	-30.349***
	(9.501)	(10.733)	(9.550)
Observations	1927	3033	4162
Adjusted R-squared	0.050	0.066	0.096

Summary: OLS estimates of the relationship between distance from *engraved* technique pioneer and delay in adopting the *engraved* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.25: Distance from the pioneer of the *etching* technique and delay in the adoption of *etching* technique (OLS)

	Delay in adoption of *etching* technique		
	(1)	(2)	(3)
	Pre-1500	Pre-1800	All
Distance from pioneer (000s km)		80.699	22.872
		(69.065)	(23.346)
Distance to coast (000s km)		218.198	95.423
		(296.418)	(157.368)
Distance to river (000s km)		89.611	144.042
		(159.707)	(96.618)
Elevation (m)		51.258	67.632
		(106.910)	(51.989)
Land suitability		413.381	226.950
		(535.259)	(296.281)
Ruggedness		-0.576	-1.661
		(4.901)	(2.891)
Observations		203	389
Adjusted R-squared		0.193	0.167

Summary: OLS estimates of the relationship between distance from *etching* technique pioneer and delay in adopting the *etching* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.26: Distance from the pioneer of the *filigree* technique and delay in the adoption of *filigree* technique (OLS)

	Delay in adoption of *filigree* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	93.028*	99.045*	77.365
	(50.646)	(56.124)	(48.598)
Distance to coast (000s km)	421.948	458.483	396.302**
	(279.814)	(371.081)	(191.465)
Distance to river (000s km)	-311.383	-48.070	302.929**
	(211.387)	(229.104)	(148.893)
Elevation (m)	-259.304	-25.605	121.086
	(215.112)	(232.792)	(100.465)
Land suitability	-199.543	-143.774	-552.393**
	(257.229)	(255.947)	(237.700)
Ruggedness	-9.605	-21.716	-15.169
	(17.258)	(17.398)	(13.438)
Observations	182	198	271
Adjusted R-squared	0.123	0.101	0.160

Summary: OLS estimates of the relationship between distance from *filigree* technique pioneer and delay in adopting the *filigree* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.27: Distance from the pioneer of the *gilded* technique and delay in the adoption of *gilded* technique (OLS)

	Delay in adoption of *gilded* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	82.203***	119.739***	103.418***
	(27.596)	(30.969)	(22.490)
Distance to coast (000s km)	115.951	184.188	125.354
	(110.002)	(234.835)	(221.243)
Distance to river (000s km)	129.460	-134.286	99.156
	(97.606)	(161.797)	(113.948)
Elevation (m)	96.628*	45.769	32.590
	(49.902)	(56.747)	(44.827)
Land suitability	-21.710	77.825	-202.871
	(137.962)	(251.806)	(196.819)
Ruggedness	-17.014**	-14.537	-14.954
	(7.263)	(11.685)	(9.713)
Observations	493	825	1061
Adjusted R-squared	0.094	0.113	0.128

Summary: OLS estimates of the relationship between distance from *gilded* technique pioneer and delay in adopting the *gilded* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.28: Distance from the pioneer of the *glazed* technique and delay in the adoption of *glazed* technique (OLS)

	Delay in adoption of *glazed* technique		
	(1)	(2)	(3)
	Pre-1500	Pre-1800	All
Distance from pioneer (000s km)	112.366***	103.925***	104.953***
	(40.225)	(39.993)	(28.164)
Distance to coast (000s km)	-152.855	-194.670	-208.303
	(275.875)	(268.939)	(259.752)
Distance to river (000s km)	86.312	-4.813	43.182
	(226.407)	(166.788)	(105.972)
Elevation (m)	-16.675	-24.628	75.408
	(95.850)	(91.072)	(58.393)
Land suitability	359.283	454.107	304.101
	(288.201)	(313.919)	(317.730)
Ruggedness	-19.678	-18.893	-19.519
	(18.713)	(15.693)	(13.055)
Observations	863	1135	1439
Adjusted R-squared	0.135	0.149	0.167

Summary: OLS estimates of the relationship between distance from *glazed* technique pioneer and delay in adopting the *glazed* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.29: Distance from the pioneer of the *hammered* technique and delay in the adoption of *hammered* technique (OLS)

	Delay in adoption of *hammered* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	65.151**	125.765***	167.747***
	(27.140)	(31.317)	(24.795)
Distance to coast (000s km)	-207.260	-383.293*	159.630
	(241.514)	(217.921)	(240.168)
Distance to river (000s km)	-124.905	-19.289	21.968
	(179.707)	(154.809)	(157.752)
Elevation (m)	-115.785	-82.187	72.421
	(143.269)	(116.574)	(95.636)
Land suitability	-159.224	-216.727	-415.906*
	(217.383)	(225.454)	(220.346)
Ruggedness	-7.711	-15.934	-17.609**
	(9.878)	(9.695)	(7.688)
Observations	736	808	1077
Adjusted R-squared	0.024	0.104	0.273

Summary: OLS estimates of the relationship between distance from *hammered* technique pioneer and delay in adopting the *hammered* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.30: Distance from the pioneer of the *hand-coloured* technique and delay in the adoption of *hand-coloured* technique (OLS)

	Delay in adoption of *hand-coloured* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	34.065	68.199	26.035**
	(50.643)	(54.143)	(13.248)
Distance to coast (000s km)	557.936	100.690	5.334
	(348.147)	(266.322)	(67.070)
Distance to river (000s km)	-2023.776***	-472.088*	-66.028
	(539.342)	(271.152)	(46.869)
Elevation (m)	589.781*	82.185	-18.656
	(305.426)	(129.858)	(40.486)
Land suitability	149.434	-56.003	-99.068
	(603.018)	(233.849)	(103.629)
Ruggedness	-22.844	-16.928	-9.853
	(16.958)	(19.198)	(8.933)
Observations	35	167	546
Adjusted R-squared	0.609	0.252	0.257

Summary: OLS estimates of the relationship between distance from *hand-coloured* technique pioneer and delay in adopting the *hand-coloured* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.31: Distance from the pioneer of the *handmade* technique and delay in the adoption of *handmade* technique (OLS)

	Delay in adoption of *handmade* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	102.254***	156.177***	116.411***
	(31.269)	(28.610)	(23.169)
Distance to coast (000s km)	101.560	6.726	243.156
	(242.078)	(258.819)	(228.997)
Distance to river (000s km)	-220.719	62.463	105.938
	(276.901)	(76.219)	(79.780)
Elevation (m)	-202.911	-249.906	71.513
	(165.998)	(179.795)	(99.394)
Land suitability	370.014	81.481	-189.156
	(264.317)	(290.401)	(263.746)
Ruggedness	2.620	-2.260	-15.094
	(13.096)	(12.559)	(11.443)
Observations	1566	1929	3590
Adjusted R-squared	0.029	0.065	0.101

Summary: OLS estimates of the relationship between distance from *handmade* technique pioneer and delay in adopting the *handmade* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.32: Distance from the pioneer of the *impressed* technique and delay in the adoption of *impressed* technique (OLS)

	Delay in adoption of *impressed* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	123.803***	119.486***	145.307***
	(34.368)	(34.025)	(38.508)
Distance to coast (000s km)	-19.967	-262.139	-297.108
	(314.320)	(342.252)	(341.984)
Distance to river (000s km)	418.730	157.871	119.135
	(344.879)	(139.473)	(116.422)
Elevation (m)	-323.252	-61.493	34.806
	(206.860)	(237.238)	(181.126)
Land suitability	33.235	204.065	96.602
	(411.801)	(366.213)	(320.848)
Ruggedness	19.430	6.993	-4.842
	(16.076)	(16.072)	(15.855)
Observations	382	422	527
Adjusted R-squared	0.059	0.062	0.110

Summary: OLS estimates of the relationship between distance from *impressed* technique pioneer and delay in adopting the *impressed* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.33: Distance from the pioneer of the *incised* technique and delay in the adoption of *incised* technique (OLS)

	Delay in adoption of *incised* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	62.972*	24.663	-6.511
	(35.916)	(30.796)	(27.716)
Distance to coast (000s km)	203.622	-66.996	-87.018
	(230.794)	(225.751)	(220.759)
Distance to river (000s km)	386.212	489.170***	479.406***
	(285.059)	(146.494)	(146.793)
Elevation (m)	-171.662	-97.051	172.693
	(134.297)	(151.323)	(148.876)
Land suitability	624.994***	591.727**	252.685
	(239.061)	(281.271)	(345.887)
Ruggedness	-12.194	-18.308*	-24.452***
	(10.793)	(10.790)	(9.092)
Observations	1586	1753	2398
Adjusted R-squared	0.063	0.064	0.097

Summary: OLS estimates of the relationship between distance from *incised* technique pioneer and delay in adopting the *incised* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.34: Distance from the pioneer of the *inlaid* technique and delay in the adoption of *inlaid* technique (OLS)

	Delay in adoption of *inlaid* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	103.755***	146.543***	138.234***
	(37.872)	(29.931)	(19.750)
Distance to coast (000s km)	14.565	260.818	545.313***
	(308.243)	(250.673)	(207.693)
Distance to river (000s km)	140.919	57.437	17.406
	(190.808)	(104.709)	(66.882)
Elevation (m)	39.393	-0.149	17.202
	(115.992)	(107.472)	(86.361)
Land suitability	492.496	305.584	53.793
	(300.302)	(331.494)	(305.291)
Ruggedness	-5.749	7.244	3.542
	(9.960)	(9.674)	(7.065)
Observations	482	575	858
Adjusted R-squared	0.125	0.211	0.294

Summary: OLS estimates of the relationship between distance from *inlaid* technique pioneer and delay in adopting the *inlaid* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.35: Distance from the pioneer of the *intaglio* technique and delay in the adoption of *intaglio* technique (OLS)

	Delay in adoption of *intaglio* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	106.348	195.813***	118.793***
	(67.003)	(64.671)	(26.946)
Distance to coast (000s km)	188.468	-162.008	-416.860
	(328.306)	(404.103)	(305.800)
Distance to river (000s km)	149.420	-200.159	-21.614
	(253.579)	(377.245)	(170.133)
Elevation (m)	-67.574	-63.031	83.020
	(230.120)	(279.876)	(216.066)
Land suitability	634.114***	513.167	249.091
	(231.708)	(365.239)	(353.483)
Ruggedness	-25.979*	-21.932	-47.174**
	(14.076)	(20.959)	(21.477)
Observations	115	219	398
Adjusted R-squared	0.191	0.296	0.320

Summary: OLS estimates of the relationship between distance from *intaglio* technique pioneer and delay in adopting the *intaglio* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.36: Distance from the pioneer of the *interlaced* technique and delay in the adoption of *interlaced* technique (OLS)

	Delay in adoption of *interlaced* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	77.913	49.569	-9.994
	(49.822)	(55.186)	(32.907)
Distance to coast (000s km)	-379.386*	-452.236*	-36.779
	(224.829)	(233.537)	(520.996)
Distance to river (000s km)	-214.812	-551.873	265.884
	(353.455)	(424.052)	(164.355)
Elevation (m)	-485.793	-1.260	228.073**
	(357.147)	(520.831)	(103.461)
Land suitability	-396.424	-37.032	93.104
	(268.122)	(412.136)	(331.630)
Ruggedness	9.971	-13.268	11.590
	(19.950)	(19.918)	(16.516)
Observations	46	56	97
Adjusted R-squared	0.295	0.089	0.133

Summary: OLS estimates of the relationship between distance from *interlaced* technique pioneer and delay in adopting the *interlaced* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.37: Distance from the pioneer of the *keyed* technique and delay in the adoption of *keyed* technique (OLS)

	Delay in adoption of *keyed* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	67.564**	68.504**	63.957*
	(32.371)	(30.249)	(37.553)
Distance to coast (000s km)	-1263.982	-1600.974**	-797.060
	(966.138)	(768.031)	(891.871)
Distance to river (000s km)	295.611	176.673	485.214
	(200.078)	(280.446)	(337.759)
Elevation (m)	779.247	1068.936	809.606
	(1006.280)	(839.706)	(558.768)
Land suitability	272.315	235.824	312.479
	(184.353)	(222.369)	(254.090)
Ruggedness	-8.188	-12.190	-8.264
	(23.679)	(23.249)	(20.588)
Observations	93	99	103
Adjusted R-squared	0.357	0.376	0.364

Summary: OLS estimates of the relationship between distance from *keyed* technique pioneer and delay in adopting the *keyed* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.38: Distance from the pioneer of the *lacquered* technique and delay in the adoption of *lacquered* technique (OLS)

	Delay in adoption of *lacquered* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	20.666	45.717**	26.341**
	(47.947)	(18.328)	(11.738)
Distance to coast (000s km)	-767.241**	-836.088***	-711.720***
	(337.729)	(125.134)	(223.176)
Distance to river (000s km)	54.476	57.604	-21.504
	(187.646)	(107.225)	(65.832)
Elevation (m)	174.744	69.668*	72.602***
	(253.646)	(38.847)	(27.220)
Land suitability	-731.063	-330.194	-194.499
	(459.012)	(226.296)	(143.544)
Ruggedness	5.502	-3.956	1.968
	(8.082)	(5.425)	(4.560)
Observations	25	79	175
Adjusted R-squared	0.241	0.455	0.427

Summary: OLS estimates of the relationship between distance from *lacquered* technique pioneer and delay in adopting the *lacquered* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.39: Distance from the pioneer of the *lead-glazed* technique and delay in the adoption of *lead-glazed* technique (OLS)

	Delay in adoption of *lead-glazed* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	39.775**	53.530***	36.679***
	(17.884)	(14.068)	(14.178)
Distance to coast (000s km)	-452.263*	-140.584	-102.565
	(262.911)	(308.457)	(343.078)
Distance to river (000s km)	-501.887	-249.013	136.478
	(320.163)	(221.783)	(162.197)
Elevation (m)	74.596	46.437	31.250
	(241.605)	(217.245)	(198.522)
Land suitability	-165.878*	-163.095*	-189.761
	(86.308)	(92.873)	(128.714)
Ruggedness	-13.065	-11.509	-7.571
	(8.544)	(9.555)	(9.540)
Observations	258	322	351
Adjusted R-squared	0.297	0.183	0.137

Summary: OLS estimates of the relationship between distance from *lead-glazed* technique pioneer and delay in adopting the *lead-glazed* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.40: Distance from the pioneer of the *lost-wax cast* technique and delay in the adoption of *lost-wax cast* technique (OLS)

	Delay in adoption of *lost-wax cast* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	111.887***	110.656**	131.096**
	(39.615)	(50.378)	(51.003)
Distance to coast (000s km)	227.498	495.665	580.985
	(302.823)	(479.291)	(467.154)
Distance to river (000s km)	194.735	202.509	279.167
	(174.581)	(262.301)	(258.940)
Elevation (m)	-239.182	-150.908	-175.658
	(151.364)	(192.229)	(172.737)
Land suitability	-152.555	-55.376	-254.210
	(298.001)	(342.506)	(355.237)
Ruggedness	2.428	1.513	-1.886
	(13.036)	(14.730)	(13.550)
Observations	202	227	249
Adjusted R-squared	0.117	0.094	0.159

Summary: OLS estimates of the relationship between distance from *lost-wax cast* technique pioneer and delay in adopting the *lost-wax cast* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.41: Distance from the pioneer of the *lustred* technique and delay in the adoption of *lustred* technique (OLS)

	Delay in adoption of *lustred* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	68.594	100.379***	95.961***
	(56.391)	(34.988)	(25.542)
Distance to coast (000s km)	49.057	19.733	-19.270
	(191.215)	(169.168)	(194.056)
Distance to river (000s km)	333.442	-132.192	-133.378**
	(212.934)	(81.539)	(59.337)
Elevation (m)	91.673	131.666	32.861
	(150.670)	(90.875)	(111.967)
Land suitability	-270.150	35.365	203.354
	(392.198)	(221.752)	(184.480)
Ruggedness	-19.134	-13.606	-15.049
	(19.108)	(13.789)	(11.791)
Observations	42	57	82
Adjusted R-squared	0.170	0.285	0.405

Summary: OLS estimates of the relationship between distance from *lustred* technique pioneer and delay in adopting the *lustred* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.42: Distance from the pioneer of the *metal technique* technique and delay in the adoption of *metal technique* technique (OLS)

	Delay in adoption of *metal technique* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	31.645*	96.927***	96.738***
	(18.000)	(21.360)	(17.189)
Distance to coast (000s km)	-89.237	-270.066	120.943
	(161.326)	(212.051)	(172.755)
Distance to river (000s km)	122.467	-19.149	25.570
	(180.411)	(128.621)	(83.469)
Elevation (m)	-77.403	-147.009	3.952
	(107.855)	(127.334)	(86.642)
Land suitability	-118.706	-32.478	-231.439
	(216.475)	(277.044)	(205.871)
Ruggedness	-6.387	-16.519*	-11.829*
	(7.654)	(8.823)	(6.454)
Observations	980	1360	2003
Adjusted R-squared	0.037	0.112	0.182

Summary: OLS estimates of the relationship between distance from *metal technique* technique pioneer and delay in adopting the *metal technique* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.43: Distance from the pioneer of the *mould-made* technique and delay in the adoption of *mould-made* technique (OLS)

	Delay in adoption of *mould-made* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	-28.565	-67.354*	-44.883
	(30.271)	(34.792)	(30.361)
Distance to coast (000s km)	140.420	65.797	-122.161
	(117.315)	(171.326)	(196.537)
Distance to river (000s km)	155.594	81.230	268.147*
	(99.973)	(148.003)	(145.409)
Elevation (m)	16.716	41.119	250.670***
	(94.908)	(108.048)	(78.833)
Land suitability	18.118	61.347	-103.751
	(198.955)	(246.158)	(311.753)
Ruggedness	-3.366	-16.819*	-31.594***
	(9.121)	(10.052)	(11.018)
Observations	765	932	1141
Adjusted R-squared	0.034	0.055	0.071

Summary: OLS estimates of the relationship between distance from *mould-made* technique pioneer and delay in adopting the *mould-made* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.44: Distance from the pioneer of the *moulded* technique and delay in the adoption of *moulded* technique (OLS)

	Delay in adoption of *moulded* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	145.827***	151.394***	148.077***
	(25.163)	(32.302)	(29.610)
Distance to coast (000s km)	-87.303	-364.227*	-326.624
	(176.383)	(187.458)	(210.460)
Distance to river (000s km)	137.473	-276.810	-101.029
	(202.246)	(258.510)	(120.527)
Elevation (m)	-210.565*	22.522	98.730
	(113.035)	(121.721)	(115.375)
Land suitability	167.527	281.608	58.026
	(169.841)	(245.460)	(251.205)
Ruggedness	-4.937	-17.250*	-18.998**
	(9.090)	(10.456)	(8.896)
Observations	386	519	632
Adjusted R-squared	0.160	0.155	0.168

Summary: OLS estimates of the relationship between distance from *moulded* technique pioneer and delay in adopting the *moulded* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.45: Distance from the pioneer of the *painted* technique and delay in the adoption of *painted* technique (OLS)

	Delay in adoption of *painted* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	163.139***	196.745***	171.755***
	(25.782)	(35.682)	(30.071)
Distance to coast (000s km)	171.927	151.013	117.905
	(241.528)	(283.197)	(266.565)
Distance to river (000s km)	568.576**	-36.415	-35.109
	(265.859)	(84.554)	(68.880)
Elevation (m)	-443.260***	-363.101	-149.096
	(159.716)	(222.437)	(123.999)
Land suitability	606.525*	969.013***	589.323*
	(333.578)	(349.760)	(324.895)
Ruggedness	-6.063	-21.667	-18.857
	(17.873)	(17.007)	(13.992)
Observations	806	1205	2209
Adjusted R-squared	0.168	0.216	0.250

Summary: OLS estimates of the relationship between distance from *painted* technique pioneer and delay in adopting the *painted* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.46: Distance from the pioneer of the *perforated* technique and delay in the adoption of *perforated* technique (OLS)

	Delay in adoption of *perforated* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	-38.348	79.961*	176.058***
	(66.269)	(44.368)	(23.487)
Distance to coast (000s km)	737.807*	231.339	-263.553
	(416.320)	(382.988)	(345.801)
Distance to river (000s km)	330.149	339.583**	89.130
	(492.114)	(146.649)	(86.631)
Elevation (m)	-512.662*	-446.951*	35.840
	(268.369)	(261.142)	(174.524)
Land suitability	1031.939***	1083.946**	593.405
	(398.947)	(437.018)	(446.481)
Ruggedness	-13.507	-22.092	-22.364
	(18.829)	(21.158)	(15.067)
Observations	446	483	712
Adjusted R-squared	0.053	0.065	0.221

Summary: OLS estimates of the relationship between distance from *perforated* technique pioneer and delay in adopting the *perforated* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.47: Distance from the pioneer of the *pierced* technique and delay in the adoption of *pierced* technique (OLS)

	Delay in adoption of *pierced* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	-88.508*	-38.203	79.265***
	(49.533)	(42.384)	(23.127)
Distance to coast (000s km)	-6.695	-232.917	-468.592*
	(302.139)	(299.851)	(250.151)
Distance to river (000s km)	717.424**	383.004***	128.594
	(352.071)	(131.257)	(95.139)
Elevation (m)	56.796	17.559	79.710
	(185.956)	(212.807)	(162.645)
Land suitability	422.106	382.403	250.211
	(283.115)	(370.273)	(371.838)
Ruggedness	-28.589*	-37.200**	-39.286***
	(15.438)	(15.676)	(14.699)
Observations	776	977	1338
Adjusted R-squared	0.068	0.067	0.125

Summary: OLS estimates of the relationship between distance from *pierced* technique pioneer and delay in adopting the *pierced* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.48: Distance from the pioneer of the *pigmented* technique and delay in the adoption of *pigmented* technique (OLS)

	Delay in adoption of *pigmented* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	45.909	125.296***	108.905***
	(43.381)	(37.202)	(20.860)
Distance to coast (000s km)	232.563	164.998	144.572
	(203.609)	(414.808)	(313.774)
Distance to river (000s km)	-155.362	101.428	31.692
	(330.311)	(107.098)	(58.068)
Elevation (m)	87.539	154.285	127.613*
	(198.794)	(97.287)	(74.072)
Land suitability	89.327	168.677	-33.074
	(247.324)	(365.448)	(319.092)
Ruggedness	-13.095	-17.259	-18.662*
	(12.838)	(11.933)	(10.273)
Observations	184	252	621
Adjusted R-squared	0.018	0.148	0.259

Summary: OLS estimates of the relationship between distance from *pigmented* technique pioneer and delay in adopting the *pigmented* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.49: Distance from the pioneer of the *plain weave* technique and delay in the adoption of *plain weave* technique (OLS)

	Delay in adoption of *plain weave* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	13.333	18.584	-1.933
	(48.333)	(66.132)	(18.797)
Distance to coast (000s km)	-120.492	-133.291	-57.688
	(93.874)	(172.105)	(243.976)
Distance to river (000s km)	417.983*	538.987*	76.451
	(237.116)	(310.624)	(55.093)
Elevation (m)	118.667	52.825	72.929
	(161.136)	(208.764)	(67.241)
Land suitability	505.013	634.099	421.753
	(455.230)	(554.236)	(312.372)
Ruggedness	9.452	-2.543	-11.364
	(10.654)	(8.961)	(8.121)
Observations	39	46	355
Adjusted R-squared	-0.082	0.018	0.124

Summary: OLS estimates of the relationship between distance from *plain weave* technique pioneer and delay in adopting the *plain weave* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.50: Distance from the pioneer of the *plaited* technique and delay in the adoption of *plaited* technique (OLS)

	Delay in adoption of *plaited* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	65.606	121.688***	24.205***
	(49.786)	(29.421)	(9.206)
Distance to coast (000s km)	60.792	-87.020	30.971
	(276.255)	(235.684)	(133.229)
Distance to river (000s km)	44.976	-62.122	-1.598
	(185.025)	(63.337)	(14.006)
Elevation (m)	-216.064	-97.768	58.448***
	(303.196)	(156.558)	(21.839)
Land suitability	-357.735	-187.866	-91.931
	(335.403)	(326.028)	(116.436)
Ruggedness	-27.751*	3.240	-0.426
	(16.045)	(14.687)	(4.069)
Observations	90	200	1090
Adjusted R-squared	0.112	0.328	0.134

Summary: OLS estimates of the relationship between distance from *plaited* technique pioneer and delay in adopting the *plaited* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.51: Distance from the pioneer of the *plated* technique and delay in the adoption of *plated* technique (OLS)

	Delay in adoption of *plated* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	38.746	73.500	79.901***
	(25.775)	(50.033)	(26.356)
Distance to coast (000s km)	311.130	724.275	704.349***
	(354.759)	(621.052)	(265.812)
Distance to river (000s km)	-333.075**	-89.208	-72.473
	(155.666)	(462.150)	(167.117)
Elevation (m)	-83.607	-185.358	-18.758
	(143.209)	(197.865)	(127.231)
Land suitability	190.466	221.875	-537.832**
	(184.449)	(221.086)	(256.291)
Ruggedness	6.531	-6.600	-1.229
	(9.150)	(17.711)	(15.228)
Observations	83	98	193
Adjusted R-squared	-0.016	0.030	0.211

Summary: OLS estimates of the relationship between distance from *plated* technique pioneer and delay in adopting the *plated* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.52: Distance from the pioneer of the *polished* technique and delay in the adoption of *polished* technique (OLS)

	Delay in adoption of *polished* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	-38.849	74.635*	133.922***
	(43.068)	(41.325)	(27.801)
Distance to coast (000s km)	-88.598	-766.029*	-292.927
	(341.012)	(393.704)	(477.897)
Distance to river (000s km)	275.218	280.147***	69.351
	(214.152)	(104.691)	(68.774)
Elevation (m)	-70.782	-61.831	123.667
	(202.157)	(208.421)	(126.786)
Land suitability	554.857*	337.720	36.755
	(287.244)	(287.429)	(325.782)
Ruggedness	4.307	-13.451	-21.976*
	(15.028)	(16.406)	(12.856)
Observations	727	895	1450
Adjusted R-squared	0.037	0.095	0.197

Summary: OLS estimates of the relationship between distance from *polished* technique pioneer and delay in adopting the *polished* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.53: Distance from the pioneer of the *punched* technique and delay in the adoption of *punched* technique (OLS)

	Delay in adoption of *punched* technique		
	(1)	(2)	(3)
	Pre-1500	Pre-1800	All
Distance from pioneer (000s km)	64.775**	87.003**	54.018
	(31.457)	(35.824)	(41.590)
Distance to coast (000s km)	424.389**	435.044**	747.708***
	(214.174)	(194.813)	(159.034)
Distance to river (000s km)	419.911**	430.886**	479.652***
	(191.050)	(205.636)	(172.019)
Elevation (m)	-431.129**	-152.096	64.616
	(168.768)	(169.370)	(124.733)
Land suitability	-232.921	-229.917	-330.025
	(161.009)	(188.034)	(221.975)
Ruggedness	13.399	-4.312	-7.774
	(11.241)	(11.832)	(12.137)
Observations	393	441	527
Adjusted R-squared	0.067	0.059	0.114

Summary: OLS estimates of the relationship between distance from *punched* technique pioneer and delay in adopting the *punched* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.54: Distance from the pioneer of the *relief* technique and delay in the adoption of *relief* technique (OLS)

	Delay in adoption of *relief* technique		
	(1)	(2)	(3)
	Pre-1500	Pre-1800	All
Distance from pioneer (000s km)	82.755***	106.309***	130.490***
	(25.768)	(27.093)	(25.555)
Distance to coast (000s km)	-22.625	-220.268	-129.904
	(254.233)	(297.395)	(296.789)
Distance to river (000s km)	113.790	-43.753	-59.801
	(194.458)	(134.009)	(87.459)
Elevation (m)	-217.754**	-139.681	-46.262
	(109.998)	(143.172)	(141.549)
Land suitability	600.657***	589.874*	468.957
	(228.080)	(329.397)	(343.120)
Ruggedness	0.991	-10.803	-17.595*
	(9.947)	(10.393)	(10.504)
Observations	686	848	1011
Adjusted R-squared	0.094	0.105	0.150

Summary: OLS estimates of the relationship between distance from *relief* technique pioneer and delay in adopting the *relief* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.55: Distance from the pioneer of the *repoussé* technique and delay in the adoption of *repoussé* technique (OLS)

	Delay in adoption of *repoussé* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	121.402***	139.728***	116.008***
	(32.573)	(41.230)	(35.749)
Distance to coast (000s km)	575.330**	586.891*	493.565*
	(236.673)	(327.872)	(299.057)
Distance to river (000s km)	-91.461	71.678	416.030*
	(235.653)	(323.201)	(212.622)
Elevation (m)	-64.204	144.167	136.123
	(134.293)	(118.167)	(94.393)
Land suitability	238.057	78.340	-295.794
	(210.133)	(254.343)	(253.508)
Ruggedness	0.385	0.146	-2.067
	(15.657)	(15.383)	(12.899)
Observations	211	251	331
Adjusted R-squared	0.118	0.132	0.186

Summary: OLS estimates of the relationship between distance from *repoussé* technique pioneer and delay in adopting the *repoussé* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.56: Distance from the pioneer of the *sewn* technique and delay in the adoption of *sewn* technique (OLS)

	Delay in adoption of *sewn* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	69.840*	-35.603***	-0.148
	(35.854)	(12.868)	(2.082)
Distance to coast (000s km)	196.446	-498.289***	-37.617
	(237.524)	(147.042)	(66.085)
Distance to river (000s km)	123.646	113.144**	19.375
	(228.221)	(55.687)	(14.579)
Elevation (m)	151.178	180.958**	47.093**
	(102.493)	(85.239)	(19.985)
Land suitability	171.500	290.534	155.649*
	(364.633)	(435.164)	(85.244)
Ruggedness	-9.551	-8.884	-2.171
	(21.967)	(14.411)	(2.688)
Observations	76	192	1416
Adjusted R-squared	0.013	0.217	0.116

Summary: OLS estimates of the relationship between distance from *sewn* technique pioneer and delay in adopting the *sewn* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.57: Distance from the pioneer of the *slipped* technique and delay in the adoption of *slipped* technique (OLS)

	Delay in adoption of *slipped* technique		
	(1)	(2)	(3)
	Pre-1500	Pre-1800	All
Distance from pioneer (000s km)	176.533***	187.801***	198.377***
	(32.418)	(36.347)	(31.544)
Distance to coast (000s km)	289.890	157.253	-106.598
	(255.973)	(288.942)	(249.382)
Distance to river (000s km)	68.595	-20.243	469.795*
	(222.075)	(224.641)	(277.452)
Elevation (m)	-732.244***	-760.774***	-373.930
	(244.004)	(247.006)	(263.859)
Land suitability	631.221**	666.162**	338.726
	(312.701)	(302.945)	(343.015)
Ruggedness	23.139	21.410	2.418
	(20.772)	(21.566)	(19.089)
Observations	641	708	839
Adjusted R-squared	0.197	0.209	0.205

Summary: OLS estimates of the relationship between distance from *slipped* technique pioneer and delay in adopting the *slipped* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.58: Distance from the pioneer of the *smoothed* technique and delay in the adoption of *smoothed* technique (OLS)

	Delay in adoption of *smoothed* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	-35.311	113.132**	167.501***
	(87.864)	(43.967)	(18.509)
Distance to coast (000s km)	97.670	-202.670	137.573
	(563.045)	(385.938)	(310.198)
Distance to river (000s km)	-272.221	121.567	5.547
	(645.053)	(189.824)	(70.371)
Elevation (m)	73.179	-30.731	165.108
	(246.928)	(217.388)	(158.043)
Land suitability	-191.819	-28.663	-16.588
	(339.825)	(371.153)	(311.353)
Ruggedness	1.971	-10.594	-18.353
	(18.948)	(19.267)	(12.132)
Observations	226	249	485
Adjusted R-squared	-0.002	0.059	0.329

Summary: OLS estimates of the relationship between distance from *smoothed* technique pioneer and delay in adopting the *smoothed* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.59: Distance from the pioneer of the *soldered* technique and delay in the adoption of *soldered* technique (OLS)

	Delay in adoption of *soldered* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	67.579**	125.047***	112.488***
	(31.480)	(39.007)	(23.914)
Distance to coast (000s km)	191.263	269.773	567.833***
	(228.085)	(296.470)	(178.920)
Distance to river (000s km)	-4.123	-27.597	293.439**
	(185.533)	(200.282)	(120.286)
Elevation (m)	-1.886	83.228	59.115
	(156.020)	(152.213)	(66.121)
Land suitability	159.615	158.247	-372.580*
	(211.870)	(233.149)	(212.778)
Ruggedness	-18.823*	-33.539***	-15.385
	(10.986)	(11.416)	(10.284)
Observations	352	443	693
Adjusted R-squared	0.039	0.105	0.234

Summary: OLS estimates of the relationship between distance from *soldered* technique pioneer and delay in adopting the *soldered* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.60: Distance from the pioneer of the *stamped* technique and delay in the adoption of *stamped* technique (OLS)

	Delay in adoption of *stamped* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	100.337***	150.080***	131.147***
	(27.892)	(41.241)	(24.059)
Distance to coast (000s km)	-137.503	-375.649*	-152.176
	(142.317)	(222.096)	(174.702)
Distance to river (000s km)	-113.450	-376.385**	-164.830
	(147.006)	(157.212)	(107.203)
Elevation (m)	-102.297	-97.797	-97.282
	(118.663)	(106.834)	(85.018)
Land suitability	-120.806	-168.717	-240.781
	(195.882)	(224.476)	(189.173)
Ruggedness	3.289	-10.938	-17.378**
	(7.936)	(9.435)	(8.123)
Observations	1308	2243	2966
Adjusted R-squared	0.091	0.173	0.197

Summary: OLS estimates of the relationship between distance from *stamped* technique pioneer and delay in adopting the *stamped* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.61: Distance from the pioneer of the *stipple* technique and delay in the adoption of *stipple* technique (OLS)

	Delay in adoption of *stipple* technique		
	(1)	(2)	(3)
	Pre-1500	Pre-1800	All
Distance from pioneer (000s km)	132.206***	150.543**	100.593*
	(19.369)	(59.481)	(52.729)
Distance to coast (000s km)	-250.716	167.558	478.086
	(432.882)	(551.431)	(448.591)
Distance to river (000s km)	-949.210	-1900.033***	-274.180
	(607.671)	(565.761)	(201.283)
Elevation (m)	-9.458	14.107	-137.992
	(292.179)	(389.207)	(221.904)
Land suitability	-333.275	-365.293	-392.903
	(359.054)	(442.458)	(258.555)
Ruggedness	-18.839	-19.071	-30.053
	(25.704)	(41.630)	(31.623)
Observations	35	111	191
Adjusted R-squared	0.296	0.472	0.377

Summary: OLS estimates of the relationship between distance from *stipple* technique pioneer and delay in adopting the *stipple* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.62: Distance from the pioneer of the *struck* technique and delay in the adoption of *struck* technique (OLS)

	Delay in adoption of *struck* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	43.061	120.969***	116.258***
	(44.665)	(45.757)	(31.426)
Distance to coast (000s km)	-32.866	-76.218	98.718
	(182.998)	(188.307)	(151.375)
Distance to river (000s km)	-632.139	-604.745*	-274.255
	(543.608)	(334.156)	(226.812)
Elevation (m)	25.416	19.099	-1.026
	(80.892)	(65.939)	(59.863)
Land suitability	-599.741**	-644.625***	-712.512***
	(251.686)	(229.074)	(203.192)
Ruggedness	7.308	-2.252	-9.453
	(10.321)	(9.414)	(9.020)
Observations	1023	1478	1727
Adjusted R-squared	0.016	0.044	0.049

Summary: OLS estimates of the relationship between distance from *struck* technique pioneer and delay in adopting the *struck* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.63: Distance from the pioneer of the *tempered* technique and delay in the adoption of *tempered* technique (OLS)

	Delay in adoption of *tempered* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	360.629***	230.581**	344.621***
	(113.929)	(103.054)	(97.838)
Distance to coast (000s km)	356.139	228.290	578.841
	(552.900)	(583.948)	(494.580)
Distance to river (000s km)	-729.015	-172.983	77.297
	(597.425)	(566.394)	(382.724)
Elevation (m)	-316.886	-577.038*	300.572
	(287.772)	(304.956)	(359.817)
Land suitability	-252.489	-263.510	-226.644
	(386.838)	(405.982)	(356.187)
Ruggedness	23.907	16.670	-1.507
	(33.647)	(31.343)	(33.214)
Observations	177	207	242
Adjusted R-squared	0.110	0.034	0.082

Summary: OLS estimates of the relationship between distance from *tempered* technique pioneer and delay in adopting the *tempered* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.64: Distance from the pioneer of the *terra sigillata* technique and delay in the adoption of *terra sigillata* technique (OLS)

	Delay in adoption of *terra sigillata* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	8.448	8.448	8.448
	(12.973)	(12.973)	(12.973)
Distance to coast (000s km)	83.972	83.972	83.972
	(90.523)	(90.523)	(90.523)
Distance to river (000s km)	-18.677	-18.677	-18.677
	(46.643)	(46.643)	(46.643)
Elevation (m)	-37.080	-37.080	-37.080
	(52.894)	(52.894)	(52.894)
Land suitability	-51.760	-51.760	-51.760
	(56.674)	(56.674)	(56.674)
Ruggedness	-2.059	-2.059	-2.059
	(2.977)	(2.977)	(2.977)
Observations	71	71	71
Adjusted R-squared	0.078	0.078	0.078

Summary: OLS estimates of the relationship between distance from *terra sigillata* technique pioneer and delay in adopting the *terra sigillata* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.65: Distance from the pioneer of the *textile technique* technique and delay in the adoption of *textile technique* technique (OLS)

	Delay in adoption of *textile technique* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	26.856	88.938**	12.520
	(26.650)	(35.676)	(7.871)
Distance to coast (000s km)	-146.554**	-169.391	-30.948
	(68.432)	(186.356)	(114.279)
Distance to river (000s km)	389.289**	-17.488	12.704
	(198.308)	(76.579)	(19.811)
Elevation (m)	218.863***	114.634**	35.121*
	(59.797)	(55.955)	(20.607)
Land suitability	177.280	252.800	83.725
	(198.645)	(322.582)	(121.085)
Ruggedness	-7.809	-6.282	-0.937
	(9.722)	(12.418)	(4.046)
Observations	76	134	837
Adjusted R-squared	0.217	0.276	0.243

Summary: OLS estimates of the relationship between distance from *textile technique* technique pioneer and delay in adopting the *textile technique* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.66: Distance from the pioneer of the *tin-glazed* technique and delay in the adoption of *tin-glazed* technique (OLS)

	Delay in adoption of *tin-glazed* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	-118.477**	10.162	10.040
	(48.788)	(7.558)	(6.880)
Distance to coast (000s km)	-505.189**	-337.342	-356.777
	(220.709)	(277.022)	(318.614)
Distance to river (000s km)	168.384	-53.033	-117.762**
	(105.116)	(53.759)	(53.121)
Elevation (m)	11.033	20.687	44.671
	(70.066)	(140.693)	(140.942)
Land suitability	-99.159	157.732	100.055
	(154.481)	(177.096)	(172.494)
Ruggedness	-9.365**	-7.486	-7.536
	(4.437)	(5.496)	(5.751)
Observations	38	102	113
Adjusted R-squared	0.648	0.313	0.308

Summary: OLS estimates of the relationship between distance from *tin-glazed* technique pioneer and delay in adopting the *tin-glazed* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.67: Distance from the pioneer of the *twisted* technique and delay in the adoption of *twisted* technique (OLS)

	Delay in adoption of *twisted* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	119.076***	168.751***	125.953***
	(31.785)	(22.978)	(17.821)
Distance to coast (000s km)	393.627**	55.856	413.817*
	(178.814)	(153.650)	(220.404)
Distance to river (000s km)	106.345	-71.809	-48.970
	(288.238)	(74.532)	(61.028)
Elevation (m)	-330.827**	-161.916	67.403
	(149.201)	(157.329)	(75.417)
Land suitability	177.299	13.944	-301.668
	(200.022)	(232.549)	(239.361)
Ruggedness	-2.677	-1.157	1.816
	(6.427)	(8.647)	(8.914)
Observations	358	424	951
Adjusted R-squared	0.061	0.183	0.309

Summary: OLS estimates of the relationship between distance from *twisted* technique pioneer and delay in adopting the *twisted* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.68: Distance from the pioneer of the *underglazed* technique and delay in the adoption of *underglazed* technique (OLS)

	Delay in adoption of *underglazed* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	-13.399**	16.803***	19.026***
	(5.773)	(4.016)	(4.395)
Distance to coast (000s km)	-161.512***	-196.517*	-223.473**
	(59.547)	(104.366)	(100.254)
Distance to river (000s km)	-101.852	95.072**	117.554**
	(67.642)	(40.296)	(51.107)
Elevation (m)	20.765	36.787	67.049
	(46.233)	(44.510)	(61.992)
Land suitability	39.387	68.495	126.330
	(74.138)	(107.229)	(121.916)
Ruggedness	3.992	-10.408***	-7.010*
	(2.591)	(2.482)	(3.593)
Observations	55	142	204
Adjusted R-squared	0.627	0.499	0.409

Summary: OLS estimates of the relationship between distance from *underglazed* technique pioneer and delay in adopting the *underglazed* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.69: Distance from the pioneer of the *wheel-made* technique and delay in the adoption of *wheel-made* technique (OLS)

	Delay in adoption of *wheel-made* technique		
	(1)	(2)	(3)
	Pre-1500	Pre-1800	All
Distance from pioneer (000s km)	196.721***	204.932***	188.177***
	(34.357)	(33.736)	(29.999)
Distance to coast (000s km)	-67.884	-145.956	-270.932
	(268.630)	(262.964)	(245.342)
Distance to river (000s km)	-89.582	-98.960	132.752
	(196.921)	(188.458)	(147.665)
Elevation (m)	-471.771***	-467.559***	-156.710
	(123.049)	(113.962)	(137.182)
Land suitability	275.843	306.876	-145.414
	(195.063)	(225.332)	(274.720)
Ruggedness	-6.836	-10.362	-19.639**
	(11.520)	(11.370)	(9.628)
Observations	896	1025	1305
Adjusted R-squared	0.196	0.213	0.209

Summary: OLS estimates of the relationship between distance from *wheel-made* technique pioneer and delay in adopting the *wheel-made* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.70: Distance from the pioneer of the *wirework* technique and delay in the adoption of *wirework* technique (OLS)

	Delay in adoption of *wirework* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	80.003**	30.001	24.479
	(39.850)	(42.498)	(26.759)
Distance to coast (000s km)	-51.499	-24.740	526.134***
	(531.302)	(458.411)	(199.640)
Distance to river (000s km)	252.098	771.760***	691.043***
	(272.444)	(246.044)	(109.725)
Elevation (m)	186.725	129.372	179.570
	(148.395)	(148.009)	(125.810)
Land suitability	68.579	-212.707	-547.867**
	(245.434)	(309.204)	(268.676)
Ruggedness	-32.596***	-36.875***	-16.523
	(11.749)	(12.621)	(13.645)
Observations	222	246	434
Adjusted R-squared	0.041	0.100	0.215

Summary: OLS estimates of the relationship between distance from *wirework* technique pioneer and delay in adopting the *wirework* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.

Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

Table 3.C.71: Distance from the pioneer of the *woven* technique and delay in the adoption of *woven* technique (OLS)

	Delay in adoption of *woven* technique		
	(1) Pre-1500	(2) Pre-1800	(3) All
Distance from pioneer (000s km)	86.198**	100.440***	9.302
	(39.870)	(25.794)	(6.813)
Distance to coast (000s km)	-64.126	-68.102	-13.484
	(68.309)	(184.263)	(109.029)
Distance to river (000s km)	-107.861	-58.281	2.585
	(358.359)	(49.379)	(11.094)
Elevation (m)	59.579	56.447	32.646**
	(81.297)	(50.224)	(14.261)
Land suitability	65.880	503.276**	142.837
	(305.297)	(250.632)	(102.833)
Ruggedness	-6.985	-13.529*	-1.770
	(9.678)	(7.355)	(2.150)
Observations	89	249	1729
Adjusted R-squared	0.045	0.322	0.129

Summary: OLS estimates of the relationship between distance from *woven* technique pioneer and delay in adopting the *woven* technique. The analysis controls for distance to coast, distance to navigable rivers, elevation, land suitability and ruggedness. All regressions control for date uncertainty and number of artefacts per site.
Notes: (i) Adoption delay is expressed in years; (ii) standard errors are clustered at country level; robust and clustered standard errors are reported in parentheses; (iii) *** denotes statistical significance at the 1 percent level ($p < 0.01$), ** at the 5 percent level ($p < 0.05$), and * at the 10 percent level ($p < 0.10$), all for two-sided hypothesis tests.

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