ONLINE APPENDIX – NOT FOR PUBLICATION

The Diffusion of Epichoric Scripts and Coinage in the Ancient Hellenic Poleis

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A Additional Estimation Results

Table A1: Estimation of $\mathcal{D}_{i,t} = a_0 + a_1 * \tanh\Big(c_1 \text{MA}(\mathcal{D}_{i,t-1}) + c_0\Big) + \mathcal{X}_i\boldsymbol{\beta} + \text{Period}_t + \epsilon_{it}$.

	(1) script	(2) script	(3) coin	(4) coin
c1	10.93**	11.62**	8.764	0.233
	(4.462)	(5.322)	(124.5)	(1.774)
c0	-3.028**	-3.247**	-0.941	-0.0874
	(1.503)	(1.650)	(21.95)	(0.711)
a1	0.376***	0.351***	0.489	6.683
	(0.139)	(0.132)	(4.696)	(54.12)
Size	No	Yes	No	Yes
ML Iteration Ct	2785	11617	1313	50000
N	1151	1151	1499	1499

Notes: Maximum likelihood estimation for parameters a_0, a_1, c_0, c_1, and $\boldsymbol{\beta}$ in $\mathcal{D}_{i,t} = a_0 + a_1 * \tanh\Big(c_1 \text{MA}(\mathcal{D}_{i,t-1}) + c_0\Big) + \mathcal{X}_i\boldsymbol{\beta} + \text{Period}_t + \epsilon_{it}$. Coefficients for the control variables $\boldsymbol{\beta}$ are not shown to save space.The regressions reported in columns 1 and 3 do not include polis size as a control variable but columns 2 and 4 do. The coefficients reported in column 4 are associated the last iteration of the algorithm, when it the maximum number of iterations, 50000, without converging.

Table A2: Spatial Diffusion: the Impact of Covariates

	Linear		0.5*tanh()		0.364/0.489*tanh()		Quadratic		Log		w/o MA(adopters)		Survival Reg	
	(1) script	(2) coin	(3) script	(4) coin	(5) script	(6) coin	(7) script	(8) coin	(9) script	(10) coin	(11) script	(12) coin	(13) script	(14) coin
Panel A: With Crow-flies MA(adopter)														
rightev	211.4***	-264.3***	193.1***	-258.0***	197.7***	-258.3***	204.1***	-254.1***	199.7***	-261.3***	76.65	-198.5***	90.98	-643.5***
	(74.33)	(60.89)	(73.39)	(60.04)	(74.10)	(59.85)	(72.10)	(61.84)	(72.07)	(61.45)	(63.71)	(31.38)	(197.1)	(110.3)
MA(Phoenician)	0.635		0.450		0.526		0.385		0.488		0.425		-3.534	
	(0.837)		(0.861)		(0.859)		(0.858)		(0.843)		(0.886)		(3.788)	
MA(Script Origins)	-0.512		-0.910		-0.910		-1.171		-0.554		3.787**		11.11	
	(1.995)		(1.915)		(1.911)		(2.070)		(1.931)		(1.520)		(7.441)	
MA(Sardis)		-7.922**		-8.061**		-8.057**		-8.109**		-8.133**		-6.075**		56.85***
		(3.607)		(3.658)		(3.657)		(3.704)		(3.689)		(2.349)		(21.67)
MA(Mines)		0.997**		0.914**		0.916**		0.891**		0.926**		0.851***		1.848**
		(0.422)		(0.419)		(0.418)		(0.439)		(0.436)		(0.249)		(0.774)
semi elas(rightev)	0.23	-0.30	0.21	-0.29	0.21	-0.29	0.22	-0.29	0.21	-0.30	0.08	-0.22	-0.10	0.72
semi elas(MA(mines))		0.11		0.11		0.11		0.10		0.11				-0.21
Panel B: With Crow-flies MA(adopter) and own size														
rightev	227.8***	-164.5***	208.9***	-157.8***	213.5***	-157.9***	220.1***	-158.5***	217.1***	-169.3***	95.87	-128.9***	182.0	-431.4***
	(76.66)	(57.19)	(75.47)	(59.46)	(76.08)	(59.44)	(74.37)	(58.68)	(74.43)	(58.93)	(64.34)	(30.13)	(195.1)	(106.6)
MA(Phoenician)	0.599		0.418		0.492		0.374		0.466		0.349		-3.933	
	(0.819)		(0.844)		(0.843)		(0.839)		(0.824)		(0.868)		(3.864)	
MA(Script Origins)	0.0974		-0.326		-0.323		-0.539		0.0243		3.779**		10.62	
	(2.017)		(1.953)		(1.952)		(2.110)		(1.965)		(1.524)		(7.341)	
psize	0.0521***	0.139***	0.0497***	0.139***	0.0503***	0.139***	0.0490***	0.139***	0.0507***	0.138***	0.0340***	0.103***	0.131**	0.306***
	(0.0170)	(0.0127)	(0.0160)	(0.0126)	(0.0161)	(0.0126)	(0.0158)	(0.0127)	(0.0166)	(0.0127)	(0.0127)	(0.00861)	(0.0534)	(0.0300)
MA(Sardis)		-2.624		-2.784		-2.785		-2.762		-2.809		-1.676		36.37***
		(2.573)		(2.577)		(2.578)		(2.580)		(2.586)		(1.652)		(10.09)
MA(Mines)		0.748**		0.673*		0.674*		0.683*		0.738*		0.695***		1.965***
		(0.375)		(0.389)		(0.388)		(0.390)		(0.384)		(0.221)		(0.719)
semi elas(rightev)	0.24	-0.19	0.22	-0.18	0.23	-0.18	0.24	-0.18	0.23	-0.19	0.10	-0.15	-0.20	0.48
semi elas(MA(mines))		0.09		0.08		0.08		0.08		0.09				-0.23
Panel C: With Crow-flies MA(adopter)														
Delian	0.0476	0.0187	0.0497	0.0176	0.0506	0.0176	0.0496	0.0178	0.0483	0.0169	-0.119**	0.0450*	-0.278**	0.336***
	(0.0601)	(0.0374)	(0.0627)	(0.0369)	(0.0628)	(0.0369)	(0.0603)	(0.0372)	(0.0601)	(0.0370)	(0.0518)	(0.0254)	(0.133)	(0.0862)
Koinon	0.249**	0.0671*	0.253**	0.0682*	0.255**	0.0681*	0.245**	0.0698**	0.244**	0.0696*	0.182**	0.0835***	0.351**	0.350***
	(0.109)	(0.0341)	(0.106)	(0.0350)	(0.107)	(0.0350)	(0.106)	(0.0351)	(0.107)	(0.0358)	(0.0883)	(0.0268)	(0.177)	(0.0974)
Panel D: With Crow-flies MA(adopter) and own size														
Delian	0.0354	0.00146	0.0379	0.000787	0.0387	0.000776	0.0381	0.000943	0.0364	-0.000129	-0.126**	0.0290	-0.316**	0.150**
	(0.0583)	(0.0305)	(0.0609)	(0.0300)	(0.0609)	(0.0300)	(0.0587)	(0.0303)	(0.0583)	(0.0302)	(0.0506)	(0.0197)	(0.130)	(0.0695)
Koinon	0.240**	0.0490	0.245**	0.0502	0.247**	0.0501	0.238**	0.0507	0.237**	0.0498	0.175*	0.0656***	0.314*	0.261***
	(0.108)	(0.0325)	(0.106)	(0.0333)	(0.106)	(0.0333)	(0.106)	(0.0333)	(0.106)	(0.0342)	(0.0895)	(0.0232)	(0.183)	(0.0740)
Observations	1143	1491	1143	1491	1143	1491	1143	1491	1143	1491	2033	2381	890	890
N(Script=1/Coin=1)	410	358	410	358	410	358	410	358	410	358	622	424		

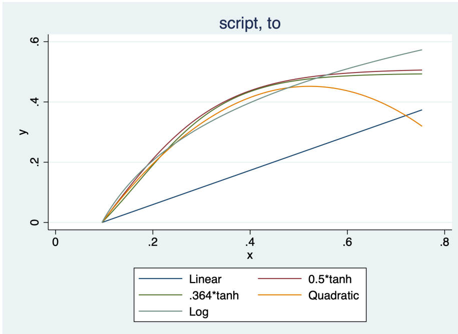
Notes: Pseudo panel and survival regressions. Columns (1) - (12) are pseudo panel OLS regressions. Columns (1) and (2) control for the linear term of MA($D_{i,t-1}$). Columns (3) and (4) control for the hyperbolic tangent terms of MA($D_{i,t-1}$). Columns (5) and (6) control for linear and squared term MA($D_{i,t-1}$). Columns (7) and (8) do not control for MA($D_{i,t-1}$). In column (1)-(6), the linear and squared terms of the MA($D_{i,t-1}$) measured in terms of crow-flies distances are controlled for. Columns (9) and (10) are survival regressions where the starting dates are assumed to be one year before the earliest observed years in our data for script and coinage. While in the original survival regressions a longer survival time (larger dependent variable value) implies a later adoption, to make the coefficients more comparable to columns (1)-(8), we add a negative sign for all coefficients in the survival regressions so that a positive coefficient means a positive effect.
Panel A and B are similar specifications, except for that Panel B additionally control for the size of the polis. The MA($D_{i,t-1}$) variables (if included) and geographical variables including ruggedness, malaria index, temperature, precipitation, elevation, and crops (barley, millet, summer wheat and winter wheat) suitability are included in all specifications but not shown. Panel C and D are the same as A and B except for that Delian and Koinon are included.

Standard errors clustered at 1 by 1 degree grid in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

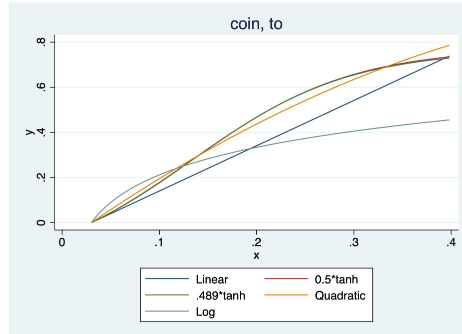
Table A3: Spatial Diffusion: the Impact of Proximity to Previous Adopters, Heterogeneity

	Linear		0.5*tanh()		0.364/0.489*tanh()		Quadratic		Log	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	script	coin	script	coin	script	coin	script	coin	script	coin
Panel A: Smaller Poleis										
MA(adopters)	1.952*	1.703	6.872***	10.06	7.253***	10.24	-8.801***	-0.719	-0.113	0.0407
	(1.134)	(1.444)	(1.957)	(8.295)	(2.482)	(8.489)	(3.265)	(3.636)	(0.366)	(0.187)
MA(adopters)^2							13.08***	5.297		
							(3.949)	(7.767)		
Inflection Pt			0.54	0.35	0.51	0.35				
AIC	484.27	340.40	476.71	343.04	479.92	343.02	454.33	341.68	491.12	342.17
Observations	526	743	526	743	526	743	526	743	526	743
N(Script=1/Coin=1)	180	81	180	81	180	81	180	81	180	81
Panel B: Larger Poleis										
MA(adopters)	0.686	0.507	12.41***	14.10	16.66***	14.23	11.19***	7.265**	0.825***	0.392**
	(1.225)	(1.423)	(3.015)	(10.62)	(5.503)	(9.995)	(2.203)	(3.029)	(0.247)	(0.161)
MA(adopters)^2							-13.64***	-13.56**		
							(2.869)	(6.220)		
Inflection Pt			0.23	0.11	0.23	0.11				
AIC	805.67	1011.04	777.77	1008.72	779.10	1008.71	769.72	1007.32	793.50	1006.72
Panel C: With Size, Larger Poleis										
MA(adopters)	0.746	-0.00957	12.40***	-0.00886	16.79***	-0.00807	11.15***	5.483*	0.830***	0.270
	(1.239)	(1.448)	(3.042)	(3.835)	(5.459)	(14.76)	(2.221)	(3.059)	(0.260)	(0.170)
MA(adopters)^2							-13.52***	-11.00*		
							(2.805)	(6.282)		
Inflection Pt			0.23	-58.04	0.23	-85.30				
AIC	798.44	967.29	770.69	971.29	771.86	971.29	762.65	965.31	786.11	965.08
Observations	625	756	625	756	625	756	625	756	625	756
N(Script=1/Coin=1)	230	277	230	277	230	277	230	277	230	277

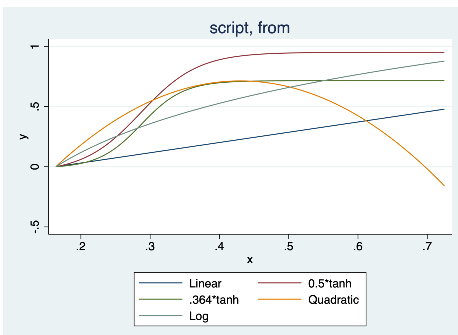
Pseudo panel OLS regressions by subsamples. Distance measures in this table are average distances as from and to a polis i. Columns (1) and (2) are results for regressions linear in MA($D_{i,t-1}$). Columns (3), (4), (5), and (6) are results for regressions with hyperbolic tangent specification. Columns (3) and (4) has the parameter before the tanh($\cdot$) term being 0.5, while columns (5) and (6) has the parameter before the tanh($\cdot$) term being 0.364 (for script) or 0.431 (for coinage). Columns (7) and (8) are results for regressions with quadratic specification. Columns (9) and (10) are results for regressions with MA($D_{i,t-1}$) in natural log. In all specifications, the linear and squared terms of the MA($D_{i,t-1}$) measured in terms of crow-flies distances are controlled for. Panel A is regressions results for the group of smaller poleis (size or predicted size being 1) and B and C are for the group of larger poleis (size or predicted size being 2 to 5). Panel C controls for the size/ predicted size of a polis. Eigenvector centralities, geographical variables including ruggedness, malaria index, temperature, precipitation, elevation, and crops (barley, millet, summer wheat and winter wheat) suitability, as well as proximity to origins (for script regressions) to origins/mines (for coinage regressions) are also controlled for but are not shown to save space. Standard errors clustered at 1 by 1 degree grid in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$



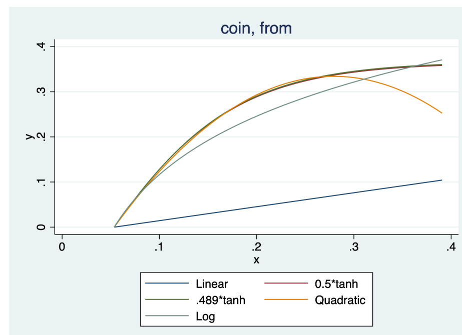
(a) Script, without Size, TO Distance



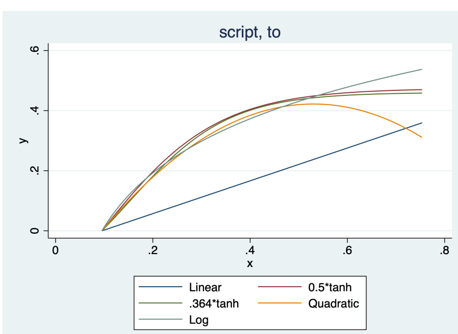
(b) Coinage, without Size, TO Distance



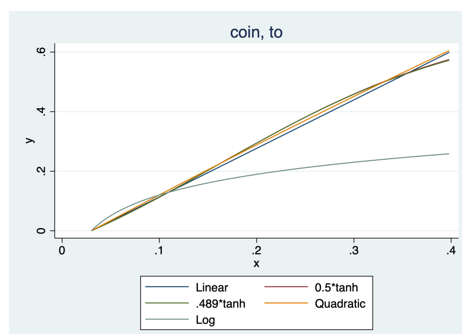
(c) Script, without Size, FROM Distance



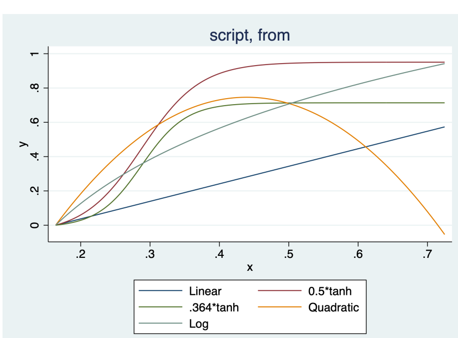
(d) Coinage, without Size, FROM Distance



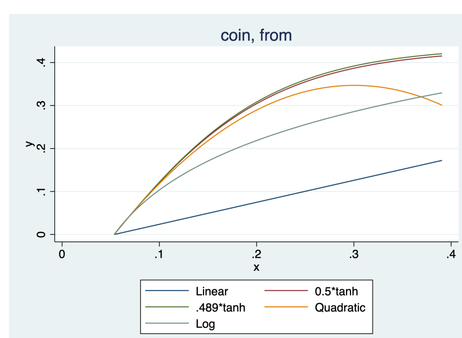
(e) Script, with Size, TO Distance



(f) Coinage, with Size, TO Distance



(g) Script, with Size, FROM Distance



(h) Coinage, with Size, FROM Distance

Figure A1: Relationship between MA($\mathcal{D}_{i,t-1}$) and adoption in different specifications
Source: Estimation corresponding to Table 2.

B Supplementary Information on the Data

Table A4: Observation Counts by Script Adoption and Coinage Issue

	N
(1) No script or coin	154
(2) No script, but has coin	118
(3) Has script, but no coin	315
(4) Has both script and coin	307
(4.1) No precise date of coin	161
(4.2) With precise date of coin	146
(4.2.1) Script earlier than coin	115
(4.2.2) Script later than coin	22
(4.2.3) Script the same date as coin	9

Table A5: Definitions of Periods for Script and Coinage Regressions

	(1) N(Script)	(2) N(Coinage)
Period 1 (725-611 BCE)	91	0
Period 2 (610-525 BCE)	162	18
Period 3 (524-465 BCE)	131	49
Period 4 (464-415 BCE)	77	41
Period 5 (414-280 BCE)	0	116

B.1 Adoption Curves

Figure A2a is the adoption curve for scripts based on raw data. The vertical axis is the cumulative number of poleis adopting a script, and the horizontal axis is the adoption date, ranging from 725 BCE to 416 BCE.

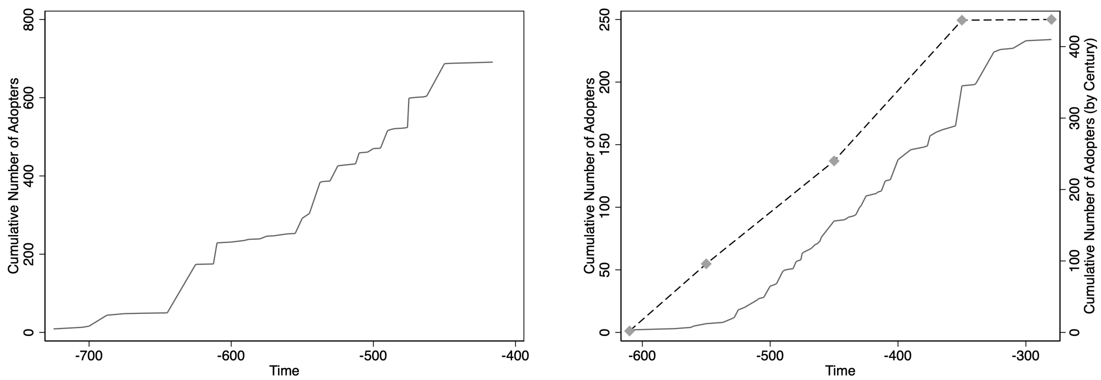
We are, however, reluctant to draw undue conclusions from Figure A2a. A first limitation is due to the fact that the script adoption process in effect ends by the time Athens officially adopts the Ionian script in 403-402 BCE. Thus we argue that because of the dominant position of Athens, the ”natural” adoption process ceases. Alternatively, this may be due to recognition that the Ionian script had become emergent, that is had prevailed. A second limitation comes from the nature of our scripts data base, Poinikastas, in which the unit of observation is scripts. It includes both local scripts (i.e., scripts associated with a single polis) as well as regional scripts. The latter are somewhat problematic for the conceptualization of the adoption process and therefore the adoption curve, as well. Whereas for regional scripts we do know their earliest date of attestation, we do not know when each polis in the respective region actually did adopt the regional script. We therefore assign the earliest date of attestation for the regional script to all poleis within the region, while in reality some poleis might have adopted at later times. The regional scripts are the cause of steep “jumps” in the script adoption curve. A third limitation stems from the fact that there exist a few scripts in Poinikastas database that we have been unable to matched to our poleis database and are thus ignored.

Figure A2b reports the adoption curve for coinage. Our observations for coinage issue by poleis lie between 610 BCE and 280 BCE. Like with scripts, the adoption process for coinage does not reflect entirely voluntary decisions by poleis though for different reasons. Athens, the coinage hegemon of the Delian League, made its own coinage mandatory on the League members, requiring them after some point to turn in their coinage to the Athenian mint in exchange for Athenian coinage.

Since we have two sources of coinage issue dates, we draw two separate adoption curves: the solid line is based on "exact" dates attested, while the dashed line is based on an augmented sample that also includes poleis for which information is attested in terms of centuries, within which coinage was issued. We therefore compute the numbers of coinage issues in each century. The vagaries of the archaeological record are responsible for the differences, including the period of observation. E.g., we only have one observation in the 3rd century BCE, that is, 280 BCE.

Caution is needed when interpreting the adoption curve with century level dates. Essentially, there are only five data points (7th to 3rd century BCE). We match the starting date and ending date in the 7th century BCE and the 3rd century BCE to be the accurate date (610 and 280 BCE), but note that there are only two observation of coinage in the 7th century BCE, at 610 BCE, which marks the beginning of the coinage era in the Hellenic world in our data, and as mentioned above, there is only one observation in the 3rd century BCE, that is, 280 BCE. For 6th to 4th century BCE, the data points are drawn at the mid point of each century. Thus, the slopes from 7th century to the 6th century BCE, and from 4th century to 3rd century BCE, can be misleading. The exact numbers of coinage issues by century, based on our data, is: 2 in 7th century BCE, 94 in 6th century BCE, 144 in 5 century BCE, 197 in 4th century BCE, and 1 in 3rd century BCE.

Figure A2: Adoption Curves



(a) Adoption Curve for Scripts (b) Adoption Curve for Coinage

Notes: The left panel shows the aggregate adoption curve for scripts, and the right panel shows the aggregate adoption curve for coinage. In the right panel, the solid line and the left vertical axis is based on the sample which we know the precise date of coiange; the dashed line and the right vertical axis is based on the augmented sample and its date is based on century. For coinage adoption, we note that there are only two observations in the 7th century BCE, at 610 BCE, and one observation in the 3rd century BCE, at 280 BCE.

C Additional Institutional and Historical Facts

The ancient Greek city-states, the Hellenic poleis, were independent entities each with its own political structure, hence the terms "political" and "politics," that provided a basic infrastructure in the form of a legal system, a process of collective-decision making, and several other institutions that constitute key predecessors of modern ones [Castoriadis (1991)].

C.1 Epichoric Scripts and the Greek Alphabet

This document provides additional historical and institutional facts in support of Chen and Ioannides (2024). Chen and Ioannides (2024) explore quantitatively data on the diffusion of the epichoric Hellenic scripts for several reasons. One is to help track the diffusion of the invention from the Phoenician script to the Hellenic scripts and their transmission over space and time as a case of ancient diffusion of technology. It is premised on the notion, succinctly put by Jeffery (1961), p. 6, among several arguments, that the Greek alphabet must have had its birth either in a part of the Greek area where people whom the Greeks called Phoenicians (Φοίνικες) [Quinn (2023)] were active, or in a part of the North Semitic area where Greeks were active. In considering alternative sites where this might have happened, Jeffery and Johnston emphasize three points: one, the alphabet must have originated in a limited area and was not created independently at a number of different sites where Greeks and Phoenicians had interactions; two, such a site had to be an established bilingual settlement of Greeks and Phoenicians rather than a mere trading North-Semitic trading post, of which there were many; and three, the alphabet's birth place must have itself been on a well-frequented trading route and/or a site with good connections with some of main trading centers in that of the world over the period 900 – 700 BCE.[1]

A second reason is to gain a better understanding of how the emergence of the epichoric scripts interacted with urbanization in the ancient Greek world. Even though Linear B, a syllabic script for an archaic version of Greek that was used in some parts of Greece down to 1400 BCE and disappeared around 1200 BCE along with the Bronze Age administrations that seem to have used it, the "Dark Ages" that followed for hundreds of years were not associated with writing until the emergence of epichoric scripts. Yet another reason is the interaction with the emergence of coinage, itself an important new technology that influenced urbanization in both similar ways, like in facilitating trade, as well as in different ones, such the dependence of coinage on access to precious metals and costly enforcement of standards.

As there exist many variants of the epichoric scripts, Chen and Ioannides (2024) argue that the key element underlying the diffusion is the *idea* of the alphabet itself, the *tacit agreement* whereby a sequence made up of a consonant and a vowel, with

[1]See Bourogiannis (2018b) for a discussion of the scope of cultural as well as economic contacts between Greeks and Phoenicians in the Aegean during the Early Iron Age.

letters denoting sounds and together denoting a syllable, which constituted a fundamental step in establishing a standardized writing for the Greek language. Thus, a small number, 24, of symbols, formed the Greek alphabet before it diffused into the Latin one in the form of the Euboean script via the Etruscans. What motivated the emergence of the alphabet itself, is less well understood. Furthermore, the various epichoric scripts are quite similar to one another, so that users of one could decipher writing in others. It is reasonable to assume that it was interaction of Greek speakers with Phoenicians arguably most likely in bilingual communities, that allowed the invention of the alphabet. What appears to still be subject of debate is exactly where and when this occurred in the ancient Hellenic world, namely the development of the form of writing in what came to be known as the Greek alphabet. The emergence of the Greek alphabet must have had profound influence on the cultural and economic development of the Hellenic world.[2]

What did motivate the invention of the alphabet? Were the needs of literature or the needs of trade? These questions continue to be hotly debated. The principal arguments in favor of the former is that there exist early attestations of writing in the Greek alphabet in the form of literature and casual writing, such as inscriptions that may indeed have been graffiti [Powell (1991; 1993)]. This is quite a contrast with *Linear B*, the earliest form of syllabic (though not alphabetic) writing of the Greek language, which preceded the Greek alphabet by the several centuries of the so-called Greek Dark Ages. Linear B documents are entirely in the form of records of economic transactions, tax records, and records of interactions between rulers, palace authorities and craftsmen ("contractors", a point forcefully made by Nakassis (2013)), all in the absence of money [Schaps (2004)]. Therefore, the question could arise as to why the next form of Greek writing would not have been invented in order to record details of, and to facilitate, the conduct of economic life.

[2]Search for the origin of Greek alphabet using theory and ancient data is conceptually reminiscent of search for lost ancient cities by Barjamovic, Chaney, Koşar and Hortaçsu (2019).

Even if the primary motivation was the accommodation of the emerging Greek literature [Powell (1991); see Powell (1993), an entertaining contribution], it would still have served as a general purpose technology, in effect a non-rival public good, and its emergence being a total factor productivity (TFP) shock [*c.f.* Ashraf and Galor (2011)] within those trade-oriented communities. Therefore, evidence on the timing of presence of a script in different locations may be critical in understanding economic development in archaic and preclassical Greece, in addition to understanding the pattern itself of the spatial evolution of Hellenic scripts as propagation of total factor productivity shocks.

The first known records of the Greek language in the form of the Linear B tablets have been found in a small number of locations, with their locations (and numbers in parentheses) being as follows: Knossos (4228), Pylos (1004), Thebes (438), Mycenae (107), Tiryns (76), Chania (52), and much fewer at a number of other locations, with writing on objects other than clay tablets. In most of those cases, the tablets were not meant to be permanent.[3] They have been preserved accidentally due to fires that destroyed the structures where they were stored. Therefore, those finds are hardly random; they are sparsely distributed and arguably very unrepresentative. The paucity of those data makes us ponder about how to further use them and therefore we have not yet merged them with the scripts data.[4]

Several scholars have argued that the Linear B writing system might have indeed been used first to record economic life, but those records were on perishable materials such as papyrus[5] and others [Waal (2020), p. 113]. This suggests that we should not adhere too closely to attested dates of script adoption and allow for errors, which we actually do in the empirical analysis.

[3] https://damos.hf.uio.no/1

[4] We thank Teddy Glaeser for his help with the Linear B tablets data and Albert Saiz for urging that we pursue this point.

[5] Jeffery and Johnston (1990), p. 57, state by appealing to Herodotus [v. 58] that before papyrus became an accepted medium, the Greeks of Ionia (the Aegean coast of Asia Minor) had been using leather for the same purpose.

The Phoenician script, known as alphabet, has 22 letters and is syllabic, with each letter standing for a consonant and an unspecified vowel. The vowels were not written. The scribes who most likely developed the Greek alphabet added letters, both to denote certain sounds, like Φ, X, Ψ and assigned vowel values to redundant (from the perspective of the Greek language) Phoenician letters. The Phoenician names of the letters, which are not known but scholars refer to them by their respective Hebrew ones, probably denoted initial consonants of words. Those names were largely adopted by the Greek alphabet. Characteristically, they are reated as foreign words in the Greek language, as indicated by the fact that they are not declined, even the ones that are associated with Greek words, like omikron and omega. The shapes of the letters, their order, and their names are very similar to their Phoenician counterparts.

The humanities and linguistics literature dwells at length on the precise nature of the innovation that the invention of the Greek alphabet amounted to, especially because it has served not only as the "mother of all European alphabets," but also of several Asian alphabets, though through different routes of transmission. The Latin alphabet, in particular, originated from the alphabet of Chalkis, Eretria, and Kyme, known as the Euboean script, through their colonies in Italy, especially Cumae, from which the alphabet was transmitted to the Romans via the Etruscans. Numerous variations followed, such as its adaptation for the needs of some Slavic languages, whereas the Cyrillic scripts were deliberately developed from the Greek for the needs of other Slavic languages. Since the creation of *pinyin*, the writing system of romanization of Mandarin Chinese, its influence has been extended even further.

As Bourogiannis (2018a) details, proximity of Phoenicians and Greeks is attested in many places in the Aegean and indeed all around the Mediterranean. Most notable is Cyprus, though several scholars doubt that that is where the Hellenic alphabet emerged from the Phoenician script. That is so because of the evidence that its Greek-speaking population held onto their own Cypriot syllabary over several centuries for political reasons [*ibid.* p. 252].[6] Critical to our empirical investigation is that scholars agree on the basis of linguistic arguments that the similarities among the epichoric scripts are so strong that the invention must have happened just once rather spontaneously in different places. It propagated thereafter and was adopted, with variations, by different Greek speaking populations at various sites and times ranging from 1100 BCE (as some argue) to 750 BCE and beyond. Generally, there is little (but still some) support for an earlier date.

Until about 10 years ago, there was general agreement that later dates were more likely. Then firmly dated new archaeological findings at Methone, a northern Greek site in the region of Pieria and colony of Eretria, argued in favor of the alphabet's being established by 733 BCE [*ibid.* p. 244]. Specifically, this finding strengthens the case for an Aegean origin due to findings of coexistence of Greek along with Phoenician (and Phrygian) letters at Methone [Papadopoulos (2016); Bourogiannis (2018a; 2018b)]. An even earlier date of 775 BCE for the existence of the Greek alphabet (though not necessarily representing Greek text) is attested at a site called Gabii in ancient Latium, Italy, for which there exists strong evidence of links with Eretria due to Eretrians' presence in Pithikoussai, a site on Ischia Island near Naples, Italy, where evidence of Greek writing has also been found, though associated with a later date. Scholars have argued that several sites around the Aegean might have accommodated Phoenician presence, including in addition to Eretria, Kyme and Oropos (all in the region of Euboea), such poleis as Athens, Delos, Thera, Rhodes and Crete. Scholars have discussed their potential as sites for the invention. However, the Euboeans seem to stand out for active and reciprocal contacts with the Eastern Mediterranean.[7] In

[6] Woodard (1997), Ch. 6, argues that scribes literate in the Cypriot syllabary were responsible for the first Greek adaptation of the Phoenician script (known as alphabet). Woodard's argument rests on investigations of the spelling principles of the Mycenaean and Cypriot syllabic scripts.

[7] An additional argument has been made that involves a Phrygian link. Linguistic arguments that involve vowels in early Greek and Phrygian, together with the Phoenician symbols from which they seem to have been derived, plus the testimony of Herodotus, argue that the place of the adoption and adaptation of the Phoenician script must have been where Greeks, Phoenicians but also Phrygians interacted. This, again, points to somewhere in the Aegean. A Phrygian connection has been elaborated most recently by Quinn (2023).

sum, while we allow for many possibilities, we do think it is somewhere in the Aegean where the Greek alphabet, via its variants, was invented. The paper tests this conjecture. Last, on a matter of terminology, we note that we adhere to the term *scripts* in deference to Jeffery (1961), but what did diffuse in the ancient Hellenic world were variants of what is nowadays known as the *Greek alphabet.*

C.1.1 Epichoric Scripts Data

We are utilizing the digitized archive of Jeffery's documents (http://poinikastas.csad.ox.ac.uk/) along with additional information from Jeffery and Johnston (1990) to create our database of scripts.[8] It is composed of 151 scripts, not necessarily very different but attested with individual poleis, and 23 regional scripts. In almost all cases for which we have evidence, a script associated with a particular polis is also used by their neighbors or other nearby poleis. The regional scripts were likely shared by poleis in the same historical region, especially as in most cases they are associated with the same dialect. Still, as the evidence of Euboea and Ionia attest, those two regions spoke similar dialects but used different scripts, and likewise with Corinth and Sparta. Johnston (1998) in discussing the potential significance of script adoption for polis identity, *polisism*, argues that the evidence in favor of a link between script and dialect is not very persuasive, but perhaps epichoric scripts were more likely a ““slip of the pen” than being associated with polis identity. Johnston does grant nonetheless that “polisism, did have some effect in perpetuating the use of home-town lettering in the propagandistic situation afforded in these sanctuaries [Delphi and Olympia] ...” [*ibid.* p. 428].

We do not know exactly why some scripts are regional while others are not, but

[8]It lists by order of appearance all 1640 items in Jeffery (1961), with details as follows: *Local Scripts of Ancient Greece* reference (with hyperlink to image), name of local script, region found (classified by means of maps), subregion, archaeological context, object type, and date range. For example, for the first line, the entries are: link to image, Attica, Central Greece (CG), Attica, Athens, Oinochoe, c. 725. In principle, these items may be classified in further detail and we are in the process of exploring these resources.

we test for the potential explanation of whether regions with better within-region communication are more likely to share a script. Specifically, we compute the average travel cost between all poleis within each region. We find that the 22 regions that do not have a regional script have greater average within-region travel costs than the 23 regions that do have regional scripts: the mean of the average within-region travel cost for regions with regional scripts is about 67% of the respective mean for regions without regional scripts, evaluated in terms of our baseline distance measure; it is 76%, and 83% in terms of our alternative distance measures.

Waal (2020), p. 111, states "alternatively, one could see the regional diversity as the results of local developments, which must have taken place over a longer period of time." As Luraghi (2010) puts it, although the local alphabets were consciously created and associated with ethnic boundaries and dialects, the problem remains how this all happens so rapidly. For our purposes, if we believe that the local development takes a long time, then the distance from each polis to particular Phoenician sites as potential origins of the innovation might not be as important. However, distance could matter when it comes to trade and to the degree of cultural differences. Since the alphabet was ultimately adopted widely, a key question is how can we judge when the inhabitants of an area first saw and/or used an alphabet? A trade-related motive could be one potential explanation, as it led to cultural mixing. On the one hand, trade increases wealth and state capacity, which might go hand-in-hand with script adoption; on the other hand, the greater prosperity brought by trade could generate additional demand for record keeping and therefore for script, but there exists no evidence of record keeping in early material. Coinage was of course crucial for trade, too, but unlike the case of script, it does depend on access to sources of precious metal, and therefore a joint treatment is appropriate.

While we are accustomed to written evidence on such media as stone and objects made of clay, writing seems to have been present on numerous other objects, including coins, decorative objects and tools. The variety of objects mentioned in the *Local*

Scripts of Ancient Greece database from *Poinikastas* is telling. In addition, most likely non-permanent media were also used, such as hides and papyrus, just as we even today use all kinds of non-durable media. Indeed, the modern Greek word for book, *biblion* ($\beta\iota\beta\lambda\acute{\iota}o\nu$), derives from the name of Byblos, modern Jbeil, one of the most ancient cities that have been inhabited continuously since at least 7000 BCE.[9]

Alphabets were a great departure from the Linear B or the Cypriot syllabary, that preceded them. The various epichoric scripts differed in many ways. To give examples, they differed in the use of the consonant symbols X, Φ, Ψ, in the use of the innovative long vowel letters ω, and η; and many others, and in many details of the individual shapes of each letter. Yet the classics scholarship maintains that they were mutually intelligible. The now standard 24-letter Greek alphabet was originally the regional variant of the Ionian cities in Asia Minor. After Athens officially adopted the Ionian script in 403-402 BCE with Eucleides as archon [D'Angour (1999)], it became the standard in most of the rest of the Greek world by the middle of the 4th century BCE. Our coding of adoption dates adheres to thess events.

We use the *Poinikastas Database* to get the earliest date when each local script is attested and in merging with our poleis data match with the nearest polis. Our database of scripts is composed of 151 scripts, attested with individual poleis but not necessarily different, and 23 regional scripts. See figure 1b for the locations of poleis with scripts.

C.2 Coinage

As Bresson (2005) and Schaps (2004; 2006) argue, coinage of precious metal was an innovation, over and above commodity money (skins, cattle, shells, pieces of metal, etc.). It signaled authority of the state via its stamp, allowed exchange rates with

[9]It lies on the coast of Lebanon from where trade with Egypt, the origin of papyrus, a common raw material for writing in antiquity, was known to have taken place.

all commodities, and thus served as unit of account, store of value and medium of exchange. These properties coincide with the modern definition of money. However, we do not claim that it was coinage that signalled the invention of money or credit. A well established literature has argued that commodity money existed even starting in the Stone Age, when various substances served as money, to be followed by metals in various forms in the Bronze Age with the establishment of weights and scales to be followed by bullion, and ultimately in the Iron Age money took the form of coinage [Kroll (2008); Rahmstorf (2016)]. Coinage was clearly the most convenient form of money, given the technology of the time, and fully consistent with Aristotle's argument in favor of coinage.[10] While coinage was certified by the issuing authority, it continued to be weighed, in part as a protection against counterfeiting. Yet, coins "as stamped pieces of metal enabled the differentiation between face and intrinsic value for the first time" [Rahmstorf (2016)]. In fact, this argument is bolstered by the fact that strictly speaking, issue of coinage in a full set of denominations by a state might not have been profitable. However, the state expended resources in order to communicate its authority, facilitate trade, and also reduce the costs of its revenue collection [Melitz (2016)].[11]

The emergence of coinage in India and China appears to come later. Schaps (2004), p. 231-233, acknowledges the controversy and dates coinage in India to probably before the invasion by Alexander the Great in the late fourth century BCE, but not earlier than Lydia. The case of China is similarly complicated, and coinage with similar functions to that of Lydia appears first in the early fifth century BCE [Kakinuma (2014)]. The fact that the technologies involved were different, punch marked silver coins in the former, and elaborate bronze cast in the latter, makes it

[10]We thank Jack Kroll and Jacques Melitz for insisting on this point in private communications.

[11]We thank Jacques Melitz for bringing to our attention that availability of coinage fluctuated widely after the Fall of the Roman Empire and, not unlike during the classical Hellenic era, not all polities continued issuing coinage through the Middle Ages. However, the fact that alphabetic writing never did disappear should not diminish to invention of coinage as a major innovation whose availability depended on resources, just as use of writing did depend on available media.

likely that they were independent inventions. As Schaps (2004) argues, the roughly contemporaneous Indian and Chinese societies were too sophisticated to have settled on clumsy imitations of the Lydian and Greek process. Coinage must have been independently invented there and curiously did not immediately spread to equally sophisticated societies elsewhere.[12]

Our data on the times of first issue of coinage are taken from two sources. One, which is available in the original database of the Stanford Polis Project, records time of issue by century; the second, which we hand-coded ourselves, uses the more detailed information available in Hansen and Nielsen, *op. cit.,* either according to attested approximate year or approximation by interval midpoints.[13] Silver coinage is the most prevalent form, with 339 vs. 187 observations, from the first and second sources respectively, followed by 284 vs. 148 for bronze. Figures 1c and 1d shows the locations of poleis with coins.

Gold and electrum coinage are much rarer. In our data 21 poleis issued gold coins and 9 poleis issued electrum coins. However, the classics literature has concluded that electrum coins were the first ones to be issued; see Hodos (2020), Ch. 3, Kallet and Kroll (2020), Van Alfen and Wartenberg (2020).

In our empirical analysis, we do not differentiate the coins by their types because it is tempting to treat silver and gold coins as substitutes. They are both made of precious metal with much higher intrinsic value than bronze and were used as money first, indeed originally in the form of bullion or *Hacksilber* [Kroll (2013)]) in trade prior to the invention of coinage.[14] Bronze coins seemed to have been used

[12]As Schaps (2006) p. 32, puts it, "Whether they each invented it independently or whether it passed from one to the other, Lydia/Greece, India, and China all proved fertile ground for an institution that neither originated nor was quickly adopted in other civilizations no less advanced culturally and economically. In fact, there are some parallels in the development of the economies of Lydia, India, and China that may be significant for our understanding of their role."

[13]Our econometric methods recognize such differences in the data. Specifically, in the cross-sectional probit models for coinage we define the coinage issue indicator using either source. But for the survival and pseudo panel analyses, we exclude the poleis for which we know the date of coinage by century only.

[14]As Kroll (2013) puts it, the advantages of coinage over bullion were one "that by obviating

very differently. They were issued both by larger poleis in small denominations to facilitate retail trade, and by smaller ones because they were cheaper to manufacture (though did depend on imports of tin), but still served as unit of account and medium of exchange. Several poleis issued multiple types of coins during their history. In the present version of the paper, we consider only the earliest date of coinage issue when a polis issued multiple coins in the history.

D Modeling Considerations for Coinage

For issue of coinage to be meaningful, it must be held as money in a dynamic setting. It is thus easiest to think in terms of a standard overlapping-generations macro model. Each polis is populated by individuals who live for two periods in the form of two-overlapping generations; individuals work when they are young, save in the form of coinage and consume when they are old. It is particularly convenient to borrow the theoretical framework of Casella (1992), because it allows studying a system of trading entities, poleis in our case, both in autarky as well as in trade and monetary, that is coinage integration. Conceptually, issue of own coinage is not strictly necessary, as coinage may be obtained from trade.[15] We may add more structure by assuming that each polis provides a public good, which along with the polis geography defines it, and finances it in two alternative ways. One could be by means of taxes on young individuals and transfers to old workers, while providing for a surplus to pay for the

weighing [of bullion], it made monetary exchange simpler, faster, and far more efficient. And two, "coinage removed the provision of money from the private sphere and placed it, like weights and measures, under the authority and the legal protection of the state, thereby maximizing the reliability of the means of exchange, which translated into further transactional efficiency." Kroll also notes that "it is reasonable to conclude that the employment and increasing supply of precious metal was probably more influential than the form in which it was transacted."

[15]In its absence, the transfer of purchasing power over time may be accommodated in two alternative ways: one, a polis-specific system of taxes and transfers; and two, "consumption loans," whereby the old sell "loans" (in a classic Samuelsonian overlapping-generations fashion) to the young. That is, the old use the proceeds of the loans to purchase the consumption good from the young. The young cash in these loans when they become old in exchange for the consumption good.

public good. A second could be by issuing coinage which young individuals accept as a store of value and which circulates within the polis economy serving all of the roles of money. Since coinage was typically in the form of precious metal alloys and carried the issuer polis insignia and signaled its authority, it could also circulate outside the polis if it was negotiable. It is known that poleis made great and costly efforts to protect their coinage against counterfeiting. In order to analyze interpolis trade, one may work with standard formulations in the international trade literature that incorporate geography, such as Allen and Arkolakis (2014). Because issuance of money in the form of coinage is a key element of our study, it is helpful to combine it with a monetary model such as Casella (1992). Shipping or travel costs constitute important frictions, and could easily be accounted for in a model like Casella (1992).

E Additional Discussion on the Spatial Evolution Model

As Brock and Durlauf (2001) explain (see also Ioannides (2013), Ch. 3), combinations of parameter values entering equation (3) may lead either to unique or to multiple equilibria at the steady state. A unique equilibrium corresponds to Brock and Durlauf (2001), Proposition 2, Part ii.b. The intuition for multiple equilibria is as follows. Conditional on a given level of intrinsic value of adoption relative to non-adoption, h, multiplied by β, the payoff-responsiveness parameter that is proportional to the inverse of the variance of the underlying stochastic shocks that affect player payoffs, there is a threshold level that the conformity effect of its neighbors' decisions must reach in order to produce multiple consistent average choice behaviors. The likelihood of multiple equilibria diminishes, given a conformity effect, if βh is very high. Given βh, the conformity effect depends both on the strength of the interaction coefficient, B_{ij}, and the dispersion of the i.i.d. shocks underlying the choice process. The hyperbolic tangent specification implies, in general, a sigmoid response that nests the possibility of a threshold value associated with an inflection point.[16] For conformity, $B_{ij} > 0$. Multiplicity requires conditions that involve all parameters, that is β, B_{ij} and h. See Brock and Durlauf (2001), Proposition 2.

Additional References

Allen, Treb and Costas Arkolakis (2014). "Trade and the Topography of the Spatial Economy". In: *The Quarterly Journal of Economics* 129(3), pp. 1085–1140.

Brock, William A and Steven N Durlauf (2001). "Discrete choice with social interactions". In: *The Review of Economic Studies* 68(2), pp. 235–260.

Casella, Alessandra (1992). "Participation in a Currency Union". In: *American Economic Review* 82(4), pp. 847–63.

Ioannides, Yannis M. (2013). *From Neighborhoods to Nations: The Economics of Social Interactions*. Princeton University Press.

Konno, Tomohiko and Yannis M. Ioannides (2019). "The exact solution of spatial logit response games". In: *Mathematical Social Sciences* 97, pp. 1–10.

Kroll, John H. (2013). "Hacksilber". In: *The Encyclopedia of Ancient History*. Wiley.

Bourogiannis, Giorgos. 2018a. "The Transmission of the Alphabet to the Aegean." 235–257. In: Niesiolowski-Spano, L., and and M. Wecowski, eds. *Change, Continuity and Connectivity. Northeastern Mediterranean at the Turn of the Bronze Age and the Early Iron Age.* Wiesbaden.

Bourogiannis, Giorgos. 2018b. "The Phoenician Presence in the Aegean during the Early Iron Age: Trade, Settlement and Cultural Interaction." *Rivista di Studi Fenici.* 46:43–88.

[16] For simplicity, this discussion rests on the intuition of the analysis in terms of average choice levels at the equilibrium of the process. In contrast, Konno and Ioannides (2019), Proposition 6, applies to the case of agents' actual stochastic environments.

Castoriadis, Cornelius. 1991. “”The Greek Polis and the Creation of Democracy.” *Philosophy, Politics, Autonomy.* 81–123.

Champ, Bruce, and Scott Freeman. 2004. *Modeling Monetary Economies.* Cambridge University Press: Cambridge.

Johnston, Alan. 1998. “Epichoric Alphabets: The Rise of the Polis or a Slip of the Pen?” 419–431. In: N. Dimoudis and A. Kyriatsoulis, editors. *Die Geschichte der hellenischen Sprache und Schrift vom 2. zum 1. Jahrtausend v. Chr.: Bruch oder Kontinuität?* Altenburg.

Luraghi, Nino. 2010. “The Local Scripts from Nature to Culture.” *Classical Antiquity.* 29(1):68–91.

Nakassis, Dimitri. 2013. *Individuals and Society in Mycenaean Pylos.* Leiden and Boston: Brill.

Pounds, Norman J. G. 1969. “The Urbanization of the Classical World.” *Annals of the Association of American Geographers.* 59(1):135–157.

Waal, Willemijn. 2020. “Mother or Sister? Rethinking the Origins of the Greek Alphabet and its Relation to the Other “Western” Alphabet.” 109–124. In: Boyes, Philip J., and Philippa M. Steele. *Understanding Relations between Scripts II: Early Alphabets.* Oxbow Books.