Anvil Age Economy: A Map of the Spread of Iron Metallurgy across Afro-Eurasia

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A large dataset is used to map the historical spread of iron use across Afro-Eurasia using a number of different methodologies. Traditional dates for the beginning of what archaeologists call the "Iron Age" in each region are unacceptable because they are imprecise and the dates themselves are reached on the basis of different methodologies. The author maps the spread of iron with a primary focus on its acceleration in use across many object classes. Three additional maps are also provided: the first critical use of iron for cutting tool or weapon, the spread of iron helmets and the spread of high-quality steel swords. While many of the maps are at the experimental stage, the results give a unique insight into technological change across history and can be used to test predictive models of historical change. As the mapping of the rise and spread of a technology has rarely or never been done before on this scale, the maps, the methodologies used, and the problems encountered provide a fork in the scholarship for more accurate and detailed successors.

1. Mapping the Emergence of Iron-Based Civilization

With the discovery of iron metallurgy and with the proliferation of objects made of iron after 1000 BCE, ancient societies experienced considerable transformation (Bebermeier et al. 2016; Pleiner 2000). Over the next thousand years the metal caused a civilizational *meta* shift (a change in the optimal mode of competition). Ancient states and their people could not live as they had before: iron ore mining and the production of hard metal objects on a vast scale revolutionized the great game of warfare and aristocratic life, resulting in new, larger empires and massively wealthy social classes beyond the royal court. Since iron could be produced at a much lower cost than bronze, the manufacture of iron objects also created a higher baseline standard of living for many of the world's poorest, who developed skilled occupations and inaugurated the first non-elite global-scale economy.

Radomír Pleiner in *Iron in Archaeology: The European Bloomery Smelters* (2000: 20–21) identified four stages in humanity's use of this civilization-forging metal.

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I. Ritual and symbolic; the exotic metal of a ruling elite.

II. Limited but regular use as a costly prestige metal and produced only in small amounts in copper smelters.

III. The first widespread production of large objects such as weapons and tools in specialist iron smelters ("Early Iron Age proper"). Iron is a means of exchange and a tribute item for states.

IV. Mass production of iron at smelting centers is achieved in locations where adequate fuel and ore are available. Sophisticated blacksmithing techniques develop and there is an explosion in artefact types. Blacksmiths become specialized into professions (such as toolmaker, armorer, swordsmith, cutler). Iron and high-quality steel are traded over long distances.

In another book-length treatment of the history of iron in Europe, Pleiner (2006: 14) defines a "Fully-fledged Iron Age" as that which "involves the large scale production of iron which became indispensable in the everyday life of the society." The map this paper constructs identifies when the transition to this new economy occurs: between stages III and IV of Pleiner's periodization.

The "Iron Age" concept as it is used in archaeology is extremely vague, and cannot be used to answer this question directly. Estimated dates for Iron Ages in different regions of the world have been produced since the early nineteenth century, but they have rarely corresponded to the turning point between Pleiner's stages III and IV. Its inventor, the Danish museum curator Christian Thomsen (at least he popularized the term) was unable to determine precise dates for his artefacts. He sorted them into chronological eras based on the prevailing material used to make cutting weapons and tools (Graslund 1987: 20). Thus the Iron Age became established as "a cultural as well as chronological era in which iron was the predominant material for the manufacture of implements and weapons" (Baum 2006: 1023).

The established approach hides potentially the most interesting features of the expanse of time known as the Iron Age within extremely broad periodizations. These chronologies can cover a thousand years[1] and are frequently broken down into distinct phases, such as early, middle, and late.[2] When does iron first have a

[1] Saudi Arabia's Iron Age is considered to date from 1300 to 300 BCE (Hoyland 2001: 36), while in the northern boreal zone of Russia it lasted 1400 years: from 800 BCE to 600 CE (Koryakova and Epimakhov 2007: 19).

[2] For example, southern Africa (de Luna 2016: 36–39). In South Africa the Early Iron Age alone lasts 700 years: 200–900 CE (Badenhorst 2009: 148). In Norway the periodization is heroically complex, with the Early Iron Age split into different phases, and phases within phases, the whole period lasting about 1000 years: Pre-Roman Iron Age; Roman Iron Age

"profound effect on economic and social structures" (Pleiner 2000: 35)? When were those few hundred years of the transition between Pleiner's third and fourth phases, from the beginnings of mass production to civilizational-scale use? These questions are not answered.

For a traditional discussion of the dates for the origin of iron use, consult, for example, Bebermeier et al. (2016); Pleiner (2000, 2006) for Europe; Tewari (2010) and Pisipaty (2019) for India; and Bronson (1999) and Wagner (1996) for China.

This study chooses to identify, for all parts of the Old World (the whole Eurasian landmass plus Africa and Island Southeast Asia), four specific types of historical spread of iron.

1. **The first acceleration in the use of iron.** When iron becomes a material used for multiple object types (military and agricultural tool use,[3] plus at least one of another use type such as construction,[4] utilitarian[5] or ornamental) with increasing frequency. Iron is used on a much greater scale 100 years after the proposed date and on a much smaller scale 100 years before the proposed date. This time reflects the most important moment of transition in humanity's production and use of iron (includes diversification[6]), and may reflect fundamental economic, military and/or social change. Map 1 presents the dates for the first acceleration of iron and is the primary map of this study (the only one referred to in the Discussion).

2. **The first critical use of iron.** When iron first almost completely replaces an older material for a critical object type—for example, bronze swords give way to iron swords or stone axes are replaced by iron axes (which are more efficient at chopping down trees). These dates are plotted in Map 2. Total replacement is not necessary for a significant impact (e.g., allowing migration through dense woodland): 70–80% dominance of the new material over the older one was considered sufficient for the transition. The "critical object type" is unlikely to be anything other than a sword or axe (though an iron scythe or plough that dramatically increased agricultural output might also count). This mo-

(Early Roman Iron Age; Late Roman Iron Age); Norwegian Migration Period (Rundberget 2016: 8–9).

[3] Axes for forestry are considered agricultural tools.

[4] For example, nails, architectural clamps, crowbars, adzes, and axes.

[5] For example, household items such as forks, spoons, hair ornaments, and stands.

[6] Diversification refers to the use of iron to produce tools and weapons plus one other object type. Ornamental/ritual items must at this stage be of a significant size to count.

ment reflects the immediate impact of iron on territorial expansion[7] and defense[8] but at this time iron can still be a relatively less-used or costly material. The map does a good job of showing the impact of iron on societies where the metal was used for axes to clear forest, such as in Africa. However, the first iron swords, especially those poorly smithed or lacking the right impurities, were often worse than their bronze alternatives (Williams 2012) so this map may be less meaningful for parts of the world where iron swords preceded iron tools (e.g., axes) as the first cutting object.

3. **First militarily significant use of iron helmets.** Use of iron helmets (Map 3) may be a good proxy for the full establishment of iron as a metal for military use, since iron swords were typically the first military use for iron. The spread of iron helmet data is intended to reflect the moment iron helmets entered into use for elite soldiers. There must be some military significance to their use: possession by a reasonable proportion of the fighting men.

4. **First militarily significant use of high-quality steel swords.** Sword quality should be a leading indicator for the quality of steel a society possesses. Whether there was enough of the best steel available to make consistently high-quality steel swords for a significant number of soldiers (Map 4) is an important consideration.

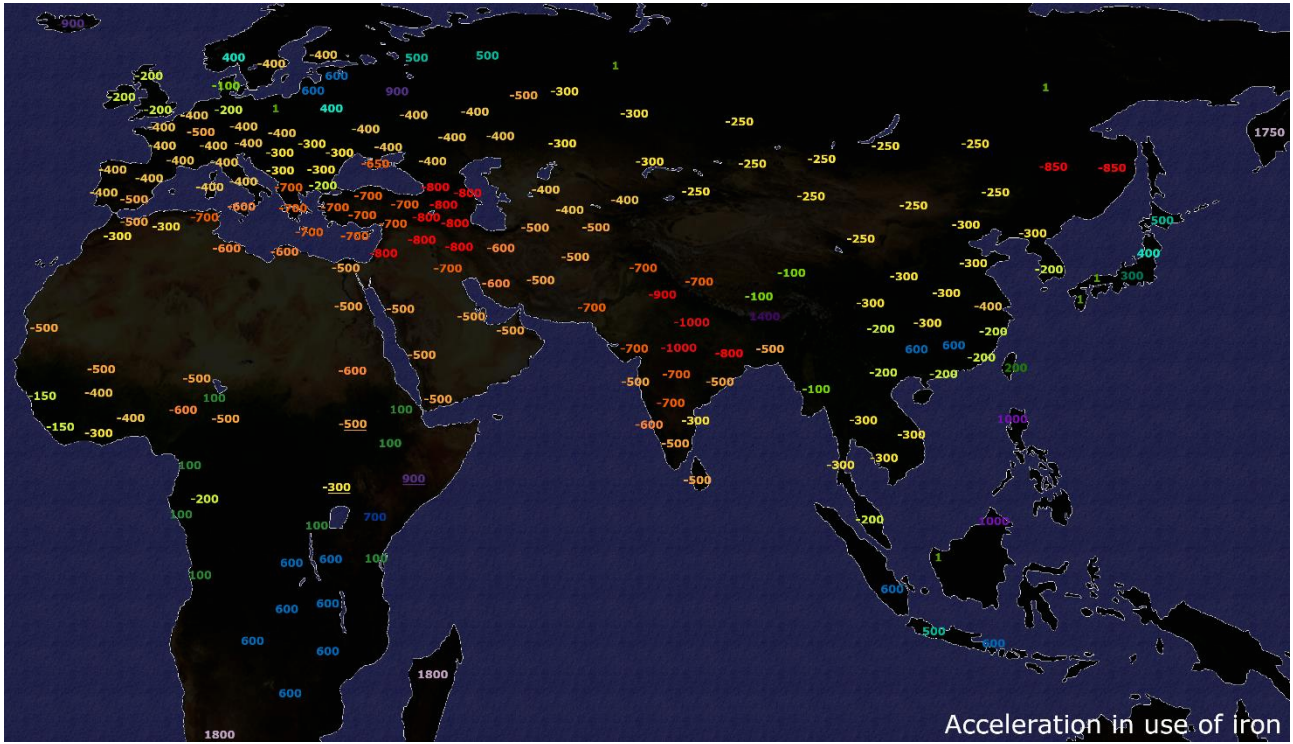
It is certainly difficult to locate precise moments when iron objects begin to be used much more frequently. The archaeological record is fundamentally imprecise, open to interpretation, and can contain misleading forms of evidence. One simple problem is that ancient aristocrats often possessed iron objects not because they used them but because they were valuable and prestigious. This means, for example, that the presence of iron armor in a burial does not confirm that it was used in battle.

Other false signals can be associated with archaeological dating methods. Radiocarbon dating must take account of historical fluctuations in the amount of carbon-14 in the atmosphere. Some dates for finds associated with furnaces can be very controversial (Chirikune 2010: 25; Holl 2009). Contamination of samples by organic material from adjacent archaeological layers of different dates can lead to odd conclusions.

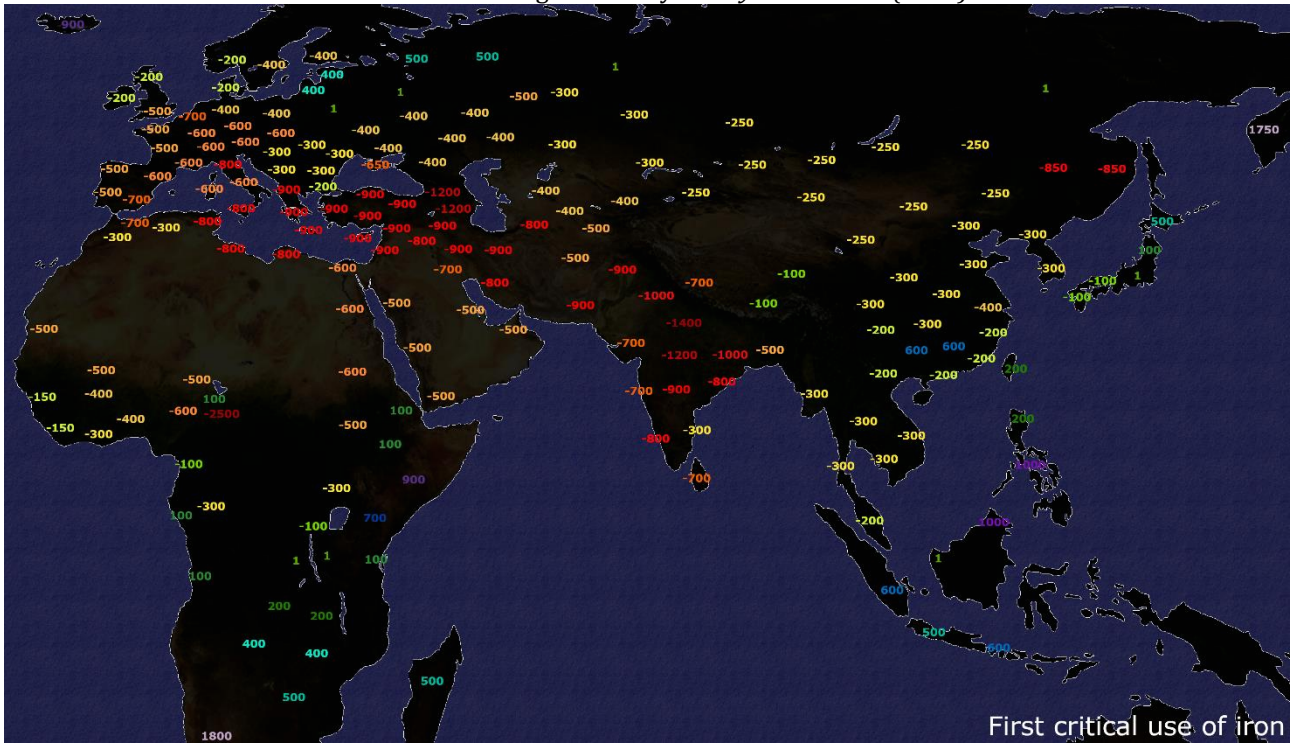
Acidic soils and the fact that iron disintegrates over time—more quickly in

[7] Clearance of forest to enable expansion of settlement into new territory.

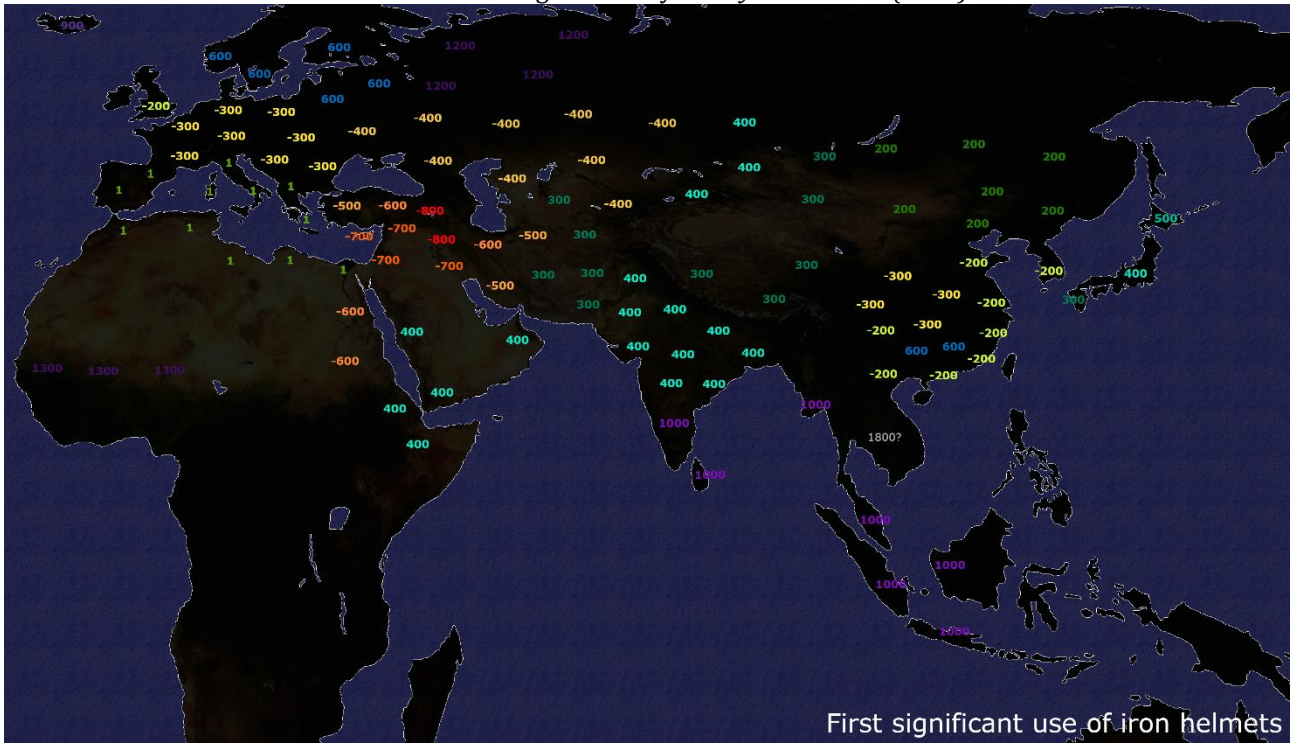
[8] For example, a transition from no swords or weak bronze swords to iron swords.



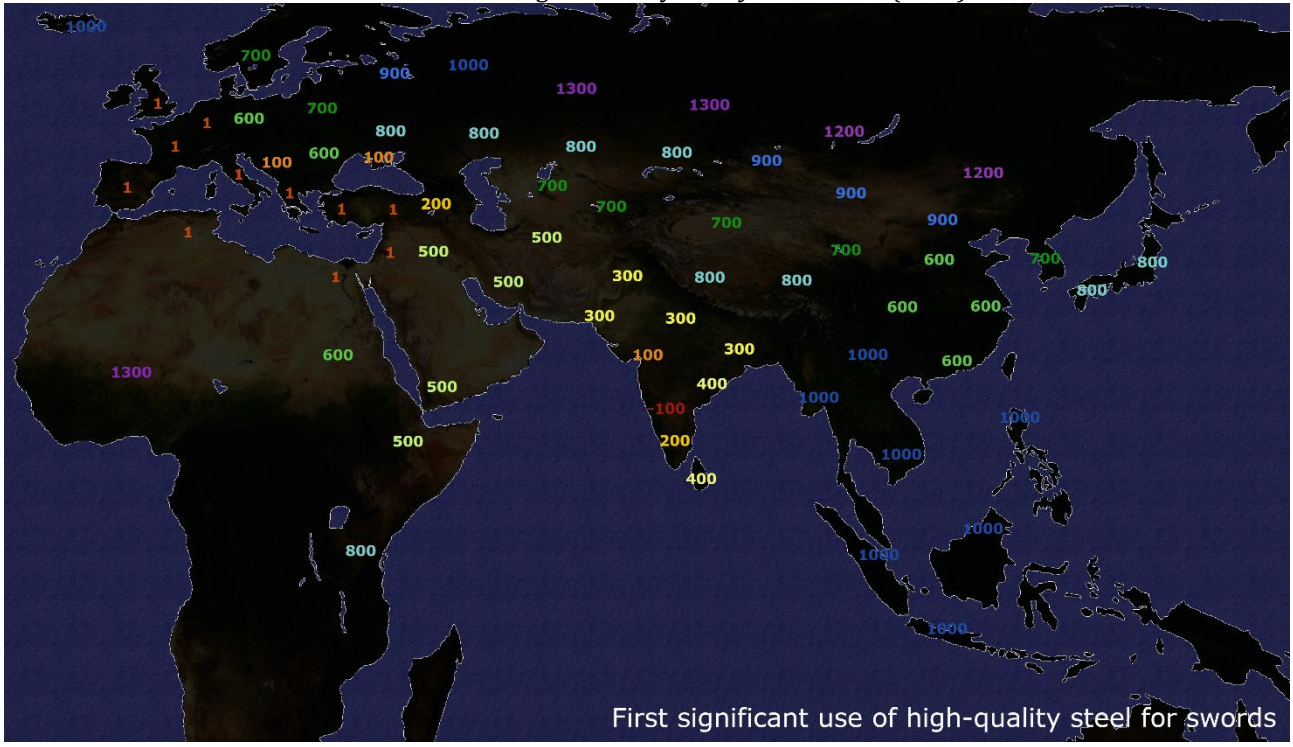
Map 1. First acceleration in the use of iron across Afro-Eurasia



Map 2. First critical use of iron across Afro-Eurasia



Map 3. Spread of iron helmets (first militarily significant use)



Map 4. Spread of high-quality steel swords

damp conditions—also make estimating dates difficult, as little evidence is left in the ground for archaeologists to work with. This problem has been noted as severe in Portugal and Japan (Disney 2009; Higham 2004: 404). Similarly, the ancient practice of recycling metal means iron objects do not always enter the archaeological record (Bebermeier et al. 2016: 164).

A particular advantage of the methodology of this study is that the principal map, showing the acceleration in use of iron, does not trawl from the shallow end of the data pool. Almost all of the dates have multiple lines of evidence. Nevertheless, the problems outlined above are a good reason why such maps should be considered a work in progress. The dates in this paper are based on recent scholarly positions, which are changing all the time and often subject to controversy and revision.

2. Constructing the Regional Survey

The raw data for the survey was acquired by consulting academic books and articles on the history of iron use, often using an online literature aggregator. Historical maps were used to identify the ancient polity the time/location referred to. The Seshat Global History Databank was also then consulted. There was greatly valued personal communication with experts and reviewers, who shared their own knowledge, recommended sources and provided papers via email. Initially the search proceeded by region (Europe, the Mediterranean, North Africa, Southwest Asia, Central Asia, etc.) then by almost every country of the Old World.

Once a critical mass of data had been collected (eventually the amassed data took up over 700 entries), a draft map was constructed. From this, gaps and areas that needed further work were established. More specific searches were conducted to fill gaps and find more data for uncertain regions.

3. The Data

The following indicators and considerations were used to create the dates for the acceleration in the use of iron (and other variables):

- Archaeological evidence of specialist iron-smelting furnaces such as tuyeres, slag deposits, or the ovens. Small amounts of iron could be smelted in a copper furnace, so the first evidence of iron slag may not always indicate mass production. These finds can be dated using chemical analysis, such as carbon-14 dating and other modern techniques.

- Archaeological evidence for iron-smelting centers. Fuel, such as wood or charcoal, rather than iron ore was the limiting reagent for ancient production of iron (Wagner 1996: 258) so local

availability of trees and landscape effects should also be considered. Experiments with furnaces of ancient design have shown that to produce 1 kg of usable iron required 10 kg charcoal and 25 hours of labor (Price 2013: 296). To this list can be added a substantial population of settled humans in the vicinity, who leave buildings such as workshops. A source of iron ore and water for cleaning it (especially where bog iron is used) are also important for the production of iron (Bebermeier et al. 2016: 159).

- Archaeological or historical evidence that societies acquired iron ingots or products through trade, or evidence for early trade routes that could have carried the trade in iron. In such cases, iron can enter into common use without the local presence of iron furnaces or smelting centers.
- Archaeological evidence that iron was used for large cutting objects, such as swords or axes. Iron only sometimes, not always, becomes the dominant material for making both agricultural and military equipment at the same time. Often there is a time lag between the adoption of iron tools and iron weapons or vice versa.
- Historical evidence, such as references to iron in historical documents or inscriptions, or evidence from cultural products such as pottery or sculptures. This is a good indicator but was rarely used on its own to influence a particular chosen date. It is more significant in weight for peripheral regions where less archaeological research has been conducted.
- Interpolation. When no evidence could be found for iron use in a particular location, or the evidence required a great deal of interpretation, the dates were chosen based on more well-attested dates for iron use in nearby locations. These uncertain dates are underlined.[9]

Table 1 presents the data, divided up by world region.

Appendix A of the supplemental materials for this study contains the raw data for the iron maps presented in this paper. Appendix B provides descriptions of the spread of iron use by region.

[9] This applies only to the map showing the acceleration in use of iron, the principal map of the study.

3. Discussion: The Observed Pattern of Spread

The current available academic data for the first acceleration in use of iron across the whole of Afro-Eurasia show that by about 200 BCE, all the core regions of ancient civilization and the steppe region had acquired a new anvil-based economy.[10] Over a millennium, from 1200 BCE onwards, whole regions made the transition, one after another. In areas most peripheral to the main centers of ancient civilization—like Japan and northern Europe—uptake is latest and the dates less closely bunched in time.

As the regional summary (Appendix B) describes, the spread of iron began as early as 1200 BCE in an area of northern India. Weapons, tools, and some building materials were all made of iron from about the time of the Janapadas, the city-states of the late second and early first millennium BCE. Central India, Southwest Asia, and the eastern Mediterranean region all transitioned within a two-hundred-year window: roughly between 800 and 600 BCE. Once the military and agricultural advantages of iron became known, the core region of classical civilization in southern and western Eurasia became the world's anvil for the production of iron.

The discovery of tempering, quenching, and carburization (for low-carbon steel) encouraged the transition as these techniques narrowed the quality gap between bronze and iron sword blades. It is possible the methods first came from India, where they had been known from very early times (Johansen 2014), but they may have been developed in other locations independently. The most important catalyst for change in Southwest Asia was the military success of the Kingdom of Urartu in eastern Anatolia (Sergey Nefedov 2019, pers. comm.). The ancient Assyrians, influenced by them, sought iron in tribute from their defeated neighbors (Moorey 1999: 292; Pleiner 2000, 14). In turn, the iron-using military model of the Assyrians was copied by the Nubians (Martin 2016).

The time lag of almost a millennium in the large-scale adoption of iron between northern India and the core region of ancient civilization in the East—China—was likely due to the formidable obstacle of the Himalayas and the jungles and mountains of southeast Asia. China also had a cast-bronze industry on a massive scale and bronze was prestigious for ritual and cultural reasons.

Southern India, Central Asia, Arabia, the Sahel south of the Sahara in Africa, and western Europe, all regions adjacent to the earliest iron economies, transitioned between 600 and 400 BCE—in just two hundred years. The western steppe and the Balkans region followed even more quickly, with the migrations of nomadic warrior groups between 400 and 300 BCE. Another vast swathe of East Asia from the eastern steppe through China to Mainland Southeast Asia transitioned to iron

[10] The economy likely emerged through a process of diffusion: through conquest, the cultural transmission of knowledge, technology and materials (such as through trade and travel) and intra-society competition between elites.

Table 1. Data used to create the maps in this study, divided up by world region

		Date or date range of spread (earliest to latest)			
Region		**Critical use**	**Acceleration**	**Iron helmets**	**Steel swords**
EUROPE		*900 BCE–900 CE*	*700 BCE–900 BCE*	*300 BCE–1200 CE*	*600–1000 CE*
Western Europe	England and Wales, France, Low Countries, Switzerland	700–500 BCE	500–400 BCE	300–200 BCE	1 CE
Southern Europe	Iberia, Italy, Sicily, Sardinia, Corsica, Balearics	800–500 BCE	600–400 BCE	1 CE	1 CE
Northern Europe	Ireland, Northern Ireland, Scotland, Iceland, Scandinavia, Finland, Karelia and Kola Peninsula	400 BCE–900 CE	400 BCE–900 CE	600–1200 CE	700–1000 CE
Central Europe	Germany, Poland, Austria, Hungary, Czechia, Slovakia	600 BCE–400 BCE	500 BCE–1 CE	300 BCE	600 CE
Southeastern Europe	Balkans, Greece	900–200 BCE	700–200 BCE	300 BCE–1 CE	1–600 CE
Eastern Europe	Belarus, Latvia, Estonia, Lithuania,	1–500 CE	400–900 CE	600–1200 CE	700–1000 CE

Region		Date or date range of spread (earliest to latest)			
		Critical use	**Acceleration**	**Iron helmets**	**Steel swords**
	Russia-Ukraine, excluding steppe				
AFRICA		*800 (or 2500) BCE–900 CE*	*700 BCE–900 CE*	*600 BCE–1300 CE*	*500–1300 CE*
Maghreb	From Morocco to Libya	800–300 BCE	700–300 BCE	1 CE	700 CE
Northeastern Africa	Egypt and Sudan (the Nile Basin)	600 BCE	600–500 BCE	600 BCE–1 CE	500–600 CE
Sahel	From Mauritania to Chad (arid)	600 (or 2500) BCE–100 CE	600 BCE–100 CE	1300 CE	1300 CE
West Africa	From Guinea to Gabon (tropical)	400–150 BCE	400–150 BCE	N/A	N/A
Central Africa	Includes Cameroon	300 BCE–100 CE	200 BCE–100 CE	N/A	N/A
Eastern Africa	From Tanzania to South Sudan, and east to Somalia	100–900 CE	100–900 CE	400 CE–N/A	500–800 CE
Southern Africa	From Zambia and Namibia to South Africa	200–500 CE	600 CE	N/A	N/A
SW ASIA		*1200 BCE–600 CE*	*900 BCE–600 CE*	*800 BCE–400 CE*	*300–500 CE*
Anatolia-Caucasus	Turkey, Armenia, Georgia, Azerbaijan	1200–900 BCE	800–700 CE	800–500 BCE	500 CE

Region		Date or date range of spread (earliest to latest)			
		Critical use	**Acceleration**	**Iron helmets**	**Steel swords**
Levant-Mesopotamia	Levant, Mesopotamia, Susiana	900–700 BCE	800–700 CE	700 BCE	500 CE
Arabia	Arabian Peninsula	500 BCE	500 BCE	400 CE	500 CE
Persia	Iran (excluding Susiana), western Afghanistan	900–500 BCE	800–500 BCE	500 BCE–300 CE	300–500 CE
CENTRAL AND NORTHERN EURASIA		*500 BCE–1 CE*	*500 BCE–1 CE*	*400 BCE–1200 CE*	*700–1300 CE*
Pontic-Caspian	The steppe belt of Ukraine and Russia	500–400 BCE	500–400 BCE	400 BCE	800 CE
Turkestan	Turkmenistan, Uzbekistan, northern Afghanistan, Tajikistan, Kyrgyzstan, Kazakhstan, Xinjiang	500–250 BCE	500–250 BCE	400 BCE–400 CE	700–900 CE
Mongolia	Mongolia, Inner Mongolia, the steppe part of Manchuria	250 BCE	250 BCE	200–300 CE	700–900 CE
Siberia	Urals, western Siberia, central Siberia, eastern Siberia	1 CE	1 CE	1200 CE	1300 CE

Region		Date or date range of spread (earliest to latest)			
		Critical use	**Acceleration**	**Iron helmets**	**Steel swords**
Arctic-Asia	The tundra and arctic regions of Eurasia, excluding Scandinavia	N/A	N/A	N/A	N/A
EAST ASIA		*850 BCE–600 CE*	*850 BCE–600 CE*	*300 BCE–600 CE*	*600–1200 CE*
Northeast Asia	Korea, Japan, the forest part of Manchuria, Russian Far East	850 BCE–500 CE	850 BCE–500 CE	200 BCE–500 CE	700–1200 CE
Tibet	Tibet, Himalayas, eastern Afghanistan	700–100 BCE	700–100 BCE	300 CE	700–800 CE
North China	Yellow River Basin, Beijing area	300 BCE	300 BCE	300–200 BCE	600 CE
Yangtze Basin	Central China from Sichuan to the Yangtze Delta	400–200 BCE	400–200 BCE	300–200 BCE	600 CE
South China	From Yunnan to Fujian, including north Vietnam	200 BCE–600 CE	200 BCE–600 CE	200 BCE–600 CE	600–1000 CE
SOUTH ASIA		*1400–300 BCE*	*1000–300 BCE*	*400–1000 CE*	*200–1000 CE*
Indus Basin	Pakistan	900 BCE	700 BCE	400–300 BCE	300 CE
Indo-Gangetic Plain	Upper Ganges (Uttar Pradesh)	1400 BCE	1000 BCE	400 CE	300 CE

		Date or date range of spread (earliest to latest)			
Region		**Critical use**	**Acceleration**	**Iron helmets**	**Steel swords**
Central India	Narmada River (Madhya Pradesh and Maharashtra)	1200 BCE	1000–700 BCE	400 CE	100 CE
Eastern India	Lower Ganges	1000 BCE	800 BCE	400 CE	300 CE
South India	Deccan plateau excluding Maharashtra and including the neighboring east and west coasts of India	900–300 BCE	700–300 BCE	1000 CE	100 BCE–200 CE
Bangladesh	Bangladesh	500 BCE	500 BCE	400 CE	300 CE
Sri Lanka	Sri Lanka	700 BCE	500 BCE	1000 CE	400 CE
SOUTHEAST ASIA		*300 BCE–1000 CE*	*300 BCE–1000 CE*	*1000–1800 CE*	*1000 CE*
Burma	Myanmar	300 BCE	100 BCE	1000 CE	1000 CE
Mainland Southeast Asia	Thailand, Cambodia, Laos, south Vietnam, Malay Peninsula	300–200 BCE	300–200 BCE	1800 CE	1000 CE
Island Southeast Asia	SE Asian archipelago: Malaysia, Indonesia, Philippines	1 CE–1000 CE	200 BCE–1000 CE	1000 CE	1000 CE

use between 300 and 200 BCE. The cyclone-battered Bay of Bengal and Arabian Sea may have prevented faster transmission by open water to Island Southeast Asia and East Africa.

Iron often spread in large quantities to new areas first by trade a long time before the extractive (smelting) technology arrived. The metal could be worked from ingots into products by local smiths (sometimes skilled migrant workers). The large number of regions that transformed their economies between 500 and 200 BCE were likely assisted by this export of iron ingots from large smelting centers. By 200 BCE iron provided a material basis for a new, popular economy across Afro-Eurasia that enriched all sectors of society.[11]

The development of iron impacted the politics, economics and militaries of states and empires in a way hitherto unseen in history. Iron metallurgy required many "levelling-ups" in human social organization: large-scale resource extraction required more massive mobilization of labor (e.g., for mining); an unprecedented use of energy (such as fuel from timber or charcoal) which resulted in landscape changes; bigger, hotter furnaces worked by teams; industrial towns; many different types of skilled metal craftsmen; secure and liquid international trade networks.

Iron use had many virtuous-circle effects on human civilization that may be measured quantitatively:

> **Agriculture:** Iron ploughs opened up land beyond river floodplains for agriculture (Kidner et al. 2009: 35). These areas could be cleared of trees with iron axes, and the harvest could be collected more efficiently with iron scythes. The raised Malthusian ceiling increased the population density of cities. Population density is linked to the creation of new ideas, art and culture.
>
> **Military:** Cheap iron enabled large infantry units, which could be armored and equipped more cost-effectively (the Roman legions being the classic example), and the size of standing armies could be increased. Mobile armored cavalry units became possible and were a powerful force on the battlefield (Chrissanthos 2008: 16–18). These military developments enabled central authorities to increase their range of effectiveness, their trade revenues, and the sizes of their bureaucracies, which increasingly could be staffed with more speciali-

[11] The novelty of the iron economy to early human civilization is loosely analogous to the recent invention of Bitcoin (2008) and Ethereum (2015)—the Crypto Economy—from which has emerged a completely new source of wealth, from silicon chips; new avenues for social advancement; and a substrate for making useful digital products.

zed professionals. The powerful militaries that recruited commoners created upward social mobility and a new counterbalance to royal dynastic power.

Economy: Iron technology encouraged wealth creation and social advancement. Iron-smelting centers produced such great excesses of iron that the metal went from being rare and precious (valued at 40 times its weight in silver by Bronze Age merchants in Old Assyria [Kidner et al. 2009: 35]) to a frequently traded good 240–360 times cheaper than silver (Pleiner 2000: 21). Ironworking increased the number of skilled trades, goods that could be used for status display, and valuable exchange goods, such as ingots of iron and high-quality steel. What was produced was traded over long distances (Pleiner 2000: 21), which stimulated the emergence of merchant classes, financial and shipping industries.

Society: Other social effects include the "democratizing" impact of access to cheaper and more effective weapons. Rulers were forced to treat their subjects with more respect. Royal and elite patronage of "world religions" became institutionalized from about this time. World religions helped increase cooperation between distant regions, which in turn aided the growing mercantile institutions.

The size of the contribution each region may have made to the spread of ironworking is not represented on this map and could be added to future versions (e.g. by showing volume of exports through directional arrows of different sizes). India was a notable early exporter of iron—exactly how important was this activity to the global spread of iron and iron-related technologies? International trade was not a new feature of civilization, but the increase in trade volume that surely occurred at this time, spurred by the spread of iron technology, had massive effects on cities and the sociopolitical order within these ancient states.

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