THE FARMING-INEQUALITY NEXUS:
NEW METHODS AND EVIDENCE FROM WESTERN EURASIA

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1. Introduction

Here we test the hypothesis that it was not farming *per se* but rather specific farming regimes – dependent on forms of wealth that could be stored, owned, accumulated and transmitted across generations – that fueled the emergence of persistent high wealth inequality in late prehistoric western Eurasia. We measure wealth inequalities by the Gini coefficient, which can be compared across sites and types of wealth. This indicator, which ranges from zero (complete equality) to one (one unit has all of the wealth), is based on the extent of wealth differences (relative to average wealth) among all pairs of households in the population (Bowles and Carlin, 2018).

We test our agronomic hypothesis using a dataset from 39 Neolithic-Iron Age sites (90 site-phases) in western Asia and Europe spanning nine thousand years (later 10th millennium BC to the early first millennium AD). We assess agronomic conditions for these cases using direct evidence of arable growing conditions and land management. Gini coefficient estimates for these cases derive from a related study (see Fochesato, Bogaard and Bowles (Submitted) where we take account of a) biases due to small sample size, b) differing population sizes, c) distinct indicators of wealth (such as house size and grave goods), d) household composition and e) population groups (e.g., slaves) excluded from the original data. Our analysis has implications not only for the development of sustained wealth inequalities in western Eurasia but also for other world regions with very different ecologies.

The transition from hunting and gathering to food production has long been associated with the emergence of widespread persistent economic inequality (e.g. (Childe, 1929, 1950, 1957, Bar-Yosef, 2001). However, the archaeology of Neolithic western Asia and Europe exhibits little evidence of lasting and substantial socio-economic differentiation (Belfer-Cohen, 1995, Byrd and Monahan, 1995, Kuijt, 1996,

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Bar-Yosef, 2014). Moreover, ethnographic and archaeological data show that substantial economic disparities are neither absent among hunter-gatherers nor ubiquitous among farmers (Hayden, 1990, Ames, 1996, Rowley-Conwy, 2001, Borgerhoff -Mulder, Bowles, Hertz et al., 2009, Halstead, 2014).

Gini coefficient estimates for Neolithic western Asia and Europe, revised for comparability (Fochesato, Bogaard and Bowles (Submitted), indicate that early farming economies were often strikingly egalitarian, with wealth disparities similar to hunter-gatherer economies in the ethnographic record (Borgerhoff -Mulder, Bowles, Hertz et al., 2009). The estimates also indicate cases of substantially greater wealth inequality from the fourth millennium BC onwards.

Our proposed explanation of the emergence of persistent substantial wealth inequality is a variant of the hypothesis from behavioral ecology that clumped as opposed to dispersed resources are the basis of dominance hierarchies in non-human animals (Vehrencamp, 1983, Mitchell, Boinski and van Schaik, 1991, Menard, 2004). Among humans the potential monopolization of clumped valuable resources is not unique to farming, as the case of highly productive and defensible fishing sites exemplifies. But by substantially raising the productivity of both land and animals, food production made land and other concentrated, defensible forms of wealth far more common than the rich resource concentrations on which hunter-gatherer wealth inequality was sometimes based. We use our estimates of wealth inequality along with evidence on the nature of farming systems to develop a clumped resources narrative describing the emergence of substantial and sustained inequality in western Eurasia.

We also draw upon a classic distinction between plough farming, in which land ownership became the basis of marked economic disparities, and hoe farming, in which this typically did not occur (Goody, 1976, Halstead, 1981, 2014, Sherratt, 1981, 2006). We use the clumped resources logic to show how a transformation of farming could support the novel emergence of elevated levels of inequality. We illustrate how this may have occurred in the late prehistoric archaeological record of western Eurasia, providing empirical evidence consistent with previous assessment of the *potential* impact of animal traction (by (Bogucki, 1993, Sherratt, 1981, 2006) for example) but tracing this impact well beyond the Neolithic.

We extend previous literature in three ways. First, we use archaeobotanical measures to distinguish two early farming systems: ‘gardens’ (i.e. labour-limited or labour-intensive farming, terms that we use synonymously) and ‘fields’ (i.e. land-

limited or land-intensive farming, also synonymous); second, we propose an economic model in which the key aspect of the garden farming systems was that production was labour-limited, in contrast to the land-limited economies of field-based farming systems; and finally we use the model to suggest a process by which labour-limited farming systems with limited inequality could have made a transition to land-limited and more unequal systems.

2. Cases studied

Our dataset builds on recent efforts to quantify wealth inequality in diverse archaeological forager and farming contexts and exploits a series of archaeological case studies in western Asia and Europe where we can also characterize farming regimes in unusual detail, using refined and integrated archaeobotanical techniques for assessing agricultural intensity and scale (Bogaard, Hodgson, Nitsch et al., 2016, Bogaard, Styring, Ater et al., 2016, Bogaard, Arbogast, Ebersbach et al., 2016, Styring, Charles, Fantone et al., 2017, Bogaard, Styring, Whitlam et al., 2018). Figure 1 shows the sites considered here.

Our unit of analysis for assessing wealth distribution is the household: a co-residential group occupying a modular architectural unit with standardized features. While the occupants of multiple units may cooperate as a larger household group, the widespread archaeological observation of modular units with redundant features suggests that they often acted as the fundamental social agents. Moreover, though wealth may sometimes be shared across households, systematic wealth sharing takes place within the house, where it is stored (Gudeman and Rivera, 1990).

The comparability adjustments underlying our dataset draw upon unusually complete archaeological or ethnographic datasets from diverse cultural contexts. Fochesato, Bogaard and Bowles (Submitted) show that these methods are robust to various forms of statistical testing and that discrete cases provide convergent results.

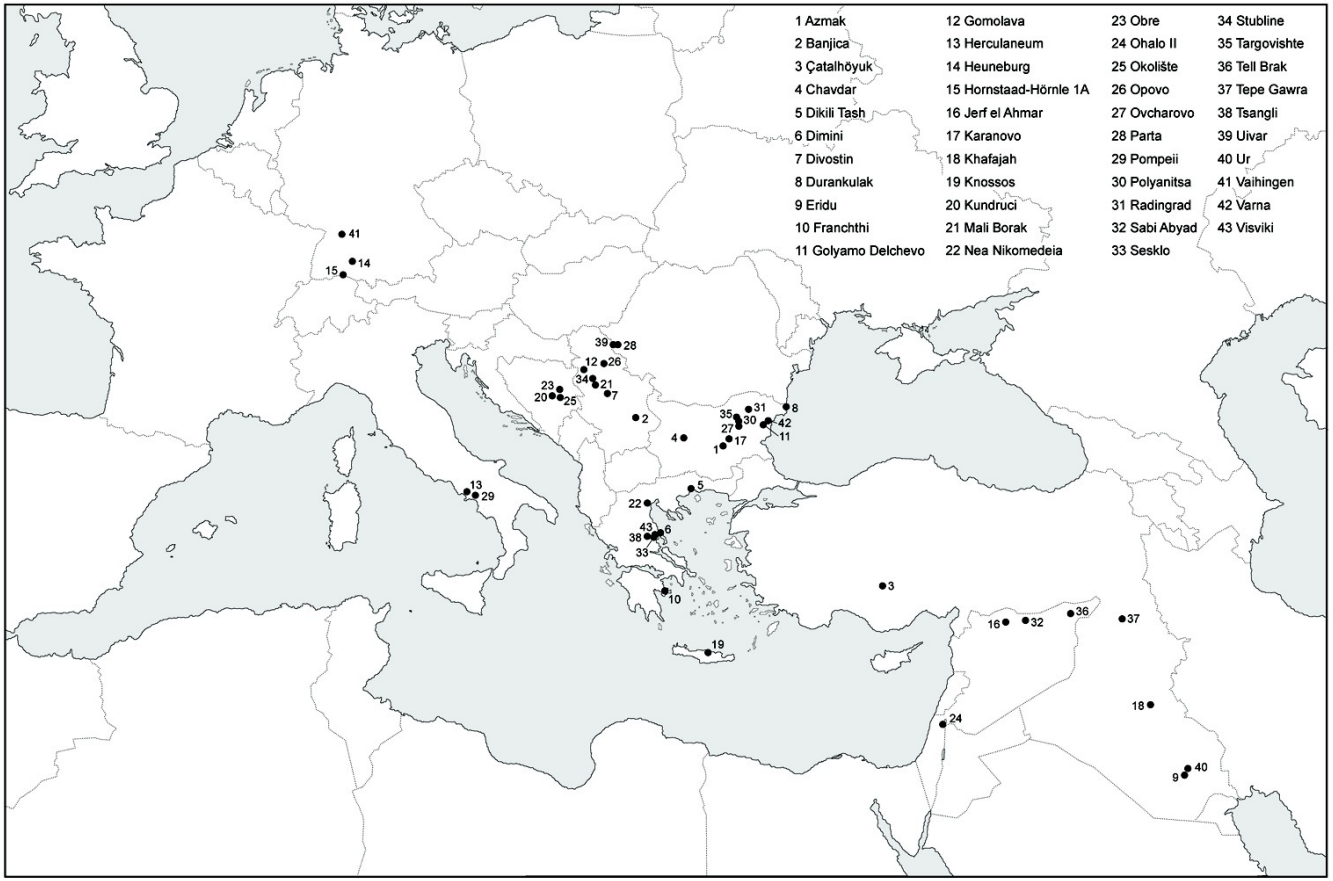

Figure 1. **Map showing the archaeological sites included in this study.**

3. Labour- and land-limited economies

Farming systems differ in terms of the factors posing the main limits to production. This difference in limiting factors is key to our argument. We model differences between two ideal types of farming system: system A is labour-limited compared to system B if labour is more valuable relative to land (or other forms of material wealth) in A than in B. This greater relative value is measured by the increase in total output that an additional unit of labour input would allow – its marginal product. In other words, labour is more scarce relative to land in A than in B, where 'scarcity' refers to how valuable labour is relative to land (that is, the relative marginal product of labour is greater than that of land).

The extent to which a production system is labour-limited depends on the goods and services constituting a people's livelihood, the nature of the production processes by which these are acquired and the relative abundance of land, labour, and other factors of production. Relevant property rights also matter. The ownable and heritable nature of slave labour, for example, makes it economically equivalent to land or other forms of material wealth. Thus, for example, where crops requiring substantial amounts of labour, such as wet rice or cotton, are produced using unfree labour or outright slavery (Scott, 2009, Beckert, 2015) the economy may be material wealth-limited rather than (free) labour-limited. Notably, western Eurasian staple crops like wheats and barleys can be grown under labour- or land-limited regimes (Bogaard, Hodgson, Nitsch et al., 2016, Bogaard, Styring, Ater et al., 2016).

Our hypothesis to be tested empirically is that (free) labour-limited farming was associated with modest levels of wealth inequality, while land-limited production was associated with significantly greater levels of wealth inequality. To frame this we introduce a model that deliberately abstracts from much of the complexity of farming to provide a lens allowing us to focus on what we regard as the most important aspects for the narrative we will develop. Halstead's recent ethnographic consideration of manual and plough-based agriculture in southern Europe (Halstead, 2014) represents these differences as a continuum, showing, for example, that ploughing *per se* need not entail a radical change in farming practice. This subtlety is crucial to the way we assess our hypothesis archaeologically (see below). But to clarify the issues involved we first introduce an idealized categorical model with just two types of farming system: labour-

limited farming and land-limited farming (the technical details are described in the online supplement).

In our model there are four factors of production (inputs): labour, manure, land and animal traction. Land and draught animals are forms of material wealth that can be owned, accumulated and inherited. In the model, labour and land are used in both labour- and land-limited farming; but manure is used only in labour-limited farming, and animal traction only in land-limited farming.

Manure and the labour-limited farming economy. Recent work on the agroecology of early farming in western Eurasia suggests that manuring could play a key role (Bogaard, Fraser, Heaton et al., 2013, Styring, Charles, Fantone et al., 2017). Manure contributes to what we term the effective supply of land by making each hectare more productive, perhaps by a factor of two or more, depending on soils, intensity of application and other factors (Slicher van Bath, 1963, Station, 1970). This in turn raises the marginal product of labour, much as would be the case if the farmer's available land area were doubled or more in size. The reason is that a little more labour on two hectares will add more to production than on a one-hectare plot. The same is true for a one-hectare plot that is intensively manured compared to the same plot without manuring; the 'effective quantity of land' is greater in the former, and the marginal productivity of labour will as a result be greater.

These key ideas are expressed in Figure 2a, where the two curves show the annual output depending on how much labour was applied to cultivation, for a farmer with a given amount of land but under two hypothetical conditions, using or not using manure. The upper curved line represents our model of the western Eurasian labour-limited economy. The slope of the line is the marginal product of labour, which decreases (the curve becomes flatter) as more labour is applied to the land, reflecting the fact that the marginal product of any production input diminishes, the more of the input is applied.

The slope (the marginal product of labour) is greater at point **b** than at point **a** (the latter reflecting a hypothetical economy in the absence of manuring). So, the application of manure increases the marginal product of labour. And (not shown) because the marginal product of land (like any input) diminishes, the more that is available, it follows that manuring – because it increases the effective land input – will reduce the marginal product of land. Thus, manuring contributes to the relatively

higher value of labour and lower value of land that is characteristic of the labour-limited economy.

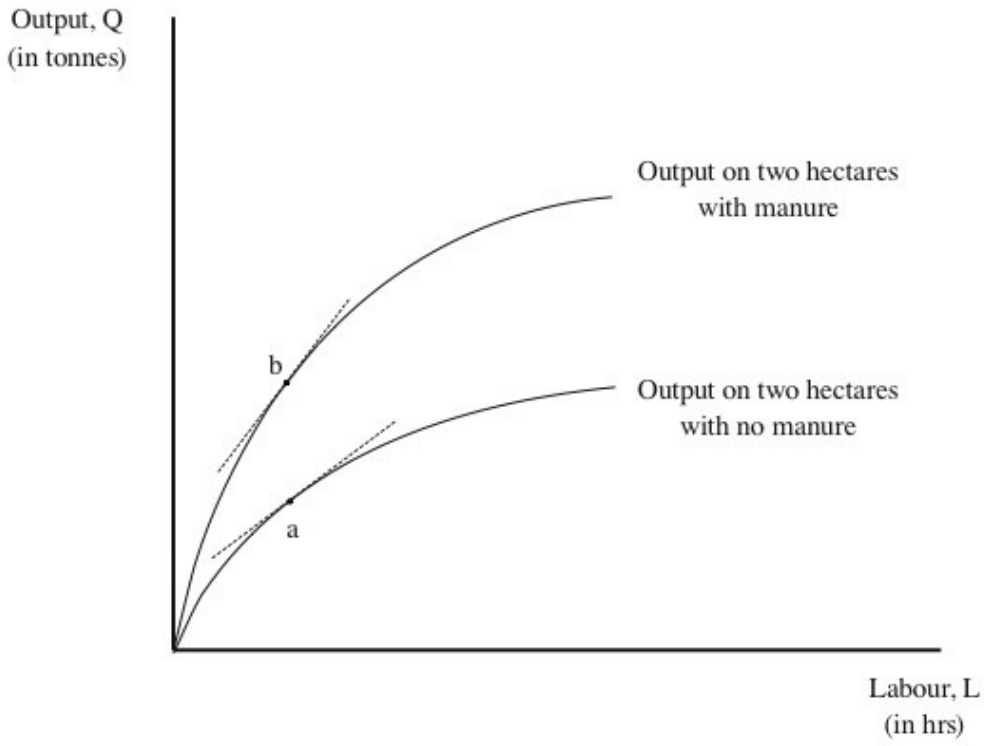

Figure 2a **The effect of manuring on output with a given amount of land.**

Animal traction and the land-limited farming economy. While in the western Eurasian economies under study manure was an effective *land*-augmenting input, animal traction was in the analogous sense *labour*-augmenting. A farmer with an ox team could prepare the same land for cultivation that would have required anywhere from 2 to 15 hoe-farmers depending on landscape factors like soil conditions and topography, but above all on the specialized nature (size and maintenance for example) of the traction animals concerned (Halstead, 1995). We use the term “ox team” here to refer to those specialized for the purpose of field preparation, as opposed to unspecialized animals (e.g. ageing milk cows, (Isaakidou, 2011). The introduction of one or more ox teams raised the marginal product of land: the increase in output made possible by a little more land was much greater if the farmer had an ox team than if not.

Figure 2b illustrates this process, showing annual output depending on the area of land cultivated by a farmer with or without an ox team. The ox team raises both the

total output (point **d** is above point **c**) and also the marginal product of land (the slope is greater at **d** than at **c**). Finally, because the use of the ox team is equivalent to an increase in the amount of labour applied to the land, the marginal product of labour will be lower with the ox team. This is why the ox team contributes to the greater value of land relative to the value of labour characteristic of the land-limited economy.

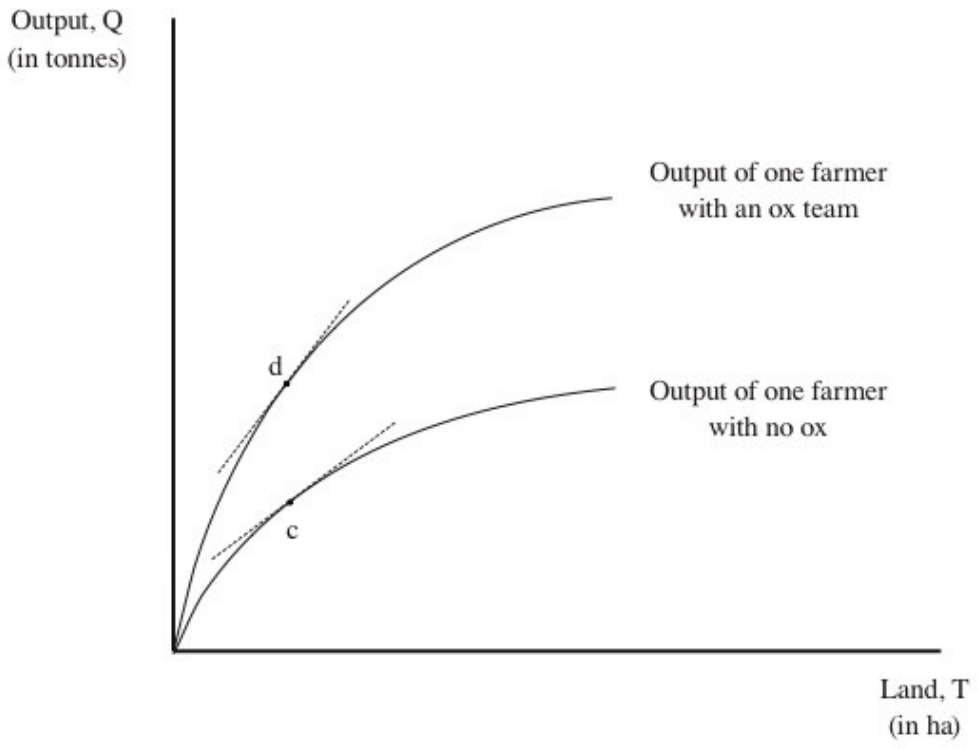

Figure 2b **The effect of animal traction on output with a given amount of labour.**

Consequences for wealth inequality. We hypothesize that in western Eurasia the emergence of more unequal economies took the form of a transition from a labour

(and manure)-intensive system of farming to a land (and animal traction)-intensive system of farming. Three consequences – all tending to heighten wealth inequality – would follow. First, disparities in land and other forms of material wealth could far exceed the differences in human capacities on which economic inequality in labour-limited economies was necessarily based. Abrupt reversals or 'shocks' in the ownership of material wealth – due to theft, the vagaries of weather, or disease – also exceed the equivalent shocks to the human capacities of surviving members of a population. Secondly, in the case of material wealth, these inequalities (including the results of shocks) are transmitted from one generation to the next to a far greater extent than is the case for human capacities, social connections or other determinants of the value of a person's labour (Borgerhoff -Mulder, Bowles, Hertz et al., 2009). A result was that wealth inequalities in any generation would be the cumulative result of shocks over many previous generations.

The third consequence of a greater importance of material wealth was indirect, operating via the cultural and institutional environments that are typically associated with a land-limited economy. In some regions a long-term trend towards increasingly autonomous households suggests the diminished importance of collective forms of co-insurance and risk pooling (Flannery, 2002). The fact that livestock, for example, are both valuable and long-lived provides a form of savings, allowing an extended family practising large-scale herding to buffer shocks so as to smooth their consumption over time (Hoddinott, 2006). This may have led more successful families to withdraw from community-based sharing institutions. The result would be heightened wealth inequalities in farming systems that became land-limited.

4. Inequality in labour- and land-limited farming economies

The diversity of farming systems. Empirically it is possible to distinguish between (relatively) labour-limited and land-limited farming systems in western Eurasia using evidence on both animal traction and crop growing conditions, the latter based on direct archaeological evidence of preserved remains of crops and their associated arable weed flora. Recent methodological work has combined functional ecological analysis of weed flora with stable carbon and nitrogen isotope analysis of crops to build a robust assessment of cultivation intensity, (Bogaard, Styring, Ater et al., 2016, Bogaard, Hodgson, Nitsch et al., 2016). Where possible we use these results

to distinguish between the labour- and land-limited farming cases in our dataset (Table provided in the online supplementary information). We represent Durankulak (Todorova, 2002) as a land-limited economy based on evidence for large-scale salt production along the Black Sea coast, the epitome of a clumped resource (Krauß, 2008, Nikolov, 2011, Nikolov, 2012, Ivanova, 2012).

Mere potential for animal traction (evidence for use of some animal draught at the relevant site or in the wider region) does not classify a case as land-limited if crop growing conditions appear to have been labour-intensively maintained (sustained high soil fertility and (mechanical) disturbance (Bogaard, 2011)). Where this detailed archaeobotanical diagnosis is not available for an individual site, we have turned to regional data from similar sites, or to available documentary sources (such as southern Mesopotamian texts (Postgate, 1992).

Extensive built irrigation works and terracing are also evidence that the economy is land-limited. The fact that farmers in southern Mesopotamia devoted substantial amounts of labour to the augmentation of available land suggests that land was relatively valuable compared to labour.

The case of late medieval Egypt demonstrates this relationship between relative labour abundance and irrigation. Complex irrigation systems required substantial amounts of labour to increase (and maintain) the amount of the scarcer factor of production: cultivatable land. After the 1348 demographic shock of the Black Death, the drastic population decline inverted the relative values of labour and land. As the opportunity cost of labour increased, irrigation systems rapidly decayed (Borsch, 2005). Along with the archaeobotanical evidence, therefore, extensive irrigation works or terracing offer evidence of land-limited production systems.

In many agricultural systems, land- and labour-intensive farming were in fact part of an agroecological continuum. Halstead's analysis of Aegean Bronze Age farming, for example, contrasts 'palatial' strategies – the deployment of specialized plough oxen to produce a narrow range of cereals, documented in Mycenean Linear B texts – with more diverse, labour-intensive smallholder farming evidenced in the archaeobotanical record (Halstead 2014: 60, 119, 319 and references therein). Such a system was fundamentally land-limited in nature, since elite maintenance of specialized plough animals raised the value of land relative to labour.

Wealth inequalities in two farming systems. Figure 3 shows the estimated Gini coefficients and the designation of each case as labour- or material-wealth-limited.

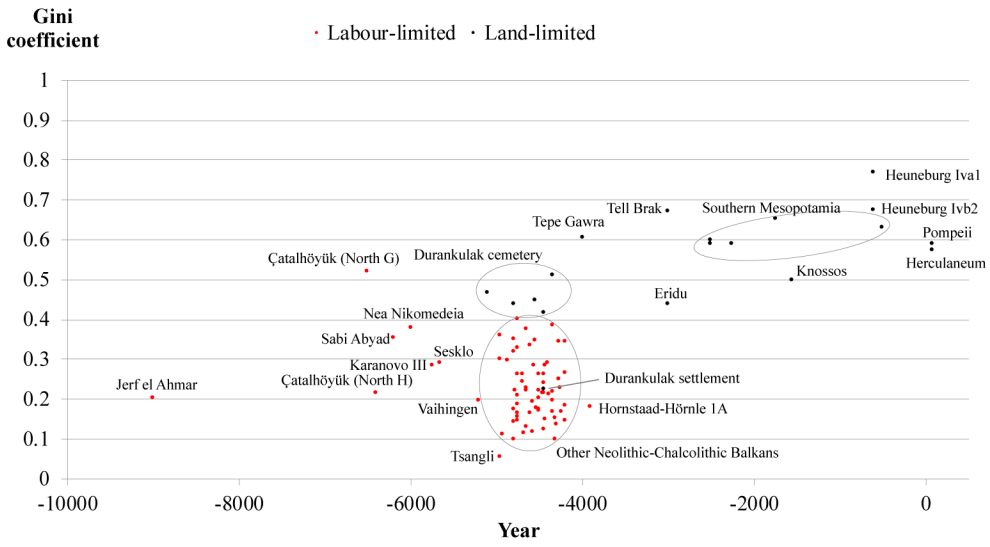

Figure 3 **Wealth inequality in labour-limited and land-limited economies.** Estimated Gini coefficients are adjusted for comparability (Fochesato, Bogaard and Bowles, Submitted). Date estimates represent the midpoint of the time intervals provided in the original sources.

Figure 4 shows the frequency distribution of Gini coefficients for the two farming systems. The difference between them in the average Gini coefficients is substantial and statistically significant. This is also true using the raw (unadjusted) Gini coefficients, when controlling for an exponential (imprecisely estimated) positive time trend, or restricting attention to a 1300-year period when both of the systems are well represented in the dataset (online supplement).

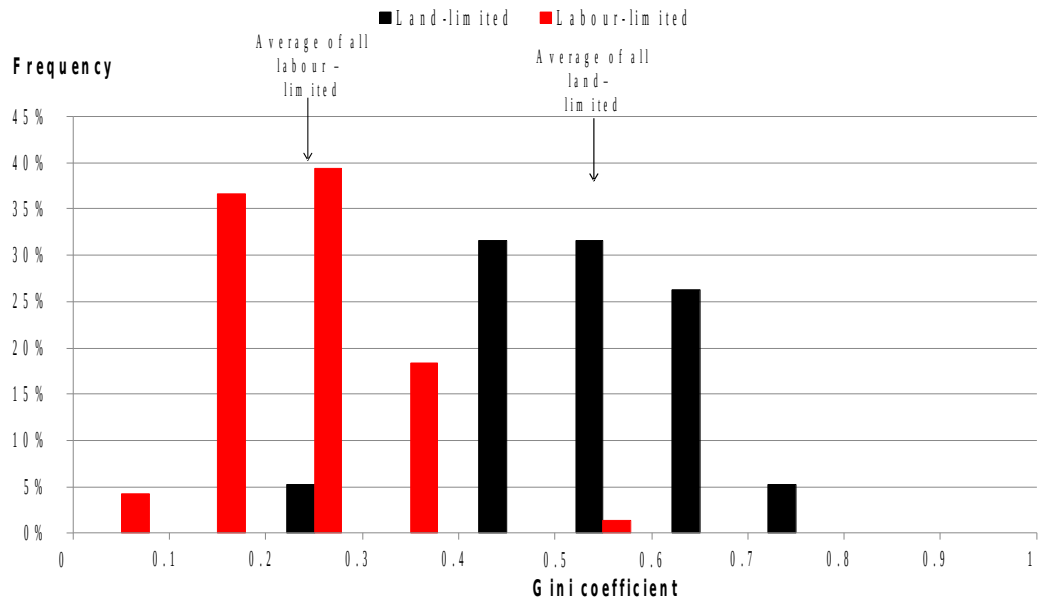

Figure 4 **The frequency distribution of the Gini coefficients for labour- and land-limited economies**. Differences in the means of the two faming systems are significant at the p=0.0001 level.

6. The transformation of an egalitarian labour-limited farming economy

Figure 3 shows that most of the earlier observations are labour-limited, while most of the later ones are land-limited, with substantial overlap between the two systems around the fourth millennium BC, and that some regional populations made a transition from the former to the latter. Our model and data provide an account of how this could occur.

Consider a population engaged in labour-limited farming, similar to point **b** in Figure 2a. How could a transition to a land-limited system illustrated by point **d** in Figure 2b occur? Our answer is based on two facts. First, by definition, in labour-limited economies labour is relatively valuable compared to land. Second, wealth disparities, while modest, are far from absent in the labour-limited populations. Even in "aggressively egalitarian" Çatalhöyük (Hodder, 2014) by our estimates the wealthiest two households had three times the average wealth in Level North.G. During the Neolithic these disparities grew significantly in some labour-limited economies. While the evidence is necessarily indirect, it seems likely that over this period, too, the

domain of private household property – the legitimate and effective right to exclude others from the use of the objects one owns – tended to expand (Halstead, 2006).

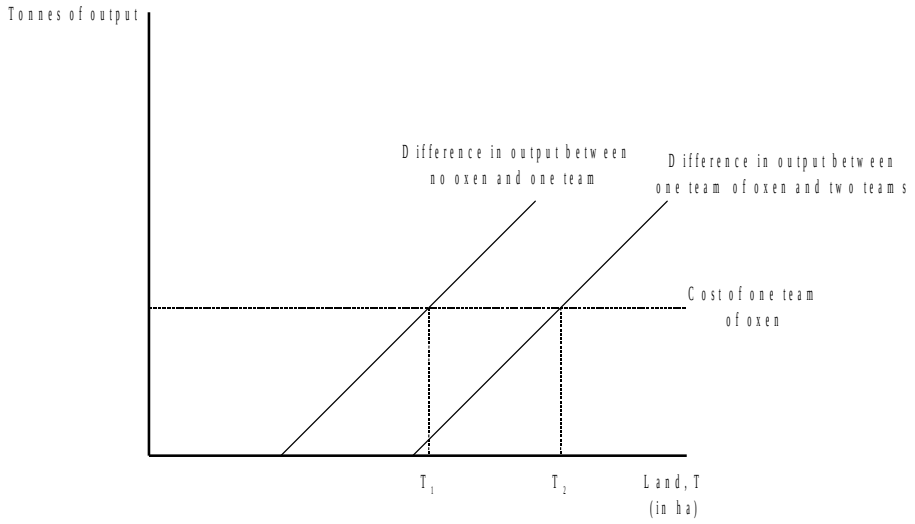

Figure 5. **Conditions under which a formerly labour-limited farmer would take up land-limited farming.**

Given this institutional setting, and pre-existing wealth inequality in a labour-limited system, there must have been many populations in which some households had access to both the resources for maintaining plough oxen and additional land for expansion (Halstead, 1995). If one of the wealthier individuals in the labour-limited economy were to consider acquiring an ox team for their exclusive use, and farming a larger area of land with less intensive labour input, what calculation would allow an assessment of the likely advantages to the household of doing this?

The rising solid line on the left in Figure 5 shows how the addition to output possible by having a single team of oxen increases the more land is available, but with the labour inputs unchanged. With little land it adds nothing. The contribution of the ox team increases for larger plots because the more land the wealthy person has, the

more valuable is the team of oxen (i.e. they are complements) (Clark and Haswell, 1964).

The dashed horizontal line represents the annual cost of acquiring and maintaining one ox team. For a person who has, or can acquire, more than T_1 units of land, the cost is less than what the team will add to production. That farmer will find it advantageous to maintain one team of oxen. A person with T_2 units of land will acquire a second team.

With oxen, the wealthy farmer will seek to acquire more land, because land will now be more valuable to the land-limited farmer-in-the-making than to the other farmers in his community. Moreover, acquiring additional land will be feasible; there will be some voluntary transfer of land from the garden farmer to the would-be land-intensive farmer that is mutually beneficial. This is a process of wealth accumulation (land and oxen) with positive feedbacks, possibly leading to elevated levels of wealth concentration. Rights to farm larger amounts of land may also have been acquired coercively.

The person 'selling' or giving up the land might become the tenant or employee of the land-and-ox owner, or part of a growing pool of labour available seasonally at harvest, when the labour demands of the extensive farming model peak. If, in the new economy, other wealthy farmers emulated the now oxen-and-land farmer, the value of land would eventually have risen (as shown by the steeper slope top curve in Figure 2b). As a result, land would now be scarce and labour abundant.

This situation would create fertile ground for the emergence of sustained inequalities. Bogucki (1999) conjectured that 'with time, the number of cattle-poor households increased in number, while the number of cattle-rich households forms a progressively smaller proportion of the population'. The population could develop a class structure: some owning a considerable amount of land and one or more teams of oxen and others working for them under some kind of subordinate relationship as renters, share croppers, clients, employees or unfree labour. This narrative is a conjecture of course, but it is consistent with ethnographies of small-scale farmers in the recent past who worked with oxen (Halstead, 2014).

Given the limited bargaining power of these newly dependent classes in a labour-abundant economy, it seems unlikely that their consumption levels would have increased proportionately with the increase in average labour productivity (that is, output per worker) made possible by the introduction of animal traction. As a result,

the cultivation of larger areas per worker would have provided a surplus capable of supporting a divergence of living standards among the owning class and the rest. Large extended households with complex multi-faceted economies including animal traction-based farming are plausible precursors of temple- and palace-based land-holding institutions (Pollock, 1999).

The transition to a land-limited economy may thus have been a step along the way not only to sustained wealth inequalities, but also to the emergence of permanent political inequalities formalized in new structures of governance. This narrative is consistent with the association of cattle traction with social prestige, emerging around the mid-fourth millennium BC in western Eurasia, the horizon highlighted by Sherratt in his secondary products revolution model (Sherratt, 1981, 2006). Though we now know that traction *per se* long predated this horizon (Isaakidou, 2006, Helmer and Gourichon, 2008, Antolín, Buxó, Jacomet et al., 2014, Gaastra, Greenfield and Linden, 2018), this was the timeframe when specialized ploughing animals came to be exploited as part of emerging extensive land-limited farming systems which fed the expanding cities of Mesopotamia, as at Tell Brak (Styring, Charles, Fantone et al., 2017). Sherratt's insight was to suggest that Near Eastern urbanization demonstrated the amplifying effects of cattle traction on production and prompted a wave of new prestigious and even ritual associations with paired cattle draught across Europe (Hadjikoumis, Robinson and Viner-Daniels (eds.), 2011).

7. Discussion

The evidence on farming techniques and wealth inequality that we have presented is consistent with the hypothesis that a sustained increase in wealth inequality in late prehistoric western Eurasia was associated with a transition from labour- to land-limited farming. These new more unequal economies were characterized by a substantial value of land or other material wealth (including slave labour) that could be accumulated and transmitted across generations. Our analysis also provides one possible process for how a labour-limited farming economy with modest inequality could be transformed into a land-limited system with elevated inequalities. This economically-driven narrative of the emergence of sustained and substantial inequality does not preclude complementary or competing accounts in which heightened power differentiation among households and other political developments play a more important or even initiating role.

Our model may also help to illuminate the farming-inequality nexus elsewhere (Kohler, Smith, Bogaard et al., 2017, Fochesato, Bogaard and Bowles, Submitted). Even where animal traction was absent – as in the western hemisphere, or in east Asia prior to the second millennium BC (Larson and Fuller, 2014) – substantial levels of inequality may similarly have arisen due to agricultural production that was material wealth-limited: for example, where the physical supply of land relative to population (and hence labour) was restricted (Moseley and Day (eds), 1982), and/or where slavery made human labour the equivalent of a material form of wealth that could be accumulated and transmitted across generations.

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