Sex, Equality, and Growth (in that order)

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Abstract: We set up a model of economic and demographic long-run development, with land and human capital as production factors, and inequality in income and reproductive success (in the form of polygynous mating) playing a central role. The model generates a slow and gradual compression of the income gap between landholders and landless, together with rising levels of human capital. This process spurts at some stage, as society endogenously transits into sustained growth. Simultaneously, inequality in income and reproductive success drops; society becomes monogamous.

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1. Introduction

> "polygyny has tended to disappear in response to egalitarian values – not values of equality between the sexes, but equality among men."
>
> Robert Wright (1994, p. 98)

> "What put an end to polygyny? *Democracy.* Power is – as it always was – a means to sex. [...] For a few million years, we hunted or scavenged for a living, and lived in fairly free democracies. Then, for the last few thousand years, many of us farmed for a living, and lived in despotisms. The tide turned, [starting] in England, in the last few hundred years. Despotism gave way, again, to democracy. And polygyny started to give way to monogamy."
>
> Laura Betzig (2002, p. 85)

The aim of this paper is to formulate a unified theory of economic and demographic long-run development of human societies, where the focus is on the interaction between class structure and reproduction. The underlying hypothesis is that the spurt in growth rates in living standards that started in Western Europe a couple of hundred years ago had something to do with increasing equality in income and power between men, the invention of democracy, and the rise of monogamy.

This theory has three elements. The **first element** is the presence of two sources of income: land and human capital. Land is excludable, and can be concentrated into the hands of a small group of agents. Human capital is more evenly distributed, due to knowledge spillovers. For modelling purposes, we let human capital be completely evenly distributed, i.e. a non-rivalry public good. (This is not crucial; what matters is that human capital is always *more* equally distributed than land.) As a result, societies where land is the major source of income tend to have a less equal income distribution than societies where human capital is more important.

The **second element** involves *differential reproductive success* across men (i.e., rich men having more offspring), and *heritability of status* from father to son (i.e., rich men's sons fare better than those of poor men). That reproductive success differs between men is well documented: in polygynous[1] societies it is rich and powerful men who have more wives and thus more offspring; in monogamous societies the rich and powerful tend to father more illegitimate children than poor men.

It is also generally true that the father's status affects his offspring. Most obviously this holds for legitimate children who stand a chance of inheriting, but even illegitimate children benefit from the father's status. For example, slaves fathered by the slavemaster tend to be better treated than other slaves, and more likely freed.

In our model, reproductive success differs between landholders and landless. Thus, in every period proportionally more agents tend to be fathered by landowners than by landless. And having a father who is a landowner makes it easier for an agent to enter the landholding class.[2] As a result, the landholding class slowly gets larger over time.

As a **third element** of this theory we let the accumulation of human capital depend on the number of people engaged in research, intellectual exploration, etc.

[1] Polygyny means that one man can take several wives. The term polygamy formally includes polyandry, meaning that a woman can take several husbands, which is extremely rare.

[2] The practice of letting only one son inherit (so-called primogeniture) is consistent with how we set up the model. We do not assume that every son of a landowner inherits the father's class status. Rather we assume a "leakage" effect: at least one son inherits his father's status, and among the remaining sons a small exogenous fraction do so too; the rest become landless.

– for short, call it *thinking*. We want to capture the idea that, in history, thinking has been the privilege of the rich. There are many ways to model this: we could e.g. let thinking be a consumption good which agents demand more of when earning more. To keep things simple we just postulate that an agent becomes a thinker if his income exceeds some exogenously given threshold.

In societies where human capital is low the landless (whose only income, recall, is from human capital) cannot afford to think. Landholders may afford to think, depending on how productive land is and how many agents share the landholdings. If land is unproductive, and/or split up between many landholders, each landholder will be poor, and no agents will be thinkers. If land instead is concentrated into the hands of only a few agents these landholders may be rich enough to become thinkers. In that sense, some inequality is needed for human capital accumulation to get started.

Consider thus a society with a very unequal land distribution. Being few to share the fruits of the land, the landholders are much richer than the landless, and thus have more offspring. As the landowning class expands more agents become thinkers, and the level of human capital gradually increases. This raises the income also of the landless (since human capital is a public good, recall). At some stage human capital reaches a critical level above which also landless agents become thinkers, so the set of thinkers suddenly comes to include *all* agents in the economy. This creates a jump in human capital productivity, pushing the economy to sustained growth in human capital: an industrial revolution. This could capture the rise in public schooling in England from 1830 and onwards (Matthews et al. 1982, Ch. 4; Galor and Moav 2004).

The process leading up to sustained growth is characterized by shrinking income gaps between landholders and landless. Mirroring this trend the degree of differential reproductive success declines over time: society becomes more monogamous. As human capital growth spurts, income gaps disappear, and society becomes fully monogamous. We argue that this fits well with the historical evidence. Anthropologist Laura Betzig argues that polygynous mating (as opposed to polygynous marriage) died out close to the 20th century. Such a late timing discounts other explanations (for example, that the Church made Europe monogamous) but fits well with a marked decline in income inequality and the birth of democracy.

We also allow human capital to affect mortality rates and the quantity-quality choice in children. This enables our model to replicate a demographic transition: mortality falls before fertility rates, and population growth rates spurt in between. Moreover, the rise in per-capita income growth is initially accompanied by a rise in population growth before the two diverge. The model thus replicates a so-called post-Malthusian phase of development, preceding the transition into sustained growth, consistent with the European experience (see e.g. Galor and Weil 2000; Lagerlöf 2003a).

But this is not a unique scenario. A society starting off with an unequal land distribution may instead follow a path where the expanding size of the landholding class dilutes each landholder's income, so much that their incomes eventually fall below the threshold for thinking. Human capital then suddenly drops, as all thinkers vanish, and the economy slowly converges back to an egalitarian hunter-gatherer state. This captures the downfall of an early civilization. Which path the economy follows depends on e.g. land productivity.

Our work adds to (and borrows from) various fields of literature, but three groups of papers can be singled out as more central. First, there is a recent upsurge of papers on long-run growth, trying to understand e.g. the industrial revolution or the demographic transition.[3] We share with most of these an element

[3]An incomplete list would include Jones (2001), Lucas (2002, Ch. 5), Galor and Weil (2000),

of endogenous human capital investment and fertility, and a general ambition to explain the same historic growth patterns. However, none of these analyzes the growth implications of differential reproductive success.[4]

Second, our paper relates to a literature on polygyny. Some early, but more micro oriented, contributions (Becker 1991; Bergstrom 1994a,1994b; and Guner 1999, Section 5.2) do not study growth, or try to explain why polygyny died out. Edlund and Lagerlöf (2002) discuss growth and polygyny, but treat polygyny as an exogenous institution. Tertilt (2003) explains, inter alia, cross-country income gaps in the world today in a model with polygyny, fertility, and saving. As Edlund and Lagerlöf (2002) she treats polygyny as exogenous.

Our way of thinking about polygyny is close in spirit to Gould, Moav and Simhon (2003), who explain "the mystery of monogamy" (i.e., the practice of monogamy in unequal societies) by thinking of it in terms of a quality-quantity trade-off in children. If mothers are important for children's quality, and if men prefer quality over quantity, then men may prefer one wife of high quality over several wives of low quality. Monogamy may thus arise at equilibrium as a voluntary choice of men, despite income inequality.[5] Moreover, it is in societies where in-

Galor and Moav (2002), Lagerlöf (2003a,b), and Tamura (2001). Other related work abstract from demographics, and thus do not try to explain the demographic transition, e.g., Goodfriend and McDermott (1995) and Hansen and Prescott (2002).

[4]Galor and Moav (2002) is an exception. They model the role played by differential reproductive success in the selection of genetically heritable traits (preferences for high quality offspring, versus high quantity). We rather model the heritability of class status.

[5]A similar point is discussed informally by Becker (1991, p. 95) who suggests that "[a]s societies have become more urbanized and developed over time, families have greatly reduced their demand for 'quantity' of children and greatly raised their demands for education, health, and other aspects of the 'quality' of children. [...] Since the marginal contribution of men to quality is much greater than quantity, our analysis predicts correctly that the incidence of polygyny has declined substantially over time."

come inequality is generated by inequality in human capital (and not in e.g. land) that rich and otherwise potentially polygynous men choose monogamy. This is not because human capital is more equally distributed than land (as we assume here), but because human capital makes it cheaper to produce high-quality offspring. In contrast to Gould et al. (2003), we do not think of modern monogamy as a mystery in the first place: we think monogamy arose because society became more equal (or more democratic). Ours is not an exhaustive explanation, but should be seen as complementary to the mechanism of quality-quantity substitution captured by Gould et al. (2003).[6]

There is also a third set of papers on growth, class structure, and ownership of production factors. Some focus on the roles played by physical and human capital for inequality in the course of industrialization (Galor and Moav 2003, 2004), or on landownership and human capital (Galor, Moav and Vollrath 2003). (See also further references therein.) Some also link land inequality to democracy: Bertocchi and Spagat (2003), for example, assume a threshold for wealth, below which agents are not allowed to vote. None of these talk about differential reproductive success. Our modelling approach is also more "black-boxed," but the mentioned papers show that there are richer ways of modelling the same mechanisms.

The rest of this paper is organized as follows. Next, Section 2 outlines some of the facts we want to explain. Section 3 starts setting up the model, describing the structure of landholdings and population, budget constraints and preferences, the concept of thinkers, and the gender dimension of the model. Section 4 illuminates the dynamics in a phase diagram, and gives some numerical examples to illustrate

[6] Another difference is that Gould et al. (2003) use a static setting, whereas we use a fully dynamic unified growth framework. Our ambition is not only (or primarily) to explain the rise of monogamy, but to argue that the changes in the class structure that mirrored rising monogamy had something to do with the take off to sustained growth.

the workings of the model. Section 5 ends with a concluding discussion.

2. The facts

2.1. Economic and demographic long-run trends

Human history has been characterized by mostly slow changes in population and living standards. It was only a couple of hundred years ago that Western Europe entered an era of sustained growth in per-capita incomes, known as the industrial revolution. This was associated with equally dramatic demographic changes: first declining mortality, later falling birth rates, and in between a phase of rapid population expansion – a process known as the demographic transition. (See Figure 2.1.)

Note that growth in population and per-capita income increased simultaneously for many years. This is sometimes referred to as the post-Malthusian phase of development, falling in between the final stage of modern growth, and the preceding, Malthusian, stage (Galor and Weil 2000). Another empirical regularity of the peak in population growth during the demographic transition is that mortality rates fell before birth rates (see e.g. Jones 2001 and Livi-Bacci 1997).

2.2. Differential reproductive success

The most effective way for rich and powerful men to father many offspring is to mate with many women, i.e., to mate polygynously. An authority on how men throughout human history have achieved this is anthropologist Laura Betzig. Across human societies she has found that measures of polygyny are positively correlated with measures of despotism and hierarchy (Betzig 1986). For instance, hunter-gatherers are not very hierarchical and also less polygynous, compared to agrarian societies.

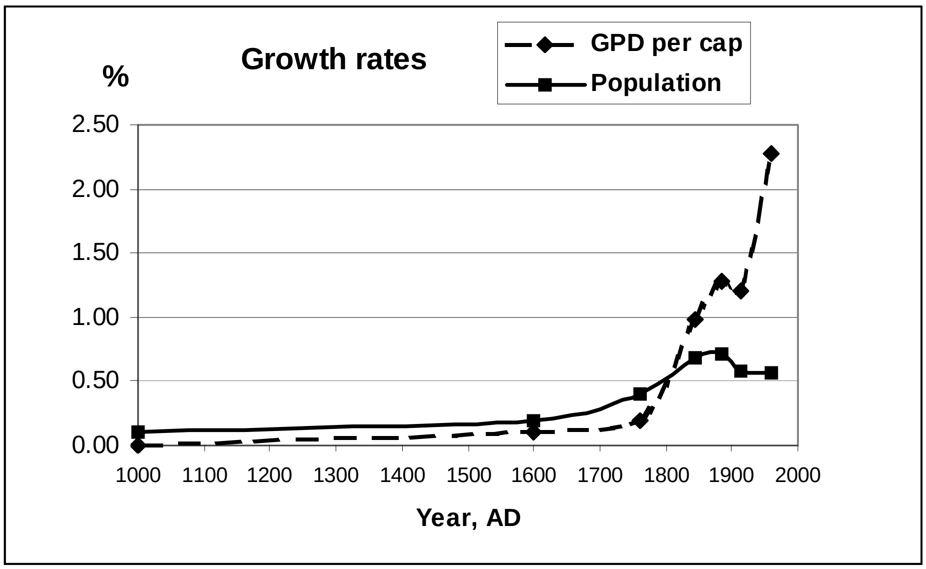

Figure 2.1: Annual growth rates in Western Europe. Sources: Maddison (1982, Table 1.2; and 1995, Table G). The years are chosen as midpoints of the periods reported.

Betzig has also examined the six "pristine" civilizations on earth, located in Mesopotamia, Egypt, China, India, South America (the Incas), and Mesoamerica (the Aztecs). (Pristine here means that they developed largely independently of each other and of later civilizations, so they can be thought of as natural experiments.) These societies were all highly unequal and despotic, and also had a very unequal distribution of reproductive resources, women: multiple wives and/or sex partners was the privilege of the ruling classes (Betzig 1993).

Betzig also documents polygynous mating in the Roman Empire, where rich men e.g. bought and held female slaves for sexual services (Betzig 1992). In medieval Europe the rich and powerful among both laymen and clergy – who were monogamously married and nominally celibate, respectively – could father many illegitimate children (Betzig 1995). The same pattern continued up until modern England, where rich men often had sex with their household servants, who tended to be young unmarried females. Another technique was to access married women by bribing their husbands (Betzig 2002).[7]

This should come as no surprise. Natural selection has designed males to strive for as many mating partners as possible, and they use whatever means, power and resources they have to conquer women. In all societies – whether they tolerate explicitly polygynous marriage or not – it is the richest and most powerful high-status men who have more sex partners. (This also holds in modern societies; see e.g. Perusse 1993.) As a corollary, more inequality in income and power tends to come with more inequality in the distribution of women, i.e., more polygynous mating. The observation that hunter-gatherers are more monogamous can thus be explained by the fact that they are more equal: an unequal income distribution requires some sort of surplus and in these societies, where most men live at the

[7] In fact, rich men's reproductive advantage need not have been only illegitimate. Clarke and Hamilton (2003) finds that wealthy men in 17th century England had more legitimate children.

same subsistence level we see small gaps in income and power (see e.g. Wright 1994, p. 94).

What is surprising is not that unequal societies historically have been polygynous, but that most of the world today has so huge gaps in incomes but is still mostly monogamous. This is what Gould et al. (2003) call "the mystery of monogamy." The richest man in the world keeps only one wife at a time. He may re-marry, and/or keep mistresses – so-called serial monogamy – but even in a life time no man alive today has monopolized thousands of women, as did the rulers in early human civilizations. Why?

2.2.1. We are more equal today

In a general sense, it seems that rich men today are somewhat more restricted with regards to what they can do with their wealth. The democratic control exercised by the state over even the richest men discounts the value of their wealth in power terms. For instance, Bill Gates cannot hire an army to force the U.S. Congress to pass laws to his liking. (He would probably lose his wealth trying anyhow, and maybe his life.) In that sense, the *effective* income distribution seems much more equal today than in those early "pristine" civilizations.

We do not think this is farfetched. In her most recent work, on polygyny in England, Laura Betzig herself links the rise of monogamous mating to the rise of democracy (Betzig 2002; see also the citations in the introduction). A central point that Betzig makes is that rich and powerful men continued to *mate* polygynously long after Europe had begun to *marry* monogamously (e.g. Betzig 1995, 2002). Of course, mating is harder to measure than marriage, but we can say something. As mentioned, one way in which rich and powerful English men achieved polygynous mating was to hire women as household servants. Betzig documents a downward trend in the number of household servants held by the

English upper classes; after a longer gradual decline the institution died out in the 20th century. This came simultaneously with a decline in the powers of the King, and we can also see a longer downward trend in the estimated number of children illegitimately fathered by the Kings of Britain. One can discuss the exact timing but these changes did not come with the spread of Christianity, or as the Church established its powers, as one may think, but closer to the 20th century, around the time of the gradual rise of democratic institutions – and surprisingly parallel with a marked increase in income equality.

The little we know about trends in the long-run income distribution indicate that we are more equal today than in polygynous times. Looking at British income data Soltow (1968) finds a declining trend from the 1400's up until today, accelerating in the 20th century. (Champernowne and Cowell 1998, Ch. 3 sum up other evidence painting a similar picture.) Fogel (2000, Ch. 4) presents data over a number of measures from the 20th century U.S. and Europe, where improved equality shows up in the Gini ratio for the income distribution; in homelessness; and in class differences in life expectancy, stature, and weight. Two-thirds of the reduction from 1700 to 1973 in the Gini ratio for England took place in the 20th century (Fogel 2000, p. 143).

Fogel's suggested explanation for the reduction in inequality in the 20th century is also consistent with the mechanism driving our model: "The factor accounting for most of the reduction that has so far been achieved in the inequality of the income distribution is the decline in the relative importance of land and physical capital, and the increasing importance of human capital (labor skills), in the process of production" (Fogel 2000, p. 157). Notably, Fogel downplays the importance of e.g. government programs. Soltow (1968, p. 29) makes essentially the same point, suggesting that to "a continued widening of opportunity of the non-propertied income groups" lay behind the fall in income inequality.

But if we believe that a more equal distribution of income and power – or, more vaguely, the birth of democracy – lies behind the rise of monogamy we must ask: what caused the transition from despotism/polygyny to democracy/monogamy?

2.3. How the father's status affects the offspring

Our theory is that differential reproductive success has worked as a force to diminish gaps in income and power. The idea is simple: if rich men have more offspring their wealth must be split up over time at a faster rate than that of the less wealthy. This should not be interpreted too literally. Land estates are often not divided equally among all sons, which has probably served the very purpose of avoiding such dilution of the wealth (cf. Chu 1991). Still, unless we buy the opposite extreme – that every son who does not inherit is as bad off as if his father had no wealth – simple logic tells us that this equalizing force cannot help but work. The issue is not whether all sons inherit the same amount of land but whether there are any benefits of being fathered by a rich man compared to a poor. We argue that there are.

2.3.1. Legitimate children

In most human societies with property rights to land legitimately fathered sons have had precedence in inheritance of the father's estate. Often the oldest son would inherit most, or all, of the land – a system called primogeniture. In that respect, the six "pristine" civilizations did not differ much from, for instance, medieval Europe. However, other legitimate children were typically not left without spoils altogether. From the birth of civilization, all the way up to medieval Europe, those of the ruler's legitimate offspring who did not inherit would typically join the intermediate classes: the military, the clergy, or some other bureaucracy (Betzig 1993, 1995). These classes were not without power, and that power ultimately rested on some form of land ownership. For example, disinherited sons who joined the clergy in medieval Europe often arrived with some land attached. If they rose in the Church hierarchy they could become just as rich and powerful as any layman, and possibly father as many (but illegitimate) offspring (Betzig 1995).

One may also argue that this is consistent with the fact that human societies have evolved in a direction of increased "complexity," with a growing number of classes and levels of government in between the ruler and the agents at the bottom of the distribution (Nolan and Lenski 1999, Ch. 6). When it comes to setting up a model, we choose to have only two classes, landholders and landless, but we may interpret the landholding class as including also e.g. the clergy, the military, etc.

2.3.2. Illegitimate children

Also illegitimate children may benefit from their fathers' status. Again, this is what we would expect: natural selection should endow men with an instinct to help all their sons – not only their legitimate first borns – since they all carry the fathers' genes.

When fathers did not leave them any bequests they did help their illegitimate children in other ways. Consider some examples. Manumission of a slave is a big transfer of wealth from the slaveowner to the slave. As a general rule slaves fathered by the slavemaster tend to be better treated than other slaves, and more likely to be freed. This pattern shows up among the Romans (Betzig 1992), in the Americas (Davis 1966, Ch. 9), and in the Southern U.S (Clinton 1982, Ch. 11). In their classic "Time on the Cross," Fogel and Engerman (1989, p. 132) note that "mulattos" were much more common among freedmen and in the cities.

Other benefits come more automatically. Genetically determined characteristics which have influenced status in many societies – skin color, intelligence, and body size – are inherited from the father. Also, among humans as well as neighboring primate species, having a powerful father can buy protection against other violent males.

3. The basic structure of the model

Consider the following overlapping-generations model. In every period t there is a continuum of agents, each living for two periods: childhood and adulthood. Each individual also belongs to either one of two sexes: male or female. In every period t there are P_t adult men and equally many adult women. (In the same period there are also P_{t+1} boys and P_{t+1} girls living in childhood.)

Men belong to either one of two classes: landowners, or rulers, and landless subjects. In period t there are P_t^R landowners and P_t^S landless agents:

$$P_t^R + P_t^S = P_t. \tag{3.1}$$

Let λ_t denote the fraction of the population belonging to the landowning class:

$$\lambda_t = \frac{P_t^R}{P_t}. \tag{3.2}$$

The total amount of land in productivity terms is denoted by M. Letting m_t denote average landholdings among members of that class we can write:

$$m_t = \frac{M}{P_t^R}. \tag{3.3}$$

3.1. Human capital and income

A landowner's income is given by

$$y_t^R = BH_t + m_t, \tag{3.4}$$

where H_t denotes human capital, earning an income of B per unit.

We normalize output per unit of land to one, and m_t (recall) denotes land per landowner. This formulation can be thought of as short-hand for a simple two-sector model: one sector uses only land, one only human capital, and both have linear technologies.

As argued above, human capital has historically been more evenly distributed than land. To capture this we here make the extreme assumption that H_t is identical across classes, i.e., a public good. The landless thus earn

$$y_t^S = BH_t. \tag{3.5}$$

Human capital of generation $t+1$ is built up according to

$$H_{t+1} = A_t H_t + \overline{H}. \tag{3.6}$$

where A_t measures human capital productivity, i.e., how well knowledge is accumulated from one generation to the next, and $\overline{H}$ constitutes the minimum level of human capital.

3.2. Thinkers

We want to capture the idea that knowledge is accumulated through intellectual activities, which are be performed only by agents who have the luxury of not being forced to spend all their time and effort working for their subsistence. One way to model this would be through a time allocation decision between "thinking" and "working," made subject to some subsistence consumption constraint. Only those who have a large enough non-labor income, and/or agents who need to work only part time to survive, would be spending time thinking.

To simplify the analysis we instead postulate that intellectual activity is performed by agents whose total income exceeds some threshold level, $\overline{y}$. Call such agents thinkers, and denote their number by X_t, as given by

$$X_t = \begin{cases} 0 & \text{if } y_t^R < \overline{y} \\ P_t^R & \text{if } y_t^S < \overline{y} \leq y_t^R \\ P_t & \text{if } y_t^S \geq \overline{y} \end{cases} . \tag{3.7}$$

In other words, when only landowners' incomes exceed the threshold, only they are thinkers; when the income of the landless (and thus also landowners) exceed the threshold, they are all thinkers; and when not even the landowners' incomes exceed the threshold, there are no thinkers.

Next, let human capital productivity, A_t, be a function of the number of thinkers in this economy. We choose the following functional form

$$A_t = A^* \left(\frac{X_t}{\theta + X_t} \right), \tag{3.8}$$

where $\theta > 0$ and $A^* > 1$ (ensuring that sustained human capital growth is possible for high enough X_t). This functional form ensures that A_t is bounded from above as the number of thinkers grows indefinitely.

3.3. Budget constraints and preferences

Let variables referring to agents belonging to the landowning and landless classes be distinguished by the super-index i ($i = S, R$). Consumption takes place only in adulthood and class-i consumption is denoted by c_t^i, and (recall) a class-i agent earns y_t^i. Moreover, he has z_t^i wives, each of whom gives birth to n_t^i children. Both

z_t^i and n_t^i are continuous. Men invest q_t^i units of the consumption good in each child, so the budget constraint can be written:

$$c_t^i = y_t^i - z_t^i n_t^i q_t^i. \tag{3.9}$$

Preferences are given by

$$U_t^i = (1-\beta)\ln(c_t^i) + \beta \ln\left\{n_t^i z_t^i \left(s_t^i\right)^{\rho(H_t)}\right\}, \tag{3.10}$$

where $\beta \in (0,1)$ and s_t^i denotes the survival rate of each offspring.

The exponent $\rho(H_t)$ denotes the weight agents put on the quality (the survival rate, s_t^i) of children, relative to quantity, $z_t^i n_t^i$. We assume that $\rho'(H_t) > 0$, i.e., parents with more human capital put a higher weight on their children's quality. This is a convenient way of generating a quality-quantity substitution in the course of economic development: in societies with more human capital parents care more about the survival rate of their children. Another way to model the same mechanisms would be to assume a higher return to investing in children's health in societies where medical and other knowledge is greater.

3.4. The survival function

The function which determines the survival rate of each child is given by

$$s_t^i = \exp\left[\frac{-1}{q_t^i}\right], \tag{3.11}$$

where we note that $\lim_{q_t^i \to \infty} s_t^i = 1$ and $\lim_{q_t^i \to 0} s_t^i = 0$, i.e., infinite (or zero) quality investment in children drives the survival rate of a child to 100 % (or zero). The exponential functional form, together with the logarithmic utility function, will give us nice closed-form solutions.

3.5. Male behavior

Maximizing utility in (3.10), subject to the consumption budget constraint in (3.9) and the survival function in (3.11) the first-order condition for n_t^i becomes:

$$(1-\beta)\left[c_t^i\right]^{-1} q_t^i z_t^i = \beta\left[n_t^i\right]^{-1}. \tag{3.12}$$

The first-order condition for q_t^i becomes

$$(1-\beta)\left[c_t^i\right]^{-1} n_t^i z_t^i = \beta\rho(H_t)\left(\frac{1}{q_t^i}\right)^2. \tag{3.13}$$

Using (3.12) and (3.13) we see that

$$q_t^i = \rho(H_t), \tag{3.14}$$

i.e., quality investment depends only on the weight on quality in the utility function, $\rho(H_t)$. This in turn is a function of human capital, which is assumed to be the same across classes. Thus, the survival rate is identical across classes, so we can disregard the index i, and write

$$s_t = \exp\left[\frac{-1}{\rho(H_t)}\right]. \tag{3.15}$$

3.6. Allocation of women

Women choose which man to marry, choosing among all men. We assume that women marry so as to maximize the number of surviving offspring, which is given by $s_t n_t^i$. [Recall from (3.15) that s_t is the same across classes.] Using the budget constraint in (3.9), together with the first-order condition in (3.12), and the optimal choice of q_t^i in (3.14), we see that per-woman fertility, n_t^i, is given by

$$n_t^i = \frac{\beta}{\rho(H_t)}\frac{y_t^i}{z_t^i}, \tag{3.16}$$

which is increasing in the income of the man, and falling in the number of wives he has. As a consequence, women simply allocate themselves so as to equalize the income-per-wife ratio (y_t^i/z_t^i) across men. Thus n_t^i is the same across classes, so we can suppress the subindex i, i.e., $n_t^R = n_t^S = n_t$.

3.7. Marriage market equilibrium

Each of the P_t^i members in class i marries z_t^i wives $(i = R, S)$. Total demand for wives is thus given by, $z_t^R P_t^R + z_t^S P_t^S$, and total supply is given by the total number of women, which is the same as the total number of men, P_t. Setting supply equal to demand and using the notation in (3.2) we can write the marriage market equilibrium as

$$z_t^R \lambda_t + z_t^S (1 - \lambda_t) = 1. \tag{3.17}$$

Next, setting $n_t^i = n_t$ in (3.16) we can write

$$\frac{z_t^R}{z_t^S} = \frac{y_t^R}{y_t^S} = \frac{BH_t + m_t}{BH_t}, \tag{3.18}$$

where the second equality uses the expressions for y_t^R and y_t^S in (3.4) and (3.5). We can use (3.17) and (3.18) to solve for the number of wives in each class:

$$z_t^R = \frac{BH_t + m_t}{BH_t + \lambda_t m_t}, \tag{3.19}$$

and

$$z_t^S = \frac{BH_t}{BH_t + \lambda_t m_t}. \tag{3.20}$$

This result can be seen as a special case of Proposition 6 in Bergstrom (1994a). It tells us that wives per man in each respective class is proportional to how much the class members' incomes deviate from the mean. The mean income in the population is given by the denominators in (3.19) and (3.20), i.e., the sum of income from human capital, BH_t, which is the same across classes, and the mean income from landholdings, $\lambda_t m_t = M/P_t$ [see (3.2) and (3.3)]. Note that the average number of wives is one, which must hold whenever there are equally many men as women, but since there are only two classes there is no man who has exactly one wife.

4. Dynamics

4.1. Class dynamics

The number of male offspring of landowners is $z_t^R n_t s_t/2$. (Half of the children are sons, half are daughters.) We assume that the only way to become a member of the landowning class is to be born into it (and being a man). If landowners have slow reproduction rates, i.e. if $z_t^R n_t s_t/2 < 1$, the next generation of landowners will be fewer than the preceding. That is, if each landowner has less than one son all sons stay in the landowning class, and P_t^R falls over time.

If $z_t^R n_t s_t/2 \geq 1$, it is not clear what fraction of the sons should inherit. The most natural theoretical approach would be to assume that landowners allocate land among sons in order to maximize their sons' reproductive success, i.e., the total number of grandchildren their sons produce. In that case it can be seen that father is then *indifferent* as to how the land is allocated. Intuitively, concentrating the inheritance to fewer offspring implies higher income and higher reproductive success for those who do inherit – but, trivially, that higher reproductive success is allocated to fewer sons. In our model, these effects cancel: the total number a grandchildren is the same, only reared by different sons.[8]

[8]Chu (1991) provides a theoretical analysis of a father's optimal allocation of bequests among his offspring, but without any explicit modelling of differential reproductive success.

Nor is it empirically clear what is a right assumption to make here. Assuming perfect primogeniture (letting only one son inherit) implies that the remaining offspring move to the landless class. Such extreme social mobility was rarely observed in early human civilizations. Rather, those of the ruler's offspring who did not inherit joined intermediate classes, such as the military, or clergy; they would rarely be left without any spoils altogether (e.g. Betzig 1993). This is also consistent with the fact that human societies have evolved in a direction of increased complexity and stratification, with a growing number of classes and levels of government (Nolan and Lenski 1999, Ch. 6). For that reason, we believe that *imperfect* primogeniture is a better assumption.

More precisely, we let the number of landowners in period $t+1$ be given by the sum of (1) the P_t^R legitimate heirs of generation t; and (2) some (small) fraction δ of the remaining offsprings. That is,

$$P_{t+1}^R = \begin{cases} \left(\frac{z_t^R n_t s_t}{2}\right) P_t^R & \text{if } z_t^R n_t s_t/2 < 1 \\ P_t^R + \delta \left\{ \left(\frac{z_t^R n_t s_t}{2}\right) P_t^R - P_t^R \right\} & \text{if } z_t^R n_t s_t/2 \geq 1 \end{cases} . \tag{4.1}$$

Note that $\delta = 0$ amounts to perfect primogeniture, keeping the size of the landholding class constant ($P_{t+1}^R = P_t^R$). The second term in the second line in (4.1) can thus be thought of as "leakage" into the landholding class of agents who would join the landless class under perfect primogeniture.

4.2. Population dynamics

Every woman has $(n_t s_t)/2$ surviving sons, and equally many daughters, so the total number of men (and the total number of women) in the economy grows at the (gross) rate $(n_t s_t)/2$:

$$P_{t+1} = \left(\frac{n_t s_t}{2}\right) P_t. \tag{4.2}$$

Setting $n_t^i = n_t$ in (3.16), and using either (3.19) or (3.20), we can write the fertility rate as

$$n_t = \beta \frac{BH_t + \lambda_t m_t}{\rho(H_t)} = \beta \frac{BH_t + M/P_t}{\rho(H_t)}, \tag{4.3}$$

where the second equality uses (3.2) and (3.3) to note that $\lambda_t m_t = M/P_t$, i.e., average land income equals the total amount of land divided by the total number of people. As seen, the fertility rate is rising in the average income, $BH_t + M/P_t$, and falling in the quality preference, $\rho(H_t)$.

Using (4.2) and (4.3), together with the expression for the survival rate, $s_t = \exp\{-1/\rho(H_t)\}$, gives a dynamic equation for the population size:

$$P_{t+1} = \underbrace{\frac{\beta}{2} \frac{BH_t + M/P_t}{\rho(H_t)}}_{n_t/2} \underbrace{\exp\left[\frac{-1}{\rho(H_t)}\right]}_{s_t} P_t. \tag{4.4}$$

4.3. The phase diagram with constant landowning class

To understand the workings of the model we first keep human capital productivity fixed, and denote it by A^0. This could be thought of as a society with perfect primogeniture, implying that the size of the landowning class (and thus the number of thinkers, X_t) is constant.

To draw a phase diagram we derive the loci along which population and human capital are constant. Setting $P_{t+1} = P_t$ in (4.4) we can write the $(\Delta P_t = 0)$-locus as

$$P_t = \frac{M}{\left(\frac{2}{\beta}\right) \rho(H_t) \exp\left[\frac{1}{\rho(H_t)}\right] - BH_t}. \tag{4.5}$$

Setting $H_{t+1} = H_t$ in (3.6) we see that $\Delta H_t = 0$ when

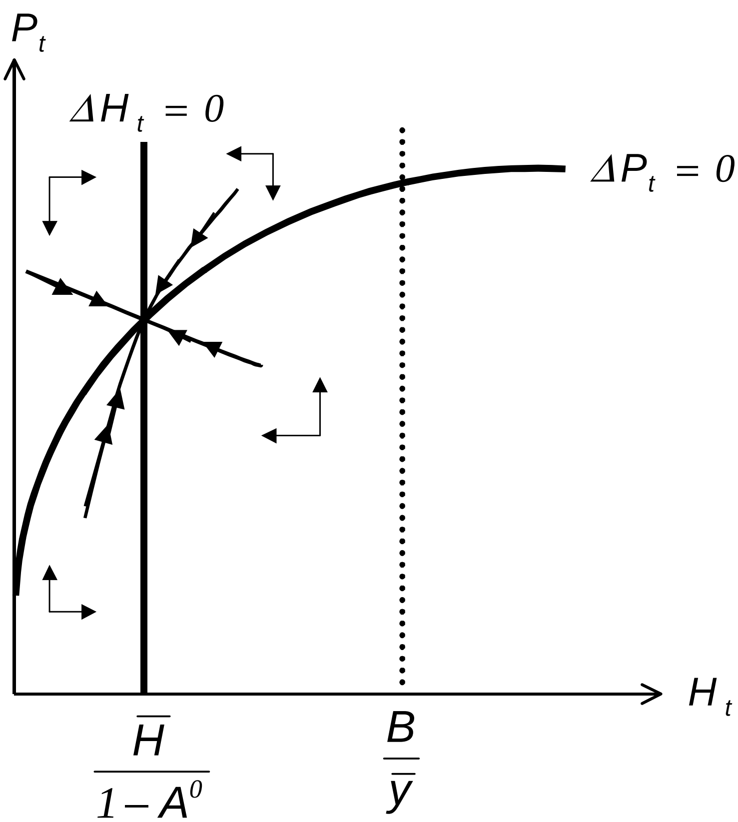

Figure 4.1: The phase diagram.

$$H_t = \frac{\overline{H}}{1 - A^0}. \tag{4.6}$$

The dynamics are shown in Figure 4.1. The economy converges to a unique globally stable steady-state equilibrium where human capital and population are both non-growing. A small one-time increase in the number of thinkers leads to an increase in human-capital productivity, A^0, shifting out the ($\Delta H_t = 0$)-locus, thus raising the steady-state levels of population and human capital.

Even though population is constant, meaning that every man has one son, landholders father more sons than the landless, i.e., differential reproductive success is at play. If we allow for some leakage into the landholding class this would make the number of thinkers (and thus A^0) slowly increase, and the $(\Delta H_t = 0)$-locus shift to the right. In that sense, we can call the steady-state equilibrium in Figure 4.1 *temporary* (cf. Galor and Weil 2000): it assumes a constant number of agents with incomes above $\overline{y}$ – i.e., a constant number of thinkers.

As the $(\Delta H_t = 0)$-locus continues to move to the right the equilibrium human capital level reaches $B/\overline{y}$. At this point, human capital is abundant enough to enable landless agents to start thinking. At this point human capital will begin to exhibit sustained growth. The model thus has the feature that changes may come slowly for a long time and then accelerate.

4.3.1. A hunter-gatherer society

Let us analyze more closely the link between the income levels of each class and the number of thinkers. Consider first a society without property rights to land – a hunter-gatherer society – implying that all men in effect belong to the landholding class: $P_t^R = P_t$. If human capital is low and population large, no man earns above the threshold level for thinking, i.e., $BH_t + M/P_t < \overline{y}$. Thus there are no thinkers in the economy $(X_t = 0)$ and human capital productivity, [given by (3.7)] is zero. Human capital is thus stuck at $\overline{H}$, and the associated steady-state level of population, which we may denote $\overline{P}$, is given by (4.5), i.e.,

$$\overline{P} = \frac{M}{(2/\beta)\,\rho(\overline{H})\exp\left[\frac{1}{\rho(\overline{H})}\right] - B\overline{H}}. \tag{4.7}$$

Such an equilibrium exists if the level of $\overline{P}$ is large enough so that $B\overline{H} + M/\overline{P} < \overline{y}$, i.e., using (4.7):

$$B\overline{H} + \frac{M}{\overline{P}} = (2/\beta)\,\rho(\overline{H})\exp\left[\frac{1}{\rho(\overline{H})}\right] < \overline{y}, \tag{4.8}$$

which holds for low enough $\overline{H}$ and/or high enough $\overline{y}$.

Note that increased agricultural productivity (M) leads to larger population but not higher per-capita income as long as the economy stays in this steady state (i.e., as long as all land is evenly distributed). In that sense, inequality is a necessary condition for the economy to leave the hunter-gatherer stage.

4.3.2. Early civilizations

If a small enough fraction of the population establishes property rights to the land, the income of each landowner rises above the threshold for thinking: the class of landowners becomes a class of thinkers. This captures the creation of an early human civilization, both because such a society is less equal than a hunter-gatherer society, and because it has more human capital, since the number of thinkers is positive.

An increase in the size of the landowning class now has two effects on landowner income, pulling in opposite directions: (1) landowner income falls since each agent has less land (M/P_t^R is lower); and (2) landowners and landless alike earn more, since there being more thinkers implies higher human capital productivity, and more human capital for all.

To pursue this analysis conjecture first that X_t is equal to the landowning population, P_t^R. We can then examine if this is indeed the case by looking at the associated income levels of the two classes (in the temporary steady state) and compare them to $\overline{y}$.

Start by using (3.6) and (3.8) to derive an expression for the temporary steady-state level of human capital as a function of the number of thinkers, X_t, under the conjecture that $X_t = P_t^R$. We can then write human capital in the temporary steady state as

$$H(P_t^R) = \frac{\overline{H}(\theta + P_t^R)}{\theta - P_t^R[A^* - 1]}, \tag{4.9}$$

where we recall that $A^* > 1$, implying that $H'(P_t^R) > 0$.[9] Using (4.9), together with (3.4) and (3.3), we can then write income levels (in the temporary steady-state) of each class as a functions of the number of landowners. Landowner income is given by

$$y_t^R = BH(P_t^R) + \frac{M}{P_t^R}, \tag{4.10}$$

and first term in (4.10) constitutes the income of the landless: $y_t^S = BH(P_t^R)$. Figure 4.2 shows how income of the two classes depend on P_t^R. The parametric example is that in Table 4.1, and the curves for landowners' incomes refer to two levels of land, M.

The landless' incomes increase monotonically with P_t^R, since more landowners implies more thinkers and thus more human capital. The income of the landowners is U-shaped, reflecting the two countervailing forces mentioned above: more landowners means less income from land per landowner, but also more thinkers and thus more human capital income. The figure also displays the threshold for thinking, $\overline{y}$. As seen there is a region of levels of P_t^R in which the number of thinkers, X_t, equals the size of the landholding class, P_t^R (as we conjectured). Moreover, letting P_t^R expand exogenously in this region we see what path the economy will follow if we let differential reproductive success feed into changes in class structure.

4.3.3. An industrial revolution and a demographic transition

Consider first the case with a high level of land productivity, $M = 2.75$. In this case, landowner income always exceeds the threshold for thinking, $\overline{y}$. If the income of the landless exceeds $\overline{y}$ the landless are also thinkers. The number of thinkers

[9] This means that sufficiently many thinkers can generate sustained growth in human capital [see (3.8) again], i.e., $H(P_t^R) \to \infty$ as $P_t^R \to \theta/[A^* - 1]$.

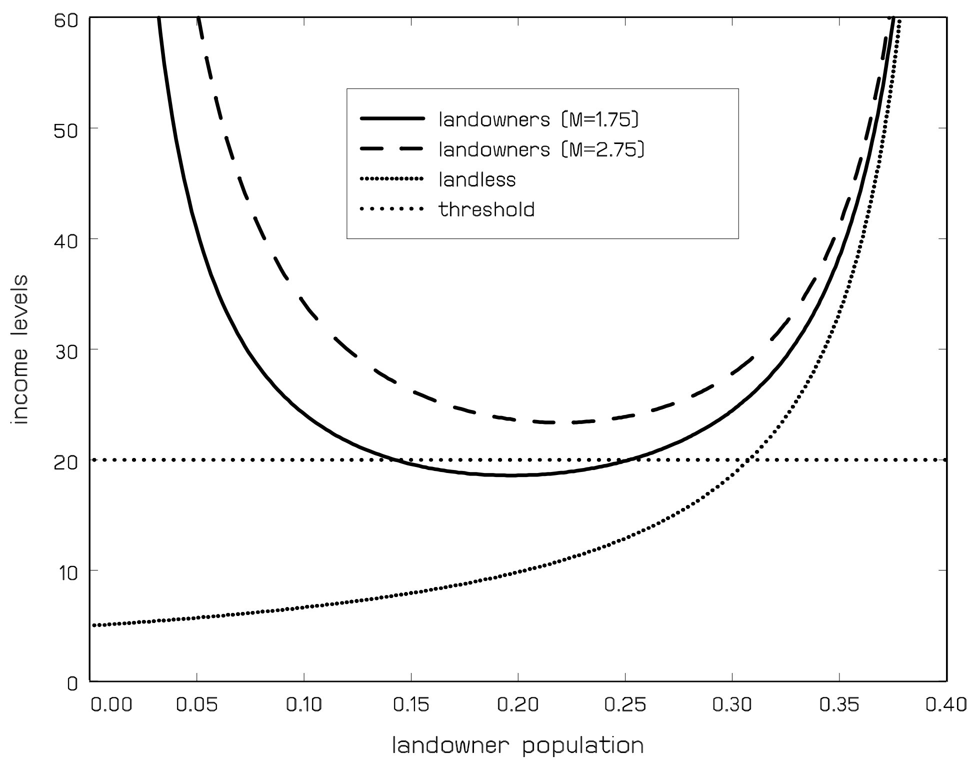

Figure 4.2: Income levels for landowners (y_t^R) and landless (y_t^S) in the temporary steady state, as a function of the size of the landowning class, P_t^R.

thus makes a discrete jump as P_t^R reaches a critical level. Thus, slow and gradual increases in P_t^R generate initially slow and gradual changes in human capital, and then a spurt: an industrial revolution.

We can understand this process in terms of Figure 4.1: a slowly rising number of thinkers shifts out the $(\Delta H_t = 0)$-locus. At some point in time the locus passes the critical level $B/\overline{y}$, the point at which non-land income exceeds the threshold for thinking, and the economy goes through an industrial revolution.

As human capital starts growing, the weight on quality, $\rho(H_t)$, rises. This leads to a quality-quantity shift in children: a fall in mortality and – with a slight lag – fertility, with an associated spike in population growth in between. Again, the way we have drawn the phase diagram in Figure 4.1 explains why. Note that the $(\Delta P_t = 0)$-locus becomes asymptotically horizontal, implying that population becomes constant in levels as human capital goes to infinity. (This need not be the case, but it holds for e.g. the numerical example in Table 4.1.) Since sustained growth in human capital pushes mortality to zero [recall (3.15)] the new constant population level must be associated with a lower rate of fertility: a demographic transition must has taken place.

Note also that the vertical distance between landowners' and landless' incomes is falling in P_t^R. This implies that the gap in reproductive success falls as we increase the size of the landholding class: society becomes more monogamous.

4.3.4. The downfall of a civilization

With low land productivity, $M = 1.75$, the diluting effects of a growing landowning class will at some stage push landowners' incomes below the threshold, so that all thinkers vanish and human capital falls to its minimum, $\overline{H}$: the civilization goes under. From there on, population slowly approaches the long-run hunter-gatherer level, given in (4.7). As long as landowners have higher incomes,

B	β	k_1	k_2	M	θ	A^*	$\overline{H}$	$\overline{y}$	P_0^R	H_0	P_0	δ
5	.99	2	4.995	2.75	12	30	1	20	.05	1.14	0.44	.005

Table 4.1: Parameter values

and thus higher reproductive success, the landowning class keeps growing. In the limit all agents become landowners, i.e., the society reverts to an egalitarian hunter-gatherer structure.

4.4. Numerical simulations

To understand better how the different components of the model interact we next demonstrate the same two simple examples (an industrial revolution and the downfall of a civilization), but now letting P_t^R change endogenously, according to (4.1).

We do this numerically, so we first need to specify a functional form for the quality-preference function, $\rho(H_t)$:

$$\rho(H_t) = k_1 + k_2 H_t, \tag{4.11}$$

where $k_1, k_2 > 0$.

The parameter values are chosen as in Table 4.1. (We do not try to fit the model to any data; these numbers are just for illustration.) We choose the values for k_2, β, and B so that the fertility rate in (4.3) converges to 2 as human capital goes to infinity, i.e., we set $k_2 = B\beta/2$. Since the survival rate goes to unity [see (3.15)], each couple having two surviving children implies a constant population.

Given these parameter values, we let the initial number of landowners, P_0^R, be .05. As seen from Figure 4.2 (which uses the same parameter values) landowner income thus exceeds the threshold, ensuring that the economy starts off with a positive number of thinkers. The initial level of human capital is calculated from

(4.9); then initial population can be derived from (4.5). We can calculate the initial fraction of the population who are landowners, λ_0, as $.05/.44 \approx 11\%$.

Given these initial values we then simulate the path the economy follows over time. Since $\delta > 0$ the landowning class grows over time – see (4.1) – which sets the dynamics in motion as described above. The path referring to the values in Table 4.1 is shown in Figure 4.3; Figure 4.4 then shows the effects of a lower M.

4.4.1. An industrial revolution and a demographic transition

Figure 4.3 displays the time path when $M = 2.75$. The diagram in the upper left corner illustrates incomes of the two classes. (Note that the rise in the size of the landowning class essentially corresponds to moving along the horizontal axis in Figure 4.2). The gap between landowners' and landless' incomes diminishes over time. This income compression proceeds first slowly, and the gap vanishes when the human capital growth takes off, since human capital is identical across classes. Inequality in the number of women just reflects inequality in income so this process mirrors also society's mating patterns. Consistent with the description in Section 2, polygyny therefore declines slowly at first; then society becomes fully monogamous relatively rapidly as sustained income growth sets in.

At the very point in time when incomes shoot off into sustained growth we see how higher levels of human capital also generate a sharp fall in mortality, and – with a slight lag – fertility, as shown in the upper right diagram.[10] In between, the growth rate of population leaps up, as seen in the lower left diagram.[11] At the

[10]The fertility rate is calculated as $n_t/2 - 1$. (This would be the population growth rate if all children survived; the mother dies after the adult phase and she has $n_t/2$ daughters.) The mortality rate is calculated as $1 - s_t$. Note that population is constant when $s_t n_t/2 = 1$, so $n_t/2 - 1$ need not equal $1 - s_t$ when population is constant.

[11]There is an increase in the vertical distance between the fertility and mortality curves around generation 600, but it is hard to see.

same time growth in per-capita income (i.e., the change in $BH_t + M/P_t$) jumps up and then stabilizes at a sustained positive rate. This also fits with the description in Section 2 (see Figure 2.1).

4.4.2. The downfall of a civilization

Consider next the same economy, but with lower land productivity (M equal to 1.75, instead of 2.75). As seen from Figure 4.2 this means that at some point in time landowner income falls below the threshold, implying that all thinkers vanish. Human capital drops to $\overline{H}$ and stays there forever. As a result, the mortality rate rises. So does the fertility rate, due to a reversed quality-quantity switch following the fall in human capital, a sort of reversed demographic transition. In between there is a sharp dip in population growth to negative numbers.

At the new stable levels of population and human capital the landowning class is still growing, and the landless class is shrinking, due to the higher reproductive success of the landowners and the assumption of imperfect primogeniture. In the long run the economy thus converges to an equal hunter-gatherer state in which all agents are landowners, and have the same income. This society thus also becomes fully monogamous.

5. Conclusions

We have presented a two-sex long-run growth model, aiming to explain a number of institutional, demographic, and economic changes in human societies since the birth of mankind. One driving force in our model is the universal human pattern of *differential reproductive success* across men: rich men have more offspring. Another is that the accumulation of human capital increases with the number of people engaged in intellectual activities, "thinking," and that this activity occurs

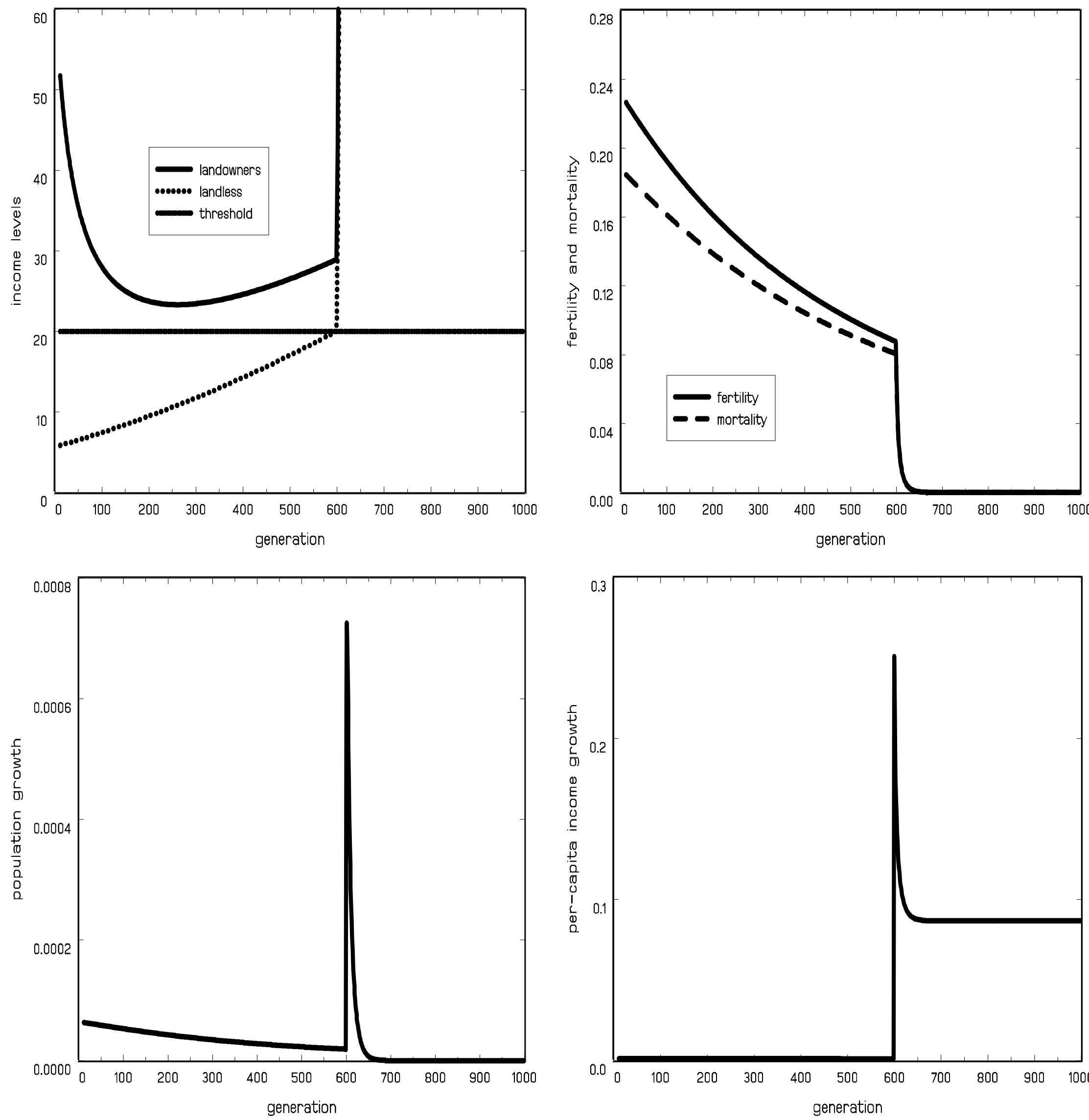

Figure 4.3: A path leading to an industrial revolution and a demographic transition.

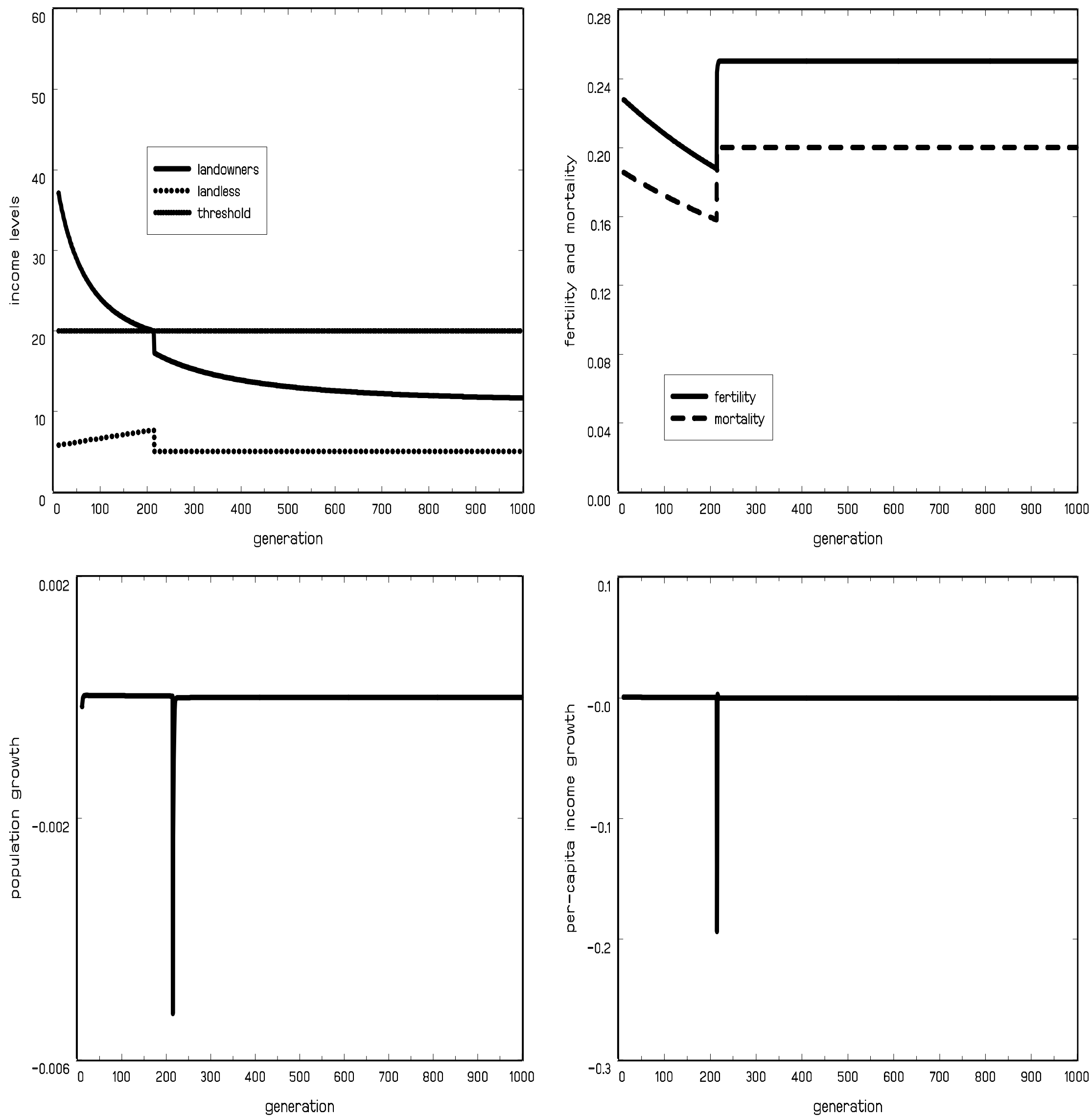

Figure 4.4: A path leading to the demise of an early civilization.

only among the very rich. A third assumption is that land is a more excludable resource than knowledge, so that land can be more unequally distributed than human capital. We let a society start off with an egalitarian (hunter-gatherer) structure with small differences in landholdings. All agents are poor, and there are thus no thinkers, and little human capital. An exogenous rise in agricultural technology – and/or a reallocation of land holdings into the hands of a few agents – sets in motion a process which at some point sparks an industrial revolution and a demographic transition.

The process leading up to these events is characterized by shrinking income gaps between landholders and landless. Mirroring this trend the distribution of women becomes more equal: society becomes more monogamous. This fits with the historical evidence which we cite. Mating was polygynous up until the time when human societies – starting with Western Europe – began developing democratic institutions, and income inequality started to fall.

An obvious objection is that the society we live in today is not completely monogamous. Our model society becomes fully monogamous in the limit, as income gaps go to zero, because land becomes less important as a source of income than human capital, and by assumption human capital is completely equally distributed. This result should not be interpreted literally. If we allow for some gaps in human capital levels the model would instead generate a steady-state income gap, with an associated steady-state degree of polygyny.

We have assumed the productivity adjusted size of land, M, to be constant. If land productivity, i.e. M, grew at some exogenous rate the landholding class' earnings from land would rise over time, which would serve to widen income gaps. At the same time, this would increase also the gap in reproductive success between landless and landholders, which would amplify the force working to equalize the land distribution. It would also generate faster growth in the size of the landholding class, P_t^R, which would raise the human capital growth rate, and hasten the industrial revolution. This would be consistent with the findings by Burkett, Humblet and Putterman (1999) that an early agricultural revolution makes the industrial revolution set in sooner.

Many of the mechanisms driving our model can be substituted for by other, more realistic, forces. These may work differently but pull in similar directions. The underlying story should still have some truth to it, unless we believe it to be a coincidence that the rise in income equality, the birth of monogamy and democracy, and the spurt in per-capita income growth rates, all took place around the same time. That is, following the rise of agriculture and civilization it took several hundred generations before these events occurred, and they all took place within a time span of, say, a couple of generations. Whether or not our answer is the right one, this seems to be a question worth addressing in the context of long-run growth theory.

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