How the West Invented Fertility Restriction

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Abstract

Early modern Europe was unusually rich by 1700, compared to the rest of the world. We argue that the 'European Marriage Pattern' (EMP) contributed to this phenomenon. By raising the marriage age of women, and ensuring that a substantial proportion remained celibate, the EMP reduced fertility by up to 40%, and raised average wages by a quarter. We present a model that explains how fertility limitation evolved. We emphasize changes in the production structure of the agricultural sector following the 14th century Black Death. Rising wages after 1349 translated into greater demand for 'luxury products', such as wool and meat. Their production was subject to economies of scale, making it profitable for large farms to hire outside labor. It was also land-using and labor-saving. Women's wages increased, and a period of working as a servant became a common feature of the life cycle of European women. Marriage was thus delayed, and fertility reduced. The Black Death thus set into motion a virtuous cycle of higher wages and fertility decline that contributed to unusually high per capita incomes.

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1 Introduction

Long before the demographic transition, Europeans restricted their fertility. West of an imaginary line from St Petersburg to Trieste, the age of marriage for women was not determined by biological fertility, but by socio-economic forces (Hajnal 1965).[1] Both the marriage age and the proportion of women never marrying varied in response to economic conditions. The so-called 'European Marriage Pattern' (EMP) combined late marriage with unrestricted fertility within marriage. On average, between a quarter and 40% of all possible births were thus avoided.

When land was a key factor of production, and only available in limited quantity, fertility limitation helped to maintain living standards. Europe by 1700 had per capital incomes far above subsistence. Average urbanization rates exceeded 10%, and in the most advanced areas were much higher. Long before technological change accelerated, European incomes were ahead of those in the rest of the world (Maddison 2001; Broadberry and Gupta 2005).[2] Land/labor ratios were higher than they otherwise would have been. The EMP has been credited by many scholars with maintaining high per capita incomes. Given that there were few births outside marriage, and that knowledge of contraceptive techniques was limited, EMP constitutes a puzzle. It required a large share of the female population never to engage in sexual activity; for the rest, abstinence until their twenties was required. Effectively, Europeans traded off higher living standards - more goods, and more food - for less sex, and fewer offspring.

In this paper, we ask how Western Europe invented fertility restriction. The emergence of the EMP is intimately connected with a set of interrelated economic

[1] The pattern was later found to be particularly strong in the North-West of Europe, and weaker in the South.

[2] A group of revisionist historians has questioned the traditional consensus that labor productivity in Chinese agriculture was low (Li 1998; Pomeranz 2000; Goldstone 2003) has argued that incomes in the Yangzi were comparable to English ones. Their analysis has not stood up to close scrutiny (Brenner and Isett 2002; Broadberry and Gupta 2005).

phenomena and social practices. Europeans - women as much as men - often spent a prolonged period of time before marriage working for a wage. They did so as apprentices or as servants, living in the household of their master, while being barred from marrying. During this period, they accumulated assets - human and financial capital - which raised their incomes after marriage. It also helped individuals improve their prospects in the marriage market, by making themselves more attractive in the eyes of a better match.

The impact of the plague is crucial for our explanation. The Black Death of 1347-49 killed between a third and half of the European population. As the number of workers fell, land/labor ratios surged. Wages increased. For a period of one-and-a-half centuries, Europeans experienced a 'golden age of labor'. Wages were high, and food was plentiful. According to the classic long-run wage series by Phelps-Brown/Hopkins, 14th century English real wages more than doubled after 1349. Under the assumptions of the basic Malthusian model, this rise in wages should have been temporary. As population recovered, the economy should have returned to the pre-plague income level. Yet as late as the 17th and 18th centuries, wages had not returned to their earlier levels, but remained 35-50% higher (figure 1) than they had been on the eve of the Black Death.

[Insert Figure 1 here]

In our model, the plague's initial impact set in motion a process that allowed living standards to be permanently higher after the Black Death - and without an acceleration of technological change. Higher wages changed not just the level of consumption, but its mix. Englishmen and women ate more meat and bought more woolen goods in the 14th and 15th centuries than their ancestors had done - they were 'superior goods' of the time. These goods needed to be produced, and the production system most suited to the task also involved the use of female labor in such a way that ensured a reduction in fertility.

The positive demand shock for products such as wool and meat produced important changes in European agriculture. By 1516, when Sir Thomas More described 'man-eating sheep' in his *Utopia*, vast parts of English agricultural land had been converted to sheep pasture. This was despite repeated interventions by the Crown (in 1489 and 1514) that attempted to stop the conversion of arable lands (Rodrick 2004). Sheep grazing - just as the production of cattle - was a land-using and labor-saving production technology. Large numbers of laborers could be replaced by a single shepherd or servant in husbandry. At a time of high wages and abundant land, pastoral farming was an ideal mode of production to adopt. Production was subject to substantial economies of scale - pastoral farming required much larger production units. It also used labor that was relatively cheaper: children and women. Combined with a positive demand shock for wool and meat, profits from sheep and cattle farming were high. Agricultural technology changed in response to factor prices, not through directed inventive efforts in the sense of Acemoglu (2002). Rather, adoption decisions in response to changing output and input prices caused a shift in the production technology in use.

By creating a demand for women's labor, expanded pastoral production enhanced female employment prospects. Since women caring for children are generally unsuited for field work with animals, this mode of production also required that female working in husbandry were unmarried. Landlords would take in young men and women, house them and feed them in exchange for their labor services. They would also offer them some additional monetary reward which would typically be saved for later use, once servants formed a new household. The system reached substantial proportions in the early modern period. Servants constituted 13% of the English population between 1574 and 1821. While some of them worked as domestic servants, enhancing the comfort of their masters – the form most familiar to readers of English crime novels - many were employed as 'productive servants', in the phrase of Adam Smith. Of all workers employed in agriculture, between a quarter and half were servants. Approximately 60% of the population aged 15-24 worked as servants (Kussmaul 1981).

In our model, the rise of female servants curtails fertility, and produces a self-sustaining increase in living standards. Once the new production system was in place, marriage ages increased and the number of children born per woman declined. Lower population pressure allowed high wages after the Black Death to persist. This in turn ensured that demand for wool and meat remained high. Pastoral farming continued to be profitable, and farm service formed as an important mode of employment for the English young into the 19th century.

Related work includes Devolver (1999), who emphasized the introduction of short-term leaseholds as a factor behind the rise of EMP. The paper that is closest in focus to ours is De Moor and Van Zanden (2005). The authors emphasize the role of Christianity, with its emphasis on the individuality of each soul and the importance of an act of the will for marriage to be valid. They also argue that the rise of a landless proletariat, combined with access to urban labor markets, militated in favor of women 'taking time to choose' their marriage partners. Because many parents were landless, they could not entice their children to stay on the land, working on the family farm in the hope of an inheritance. Thus children sought out outside earnings opportunities, especially when these were attractive (such as after the Black Death). Compared to our paper, De Moor and Van Zanden do not emphasize the link between a particular production technology (pastoral agriculture with increasing returns) and the income shock arising from the Black Death. They also do not explicitly model the implications for marriage age and income levels from the adoption of EMP.

Our paper forms part of a broader body of work that seeks economic explanations for fertility change. The Princeton European Fertility Project (Coale and Watkins 1986) emphasized the importance of cultural and linguistic elements in the diffusion of fertility limitation in the 19th century. In contrast, work in the spirit of Barro and Becker (1989) has emphasized the importance of economic incentives, and in particular, the changing payoffs to investments in child quality.

2 Historical Context and Background

In this section, we discuss the historical background and context of EMP's emergence. We first summarize evidence about fertility limitation first, and then examine the connection with changes in agricultural production. Finally, we compare European and Chinese fertility patterns and agricultural norms.

The origins of the 'European Marriage Pattern' cannot be determined with accuracy. Two key indicators are key: the percentage of women never marrying, and the age at (first) marriage for women. Only for the former is information available for periods for which family reconstitutions have not been performed. The typical age at first marriage in European parts of the Roman Empire was 12-15 for pagan girls, and somewhat higher for Christian girls. Age at marriage in medieval times appeared to be somewhat higher than in Roman times, but not by a large margin. For a group of Lincolnshire villages, Hallam (1985), estimated ages at first marriage for women of around 20.

The percentage never marrying is not easy to establish. In St.Germain de Pres, some 16% of women were unmarried in 800. Also in the 9th century, in Villeneuve-Saint-Georges, 12% of women probably never married. We do not know how representative these figures are. What is clear is that both a marriage age above the biological age of fertility, and a pattern of some women never marrying, had its origins in the period before the 14th century (Laslett and Wall 1972).

The European marriage pattern in its full form emerged after the Black Death. According to Hajnal (1965; Hajnal 1982), one of its key components is the postponement of marriage until age 25 and beyond.[3] England in the early modern period registered an average age at first marriage for women of 26 years, and 17.5% never married. Table 1 gives an overview of the range of historical experience in the 17th century:

[3]There are regional exceptions. For 14th century Sussex, for example, there is little evidence of the European Marriage Pattern being in place (Mate 1998).

[Insert Table 1 here]

Within marriage, fertility was nearly unconstrained. Table 2 shows marital fertility by age group, for Hutterites (a modern-day Canadian sect practicing no birth control), Western Europe before 1800, and China. In 18th century Germany, some 20% of women married aged 30 and over (Knodel 1988).

[Insert Table 2 here]

Northwestern Europe in particular evolved a 'low pressure demographic regimes' (Wrigley 1997). Negative economic shocks were largely absorbed through Malthus's preventive check, rather than the positive check - births were curtailed through changes in nuptiality, instead of death rates surging.[4] As economic conditions worsened, the system became more restrictive with respect to marriage. As life expectancy fell and conditions became less favorable, partly under the influence of declining land-labor ratios in England after 1600, the age at marriage increased, and gross reproduction rates fell (Wrigley and Schofield 1981; Wrigley 1997).

Changes in European agriculture

In the period leading up to the Black Death, European agriculture displayed a trend towards declining labor productivity. Campbell (2000) shows that prior to the plague and the hunger crises of the early 14th century, output per head in English agriculture was falling. Diets shifted from pastoral to arable products. These trends reversed after the Black Death. Immediately after the initial shock in 1348-9, prices of foodstuff collapsed by 45 percent, while cash wages increased by 25% (Campbell 2000). These gains did not persist to the same extent for long, but the Black Death became a turning point for real wages regardless. By 1450, real wages in England were 50% higher than they had been on the eve of the

[4]In extreme cases, some 75% of the female population would not marry. This was apparently the case amongst daughters of the Milanese nobility between 1600 and 1650 (Clark 2007).

plague, and more than twice as high as they had been before the Great Famine of the 1310s and 1320s. Per capita consumption of food overall grew, but richer consumers triggered a 'shift from corn to horn' (Campbell 2000). Where grains had been consumed directly, as porridge or bread, ale-drinking expanded. Meat and milk consumption more than doubled (based on estimates of changes in the number of non-working animals on farms).

Landowners responded to the shock of the Plague in a number of ways. Sheep-corn husbandry expanded everywhere, but the phenomenon was most pronounced in Southern England, especially the downlands. Pasture was replacing arable land at a high rate. Campbell estimates that grain acreage declined by approximately 15 percent after 1349, while the number of livestock expanded by 40 percent. Much of the increase was concentrated amongst non-working livestock, which grew by 90 percent. Sheep-farming expanded, as did the ranching of cattle for meat and milk. In addition, agricultural production became much more capital-intensive. As Campbell (2000) points out, the use of horses and oxen for transport, as well as in ploughing, expanded. Given how costly labor had become, landlords now had incentives to invest more in better ploughs and farm implements.

Finally, farm sizes increased after the 14th century. While much attention has focused on the parliamentary enclosures of the 18th century, there are good reasons to believe that the big rise in farm output between the plague and the onset of the industrial revolution had to do with an earlier period of enclosure - termed the 'Yeoman's enclosure' by Allen (1992). While 80% of English farms had been smaller than twenty acres before the plague, a majority - over 60% - of farms were larger than 100 acres by 1600. Increasing farm sizes allowed farmers to use more beasts of burden. The pattern thus set after the Black Death reversed the earlier trend towards declining labor productivity. Labor productivity began to grow, initially as a result of greater land-labor ratios. By the end of the early modern period, English agriculture used unusually high numbers of horses per worker and per unit of land.[5]

Labor productivity grew substantially, as did TFP. Allen (1992) estimated that TFP in English agriculture more than doubled in the early modern period up to 1700. These gains also overshadowed those during the so-called 'agricultural revolution' of the 18th century (Allen 1999). The rising value of labor in general, combined with changing patterns of agricultural production - in particular the increase of livestock production - made female labor more valuable. Landlords increasingly hired 'productive servants' to help on the larger farms (Kussmaul 1981). Since pasturalism has fairly evenly-spread labor requirements throughout the year, employing servants year-round - instead of hiring agricultural laborers for daily wages during periods of peak demand - became increasingly attractive.

Comparison with China

That Chinese fertility was 'unconstrained', compared to Europe, has been a staple of the demographic literature since the days of Malthus. Malthus himself, in his discussion of the positive and the preventive checks, emphasized that only Europe appeared to have evolved an elaborate system where the latter operated effectively. It appears that Malthus was (almost) wrong. The age at first marriage was low in China, and marriage was near-universal for women, as Malthus had emphasized. However, as recent detailed work on historical Chinese demography has demonstrated (Lee and Wang 1999), two factors limited fertility - infanticide and low fertility within marriage. Especially female children were killed often, either through neglect or directly. This reduced fertility rates. In addition, marital fertility within marriage was 25-50% lower in China than in Europe (table 2).[6] While the reasons behind the remarkably low fertility rates are not well-known, poor nutrition leading to infertility may have been a contributing factor.

[5] The number of horses per worker was 80% higher than in France, and 40% higher per unit of land (Wrigley 1988).

[6] (Lee and Wang, 1999).

Overall, Chinese population growth rates were not as high as they could have been in the absence of infanticide and limited marital fertility. Despite these important qualifications, the fact remains that Chinese population size increased by a factor of over 5 between 1400 and 1820, while Europe only grew by a factor of 3.2 - annual population growth rates were 0.4% and 0.28%, respectively. In other words, Chinese population growth was approximately 1/3 faster than in Europe, largely as a result of early and universal marriage. Data from the 19th century suggests that Chinese birth rates were around 35/1000, broadly similar to early modern European ones (Clark 2007). Since Chinese incomes were markedly lower, this implies that for any given wage, fertility rates were substantially higher in China than in Europe.

European farms were substantially larger than Chinese ones. Table 3 compares farm sizes in the areas that were relatively most advanced - England and the Yangtze Delta. Compared to pre-plague English farm, Chinese peasants tilled land that was between one third and one quarter in size. After the Black Death, English farm sizes grew dramatically, increasing by a factor of five by 1600. By 1800, they had doubled yet again, to 150 acres. In China, continuous population pressure, combined with the practice of partible inheritance, put downward pressure on farm sizes. In the two centuries after 1400, they fall by between 25% and 50%, before declining to no more than an acre by 1800. At the dawn of the nineteenth century, English farms were thus, on average, 150 times larger than Yangtze ones. According to the calculations by Allen (2007), land productivity in the Yangtze Delta was 9 times higher than in the English midlands, mainly because labor input was higher by a factor of 10.

[Insert Table 3 here]

The second distinct difference between Chinese and European agriculture concerns the use of draft animals, and the prevalence of pastoral farming in general. While Chinese sixteenth century writers observed that 'the labor of ten men equals that of one ox'[7], the use of draft animals declined in the Ming and Qing period. Animal use disappeared almost entirely, except for the most arduous tasks, by the mid-Qing period.[8] The reason is that labor was cheap, while the land needed to feed an ox was dear. Chinese farmers demonstrated great ingenuity in finding ever more ways to use human labor to raise yields per hectare. To the annual rice crop, winter wheat was added, and multiple rounds of fertilizer spreading enhanced fertility (Goldstone 2003). Beyond a certain level, population pressure will endogenously ensure that production becomes more labor-intensive and less capital-intensive. This is especially true if land is continuously subdivided as a result of inheritance laws.[9]

Declining farm sizes also meant that there was ever less scope for female employment in agriculture. Only rice and grain cultivation requiring greater physical strength remained, and the labor requirements could be satisfied by the existing male labor force on the small plots. As Li (1998) has argued, women were increasingly superfluous for agricultural tasks, which were also less and less well-matched to their comparative advantages. They consequently sought employment outside agriculture, in home production of textiles through spinning and weaving. Overall, the 'market value' of female labor declined during the Ming and Qing periods, as a result of falling labor productivity overall combined with changes in the pattern of production arising from growing 'agricultural involution' (Geertz 1963). Even authors skeptical of the 'involution hypothesis' conclude that female wages were only 25% of male wages in 1820s China, whereas English women's wages were equivalent to 50-63% of English male wages (Allen 2007).

[7] Cited after (Brenner and Isett 2002).

[8] The view is controversial. Wider availability of bean cake may have helped the increased use of oxen after 1620 (Allen 2007).

[9] Allen (2007) argues that agricultural productivity in the Yangzi was no more than 20% higher than in England. However, since his estimates are partly based on Chinese data for the early 20th century, the accuracy of his conclusions may be questioned.

3 Model

This section presents a simple model that captures the basic mechanisms determining pre-industrial labor supply and marriage decisions. The economy is composed of N peasants – split equally into women and men – who work, consume, and procreate. Each peasant is endowed with one unit of time per period. Men always work. Therefore male labor supply is given by $L_M = N/2$. Men and women form couples and live together in households when married. Therefore, L_M also represents the number of households in the economy. Women allocate their time between work and marriage. When married, women do not work; they spend all their time raising children. For simplicity, we assume that wages are the only source of income for peasants. There is also one landlord who owns all land T, which is in fixed supply. The landlord does not work. Peasants rent a fixed amount of land, T_p on aggregate, from the landlord. In addition, the landlord owns land $T_k = T - T_p$ that is not rented out to peasant farmers.[10] Instead, farmers are paid to work on his land.

There are two technologies to produce food. Both use land and peasant labor as inputs. First, grain production is physical labor intensive, giving a large comparative advantage to men. Second, cow-herding and sheep-farming requires less arduous labor, so that women and men are equally productive. In addition, pastural agriculture needs a minimum land size to be productive – enough land to graze livestock. Historically, minimum farm sizes for cattle-ranching and sheep-farming have been much larger than for arable farming. Pastural agriculture therefore exhibits increasing returns.

The economy is Malthusian – there is a unique long-run equilibrium income level. It depends on fertility and mortality schedules. The latter is exogenously given and declines in consumption. Fertility, on the other hand, is endogenous and

[10]To avoid confusions with labor l, we use the subscript k for the landlord – recalling that kings owned large land areas may serve as a mnemonic.

depends on the age at marriage. Before marriage, women do not have children. During marriage, there is no birth control and children arrive with the frequency p. Delaying marriage is therefore the only 'contraception technology.'

In the absence of TFP increases, death rates equal birth rates, and N is constant in equilibrium. An increase in productivity temporarily relieves Malthusian constraints; population can grow. Without *ongoing* productivity gains, however, the falling land-labor ratio drives wages back to their original equilibrium level. Per-capita income is thus self-equilibrating. An epidemic like the plague has an economic effect akin to technological progress: it causes land-labor ratios to rise dramatically. This leaves the remaining population with greater per-capita income. Without shifts in the birth or death schedules, subsequent population growth pulls the economy back to its earlier equilibrium – any escape from Malthusian stagnation is temporary.

However, in our model, the scarce labor supply after the plague prompts the landlord to switch to a technology that saves the most expensive factor: male labor. Abundant land makes the cattle technology more productive. As a consequence, the demand for female labor rises, and so do female wages. Women decide to marry later, and work longer. The "European Marriage Pattern" is born. We argue that this mechanism captures an important element of the European experience in the centuries between the Black Death and the Industrial Revolution. The new equilibrium has lower birth rates, combined with higher per capita incomes. This mechanism can explain the slow convergence back to pre-plague population levels after 1349, and the emergence of higher incomes.

3.1 Households

At the beginning of each period, or adult lifetime, one male and one female meet and form a couple. Whether or not they physically form a household and live together from the beginning of the period depends on the female labor decision.

However, even if a couple initially lives at separate places, they make joint decisions, maximizing (hypothetical) household utility. Each male individual supplies one unit of labor inelastically throughout his lifetime. Men's contribution to household income is therefore w_M. Couples decide about female labor supply $l_F \in [0, 1]$, trading off wage income w_F against family life and child raising. In our simplified framework, women are only productive in cattle production, operated by the landlord. When working for the landlord, women live separate from their fiancé. The fraction l_F of lifetime can therefore be interpreted as the celibate period for both men and women. During celibate life, couples are abstinent, such that the probability of childbearing is zero. This changes once couples marry and live together. The fraction $1 - l_F$ represents the share of lifetime that couples spend married. There is no contraception technology, and children arrive with probability p. In other words, each unit of time spent in marriage leads to p births. Therefore, the number of offspring per couple is given by

$$b = p(1 - l_F) \tag{1}$$

Women do not work during marriage; they exclusively care for their children. The survival rate of children depends on average consumption of peasants. Child mortality is the sole driver of aggregate death rates. Among adults, death rates are zero until the period is over. The number of children per family that die is given by

$$d = d_0 \, \bar{c}^{\,\varphi_d} \,, \tag{2}$$

where $\varphi_d < 0$ is the elasticity of child mortality with respect to average household consumption ($\bar{c}$), and d_0 is a constant. Consequently, child mortality falls as p.c. income rises.[11] The assumption that d depends on average rather than individual household consumption is a common one (see for example Jones, 2001). Since

[11] Both b and d should be interpreted relative to the reproduction rate. For example, with two surviving children per couple needed to maintain a constant population, $b - d = 1$ means 3 surviving offspring and thus net population growth.

households take average consumption as given, child mortality does not interfere with optimal labor supply decisions. This simplifies the analysis.[12]

At the end of each period, parents die and surviving offspring form the next adult generation. There is no investment or bequests to children – all income is spent for consumption during the adult period of life. Both men and women care about the household as consumption and decision unit. They draw utility from aggregate household income and the number of children. The household financial budget constraint is $c \leq w_M + w_F l_F$. Household utility is given by

$$u(c_p, b) = (1-\mu)\frac{(c_p - \underline{c})^{1-\phi}}{1-\phi} + \mu\frac{b^{1-\eta}}{1-\eta} \tag{3}$$

We assume $\mu \in (0,1)$, $\eta \in (0,1)$, and $\phi \in (0,1]$. The parameter $\underline{c}$ denotes a form of subsistence food consumption. If consumption level of peasant households is low, $c_p \leq \underline{c}$, they spend all income on grain consumption, which ensures that minimum caloric requirements are met. If peasant income grows, enabling $c_p > \underline{c}$, households start to demand meat in addition to grain. In a standard Stone-Geary setup (e.g., Voigtländer and Voth, 2006), this demand shift is driven by a zero elasticity of substitution between the two goods if $c_p \leq \underline{c}$, and a positive elasticity otherwise. Here we simplify the analysis. We still assume that grain and meat are not substitutable if consumption is low. However, in our stylized setup, the two forms of nutrition become perfect substitutes if $c_p > \underline{c}$. This is a special case of the Stone-Geary setup, with infinite elasticity of substitution between food and grain in rich economies. Consequently, the price of grain equals the price of meat, provided that the latter is produced and demanded. This completes the peasant demand. The landlord's only source of income are land rents, rT. To keep matters simple, we assume that the landlord spends his income in the same proportion as

[12]A historical justification is that the main cause of child mortality were diseases like diarrhea and typhus, whose spread depends on hygienic conditions (and therefore income) in the wider environment, rather than in the individual family.

peasants for the two goods.[13] Market clearing in this stylized setup implies:

$$Nc_p + c_k = \begin{cases} Y_g, & \text{if } Y_m = 0 \\ Y_g + Y_m, & \text{if } Y_m > 0 \end{cases} \tag{4}$$

where Y_p (Y_m) denotes aggregate production of grain (meat). Two conditions must be fulfilled for meat to be produced. First, there must be demand for meat, i.e., $c_p > \underline{c}$. Second, the scale of meat production must be large enough to compensate fixed costs. This condition requires a high land-labor ratio, as explained below. A major shock to population can cause meat production to become feasible: It increases the land labor ratio – fulfilling the second condition – and raises p.c. income, such that peasants demand meat.

Given w_M and w_F, households maximize (3) subject to the time constraint $0 \leq l_F \leq 1$ and their budget constraint. In the absence of bequests and investments, the latter holds with equality. The household optimization is then given by

$$\max_{l_F} = (1-\mu)\frac{(w_M + w_F l_F - \underline{c})^{1-\phi}}{1-\phi} + \mu\frac{(p(1-l_F))^{1-\eta}}{1-\eta} \tag{5}$$

The optimization problem is static, which simplifies our analysis. This is similar in spirit to Jones (2001) and can be derived from a more general dynamic optimization problem under two assumptions that we have made. First, utility depends on the flow of births rather than on the stock of children. That is, parents care about their own children, but not about their children's offspring. Second, we assume that child mortality depends on average per capita consumption, which individual households take as given. With these assumptions, the more standard dynamic optimization problem (e.g., Barro and Becker, 1989) reduces to a sequence of static problems as given in (5).

[13] One justification is that monarchs or feudal lords spent much of their budget for construction and warfare – performed by workers or soldiers that did not participate in food production. Their living standards were similar to those of peasants. Therefore, the landlord's riches translate into peasant-like food demand. That is, soldiers and builders, just like peasants and farmers, consume grain rather than meat. When p.c. incomes grow and peasants begin to consume meat, construction workers will require the same diet in order to remain indifferent between the two professions.

3.2 Technology

There are two ways to produce food in our model: grain (g) and meat from cattle (c). The grain technology involves labor and land. This technology is highly intensive in physical labor, like ploughing or reaping. Men are therefore relatively more productive than women in grain production. In our stylized setup, we take this comparative advantage of men to the extreme and assume that women have zero productivity in grain production. The grain technology is then given by:

$$Y_g = A_g L_M^{\alpha} T_g^{1-\alpha} \ , \tag{6}$$

where T_g and L_M, respectively, denote land and male labor employed in producing grain.

The second technology produces meat, using labor, land, and livestock (calves or lambs) as inputs. Cattle production is less physical-labor intensive than producing grain. Consequently, it is a more suitable technology for female labor. Women are therefore *relatively* more productive in meat production.[14] Again, we take this to the extreme in our stylized model and assume that men are unproductive in cattle production:[15]

$$Y_c = A_c L_F^{\alpha} T_c^{1-\alpha} - \varrho L_F \ , \tag{7}$$

where L_F is female labor and T_c is land used in cattle production. The parameter $\varrho > 0$ is related to a fixed cost in output *per worker*. When producing cattle, young livestock is needed as an initial input, which is costly. The larger the production scale, the more livestock input is needed. The overall input cost in meat

[14]The general setup uses a CES technology, where men and women are imperfect substitutes and the labor composite is given by $\left(\tau_i L_{M,i}^{\sigma} + (1-\tau_i) L_{F,i}^{\sigma}\right)^{\frac{1}{\sigma}}$ for $i = g, c$ and with $\sigma \in (0,1)$. In the general case, we have $\tau_g > \tau_c$, i.e., men have a comparative advantage in the physical-labor intensive grain production. The stylized setup has $\tau_g = 1$, and $\tau_c = 0$.

[15]What accounts for our main result is that women have a *comparative* advantage in the production of the superior good, i.e., meat. To keep matters as simple as possible, we assume an absolute productivity advantage for now.

production is thus scale-dependent.[16] An important assumption is that the cattle technology is only available to owners of large land areas, i.e., to the landlord in our model. Historically, this is motivated by the size differences of farms in areas of pastural vs. arable cultivation (Campbell 2000). Analytically, a minimum land requirement for cattle production would provide an alternative specification with similar implications for who engages in production. To save on notation and concentrate on the main mechanism, we do not model this dimension explicitly – instead we assume that only the landlord produces meat. This assumption is important because, together with the fact that female labor is productive only in cattle production, it ensures that women have to leave the household to work.

3.3 Location of Production

The landlord owns an area T of land. He leases a fixed part T_p to peasants and manages the remainder, employing hired labor. Each farmer household therefore rents land T_p/L_M (recall that L_M represents both total male labor supply and the number of men, each of whom form one household). When population falls, like after the Black Death, the land available per household rises. Peasants do not have access to the large scale cattle technology and therefore use all their land to produce grain. Let $L_{M,p}$ denote the amount of male labor employed in peasant production. The total output of grain, produced by peasants, then follows from (6):

$$Y_{g,p} = A_g L_{M,p}^{\alpha} T_p^{1-\alpha} \tag{8}$$

[16]More specifically, suppose that each units of labor can tend $\hat{\varrho}$ pieces of cattle. More tending does not increase productivity, whereas less tending lowers output proportionately because cattle can escape, predators take their toll, etc. The production function (7) is then given by $Y_c = A_c \left(\min\left\{S/\hat{\varrho},\ L_F\right\}\right)^{\alpha} T_c^{1-\alpha}$, where S denotes the stock of cattle. Optimal production requires $S = \hat{\varrho} L_F$, i.e., one unit of labor tending $\hat{\varrho}$ heads of cattle. Young cattle are costly; suppose that its price (in terms of grown-up cattle) is p_S. Then the livestock input cost of producing Y_c units of meat is $p_S S = p_S \hat{\varrho} L_F$. Defining $\varrho \equiv p_S \hat{\varrho}$ yields the production function (7).

The landlord hires labor at its marginal product to produce grain and – under the conditions specified above – cattle on the remainder of the land, $T_k = T - T_p$. The landlord's grain production is therefore given by

$$Y_{g,k} = A_g L_{M,k}^{\alpha} T_{g,k}^{1-\alpha} \,, \tag{9}$$

where $T_{g,k}$ is the land that the landlord allocates to grain production, and $L_{M,k}$ denotes the corresponding male labor input. In the absence of meat production, $T_{g,k} = T_k$. Otherwise, the landlord dedicates T_c to graze cattle, such that $T_{g,k} + T_c = T_k$.[17] This production involves only female labor. The landlord's meat output is thus given by (7).

This description finishes the setup of our basic model. Next, we show how male labor is allocated between production on the peasants' and the landlord's soil. In addition, we examine the female labor supply decision.

3.4 Allocation of Labor

Male peasants optimally allocate their labor supply between working on their own soil – paying the land rents and keeping the remaining output – and working for the landlord for a wage rate $w_{M,k}$. When working on their rented land, the marginal product of peasant labor is given by

$$w_{M,p} = \alpha A_g \left(\frac{T_p}{L_{M,p}} \right)^{1-\alpha} = \alpha A_g \left(\frac{t_p}{l_{M,p}} \right)^{1-\alpha} \,, \tag{10}$$

where $t_p = T_p / L_M$ is the land-labor ratio (i.e., land per peasant household), and $l_{M,p} = L_{M,p} / L_M$ is the share of male labor allocated to rental-soil production. Peasants pay the rental rate

$$r_p = (1-\alpha) A_g \left(\frac{L_{M,p}}{T_p} \right)^{\alpha} \,. \tag{11}$$

[17] Since only the landlord's land is large enough for cattle production, an additional subscript k is not necessary – whenever we talk about Y_c it is produced by the landlord.

The landlord pays hired workers their marginal product. In the case of grain production, operated by men, this implies

$$w_{M,k} = \alpha A_g \left(\frac{T_{g,k}}{L_{M,k}} \right)^{1-\alpha} = \alpha A_g \left(\frac{t_{g,k}}{l_{M,k}} \right)^{1-\alpha} , \tag{12}$$

where $l_{M,k} = L_{M,k}/L_M$ denotes the share of male labor spent working for the landlord. The landlord's soil that is allocated to each worker in grain production is given by $t_{g,k} = T_{g,k}/L_M$. When the landlord also produces meat, the corresponding female wage rate follows from (7):

$$w_F = \alpha A_c \left(\frac{T_c}{L_F} \right)^{1-\alpha} - \varrho \; = \; \alpha A_c \left(\frac{t_c}{l_F} \right)^{1-\alpha} - \varrho \, , \tag{13}$$

where $l_F = L_F/L_M$ is the share of their lifetime that women spend working.[18]

Optimal allocation of the soil operated by the landlord requires that the land return to cattle and grain production equalize. Using (7) and (9), this implies

$$r_k = (1-\alpha) A_g \left(\frac{L_{M,k}}{T_{g,k}} \right)^{\alpha} \; = \; (1-\alpha) A_c \left(\frac{L_F}{T_c} \right)^{\alpha} . \tag{14}$$

Therefore, in equilibrium the land per worker in the landlord's cattle production is proportional to its counterpart in grain production:

$$\frac{T_c}{L_F} \; = \; \left(\frac{A_c}{A_g} \right)^{\frac{1}{\alpha}} \frac{T_{g,k}}{L_{M,k}} , \tag{15}$$

where the factor of proportionality is give by the TFP ratios – relatively more land is dedicated to the more productive technology.

Peasants optimize their overall wage income from working on their rented soil and working for the landlord. This implies that the marginal returns to both types

[18] Recall that L_M denotes total male labor supply as well as the number of households, because men spend all their time endowment (one unit) working. Consequently, L_M also represents the number of women in the economy.

of employment must equalize: $w_{M,p} = w_{M,k}$. Using this together with (10) and (12) we obtain:

$$\frac{T_{g,k}}{L_{M,k}} = \frac{T_p}{L_{M,p}}\,, \tag{16}$$

that is, the land-labor ratio in grain production is the same on peasant and landlord soil. Re-arranging, and taking into account that the male labor shares must add up to one, yields

$$\frac{L_{M,p}}{L_{M,k}} = \frac{l_{M,p}}{1-l_{M,p}} = \frac{T_p}{T_{g,k}}\,. \tag{17}$$

This delivers a first important result. In the absence of meat production, (17) pins down the relative male labor supply. Recall that T_p is fixed. If the landlord produces only grain, $T_{g,k} = T_k = T - T_p$ is also fixed. Therefore, men spend a fixed share of their lifetime $l_{M,p}$ working on the soil they rent, and spend the remainder as laborers on the landlord's land. Note that this share is constant regardless of population density or productivity increases – as long as they are not large enough to render meat production profitable. Women do not work because the technology that uses their labor input does not operate. Therefore, in a grain-only economy with our Malthusian setup, labor shares stagnate even if wage levels change. Because of the constant female labor supply, birth rates stagnate, too. We will revisit this result when analyzing the long-run equilibria.

Things looks different when the economy is rich enough for meat production to be profitable. In this case, female labor supply is positive and has an impact on male labor allocation because the landlord re-allocates his soil between cattle and grain production. To disentangle these effects, we first plug (15) into (13), which yields

$$w_F = \alpha A_c \left(\frac{A_c}{A_g}\right)^{\frac{1-\alpha}{\alpha}} \left(\frac{T_p}{L_{M,p}}\right)^{1-\alpha} - \varrho = \alpha A_c \left(\frac{A_c}{A_g}\right)^{\frac{1-\alpha}{\alpha}} \left(\frac{t_p}{l_{M,p}}\right)^{1-\alpha} - \varrho\,. \tag{18}$$

To interpret this equation, let us start with the relatively poor grain-only economy. As we have shown above, $l_{M,p}$ is constant in this case. Abstracting from technological progress for now, all other terms in (18) are also constant, with the exception of the peasant land-labor ratio t_p. The latter is therefore the sole determinant of the (hypothetical) female wage in a grain-only economy. If population is large, such that land is scarce, w_F is negative. This reflects the fact that the cattle technology is infeasible. Intuitively, when workers are abundant, little land per worker would be allocated for pasture by an optimizing landlord. This renders meat production unprofitable, because it depends on abundant grazing land.

With large population losses during the plague, the land-labor ratio t_p rises dramatically. As a consequence, w_F becomes positive, and meat production is profitable. If the shock is large enough to additionally trigger demand for meat, the landlord allocates part of his land to the cattle technology. This reallocation of land also leads to a redistribution of male labor shares. Male farmers spend more working time on the land that they rent. This effect is driven by the following mechanism: Since T_c becomes positive with the introduction of meat production, the landlord dedicates less land to growing grain; $T_{g,k}$ falls. Therefore, the wages that the landlord pays fall *relative* to the marginal product of labor on the peasants' rented land (of course, both rise in absolute terms after the plague). This renders working on the landlord's arable fields less attractive in comparative terms. Consequently, as formally given by (17), $l_{M,p}$ increases. This is the mechanism underlying the incentives to reintroduce serfdom in areas (Eastern Europe) where it was politically feasible to do so, thus ensuring an adequate labor supply for the lord of the manor.

3.5 Fertility and Female Labor Supply

The missing piece in order to close the model is female labor supply. Next, we derive this variable as a function of male and female wage rates. The household optimization problem (5) yields:

$$b = \left(\frac{\mu}{1-\mu} \, p \, \frac{(c_p - \underline{c})^{\phi}}{w_F} \right)^{\frac{1}{\eta}} \tag{19}$$

To explain the intuition behind this equation, let us first focus on an economy where consumption is large relative to $\underline{c}$ and meat gross output per worker $(Y_c/L_F + \varrho)$ is large relative to ϱ. Both conditions are satisfied if the land-labor ratio is very high. In this case, we can ignore $\underline{c}$ and focus on c_p^ϕ/w_F in (19). In addition, w_F is linearly proportional to w_M, which follows from (10) and (18) because ϱ is relatively unimportant, too. In this setup, what is the effect of ongoing increases in productivity? Note that since l_F must be fixed in the long-run, peasant consumption is proportional to the wage level: $c_p = w_M + w_F l_F$. Rising income then has two effects: An income effect (richer peasants want both more children and consumption) and a substitution effect (a shift away from children towards work, which becomes more rewarding with increasing productivity). If $\phi < 1$, the second effect dominates, such that more productivity leads to fewer children. This reflects well the facts in the modern world, but contradicts the historical experience in Western Europe, where birth rates increased in per capita income. In other words, there is no role for a dominant substitution effect in our model. We therefore choose $\phi = 1$, such that income and substitution effect cancel each other. This delivers a constant birth rate at very high income levels. But what about the historically observed positive relationship? The answer lies in a third effect, the subsistence effect. Setting $\phi = 1$ allows us to focus exclusively on this mechanism.

To analyze the subsistence effect, we go back to a relatively poor economy, where c_p is close to, but larger than, $\underline{c}$. For the moment we still assume that $\varrho \approx 0$, such that w_F is proportional to the overall income level. Suppose that income *falls*, pulling c_p yet closer to $\underline{c}$. Then the marginal utility of consumption rises dramatically and female peasants work more, giving birth to fewer children. Therefore, the subsistence effect implies that income and birth rates move in the same direction. The same argument holds when $\varrho > 0$, as long as it is sufficiently small relative to cattle productivity, such that this technology is profitable at $c_p = \underline{c}$. We argue that this reflects the European experience after the plague, where meat production was feasible and birth rates moved in parallel with income. On the other hand, if ϱ is large relative to cattle productivity, meat production is not feasible. Therefore, even if $c_p > \underline{c}$ the cattle technology is not employed. Consequently, women do not work, and birth rates are constant and high. We argue below that this is the case for China.

Before turning to the long-run equilibria in our Malthusian setup, we derive an expression for female labor in equilibrium. Substituting for b from (1), for c_p from the household budget constraint $c_p = w_M + w_F l_F$, and imposing $\phi = 1$ in (19), we obtain

$$\frac{(1-l_F)^{\eta}}{\frac{\mu}{1-\mu}p^{1-\eta}} - l_F = \frac{w_M - \underline{c}}{w_F} \tag{20}$$

This implicity determines the share of lifetime that female peasants spend married, l_F, as a function of gender-specific wages. With constant TFP, the latter grow hand-in-hand with the land-labor ratio. We can therefore derive all variables of interest as functions of the male wage rate.

3.6 Long-run Equilibria

In the following, we analyze the long-run equilibria implied by our model for regions with European (English) and Chinese (Yangze) characteristics. We begin with Europe. If wages are high and land is not too productive, livestock raising becomes profitable. The switch to cattle production can occur at relatively low wages in Europe. As long as wages are high enough to enable meat consumption by peasants, the cattle technology is in use. Landlords can profit from raising livestock because one key input, land, is relatively cheap. In addition, the more fluid adoption of cattle production reflects the fact that European agriculture depends on teams of oxen and horses pulling plows to an extent that Chinese agriculture does not. There are also important synergies between the dominant type of arable production and food required for cattle. It is only because of the lack of demand for meat that the cattle technology is not employed initially. Therefore, women do not work and spend all their lifetime in marriage, which leads to high birth rates. This is shown in figure 2. Because of the high population pressure, land labor ratios – and thus per-capita income – stagnate at the low level in equilibrium E_L.

[Insert Figure 2 here]

Small increases in the land-labor-ratio raise p.c. income temporarily. However, because death rates fall while birth rates remain unchanged, the (male) wage eventually converges back to E_L. Only a large shock, like the plague, can raise land-labor-ratios and wages sufficiently to pass the threshold consumption level $\underline{c}$. With wages higher than $\underline{c}$, peasants start to consume meat. At the same time, the cattle technology begins to be used extensively. As explained above, because of the subsistence effect, female labor force participation is high when consumption is close to $\underline{c}$. Correspondingly, birth rates are low, but they rise in productivity, i.e., in the land-labor ratio. The downward shift of the birth schedule together with its subsequent upward-sloping characteristic reflect the nature of the EMP.[19] It combined lower fertility overall with the function of a "shock absorber", producing higher fertility in good years and curtailed nuptiality in bad ones. The economy thus converges to a new stable long-run equilibrium, E_H, which involves lower birth and death rates as well as higher p.c. income.

Figure 3 shows female labor supply as a function of the productivity of arable (A_g) vs. pastoral (A_c) production. At high levels of grain/cattle productivity, women will not work in the fields. If it were possible, they would even transfer their time endowment to their husbands to spend as much time as possible performing high-productivity agricultural labor. However, the $l_F \geq 0$ constraint is binding. Thus, female peasants never work, and birth rates remain at a high level. Even at high productivity levels (and thus high wages), Chinese birth rates do not fall. This is because the cattle technology is never employed. Intuitively,

[19]In a setup with heterogenous agents, this would explain the often-noted fact that EMP was adopted first by the lowest classes in society.

rising land-labor ratios increase productivity of both grain and cattle production. If the former is very productive relative to the latter, as in China, grain production remains the dominant technology.

[Insert Figure 3 here]

Figure 4 combines all the key analytical steps in our model. For the case of China, we leave all model parameters unchanged, except for one. The only difference between the two regions is that land productivity in Europe is lower, while land-labor ratios for any given wage are higher. This is shown in figure 4. Because meat production has to compete with arable agriculture, which is unusually productive per unit of land, the wage at which cattle raising becomes profitable is much higher in China. Under plausible parameter values, the switch to cattle production never occurs. As a consequence, when the plague hits China and raises p.c. income beyond the subsistence level, the cattle technology is still not adopted – despite the fact that there would potentially be demand for meat.

In Europe, in contrast, productivity in grain agriculture is not sufficiently high for the economy to be in the "danger zone". As the plague hits, the change in factor prices raises the relative productivity of pastoral farming vis-à-vis arable production. Female labor supply jumps, and fertility declines. In China, the plague does not trigger the emergence of a demographic regime comparable to the EMP because even high wages cannot compensate for the productivity advantage of grain production. The only long-run equilibrium is E_L, with a low land-labor-ratio and low p.c. income levels. In a paradoxical way, China's high land productivity emphasized by the revisionist "California School" (Pomeranz 2000, Goldstone 2003) undermines the prospects to adopt fertility limitation along European lines. Our minimalist model thus captures five important elements of the divergence between Europe and China: i. No emergence of female labor outside the household in China ii. Limited livestock production iii. Low land-labor ratios iv. High(er) fertility through early (and near-universal) marriage v. Lower per capita incomes.

[Insert Figure 4 here]

4 Conclusions

Even in a Malthusian world, the 'iron law of wages' need not hold. Births and deaths may be the prime determinants of living standards, influencing land-labor ratios and the productivity of workers. Nonetheless, if either death schedules or birth schedules are malleable, incomes can change substantially. The equilibrating forces in such a world may still be 'Malthusian', but they need not lead to the *same* equilibrium point.[20]

In this paper, we have argued that changes in European fertility behavior were important for the persistence of high per capita incomes before 1800. In particular, fertility restriction through the 'European Marriage Pattern' allowed Europeans to avoid the worst consequences of high fertility in other parts of the world. The EMP evolved in response to a large shock - the great plague of the 14th century. Because of the fall in population as a result of the Black Death, incomes increased. In the 'golden age of European labor', workmen's diets became abundant in ale and meat. Demand for manufactured products, mainly textiles, surged. To provide these goods, agricultural production had to switch 'from corn to horn' (Campbell 2000), with large increases in the number of cattle kept for meat and milk, and of sheep for wool.

The rise of livestock farming went hand-in-hand with a strengthening of the women's economic role. Since most tasks in husbandry were not particularly strenuous, female labor could easily be used. After the Black Death, when wages were high, owners of large estates began to substitute arable farming, with its high demand for adult male labor, for husbandry, which required less labor, some

[20]Mokyr and Voth (2009) make a distinction between a weak and a strong form of the Malthusian model, where the former is subject to the same equilibrating forces, and the latter yields the 'iron law of wages'.

of which could be supplied by women. They did so in order to economize on expensive male wages, and to seize the opportunities arising from the positive demand shock for meat, milk, and wool.

Women mainly worked on farms as servants in husbandry, helping with the milking of cows and the shepherding of flocks of sheep. Working as a servants involved a switch from the parental household to the one of the lord. Marriage was not allowed. By working as servants for a few years, women could earn and save, increasing their chances of a better match in the marriage market. Because the Black Death changed the pattern of production and raised the demand for female labor, it also helped to reduce fertility rates, by raising the age at first marriage. We thus explain the concurrent emergence of late marriage, higher incomes, low fertility, and an agricultural system using and producing unusually large numbers of farm animals.

In comparative perspective, we emphasize recent findings that underline the importance of high land productivity in China. Because of the subdivision of plots, the high productivity of rice paddy agriculture, and increasing intensification of land useage, output per acre in China was high. We argue that this was a barrier to adopting land-using and labor-saving technologies such as cattle farming. Thus one of the weaknesses of the European agricultural system – it's reliance on land-intensive cultivation – combined with the effects of the plague to help the adoption of fertility limitation in Europe.

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Figure 1: Population and real wages in early modern England

Source: Clark (2005)

Figure 2: Long-run equilibria in Europe

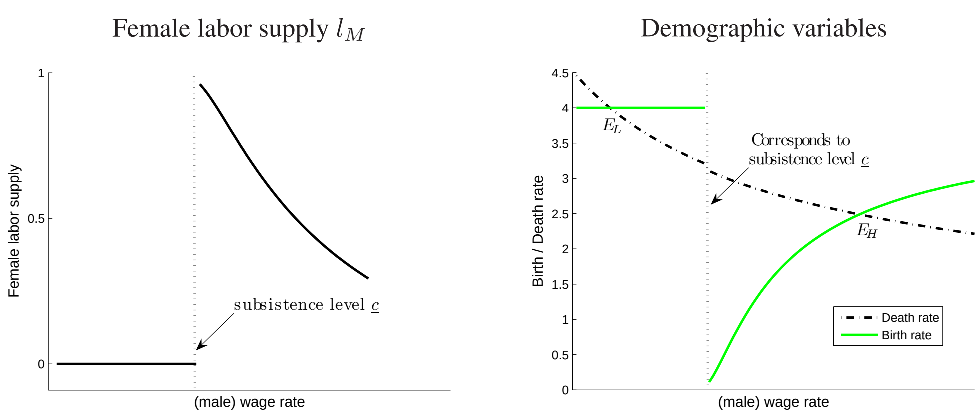

Figure 3: Female labor supply vs. relative TFP in grain and cattle production

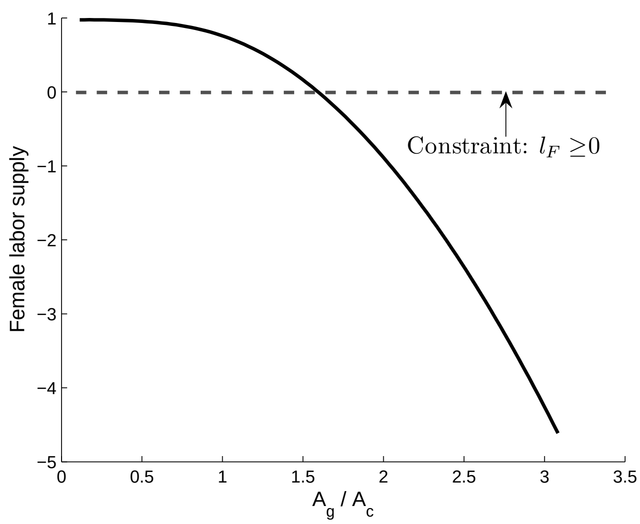

Figure 4: Long-run equilibria in Europe and China

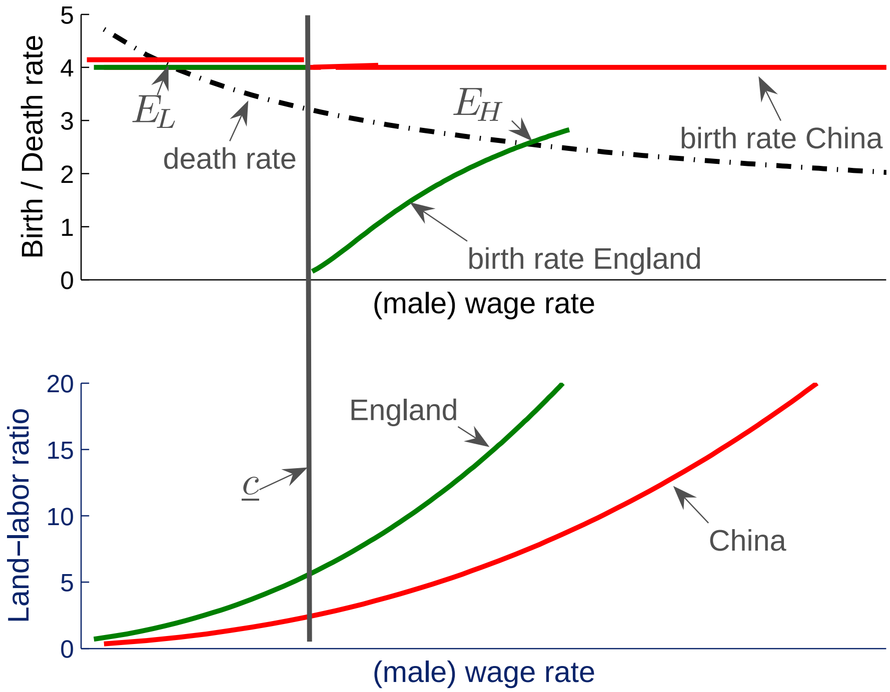

Table 1: Age of marriage and marital fertility in seventeenth century Europe

	Average Age of Women at First Marriage	Cumulative Marital Fertility (20-44)
England	25	7.6
France	24.6	9
Belgium	25	8.9
Germany	26.4	8.1
Scandinavia	26.7	8.3
Switzerland	-	9.3

Note: Cumulative marital fertility = number of live births per married women married aged 20 to 44.
Source: Flinn (1981).

Table 2: Marital fertility rates (births per year and woman)

Age	Hutterite	Western Europe before 1800	China
20-24	0.55	0.45	0.27
25-29	0.502	0.43	0.25
30-34	0.447	0.37	0.22
35-39	0.406	0.3	0.18
40-44	0.222	0.18	0.12

Source: Clark (2007).

Table 3: Average farm size in England, China, and the Yangzi delta 1300-1850 (acres)

Year	1279	c.1400	c.1600	c.1700	1750	c.1800	1850
England	13.9		72	75		151	
China		4.2	3.4				2.5
Big Yangzi delta		3.75	1.875	1.875	1.25	1.16	1.04
Small Yangzi delta		2.89				1.04	

Source: Brenner and Isett (2002). English figures are from Allen (1992).