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Abstract

Europeans restricted their fertility long before other parts of the world did so. By raising the marriage age of women, and ensuring that a substantial proportion remained celibate, the "European Marriage Pattern" (EMP) reduced childbirths by up to 40%. We analyze the rise of this first socio-economic institution in history that limited fertility through delayed marriage. Our model emphasizes changes in agricultural production following the Black Death. The production of meat, wool, and dairy (pastoral products) increased, while grain production declined. Women had a comparative advantage producing pastoral goods. They often worked as servants in husbandry, where they remained unmarried long after they had left the parental household. In a Malthusian world, this translated into lower population pressure, raising average wages by up to a quarter. The Black Death thus set into motion a virtuous circle of higher wages and fertility decline that underpinned Europe's high per capita incomes. We demonstrate the importance of this effect in a calibration of our model.

JEL: E27, N13, N33, O14, O41

Keywords: Fertility, Great Divergence, Epidemics, Demographic Regime, Long-Run Growth

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1 Introduction

Fertility decline is a key feature of the transition to self-sustaining growth. A large literature in economics seeks to explain why fertility fell at the same time as incomes began to grow after 1850, emphasizing the greater importance of child quality (Barro and Becker, 1989) or cultural factors associated with the demographic transition (Princeton Fertility Project). What is not well-understood is how fertility became a choice variable at all. Long before the advent of modern growth, Europeans restricted their fertility: Women often married as late in Europe before 1750 as they did in the late 20th century.[1] Since medieval times, in an area West of a 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).[2] 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. It also constitutes a puzzle. EMP required a large share of the female population never to engage in sexual activity; for the rest, abstinence until their twenties was necessary.[3] Effectively, Europeans traded off higher living standards – more goods, and more food – for less sex, and fewer offspring.

EMP contributed to higher incomes. By 1700, European incomes were far above subsistence. In the view of many scholars, the continent also produced more per capita than the rest of the world (Maddison, 2001; Broadberry and Gupta, 2005).[4] Since technological change was slow, other factors must have been responsible for high output (Voigtländer and Voth, 2009). On average, between a quarter and 40% of all possible births were avoided as a result of EMP (Clark, 2007). Since land was in fixed supply, fertility restriction paid in terms of higher incomes. EMP also acted as a "shock absorber" – fertility restriction became more severe as times became harder.[5] While there is agreement that EMP was a unique social institution with a large economic impact, there is no widely accepted interpretation of its emergence.

In this paper, we develop a simple Malthusian model with two sectors of agricultural production to explain the early adoption of fertility restriction in Western Europe. Each sector produces a single good – grain and 'horn' (pastoral products). Grain production is performed by peasant households, using male and female labor. Women are less productive in this sector. Grain-related activities such as plowing, threshing, and harvesting were typically performed by men because of the great physical strength required. Horn

[1]For example, average female age at first marriage was 25.1 in the UK in 1991 (UK Office of National Statistics dataset ST33212). In the 17th century, the average was 25 (Flinn, 1981). In West Germany the figure in 1992 was 26.5; it had been 26.4 in the 17th century (Flinn, 1981).

[2]The pattern was particularly strong in the North-West of Europe, and weaker in the South. Other areas of the world practiced fertility control in the form of infanticide. The type of fertility control we seek to explain involves a voluntary decision, possibly mediated through a socio-economic institution, that avoids births.

[3]There were few births outside marriage, and knowledge of contraceptive techniques was limited.

[4]Average urbanization rates reached 10%, and in the most advanced areas, rates were even higher. China, on the other hand, saw stagnation at a rate of 3% (Maddison, 2001). A group of revisionist historians has questioned the traditional consensus that labor productivity in Chinese agriculture was low (Li, 1998; Pomeranz, 2000; Goldstone, 2003). Pomeranz in particular has argued that incomes in the Yangtze were comparable to English ones. Their analysis remains controversial (Brenner and Isett, 2002; Broadberry and Gupta, 2005).

[5]Kelly (2005) shows that negative shocks to output as a result of adverse weather led to lower fertility. This helped to stabilize per capita output.

production is operated by landlords on large demesnes. Both sexes are equally productive in this sector: Shepherding, dairying and related activities are less physical labor intensive. Both sectors use land as an input, but pastoral farms do so more intensively.

The economy is Malthusian – death rates respond to economic conditions. In the initial steady state, land-labor ratios are low, and so are incomes. Grain cultivation provides most of the food. Female labor is not used intensively. Then, a mortality shock raises land-labor ratios. The horn technology, using land more intensively, now becomes viable. Women begin to work in husbandry, which involves dwelling away from home. Thus, marriage is delayed and fertility declines. While the economy does not lose its Malthusian characteristics, income gains become sustainable. Low fertility keeps land-labor ratios high – the economy transitions to a new steady state with a higher per capita income. In addition, the new regime helps to stabilize incomes. If productivity is temporarily lower, and incomes fall, the marginal utility of consumption increases. This drives women to work more in pastoral agriculture; fertility falls. This in turn reduces pressure on land-labor ratios and cushions the impact of negative productivity shocks. As a result, under EMP, incomes are more stable than they would be without fertility restriction. Eventually, EMP disappears when aggregate productivity grows beyond a threshold level.

The event that triggered the change to a low-fertility regime in Europe was the Black Death. It killed between a third and half of the European population. As the number of workers fell, land/labor ratios increased. Wages were high, and food plentiful. For one-and-a-half centuries, Europe saw a 'golden age of labor.'[6] According to the Malthusian model, this rise should have been temporary. As population recovered, incomes ought to have returned to pre-plague levels. Yet as late as the 17th and 18th centuries, per capita output in Northwestern Europe remained 35-50% higher than it had been on the eve of the Black Death (Maddison, 2007).[7]

Female labor became more valuable after 1348-50 because higher incomes raised meat, dairy, and wool consumption. By 1516, when Sir Thomas More wrote of 'man-eating sheep' in his *Utopia*, vast parts of English agricultural land had been converted to sheep pasture.[8] Sheep grazing and cattle raising were land-using and labor-saving. Many laborers could be replaced by a single shepherd or servant in husbandry. At a time of high wages and abundant land, pastoral farming was a profitable mode of production. Importantly, it used labor that was relatively cheap: Children and women.

By creating demand for women's labor, expanded pastoral production enhanced female employment prospects. It did so through an institution that also curtailed female fertility. Landlords regularly took in young men and women, housed them and fed them in exchange for labor services.[9] Of all workers employed

[6] According to the classic long-run wage series by Phelps-Brown and Hopkins (1981), 14th century English real wages more than doubled after 1349. More recent studies also show marked increases (Clark, 2005; Apostolides, Broadberry, Campbell, Overton, and van Leeuwen, 2008).

[7] If we focus on the wages of farm workers – arguably a better indicator of agricultural output per head – English wages and output at the early modern trough (in 1600) remain roughly 50% higher than on the eve of Great Plague (Apostolides et al., 2008).

[8] This was despite repeated interventions by the Crown (in 1489 and 1514) that attempted to stop the conversion of arable lands (Rodrick, 2004).

[9] They would also offer them some additional monetary reward which would typically be saved for later use, once servants formed a new household (Kussmaul, 1981).

in agriculture, between a third and half were servants. 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, most were employed as 'productive servants.' Kussmaul (1981) estimates that 60% of the population aged 15-24 were so employed; most early modern youth worked as servants at some point in their lives. Since women with children are generally unsuited for field work with animals, service also required that maids remained unmarried.

We are not the first to argue that the Black Death caused important changes in the European economy. Van Zanden (2002) concluded that the rapid rise of the Netherlands during the early modern period owed much to the economy's transformation after 1350. Epstein (2000) argued that institutional constraints on growth were removed, Mancur-Olson-style, by the plague. Herlihy (1997) speculated that the emergence of fertility restriction may have been linked to the effects of population losses after the plague, and Smith (1981) suggested that the rise of farm service may have been one of the reasons for greater fertility control. Finally, Pamuk (2007) surveys the evidence that the Black Death ushered in a transformation of the European economy, reducing and then reversing the income gap between Southern and Northwestern Europe. The nature of the Malthusian world before 1800 is examined *inter alia* in Clark (2007) and Wrigley, Davies, Oeppen, and Schofield (1997).[10]

Related work on the origins of the European Marriage Pattern includes Devolder (1999), who emphasizes the introduction of short-term leaseholds as a factor behind the rise of EMP. Foreman-Peck (2009) builds a model in which European fertility restriction follows from changes in mortality patterns. The paper that is closest in focus to ours is de Moor and van Zanden (2005). The authors emphasize the role of Christianity because it underlines the spiritual 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. Thus, children sought out outside earnings opportunities, especially when wages were high (such as after the Black Death).

Our paper forms part of a broader body of work on the causes of fertility change. The Princeton European Fertility Project (Coale and Watkins, 1986) argued that culture was crucial for the diffusion of fertility limitation in the 19th century.[11] Much of the work on fertility restriction after 1850 has emphasized rising returns to investments in child quality (Barro and Becker, 1989). An alternative strand in the literature focuses on the opportunity cost of female labor (Becker, 1960; Mincer, 1963). Butz and Ward (1979) as well as Heckman and Walker (1990) find evidence that higher male wages raise fertility, while higher female wages lower them. Schultz (1985) showed that a large part of fertility decline in 19th century Sweden was driven by world demand increasing the price of butter relative to grain. This raised wages of women working in husbandry, who in turn delayed marriage. Attention has also focused on the changing cost of children as a result of nineteenth-century compulsory schooling laws and factory acts restricting child labor

[10] The extent to which negative shocks raised death rates and lowered fertility rates is discussed by Anderson and Lee (2002), Galloway (1988), Crafts and Mills (2008), Nicolini (2007), and Kelly (2005).

[11] Recent work using disaggregated data for Bavaria and for France has questioned this conclusion (Brown and Guinnane, 2001; Murphy, 2006).

(Doepke, 2004; Puerta, 2009). Recently, Greenwood, Seshadri, and Vandenbroucke (2005) have explored the impact of labor-saving household technology on fertility, while Doepke, Hazan, and Maoz (2007) argue that one-off negative shocks to the value of female labor can lead to large increases in fertility.[12]

Relative to this literature, we make a number of contributions. We present the first economic model in which the European Marriage Pattern arises endogenously, in response to a positive, large shock to income. We focus on the emergence of a new regime in which fertility is both lower on average, and responds positively to higher wages. In our model, massive fertility restriction arises without a role for human capital, in contrast to models in the spirit of Barro and Becker (1989). Also, heterogeneity in wages or tastes plays no role (Jones, Schoonbroodt, and Tertilt, 2008). Our approach emphasizes female opportunity cost, as determined by changes in the structure of agricultural production following the Black Death. Our modeling exercise is in the spirit of what has been called "Institutional and Comparative Historical Analysis" (Greif, 1998). In effect, we argue that a new socioeconomic institution emerges in response to a sharp change in factor prices. We are also the first to assess quantitatively EMP's contribution to high European per capita output, using a calibrated model of the Malthusian economy.

Several papers in the unified growth tradition are closely related to our work. Unified Growth Theory seeks a single explanation of the transition from 'Malthusian stagnation' to self-sustaining, rapid growth (Galor, 2005; Hansen and Prescott, 2002; Galor and Weil, 2000; Kremer, 1993). Papers in this literature typically assume that as growth takes off, the return to human capital rises, which then lowers fertility (Becker, Murphy, and Tamura, 1990; Lucas, 2002; Jones, 2001).[13] The unit of analysis is typically the world as a whole, not individual countries. Instead, we focus on cross-sectional differences since we seek to pin down the contribution of fertility to Europe's precocious rise to riches. We also emphasize the potential for fertility to change substantially prior to the "take-off," and without changes in the return to human capital. In our model, permanently higher incomes are solely determined by the profitability of pastoral production.[14]

We proceed as follows. Section II discusses the historical background and context. In section III, we present our model of fertility restriction. Next, we calibrate our model. For plausible parameter values, the same shock to land-labor ratios can lead to the adoption of very different agricultural and fertility regimes in Europe and China. Section V concludes.

[12] They argue that the use of women in US wartime production during 1940-45 generated a negative externality for younger cohorts, who then engaged in more child-bearing.

[13] Fernandez-Villaverde (2001) presents a model in which the declining relative price of capital during the Industrial Revolution raises skill premia, and thus generates incentives to trade child quality for quantity.

[14] Our theoretical setup shares some similarities with Galor and Weil (1996), where the complementarity between capital and labor is stronger for women than for men. In their model, technological change drives the entire transition. An initial gain in capital intensity leads to fertility decline through a rise in the opportunity cost of female time. This then increases incomes, which also causes capital-deepening. In contrast to their setup, we are not trying to model a transition to self-sustaining growth. Rather, we emphasize the emergence of a new institution that underpins higher per capita output.

2 Historical Context and Background

In this section, we discuss the historical background and context of EMP's emergence. We first survey the available evidence about the rise of fertility limitation in Europe, and then summarize changes in agricultural production and consumption after the Black Death. Next, we examine the connection between nuptiality and the organization of agricultural production, and describe EMP's decline after 1750. Finally, we compare European and Chinese fertility patterns.

2.1 The Origins of the European Marriage Pattern

The European Marriage Pattern has four defining characteristics – a high percentage of women never marrying, a late female marriage, few births out of wedlock, and unrestricted fertility within marriage.[15] The emergence of late marriage is the single most striking – and the seemingly most "modern" – feature of EMP. It can be traced with reasonable accuracy before the arrival of the Black Death. In the European parts of the Roman Empire, it was 12-15 for pagan girls, and somewhat higher for Christian girls. Age at marriage in the Middle Ages appears to be have been somewhat higher than in Roman times, but not by a large margin. For a group of medieval Lincolnshire villages, Hallam (1985) estimated ages at first marriage for women of around 20. Thus, both a marriage age above the biological age of fertility, and some women never marrying, probably originated in some areas before the 14th century (Laslett and Wall, 1972). However, the European Marriage Pattern, with marriage postponed to age 25 and beyond, emerged fully after the Black Death (Hajnal, 1965, 1982). England in the early modern period registered an average age at first marriage for women of 26 years, and 17.5% never married. Scandinavia saw even higher ages at first marriage, but total fertility rates were greater than in England.[16] Table 1 gives an overview of the range of historical experience in the 17th century:

[Insert Table 1 here]

Within marriage, fertility was largely 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. Chinese fertility within marriage was low largely as a result of infanticide, as we discuss below. In 18th century Germany, some 20% of women married for the first time aged 30 and higher (Knodel, 1988).

[Insert Table 2 here]

[15] The percentage of females never married needs to be established through family reconstitutions, which track cohorts over the entire life cycle. For the period before 1500, these are not available. Instead, one can look at the proportion of women unmarried at a particular point in time. Because some women will eventually find husbands and have children, this constitutes a strict upper bound on the percentage never marrying. In St Germain-des-Prés in 801-20, for example, some 16% of adults were unmarried. Since men greatly outnumbered women, the proportion of unmarried women was probably much less. In the 9th century, in Villeneuve-Saint-Georges, up to 12% of adults had never married (Hallam, 1985).

[16] The difference is driven by a higher percentage of women never marrying in England.

Northwestern Europe in particular evolved a 'low pressure demographic regime' (Wrigley et al., 1997). Negative economic shocks were largely absorbed through Malthus's preventive check (lower nuptiality), rather than the positive check (death rates surging). 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 et al., 1997).

There are many reasons to believe that fertility restriction through late marriage was voluntary. Children were relatively independent from their parents by their teenage years, and became fully legally independent at age 21 – several years before the average age of first marriage. The law did not ban early marriages. In England, the legal age for marriage was 12 for women, 14 for men. Early marriages occurred, with the first age at marriage for women ranging from 16 to 45 (Clark, 2007). While the authorities attempted to raise age at marriage – by having extended apprenticeships, for example – there were plenty of ways to ignore or circumvent restrictions, especially in the larger towns (Ingram, 1985; Clark, 2007). Nor is there evidence that the "passion between the sexes" (as Malthus called it) was any less acute in early modern Europe than elsewhere. One out of seven marriages in 17th century England was followed by the bride giving birth within 8 months; the proportion could be as high as 40% (Wrigley and Schofield, 1981).

2.2 Changes in Production and Consumption after the Black Death

Prior to the Black Death, European agriculture suffered from declining labor productivity. Campbell (2000) argued that before the plague and the hunger crises of the early 14th century, output per head in English agriculture was falling. The more recent results by Apostolides et al. (2008) show declining agricultural production per worker and acre before 1350. 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 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 increased. As consumers grew richer, their consumption patterns shifted from 'corn to horn' (Campbell, 2000). There is ample evidence that 'luxury foods' such as meat, fish, and dairy products accounted for a far greater proportion of food expenditure after 1350 than before. Where grains had been consumed directly, as porridge or bread, ale-drinking expanded. Meat and milk consumption increased markedly. Based on changes in the number of non-working animals on farms, it approximately doubled. Since workers on large estates received some of their payments in kind, we also have more direct evidence on consumption patterns. Dyer (1988) analyzes the case of English farm workers, and shows that the percentage of calories coming from meat and fish rose from 7% in 1256 to 26% in 1424. By value, average spending increased from 20.5% pre-plague to 38.5% post-plague.

Landowners responded to the changes following the Great Plague in a number of ways. Apostolides et al. (2008) summarize changes after 1350 as follows:

> "Between the mid-thirteenth century and the mid-fourteenth century, factor costs and property rights encouraged lords to manage their demesnes directly and concentrate on arable production. Following the Black Death, however, lords found it ... increasingly expensive to hire wage labour, following a substantial increase in wage rates. Those lords who continued to farm directly switched away from labour intensive arable production to mixed husbandry and pastoral production, leaving arable production to peasants who could rely mainly on family labour ..."

After 1350, pasture replaced arable land at a high rate. Meat and wool production thus came to be concentrated on the larger estates. Sheep-farming husbandry expanded everywhere, as did the ranching of cattle. The trend was particularly pronounced in Southern England. Campbell estimates that grain acreage declined by approximately 15 percent after 1349, while the number of livestock expanded by 40 percent to meet buoyant demand. Much of the increase was concentrated amongst livestock reared for meat and milk, which grew by 90 percent. The estimates of Apostolides et al. (2008) suggest that pastoral output (in constant prices) increased by 22% between 1348 and 1555, while arable output only grew by 7%. Since population was still below its medieval peak, per capita consumption grew even faster – by more than 40% by 1550 for pastoral products, while arable output was up by 23% (cf. Table 3). Milk production per head was up by 150%, beef by 130%, and pork by 280%.

[Insert Table 3 here]

The advantage of switching to pasture for large landowners was twofold. First, it allowed lords to operate with less labor overall. The evidence suggests that per acre, a farm specializing in husbandry required 15-25% fewer hands than an arable one. Second, the labor itself was cheaper – women (and partly, by boys) replaced labor by adult males. On larger farms, moving from arable to pastoral production typically increased women's share of the workforce from 19 to 31%; on the smaller ones, from 26 to 34%. Thus, the switch from 'corn to horn' also produced a shift in demand from male to female labor.[17]

Also, average farm size increased after the 14th century. What Allen (1992) called the 'Yeoman's enclosure' (before the Parliamentary enclosures in the 18th century) led to a big rise in farm output between the plague and the onset of the Industrial Revolution. Some 80% of English farms had been smaller than twenty acres before the Black Death. By 1600, over 60% were larger than 100 acres. Increasing farm sizes allowed farmers to use more beasts of burden. Changes in capital intensity facilitated the saving of expensive (male) labor. Labor productivity began to grow, initially as a result of higher land-labor ratios. Investment in drainage, marling, and liming was massive. In addition, English farmers used draft animals in great numbers. By the eighteenth century, the number of horses per worker was 80% higher than in France, and 40% higher per unit of land (Wrigley, 1988).

[17] We use information on the composition of employment per acre from Allen (1991), who gives figures for England in 1770, for various farm sizes. We use his values for 100 (small) and 250 (large farms), and employ the size distributions in Allen (1988).

2.3 Farm Service and Fertility Restriction

As in most agricultural societies, children in their teens and twenties worked in Northwestern Europe – but they did so in an unusual way. An Italian visitor to England in the 16th century marveled at the fact that most parents would send their children away at an early age "for another 7 or 9 years... and few are born who are exempt from this fate" (McIsaac Cooper, 2005). As we have seen, apprenticeships and service in agriculture were a standard part of an English adolescent's life. We briefly summarize how service in husbandry became a key institution that raised marriage ages in early modern England.

After 1349, all types of labor, including female labor, became more expensive. This partly reflected the changing patterns of agricultural production. As horn production increased, so did the labor demands of pastoral farming. Landlords increasingly hired 'productive servants' to help on the larger farms (Kussmaul, 1981). Pastoralism has fairly evenly-spread labor requirements throughout the year. This makes it attractive to employ servants year-round, instead of hiring agricultural laborers on daily wages. The latter, used mainly in the arable areas, are more suited to a production cycle characterized by a brief period of peak labor demand during the harvest season. Pastoralism and the processing of its products is also singularly suited to the employment of women (Smith, 1981). Work as shepherdesses, as milkmaids or in spinning wool required less physical strength than plow agriculture.

For women and men, life as a servant in husbandry involved a commitment to remain unmarried. The *Museum Rusticum*, an 18th century periodical on rural affairs, called service "a covenanted state of celibacy." Marriage typically implied an immediate termination of service. Kussmaul (1981) calculates that 65% of servants married immediately before or after the end of their contracts.[18] The reason for these strict rules is that servants were entitled to room and board in exchange for labor services. Marriage and childbearing reduces female labor supply, and makes it more variable. As such, it would have been incompatible with the labor requirements in pastoral agriculture. Thus, as Macfarlane (1970) observed, "the system of farming out the children, which permitted them a moderate freedom without forcing them to resort to marriage, allowed them to marry late."

Women's service in husbandry reduced fertility rates by delaying marriage. This is most evident in the cross-section of ages at first marriage, documented by Kussmaul (1981). Figure 1 shows the connection with fertility. The larger the proportion of farm servants in total labor, the higher the proportion of females unmarried. We conclude that there is good prima facie evidence that more pastoral production was linked to fertility restriction through the institution of farm service.

[Insert Figure 1 here]

2.4 The Decline of EMP

English fertility increased rapidly during the second half of the eighteenth century. The causes of this marked change are not well-known, but a number of hypotheses have been advanced (Wrigley, 1983).

[18] She also notes that in a number of cases, female servants were permitted to stay in the house of their master for the remaining duration of their contracts.

Initially, England had a particularly strong, "low-pressure" form of the European Marriage pattern, with late marriages and low rates of illegitimacy. After the 1730s, mean ages at first marriage began to trend down for both men and women. By the 1830s, they had fallen from 26 for women (and 27 for men) in 1700 to 23 (and 25, respectively). Illegitimacy, which had accounted for a mere 1% in the 1650s, rose to more than 6% after 1800. Population growth accelerated from zero to 1.75% per annum (Wrigley et al., 1997).[19]

As the eighteenth century wore on, a number of factors reduced female employment opportunities in husbandry. Snell (1981) argues that as grain prices rose in the 18th century relative to the price of meat and dairy products, pastoral production declined. In addition, land productivity in English agriculture began to rise after 1700 (Apostolides et al., 2008). Since meat production was more land-using than grain production, this made pastoralism overall less profitable. However, lower wages for female labor alone cannot be a sufficient explanation – based on the classic pattern in early modern England, this would simply raise the marriage age.

The institution of farm service for young women itself was gradually vanishing, as a result of economic change. The seasonal peaks in marriage patterns became smaller after the 17th century. There were typically two pronounced peaks in the frequency of marriages – in May/June and September/October. These reflected the end of the hiring cycle for servants – spring in husbandry, after the lambing season, and fall in arable farming, after the harvest. Marriages celebrated after the lambing and shearing season brought the typical work-year in pastoral agricultural to an end. Importantly, as Kussmaul (1988) shows, the overall marriage age and the proportion of spring marriages fell in tandem. Spring marriages became markedly less important after 1700 (Figure 2). Thus, late marriage and horn production declined in parallel.

[Insert Figure 2 here]

As agricultural employment as a percentage of the total fell, the annual hiring cycle for servants in agriculture left less and less of a trace in the seasonality of marriages. Cottage shop manufacturing offered a chance to earn a living, while already having children.[20] For a given decline in the land-labor ratio, female wages fell by less; thus women could marry earlier, and still earn the same. The decline of England's low fertility regime may therefore have been brought on by the same factors that determined its rise during the early modern period – changes in the opportunity cost of female labor in the late teens and early twenties, as determined by employment conditions for servants in husbandry.

2.5 Chinese Demography

For women, marriage occurred early and was near-universal in China. For the period 1640-1870, the percentage of women not married by age 30 ranged from 4% in Beijing to 1% in Liaoning (Lee and Feng,

[19] Wrigley (1983) examined the contribution of fertility to the acceleration in population growth after 1750. Some of the underlying data has been revised by Wrigley et al. (1997), but the relative contributions of fertility increase and mortality decline have not been recalculated.

[20] The effect on marriage age is not always clear-cut. Some studies find a decline in the age at first marriage for women in proto-industrializing areas; others show that higher nuptiality preceded the spread of cottage-shop manufacturing (cf. Hudson, 1996).

1999). The age at first marriage for women was also low. Amongst members of the Imperial Qing family in Beijing, age at first marriage was 15.5-19 years in the 17th century. By 1840, it had risen to 22 years. Marriage outside the urban areas, and amongst those not belonging to the nobility, probably continued to occur much earlier. In the early 20th century, Chinese women on average married aged 17.5 (Lee, Feng, and Ruan, 2001). For men, the same is not true. A significant proportion remained unmarried by age 30. The main reason was the unavailability of women. Due to female infanticide, and the practice of taking multiple wives, many men could not marry. The overall proportion in 1800 was around 22%, compared to 45% in England, Norway, and Sweden. The average age at marriage for men was 21-22 (Lee and Feng, 1999).

The extent to which Chinese demography resulted in higher fertility and greater pressure on living standards is controversial. While female marriage occurred early and was almost universal (and only female nuptiality matters for demographic growth), infanticide and fertility limitation within marriage reduced population growth rates (Lee and Feng, 1999; Feng, Lee, and Campbell, 1995; Wolf, 2001). This would suggest that, contrary to Malthus' famous claim, Chinese fertility was not 'unconstrained.' In addition, data from the 19th century suggests that Chinese birth rates were around 35/1000, only slightly higher than early modern European ones (Clark, 2007). This could be interpreted as a sign that differences between European and Chinese fertility behavior have been overstated. Yet Chinese incomes were much lower. Thus – since European fertility increased in wages – fertility rates were higher in China than in Europe *for any given wage*.

We do not take a stand on the broader issue whether China experienced greater population pressure. Delayed marriage constitutes a key difference in behavior compared with China. It also clearly reduced fertility in Europe. Whether infanticide and lower fertility within marriage in the Far East achieved similar effects is not crucial for our argument.[21]

3 Model

This section presents a simple model of what determined pre-industrial labor supply and marriage decisions. The economy is composed of N female and N male peasants who work, consume, and procreate.[22] People live for two periods, childhood and adulthood. Children do not work or consume. Adult peasants form couples and make joint decisions to maximize household utility, facing a tradeoff between female work time and having children. Adulthood is equivalent to the fertile years in a woman's life. For simplicity, we assume that wages are the only source of income for peasants.

There are two technologies to produce consumption goods. Both use land and peasant labor as inputs.

[21] We note in passing 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 (Maddison, 2001). In other words, Chinese population growth was approximately 1/3 faster than in Europe.

[22] We call all economic agents that are not large landowners 'peasants' (landholders subsisting by working a small plot). This is a useful description for all countries except England, where there were no peasants in the strict sense of the word. Instead, most tenant farms were relatively large (as we discuss in section 4), and were often operated with hired labor. We use the 'peasant' terminology for simplicity. In our model, it merely implies that large landowners have an advantage producing pastoral products compared to 'peasants.'

Grain production is labor-intensive, while horn production (cow-herding and sheep-farming) uses relatively more land. In addition, grain production requires arduous physical labor. Thus, men are more productive than women. In less strenuous pastoral labor, men and women are equally productive. A landlord owns all land T, which is in fixed supply. He does not work. Peasants rent land T_g for grain production. On the remaining land $T_h = T - T_g$, the landlord operates large-scale horn production, hiring peasant labor. Historically, cattle ranches and sheep farms have been much larger than arable farms. Therefore, we assume that only the landlord disposes of demesnes large enough for commercial horn production; peasants can only grow grain on the lots that they rent.

Male and female adult peasants are endowed with one unit of time each, which they split optimally between arable and pastoral production. With a sufficiently large comparative advantage in the arduous grain production, men decide to work only in this sector. When married and living together with their spouse, women also work in grain production on the rented soil. However, their marginal product is low. In order to work in pastoral production (husbandry), women are required to be unmarried and dwell away from home at the landlord's demesne. Thus, peasant couples face a tradeoff of raising children versus female work in the potentially more rewarding horn sector.

The economy is Malthusian – the steady state income level depends on fertility and mortality schedules. The latter declines in consumption. Fertility, on the other hand, is endogenous and depends on the age at marriage. Before marriage, women do not have children. During marriage, there is no birth control and children arrive with frequency π. Delaying marriage is therefore the only 'contraception technology.' We define the European Marriage Pattern as follows:

Definition. *Let $\overline{b}$ be the birth rate when women spend all their adult life married. Then EMP is a demographic regime that involves (i) $b < \overline{b}$ because women remain unmarried throughout a part of adulthood, and (ii) b increases in p.c. income.*

Our model describes how EMP can emerge as a consequence of major population losses; it also analyzes productivity characteristics that favor the emergence of EMP. An epidemic like the plague causes land-labor ratios to rise dramatically. This leaves the remaining population with greater per-capita income. As long as birth and death schedules are unchanged, the economy returns to its earlier equilibrium – any escape from Malthusian stagnation is temporary. However, in our model, the plague prompts the landlord to shift production from 'corn to horn.' Cattle and sheep farming use the abundant factor of production – land – and can be operated with cheap labor – that of women. Thus, the demand for female labor rises, and so do female wages. Women work in horn production for part of their life, which requires them to dwell away from home. Thus, they marry later. 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. Because of later marriage, the birth schedule shifts downward (property (i) of EMP). In addition, a subsistence effect makes birth rates increasing in income (property (ii)). The new steady state has lower birth rates, combined with higher per capita incomes. This mechanism can explain the slow rise of population levels after 1349, and the persistence of higher output per capita.

3.1 Household Formation and Fertility

Adult peasants live for one period. At the beginning of each period, male and female peasants meet and form N couples. Independent of whether or not they live in the same location, they make decisions jointly, maximizing household utility. Male and female peasants each provide one unit of labor per period and allocate it to grain and horn production. For simplicity, we ensure that the male comparative advantage in grain production is large enough such that men only work in this sector. Men's contribution to household income is thus equal to the male wage rate in grain production, $w_{M,g}$. Women split their labor supply between the two sectors. When working in husbandry (horn production), peasants are required to dwell away from home at the landlord's location. Marriage is not allowed, and women live separated from their fiancé while earning the wage w_h.[23] The fraction l_h of adult lifetime that female peasants work in horn production is endogenously determined; it can be interpreted as the celibate period for both men and women. The probability of childbearing is zero during this period. After marrying, man and wife move in together, and women work in peasant grain production at home. Their marginal product in this sector is given by $w_{F,g}$. The fraction $1 - l_h$ is the share of lifetime that couples are married. There is no contraception. Married couples produce π births per unit of time.[24] Therefore, the number of offspring per couple is given by

$$b = \pi(1 - l_h) \tag{1}$$

The share of lifetime married also corresponds to female labor supply in peasant grain production, $l_{F,g} = 1 - l_h$.[25] Female labor supply in horn production, l_h, is thus determined by the trade-off between relative female wage income in horn vs. grain, $w_h/w_{F,g}$, and child rearing during marriage. When the horn sector does not operate, $l_h = 0$ and $b = \bar{b} = \pi$.

Death rates among adults are zero until a given period is over. Overall mortality is thus driven exclusively by child mortality.[26] The survival of children depends on average peasant consumption. The number of children dying per family is given by

$$d = d_0 \ \left(\bar{C}_p/\underline{c}\right)^{\varphi_d} \ , \tag{2}$$

where $\varphi_d < 0$ is the elasticity of child mortality with respect to average consumption of peasant households ($\bar{C}_p$), and d_0 is the death rate at subsistence consumption $\underline{c}$.[27] Consequently, child mortality falls as p.c. income rises. Note that below subsistence consumption, individuals suffer from hunger, but do not necessarily die – mortality increases continuously as $\bar{C}_p$ falls below $\underline{c}$. At the end of each period, parents die and

[23]Because only women work in horn production, we do not need extra subscripts for male or female peasants; the subscript h is sufficient.

[24]For simplicity, we treat π as a deterministic frequency, rather than as probability draws. In addition, we assume that child mortality does not directly influence birth rates. Thus, there is no role for precautionary children in our model.

[25]We thus implicitly assume that working at home in grain production is compatible with raising children. In addition, the fact that female peasants spent much of their time caring for children is a further justification for their relatively lower productivity in grain production.

[26]Historically, child mortality was the main driver of overall life expectancy.

[27]A historical justification for child mortality depending on average (rather than individual) income is that its main cause were diseases like diarrhea and typhus, whose spread depends on hygienic conditions (and therefore income) in the community.

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 draw utility from the number of children and from consuming two goods: Grain ($c_{p,g}$) and horn products (meat, milk, wool – denoted by $c_{p,h}$). We use grain as the numeraire; the price of horn goods is denoted by p_h. In order to focus on the main mechanism, we simplify the analysis by assuming that grain and horn products are perfect substitutes, such that the composite consumption index is given by $C_p = c_{p,g} + c_{p,h}$. Conveniently, this implies that the price of grain equals the price of horn, provided that the latter is produced. Consequently, $p_h = 1$. Relative price effects thus do not influence our results.[28] The household budget constraint takes the form $C_p \leq I_p$, where peasant household's income is given by

$$I_p = w_{M,g} + w_{F,g}(1 - l_h) + w_h l_h \ . \tag{3}$$

Because men work only in grain production, they contribute $w_{M,g}$ to household income. Women split their labor supply between grain and horn, as represented by the second and third term in (3), respectively.

When household income is large enough to allow above-subsistence consumption, household utility is given by

$$u(C_p, b) = (1 - \mu)\ln(C_p - \underline{c}) + \mu \ln(b - \underline{b}), \quad \text{if } I_p > \underline{c} \tag{4}$$

where $\mu \in (0, 1)$ represents the relative importance of children vs. consumption for peasant families. This is similar to Galor and Weil (1996) and is a special case of Jones' (2001) model.[29] We do not explicitly model utility for the below-subsistence case. Instead, we assume that the marginal utility of consumption is large but not infinity in this case, such that households still have at least $\underline{b}$ children.

The landlord does not work and does not draw utility from children. Therefore, he does not influence fertility directly. The landlord has the same consumption preferences as peasants, $C_k = c_{k,h} + c_{k,g}$.[30] His only source of income are land rents, rT, and his budget constraint is given by $C_k \leq rT$.

Given $w_{M,g}$, $w_{F,g}$, and w_h, peasant households maximize (4) subject to the time constraint $0 \leq l_h \leq 1$, the birth rate given by (1), and their budget constraint. In the absence of bequests and investments, the latter holds with equality, i.e., $C_p = I_p$. The household optimization problem is then given by

$$\max_{l_h} \left\{(1 - \mu)\ln\left[w_{M,g} + w_h l_h + w_{F,g}(1 - l_h) \ - \ \underline{c}\right] \ + \ \mu \ln\left[\pi(1 - l_h) - \underline{b}\right]\right\} \tag{5}$$

[28] Of course, perfect substitutability between two types of food is a strong assumption. However, evidence suggests a high elasticity. We already discussed the large rise in the share of calories coming from meat and fish in England after the Black Death. In other areas of the world, where populations of European origin were faced with cheap and abundant meat (such as in Argentina), consumption also grew massively. In the 1980s, Argentine beef consumption was 70-80 kg per capita, twice as high as in the US (Jaffee and Gordon, 1993). In the 19th century, it may have been as high as 120 kg (Salvatore, 2004).

[29] In a more general setup, rising income in a rich economy ($I_p >> \underline{c}$) 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). In our setup with log-preferences, income and substitution effect cancel each other. This choice allows us to focus on the subsistence effect that operates when I_p is close to $\underline{c}$, as well as on the effect of relative wages in horn production on female labor supply.

[30] While land-owners were not consuming goods in the same proportions as peasants, the staff they employed in large numbers were. We abstract from any systematic differences for ease of exposition. 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.

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 in (2) that child mortality depends on average per capita consumption. Since households take average consumption as given, child mortality does not interfere with optimal labor supply decisions. With these assumptions, the more general dynamic optimization problem (e.g., Barro and Becker, 1989) reduces to a sequence of static problems as given in (5).

3.2 Technology and Location of Production

Production technologies of both grain (g), and horn (h) use labor and land as inputs. Grain is produced according to:

$$Y_g = A_g \widehat{L}_g^{\alpha_g} T_g^{1-\alpha_g} \ , \tag{6}$$

where A_g is TFP, α_g is the labor share in grain production, T_g is land dedicated to grain, and $\widehat{L_g}$ denotes effective peasant grain-labor supply. The latter is given by:

$$\widehat{L}_g = L_{M,g} + \rho L_{F,g} \ . \tag{7}$$

where $L_{M,g}$ and $L_{F,g}$ denote male and female grain-labor input, respectively. While both types of labor are perfectly substitutable, men have a relative advantage compared to women because grain farming requires intense physical labor, such as ploughing, threshing, and reaping. We capture this fact by the parameter $\rho < 1$.

The horn technology is less labor-, and more land-intensive than arable production. This is represented by $\alpha_h < \alpha_g$ in the production function

$$Y_h = A_h L_h^{\alpha_h} T_h^{1-\alpha_h} \ , \tag{8}$$

where A_h denotes TFP, T_h is land, and L_h is total labor input in horn production. Men and women are equally productive in the horn sector. However, below we choose parameters such that male wages in grain exceed those in horn production. Hence, male peasants only work in arable agriculture on the soil they rent, while female peasants allocate their time between grain and horn. This simplifies our analysis, but is not crucial for the main result. With only women working in horn and the number of female peasants equalling the number of households, we have $L_h = N - L_{F,g}$.

We assume that the horn 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 pastoral vs. arable cultivation (Campbell, 2000). Analytically, a minimum land requirement for horn 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 horn. This assumption is important because it ensures that women have to leave the peasant household to work in pastoral farming.

The landlord owns an area T of land. He leases a part T_g to peasants and operates pastoral farming on the remainder $T_h = T - T_g$, hiring peasant workers at their marginal product.[31] The split of land is determined endogenously as shown below. We normalize land by the number of peasant households: $t = T/N$ represents the aggregate land-labor ratio, while $t_g = T_g/N$ and $t_h = T_h/N$ are land per household in grain and horn, respectively.[32]

Each peasant household therefore rents land t_g. Because peasants do not have access to the large-scale horn technology, they use all their rented land to produce grain. Consequently, there is a clear division of production by location: Peasants grow grain on rented land close to their dwellings, while the landlord operates horn production on separated large demesnes. However, the horn technology is not always in operation. We discuss the corresponding mechanism in detail below.

This completes the basic setup of our model. Next, we derive factor payments and show how land is allocated between grain and horn production. In addition, we examine the female labor supply decision.

3.3 Factor Payments and Allocation of Labor

Peasant households optimally allocate their labor supply between working on rented soil – paying rents to the landlord while keeping the remaining output – and working for the landlord in horn production at the wage rate w_h. While male peasants work only in grain production, female peasants optimally split their labor allocation between horn and grain. When growing grain on rented land, the marginal product of male labor is given by

$$w_{M,g} = \alpha_g A_g \left(\frac{T_g}{\widehat{L}_g}\right)^{1-\alpha_g} = \alpha_g A_g \left(\frac{t_g}{\widehat{l}_g}\right)^{1-\alpha_g} , \tag{9}$$

where $\widehat{l}_g = \widehat{L}_g/N$ is effective labor supply per household in grain production. When married and working at home in grain growing, women's marginal product is below the male one, and is given by

$$w_{F,g} = \rho\, w_{M,g} \tag{10}$$

Since men only work in grain and there are N male peasants, we have $L_{M,g}/N = 1$. In addition, $L_{F,g}/N + L_h/N = l_{F,g} + l_h = 1$ must hold because women work one unit of time. Using (7), we can thus express effective labor in grain production per household as a function of the share of female lifetime spent working in horn, l_h:

$$\widehat{l}_g = 1 + \rho(1 - l_h) \, . \tag{11}$$

[31] Alternatively, we could assume that landlords manage the production on all their land, paying grain and horn workers their marginal product. The crucial assumption for our mechanism is that large-scale horn production requires the corresponding workers to dwell away from home.

[32] Strictly speaking, the aggregate land-labor ratio is given by $T/(2N)$, accounting for female labor. However, we refer to the proportional term T/N in the following.

Next, we turn to pastoral production. When the landlord produces horn goods, he pays the wage rate:

$$w_h = \alpha_h A_h \left(\frac{t_h}{l_h}\right)^{1-\alpha_h} . \tag{12}$$

We choose sectoral TFPs such that $w_h < w_{M,g}$ for the relevant range of aggregate land-labor ratios. This ensures that male peasants work only in grain production while all labor in horn is provided by women.

Peasant households pay the rental rate r_g, while the return to land in horn production is r_h, as given by:

$$r_g = (1-\alpha_g) A_g \left(\frac{\widehat{l}_g}{t_g}\right)^{\alpha_g} , \quad r_h = (1-\alpha_h) A_h \left(\frac{l_h}{t_h}\right)^{\alpha_h} \tag{13}$$

Optimal allocation of the soil operated by the landlord requires that the land return in grain and horn production equalize: $r = r_g = r_h$. This implies:

$$\frac{t_g}{\widehat{l}_g} = \left(\frac{A_g}{A_h}\,\frac{1-\alpha_g}{1-\alpha_h}\right)^{\frac{1}{\alpha_g}} \left(\frac{t_h}{l_h}\right)^{\frac{\alpha_h}{\alpha_g}} . \tag{14}$$

This equation says that land per effective worker in grain is proportional to its productivity-adjusted counterpart in horn production, provided that the landlord operates the latter. Land per effective labor in grain relative to horn increases in (i) in the TFP ratios – relatively more land is dedicated to the more productive technology, and (ii) in the land-intensity of grain relative to horn, as governed by α_g and α_h. Note that because of (i), countries with high TFP in grain production dedicate relatively less land to horn. This will become decisive when we compare Europe with China.

Much of our analysis relies on changes in the aggregate land-labor ratio t. The following proposition shows how sector-specific land-labor ratios change with their aggregate counterpart.

Proposition 1. *If both technologies operate and the aggregate land-labor ratio $t = T/N$ grows, then the ratio of land to (effective) labor increases in both sectors, i.e., $\frac{d(t_g/\widehat{l}_g)}{dt} > 0$ and $\frac{d(t_h/l_h)}{dt} > 0$.*

PROOF. If both technologies operate and land per household t increases, market clearing implies that land-labor ratios must increases in at least one of the two sectors. Following (14), $d(t_g/\widehat{l}_g)/dt$ and $d(t_h/l_h)/dt$ have the same sign. Consequently, both derivatives are positive. □

Next, we use (9), and (14) to derive the wage rate in grain as a function of the horn land-labor ratio:

$$w_{M,g} = \alpha_g A_g \left(\frac{A_g}{A_h}\,\frac{1-\alpha_g}{1-\alpha_h}\right)^{\frac{1-\alpha_g}{\alpha_g}} \left(\frac{t_h}{l_h}\right)^{\frac{\alpha_h}{\alpha_g}(1-\alpha_g)} . \tag{15}$$

We have now obtained all wage rates as functions of the land-labor ratio in horn, t_h/l_h. Finally, we derive the ratio that determines whether or not the horn technology operates: The relative return to female labor in horn vs. grain. We divide (12) by the female marginal product in grain production (given by (10) and (15)) to obtain:

$$\frac{w_h}{w_{F,g}} = \frac{\alpha_h}{\rho\,\alpha_g} \left(\frac{A_h}{A_g}\right)^{\frac{1}{\alpha_g}} \left(\frac{1-\alpha_h}{1-\alpha_g}\right)^{\frac{1-\alpha_g}{\alpha_g}} \left(\frac{t_h}{l_h}\right)^{\frac{\alpha_g-\alpha_h}{\alpha_g}} . \tag{16}$$

The return to female labor in horn vs. grain is therefore driven by three components in our model.[33] First, if grain technology is highly productive relative to horn technology (A_h/A_g is small), female wages in horn are relatively low. Second, the same is true if women are very productive in grain (ρ is high). Finally, and most important for our mechanism, $w_h/w_{F,g}$ grows when land becomes more abundant, as the following corollary shows.

Corollary 1. *Provided that both sectors operate, the relative female wage in horn is increasing in the aggregate land-labor ratio:* $d(w_h/w_{F,g})/dt > 0$.

PROOF. Since $\alpha_g > \alpha_h$ and $d(t_h/l_h)/dt > 0$, this result follows from deriving (16) with respect to t. □

Workers in the more land-intensive horn technology profit relatively more from increases in farmland. Conversely, if land is scarce because of population pressure, w_h is below $w_{F,g}$. In this case female workers do not supply labor in horn production. For higher land-labor ratios, the relative wage exceeds one, and it becomes increasingly attractive for female peasants to work in the horn sector. Because this requires dwelling away from home, marriage is delayed and EMP can emerge. We argue that this mechanism reflects the European experience after the Black Death, where land-labor ratios nearly doubled within a few years.

3.4 Fertility, Female Labor Supply, and Emergence of EMP

The missing piece to close our model is female labor supply. We derive it as a function of male and female wage rates. As a first step, household optimization (5) yields:

$$b - \underline{b} = \pi \, \frac{\mu}{1-\mu} \, \frac{I_p - \underline{c}}{w_h - w_{F,g}} \tag{17}$$

This equation holds under two conditions. First, the relative wage condition $w_h > w_{F,g}$; otherwise the horn technology does not operate and women marry at the beginning of the period, giving birth to π children. Assume for now that $w_h > w_{F,g}$ is satisfied. Second, (17) entails an income condition: $I_p > \underline{c}$, i.e., that peasant household income is sufficient to grant above-subsistence consumption. With income approaching the subsistence level, birth rates converge to $\underline{b}$. Because we assume that the marginal utility of consumption approaches infinity for below-subsistence consumption, $b = \underline{b}$ holds whenever $I_p \leq \underline{c}$. Note that female labor in horn is at its upper bound when fertility is at its minimum $\underline{b}$. That is, women cannot work more than $\bar{l}_h = 1 - \underline{b}/\pi$ in horn production because otherwise fertility drops below $\underline{b}$. Therefore, we have $l_h = \bar{l}_h$ whenever horn is viable ($w_h > w_{F,g}$) and $I_p \leq \underline{c}$. The corresponding household income is then given by

[33] In a more general setup with imperfect substitutability between grain and horn products, there is a third component: $w_h/w_{F,g}$ is additionally increasing in the relative price of horn products. If p_h is large, w_h is high, and the horn technology is employed. This reinforces our mechanism because meat and wool were luxury goods – demand for horn products thus surged when incomes rose after the plague.

$I_p(\bar{l}_h) = w_{M,g} + w_{F,g}(1 - \bar{l}_h) + w_h \bar{l}_h$. Note that $I_p(\bar{l}_h)$ is increasing in t. We can thus use the income condition $I_p(\bar{l}_h) \leq \underline{c}$ together with the relative wage condition to pin down the behavior of female labor in horn. Using (3), we solve (17) for l_h.

$$l_h = \begin{cases} 0, & \text{if } w_h \leq w_{F,g} \\ \bar{l}_h, & \text{if } w_h > w_{F,g} \text{ and } I_p(\bar{l}_h) \leq \underline{c} \\ (1-\mu)\bar{l}_h - \mu\, \frac{w_{M,g} + w_{F,g} - \underline{c}}{w_h - w_{F,g}}, & \text{if } w_h > w_{F,g} \text{ and } I_p(\bar{l}_h) > \underline{c} \end{cases} \tag{18}$$

Figure 3 illustrates the two conditions used in (18). The upper panel depicts both $w_h/w_{F,g}$ and $I_p/\underline{c}$ as functions of land available per peasant household, T/N. Wages in grain and horn (and therefore household income I_p) grow with T/N. In addition, as shown in Corollary 1, the relative wage $w_h/w_{F,g}$ grows with land per household. The lower panel in Figure 3 relates the two conditions with female labor supply in horn (l_h). We begin with low T/N. Because of the relative wage condition (dashed line), work in horn is worthwhile only if it pays more than the marginal product in grain production at home. Thus, for $w_h/w_{F,g} \leq 1$, women do not work in horn, such that $l_h = 0$. Growing T/N eventually leads to $w_h/w_{F,g} > 1$, making the horn sector attractive for female labor (beyond point A). The exact level of l_h then depends on the income condition, depicted by the solid line in the upper panel. If T/N – and thus income – is low, i.e., if $I_p(\bar{l}_h)/\underline{c} \leq 1$, peasants are close to starvation. In this case households supply the maximum possible female labor in horn, $\bar{l}_h$, in order to add the wage premium $w_h > w_{F,g}$ to income.

Further increases in T/N finally allow above-subsistence consumption (point B, where $I_p/\underline{c} = 1$). With T/N rising beyond this point, two effects govern female labor supply decisions in the third line of (18). First, a relative wage effect leads to *rising* work in horn when w_h increases relative to $w_{F,g}$. Second, a subsistence effect implies *falling* female labor in horn production as income grows. To understand the subsistence effect, let us analyze a relatively poor economy, where I_p is close to, but larger than, the expenditure needed for subsistence consumption, $\underline{c}$. Thus, l_h is below its upper bound. Now suppose that productivity *falls* at the same rate in both grain and horn, pulling income yet closer to the subsistence level but leaving $w_h/w_{F,g}$ unchanged. Then the marginal utility of consumption rises dramatically. Therefore, for a given premium $w_h > w_{F,g}$, female peasants shift labor supply to the horn sector, delaying marriage and giving birth to fewer children over their lifetime.[34] Consequently, the subsistence effect implies that income and female labor shares in horn move in opposite directions. For our choice of parameters the subsistence effect dominates when income is small, while the relative wage effect eventually prevails when income is large.[35]

[Insert Figure 3 here]

Figure 3 also illustrates a crucial condition for the emergence of EMP. The subsistence effect is important only if B lies to the right of A, that is, when labor in horn becomes viable at a T/N where households are poor. This generates strong incentives for female peasants to work in horn for the wage premium

[34] With declining productivity, this continues until the number of children falls to $\underline{b}$, where $l_h = \bar{l}_h$.

[35] For large T/N, l_h becomes eventually upward sloping (not depicted in Figure 3).

$w_h > w_{F,g}$. The following proposition states the conditions under which EMP emerges as a consequence of major population losses.

Proposition 2. *EMP emerges over some range of T/N if and only if $\frac{T}{N}\big|_{w_h=w_{F,g}} < \frac{T}{N}\big|_{I_p=\underline{c}}$, i.e., if the horn technology becomes economically viable at land-labor-ratios that do not yet grant subsistence consumption.*

PROOF: See Appendix A.1.

Graphically, Proposition 2 says that point A in Figure 3 has to be to the left of point B for EMP to emerge. In other words, EMP emerges when income is below subsistence at the point where horn becomes viable. If this holds, the subsistence effect (making work in horn more necessary for *smaller* T/N) overcompensates the relative wage effect (making work in horn more attractive as T/N rises). Thus, on net, l_h falls in T/N – and birth rates rise – at least over some range of T/N. On the other hand, if A lies to the right of B, the income effect more than offsets the substitution effect, and EMP does not emerge. The proof of the proposition builds on this intuition. Proposition 2 has implications for the relative productivity across sectors and genders that allow EMP to emerge. We assume that the densely populated pre-plague economy has land-labor ratios below the ones in point A. The plague raises T/N dramatically. Corollary 2 discusses under which condition this leads to the emergence of EMP.

Corollary 2. *The following properties favor the emergence of EMP in response to large population losses: (i) TFP in the grain sector, A_g, is relatively low, (ii) TFP in the horn sector, A_h, is relatively high, and (iii) women are relatively unproductive in grain production (ρ is relatively small).*

PROOF: See Appendix A.2.

We show in section 4 that conditions (i)-(iii) were more likely to hold in Europe than in China when both regions were hit by the plague in the 14th century. Before turning to this comparison, we simulate our model and illustrate the main results.

3.5 Solving the Model for Given Land-Labor Ratios

In this section we solve for wages, female labor supply, and birth rates for *given* land-labor ratios t. We assume that the condition in Proposition 2 holds and distinguish three cases for the model economy: (a) a land-abundant one, where both technologies operate and female labor in horn is below its upper bound $\bar{l}_h$; (b) a more land-scarce economy with both technologies in use but binding labor supply constraint such that $l_h = \bar{l}_h$, and (c) an economy with very small land-labor ratios where the horn technology does not operate.

Grain and horn production

We start by describing the equilibrium where both technologies operate ($w_h > w_{F,g}$) and peasant consumption exceeds subsistence ($I_p > \underline{c}$). Market clearing in this case requires that total income (peasant households' wages and the landlord's rents) is spent on grain and horn consumption:

$$N(w_{M,g} + w_{F,g}(1 - l_h) + w_h l_h) + rT = Y_g + Y_h \ . \tag{19}$$

Because land is optimally allocated between the two technologies, rental rates in horn and grain production equalize. Thus, r is given by (13). Substituting for r, using (6) and (8), dividing by the number of households in (19), and substituting for $\widehat{l_g}$ from (11), we obtain:

$$w_{M,g} + w_{F,g}(1 - l_h) + w_h l_h + (1 - \alpha_h) A_h \left(\frac{l_h}{t_h} \right)^{\alpha_h} t = A_g \left(1 + \rho(1 - l_h)\right)^{\alpha_g} (t - t_h)^{1-\alpha_g} + A_h l_h^{\alpha_h} (t_h)^{1-\alpha_h} \tag{20}$$

We now have a system of 5 equations: (10), (12), (15), the third case of (18), and (20) with 5 unknowns: $w_{M,g}$, $w_{F,g}$, w_h, l_h, and t_h, which we solve numerically. This completes case (a). Next, we turn to (b).

With falling land-labor ratios, peasant consumption approaches the subsistence level. The marginal utility of consumption surges, boosting female labor supply. Eventually, the female labor supply constraint becomes binding: $l_h = \bar{l}_h$, representing the second case in (18). As long as both technologies operate, the remaining equations are unchanged. This completes the two cases where both grain and horn goods are produced. Next, we turn to the grain-only economy – case (c).

Only grain production

For small land-labor ratios, Corollary 1 implies that women's (shadow) wages in horn fall below their counterpart in grain. This pushes women out of horn labor – it is more profitable for them to contribute to home grain production. Consequently, $l_h = 0$ and horn goods are not produced; (11) simplifies to $\widehat{l_g} = 1 + \rho$. This, together with the fact that all land is dedicated to grain, i.e., $t_g = t$, can be used to obtain male and female wages from (9) and (10). Women marry immediately when turning adults, and birth rates do not depend on economic conditions; they are constant and high, $b = \pi$. This completes the description of all variables when only grain is produced. We have now solved the model for all three cases for given land-labor ratios.

3.6 Simulation

In this section we solve the system of equations described above. Before turning to the simulation results, we calibrate our model.

Calibration

To calibrate our model parameters for Western Europe, we focus on England, where births were particularly responsive to economic conditions (Lee, 1981; Wrigley and Schofield, 1981). The labor shares of production in grain and horn are central for our model. We use $\alpha_g = 0.7$ and $\alpha_h = 0.4$.[36] For the productivity of women relative to men in grain we use $\rho = 0.5$, reflecting the observation that English women's wages were equivalent to 50-63% of English male wages (Kussmaul, 1981; Allen, 2009). Turning to the demographic parameters, we choose $\pi = 3$ (peasant families have three children when women do not work in horn), $\underline{b} = 2$ (two children is the lower bound for birth rates). This is the simplest way to incorporate the fact that EMP avoided up to one third of all births (Clark, 2007). Our choice of $\mu = 0.3$ ensures that fertility does not converge back completely to π when reaching its maximum level. Next, we choose TFP in grain and horn, $A_g = 1.45$ and $A_h = 1.50$. Together with α_g, α_h, and ρ, this ensures that the horn technology becomes feasible before consumption reaches the subsistence level, allowing EMP to emerge. These parameters also grant that $w_{M,g} > w_h$ for the relevant range of T/N, which ensures that men only work in grain production.[37] We refer to subsistence income in England as the level during the early 14th century famine, when few horn products were consumed (see Table 3), and normalize $\underline{c} = 1$. For the elasticity of death rates with respect to income we use $\varphi_d = -0.55$, as estimated by Kelly (2005) for the period 1541-1700 in England, using weather shocks as a source of exogenous variation. Finally, we choose $d_0 = 0.95\pi$ in (2). This implies that the pre-plague steady state involves close-to-subsistence income, as shown below.

Simulation results for given T/N

In this section, we present all model results as a function of land per peasant household, $t = T/N$. Figure 4 shows the allocation of labor between horn (l_h) and grain ($1 - l_h$), together with fertility – which in turn results from l_h according to (1). Figure 5 illustrates the allocation of land and income shares as functions of t. In addition, both figures show the cutoff-points for relative wages ($w_h = w_{F,g}$) and peasant household income ($I_p(\bar{l}_h) = \underline{c}$) that follow from (18).

[Insert Figure 4 here]

For very small land-labor-ratios, the horn technology does not operate because $w_h \leq w_{F,g}$, and no land is allocated to horn production. Birth rates are high because couples marry early, given that women do not work in husbandry. As land per household increases, the horn technology becomes economically viable ($w_h > w_{F,g}$). Because consumption is still below subsistence ($I_p(\bar{l}_h) \leq \underline{c}$), incentives to work are huge. Female labor supply is at its upper bound $\bar{l}_h$, such that only $b = \underline{b}$ children are born per peasant household. The landlord now uses part of his soil for horn production and dedicates less to grain. The use of the more land-intensive horn production leads to a redistribution of overall income from peasant households to the

[36] This is calculated as follows: We take the estimates of revenue and cost on arable and pastoral farms from Allen (1988) and combine them with the figures for labor cost per acre from Allen (1991). We find that both relative to costs and revenue, labor's share in pastoral farming is approximately half of the value in arable production. Ideally, we would want to compare labor cost with total value added. This is not available. Apostolides et al. (2008) show an average labor share in English agriculture, 1380-1700, of 0.5. According to their figures, arable production was 32% of total agricultural production, while pastoral farming accounted for 68%. We chose $\alpha_g = 0.7$ and $\alpha_h = 0.4$ so that the average weight of labor in agriculture is identical with the observed value of 0.5: $0.32 \times 0.7 + 0.68 \times 0.4 = 0.496$.

[37] Before the plague, $T/N \approx 0.3$, and this figure rises to roughly 0.55 after the plague. With our parameters, $w_{M,g} > w_h$ holds for $T/N < 0.85$.

landlord.

[Insert Figure 5 here]

Finally, we consider the case where soil is abundant enough to allow for above-subsistence wages ($I_p(\bar{l}_h) > \underline{c}$). Female labor supply decreases with growing t, because the need for consumption (and thus work in the more rewarding horn sector) becomes less severe. Facing a trade-off between consumption and family life, richer households opt for the latter. This subsistence effect is responsible for the upward sloping fertility schedule in the vicinity of the cut-off point $I_p(\bar{l}_h) = \underline{c}$. Fertility rises with the land-labor-ratio, but does not reach the previous extreme level where horn production did not occur. This reflects the main features of EMP – a downward shift of birth rates with a simultaneous upward-sloping pattern. Eventually, for large t, the subsistence effect loses importance, and the relative wage effect dominates: $w_h/w_{F,g}$ grows in tandem with t, which renders work in horn more attractive. This explains the slightly downward sloping fertility for high land-labor ratios. However, for our analysis the region with close-to-subsistence consumption is the relevant one, and there fertility increases in the land-labor ratio.

Steady States and Magnitude of EMP's Impact

We now turn to the steady states and the contribution of EMP to sustaining higher p.c. income levels after the Black Death. The left panel of Figure 6 shows that two steady states exist for an economy in which EMP can emerge.[38] The first steady state (E_L) has high population pressure and low p.c. income, and the second (E_H) involves lower fertility and higher peasant income. In our calibration, peasant household income in E_H is about 20% above the pre-plague level. Both steady states are stable, and the plague can induce the transition from E_L to E_H. This occurs when the increase in land-labor ratios is large enough to trigger the emergence of EMP, such that birth rates fall below death rates and the economy converges to E_H from the left. Very large population losses can push the economy beyond E_H, from where it converges back to E_H. The latter captures the European experience, where wages surged in the aftermath of the plague and decreased as population recovered – remaining, however, above their pre-plague level.

[Insert Figure 6 here]

Next, we compare our model's prediction with historical estimates of the elasticity of birth rates with respect to income, φ_b. We assume that birth rates are not responsive to income before the Black Death, so that $\varphi_b^{\text{before}} = 0$. After the plague, EMP makes birth rates increasing in income such that $\varphi_b^{\text{after}} = 1.41$, as estimated by Kelly (2005).[39] Kelly's 2005 elasticity estimates are based on short-run exogenous income variation (weather shocks). To create a comparable variation in our model, we hold T/N fixed at its steady state level in E_H. We then simulate the model when TFP shocks affect A_g and A_h in the same proportion –

[38] To allow an immediate interpretation of the magnitudes involved, the figure plots peasant household income on the horizontal axis. See Figure 4 for the same plot with T/N on the x-axis.

[39] Similar to (2), the equation $b = b_0 \left(\bar{C}_p/\underline{c}\right)^{\varphi_b}$ determines birth rates as a function of average peasant consumption, $\bar{C}_p$. We choose $b_0^{\text{before}} = \pi$ and $b_0^{\text{after}} = 2/3\pi$, such that birth rates drop by 1/3 at the onset of EMP.

that is, we assume that weather shocks are not sector-biased. The right panel in Figure 6 shows the results of this exercise – given by the dots around the steady state E_H (corresponding to TFP shocks of up to 15%). The implied slope compares well with the one corresponding to Kelly's 2005 estimates (dashed line). Note that for our model structure, φ_b is not constant. In a final comparative exercise, we show the magnitude of EMP's impact under the assumption that φ_b is constant once income exceeds subsistence. This results in a new steady state E'_H, with an income-increase of about 30%. This number is broadly similar – if slightly larger – than our model prediction. Our findings underline the importance of fertility restriction for increasing living standards in early modern Europe. At the same time, it is clear that EMP alone cannot account for all of the European (English) lead in terms of per capita income in 1700. Additional factors may include a different mortality regime, as well as (to a limited extent) technological change. We examine the contributions of these factors in Voigtländer and Voth (2008) in detail.

The Decline of EMP

In addition to explaining the emergence of EMP, our model can also account for its decline in the wake of the Industrial Revolution (see Figure 2). With increasing productivity, subsistence consumption can be attained at ever smaller T/N ratios. Thus, point B in Figure 3 is shifted to the left. At the same time, assuming that A_g and A_h grow at similar rates, the location of point A does not change (see equation (16)). Eventually, B will lie to the left of A, and EMP vanishes. With growing productivity, the subsistence effect loses its importance, such that birth rates are no longer upward sloping in p.c. income. This concludes the discussion of our mechanism. Next, we use our theoretical insights to shed light on the differential international experience in the aftermath of the Great Plague.

4 International Comparisons

Western Europe was not the only area to suffer from the Black Death and other devastating plagues. Yet it is the only one to have evolved a regime of fertility restriction based on a socio-economic institution that avoided births through delayed marriage. In this section, we examine how other regions fared – and why they did not evolve a similar way of reducing fertility. Following our argument above, specific European characteristics triggered the emergence of EMP. Below we argue that other regions had less favorable characteristics in the sense of Corollary 2. Thus, EMP did not emerge, and p.c. incomes converged back to the high-population / low income steady state after major population losses.

4.1 Divergence within Europe

Fertility control in Northwestern Europe was particularly stringent. In Southern Europe, EMP reduced fertility by less. In Eastern Europe, EMP did not exist at all. Why did such contrasts prevail within Europe?

In Southern Europe, both age at first marriage and the percentage never marrying were lower than in the Northwest. Population recovered relatively quickly from the impact of the Black Death. In Italy and Spain, it returned to the pre-1350 peak by the 16th century. In contrast, England probably did not reach pre-plague population levels until the 17th or even the 18th century.[40] Rapid recovery of Southern European populations also reversed post-plague wage gains. Changes in agriculture were less pronounced. In particular, while the temporary spike in incomes after 1350 improved wages, it did not lead to the evolution of service as a standard phase in the transition from childhood to adulthood. If the shock of the plague was similar, why did it not cause a similar host of social and economic changes? According to Corollary 2, A_h/A_g is crucial. We argue that low horn productivity A_h prevented the emergence of EMP in Southern Europe, while high grain productivity A_g had the same effect in Eastern Europe.

Agricultural conditions in Mediterranean countries did not favor the pastoral farming of the type common in Northwestern Europe. Land productivity was often even lower than in Northern Europe. In particular, low rainfall made it impossible to keep large herds of cattle and sheep in the same area year-round. Transhumance – the driving of livestock from one area to another – is an ancient custom in Mediterranean countries, with numerous routes recorded as far back as Roman times. The most famous is arguably the Spanish Mesta – a council of shepherds that controlled transhumance under a grant from the Spanish King, allowing them to drive their flocks across a vast stretch of territory extending from Extremadura and Andalusia to Castile.[41] Thus, where the grass was not green enough for year-round husbandry, female employment opportunities were reduced. Traversing sparsely populated areas on their own was not compatible with women's social role in early modern Europe. Work in husbandry remained a male occupation. Without the rise of service in husbandry as a typical phase in young woman's life, marriage ages remained low.[42]

In Eastern Europe, grain productivity was unusually high. Especially in Western Russia and Ukraine, land is unusually fertile (Nunn and Qian, 2009). Thus, after the plague, landlords continued to farm their estates using serf labor in arable production. During the early modern period, large grain surpluses were often exported. In addition, the plague did not strike with the same force as it did in Western Europe. Instead of arriving from Mongolia via the Russian steppes, the disease took a detour via the Black Sea and the Mediterranean to reach Europe. Population declines in Eastern Europe were therefore probably smaller than they were in the West. In the presence of high grain productivity, and without a major jump in land-labor ratios, cattle and sheep farming remained uncompetitive vis-a-vis grain production.[43]

[40]There is considerable uncertainty about the size of the pre-plague population in England. Slow recovery was not a universal feature of the Northwestern European experience – the Netherlands experienced rapid population growth (Pamuk, 2007).

[41]Originally, shepherds took advantage of the agricultural no-man's-land between Christian and Muslim areas of control. Gradually, the use became institutionalized.

[42]Similar questions could be raised about the non-emergence of EMP in the early medieval period, when land-labor ratios were high. For the emergence of EMP, a large-scale, commercial-operated 'horn' sector is key. While we do not explicitly model this aspect, functioning markets for relatively long-distance trade were crucial. These did not exist in the early Middle Ages.

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4.2 Comparison with China

Can our model account for the different experience in China? The Middle Kingdom also suffered from a devastating plague outbreak in the 14th century. Why did the same shock, in an area suffering from declining marginal returns to labor, not lead to the emergence of a 'low pressure' demographic regime? We argue that high Chinese grain productivity A_g was key.

Grain production in China was approximately 4 times more efficient than in England. We use the figures by Allen (2009) on output per acre and output per day, weighting them with a labor share of 0.5.[44] Chinese land productivity was 700% of English land productivity in grain, and labor productivity was 86%. This implies a weighted average of 392%. The main reason for high land productivity was the limited size of plots: Chinese farms were markedly smaller, and labor input per acre much higher, than in England. Continuous population pressure led to increasing subdivision of farms. Table 4 compares farm sizes in the most advanced areas – England and the Yangtze Delta. At the dawn of the nineteenth century, English farms were thus, on average, 150 times larger than Yangtze ones.

[Insert Table 4 here]

High productivity in Chinese grain production reflected the use of numerous techniques designed to raise output per unit of land. All of them required more labor – rice paddy cultivation, the use of bean cake as fertilizer, and intercropping with wheat (Goldstone, 2003; Brenner and Isett, 2002). The relatively low productivity of grain production in England is reflected in its low share in total output. Arable production accounted for only 32% of agricultural output in England, according to Apostolides et al. (2008)'s figures.[45] In contrast, grain accounted for almost all of China's agricultural production.

While Chinese farms used all means available to raise output per unit of land, the same is not true of output per worker. Ever fewer draft animals were in use. While Chinese 16th century writers observed that 'the labor of ten men equals that of one ox,'[46] the use of draft animals declined in the Ming (1368-1644) and Qing (1644-1911) period. Animal use disappeared almost entirely, except for the most arduous tasks, by the mid-Qing period.[47] The reason is that land needed to feed an ox was dear. Most farms were also too small for keeping an ox.

Ever smaller farm sizes in China also meant that there was much less scope for female employment in agriculture. Labor requirements could be satisfied by the existing male labor force on small plots. As Li (1998) has argued, women were increasingly rendered 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 combined with changes in the pattern of production arising from growing 'agricultural involution' (Berkeley,

[44] From his figures, we derive an estimate of output per acre in arable farming in the midlands of 3.5 pounds per acre.

[45] Allen (2009) implies a somewhat higher figure of 44%

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

[47] The view is controversial. Wider availability of bean cake may have helped the increased use of oxen after 1620 (Allen, 2009).

1963). Even authors skeptical of the involution hypothesis conclude that female market wages were only 25% of male wages in 1820s China, whereas English women's market wages were equivalent to 50-63% of English male wages (Kussmaul, 1981; Allen, 2009).[48] Since plowing with oxen had disappeared, the strength requirements of grain and rice production were lower. This eroded the relative male advantage in the grain (rice) sector. Therefore, ρ was higher than in Europe. As our Corollary 2 argues, this made the emergence of EMP more difficult. In sum, large A_g paired with relatively high ρ in China avoided the shift to pastoral agriculture and thus the emergence of a female labor market.

To capture the Chinese experience in our model, we leave all parameters unchanged except one – grain productivity in China is higher, i.e., $A_g^{\text{China}} > A_g^{\text{England}}$, while $A_h^{\text{England}} = A_h^{\text{China}}$. Above, we derived an estimate of $A_g^{\text{China}} = 4 \cdot A_g^{\text{England}}$. In our calibration, as soon as $A_g^{\text{China}} > 1.5 \cdot A_g^{\text{England}}$, EMP does not emerge. This follows from Proposition 2 because $A_g^{\text{China}} > 1.5 \cdot A_g^{\text{England}}$ implies $\frac{T}{N}\big|_{w_h = w_{F,g}} > \frac{T}{N}\big|_{I_p = \underline{c}}$.[49] Intuitively, grain is so productive in China that horn becomes economically viable only for large T/N ratios. However, at this point p.c. income is high, and the subsistence effect is weak, such that birth rates do not rise with income. Consequently, the plague does not trigger the emergence of a demographic regime comparable to EMP in China. After the plague, wages converge back to the only long-run equilibrium E_L. Another implication of $A_g^{\text{China}} > A_g^{\text{England}}$ is that land-labor ratios for any given wage are higher in England – more land is needed to sustain a given population – as shown in the lower panel of Figure 7.[50] This theoretical finding reflects the findings in Allen (2009), who shows that English agriculture operated with land-labor ratios that were higher than Chinese ones by a factor of 9.5.

[Insert Figure 7 here]

In a paradoxical way, China's high land productivity, as emphasized by the revisionist 'California School' (Pomeranz, 2000; Goldstone, 2003), undermined its chances of adopting fertility limitation along English lines. Our minimalist model thus captures five important elements of the divergence between England and China: (i.) No market for 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, and (v.) Lower per capita incomes.

5 Conclusion

Why did Europe evolve a system of delayed marriage that reduced fertility centuries before the rest of the world? We argue that the impact of the Black Death was key. Fertility restriction emerged as an indirect

[48] In our model, female market wages are represented by w_h. Low $w_h/w_{M,g}$ is thus an indicator for relatively high productivity in grain (i.e., small A_h/A_g in China).

[49] $A_g^{\text{China}} > A_g^{\text{England}}$ has two effects on China relative to England: First, it decreases $w_h/w_{F,g}$, shifting point A in Figure 3 to the right. Second, it raises p.c. income for given land-labor ratios, shifting point B to the left. If this relocates B to the left of A, EMP does not emerge.

[50] The kink in English peasant household income results from the higher average land intensity of production when the horn sector starts operating. This redistributes total income in favor of the landlord (see the right panel of Figure 5).

consequence of high land-labor ratios after 1348-50. The Black Death reduced population by between one third and half. Land-labor ratios rose markedly. This favored the sector that used land more intensively – 'horn' production (Campbell, 2000). Many more cattle were kept for meat and milk, and many more sheep for mutton and wool. The rise of large-scale livestock farming strengthened women's economic role. Female labor is better suited to shepherding and milking than to ploughing or threshing. Owners of large estates began to switch from arable farming, with its high demand for adult male labor, to husbandry, which required less strenuous labor, some of which could be supplied by women. In this way, the plague raised the demand for female labor.

Women mainly worked on farms as servants in husbandry, milking cows and shepherding flocks of sheep. Working as a servant involved a switch from the parental household to the master's. Contracts forbade marriage. By working as servants for a few years, women could earn and save, raising their prospects of a good match in the marriage market. Because the Black Death changed the pattern of production and raised the demand for female labor, it also reduced fertility rates through a higher age at first marriage. We thus explain the concurrent emergence of late marriage, higher incomes, and low fertility.

As a consequence, even in a Malthusian world, the 'iron law of wages' need not hold. If death schedules or birth schedules change, steady-state incomes can change substantially. The equilibrating forces in such a world may still be 'Malthusian,' but they need not lead incomes back to the *same* equilibrium point.[51] We argue that changes in European fertility behavior were important for the persistence of unusually high per capita incomes long before the Industrial Revolution. In particular, fertility restriction through the 'European Marriage Pattern' helped to avoid the downsides of high fertility apparent in other parts of the world. By stabilizing incomes at a high level by 1700, EMP may well have laid some of the foundations for Europe's early transition to self-sustaining growth (Voigtländer and Voth, 2006). EMP also reduced the volatility of income – bad shocks were partly compensated by lower fertility. In models in the spirit of Acemoglu and Zilibotti (1997) and Greif and Sasson (2009), this facilitates the transition to self-sustaining growth.

Our model can also account for the divergent fortunes of Europe compared to China. China was subject to a similar plague shock as Europe. Nonetheless, China did not develop a system of fertility restriction through late marriage. Marriage remained universal, and occurred early. We argue that this was an indirect consequence of high land productivity in Chinese agriculture. Rice paddies were highly productive; intercropping with wheat raised output per acre in China further. This turned out to be a mixed blessing. High land productivity acted as a barrier to adopting land-using and labor-saving technologies such as livestock farming. Paradoxically, one of the weaknesses of the European agricultural system – low land productivity – facilitated the emergence of a low fertility regime after the Black Death.

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

Appendix

A.1. Proof of Proposition 2

By definition, EMP requires that l_h in equation (18) be decreasing in household income over some range of $t = T/N$, such that birth rates are increasing. As a first step, we re-arrange the third line of (18) using (10):[52]

$$l_h = (1-\mu)\bar{l}_h - \mu \underbrace{\frac{\frac{1+\rho}{\rho} - \frac{\underline{c}}{w_{F,g}(t)}}{\frac{w_h(t)}{w_{F,g}(t)} - 1}}_{\equiv Z(t)} \tag{A.1}$$

Using $b = \pi(1 - l_h)$ we obtain:

$$b = \underline{b} + \mu(Z(t) + \bar{l}_h) \tag{A.2}$$

EMP therefore requires $Z(t)$ to be increasing in t over some range.[53] Throughout the proof, we thus focus on the derivative of Z with respect to t:

$$\frac{dZ}{dt} = \frac{\frac{\underline{c}}{w_{F,g}^2}\left(\frac{w_h}{w_{F,g}} - 1\right) \cdot \frac{dw_{F,g}}{dt} - \left(\frac{1+\rho}{\rho} - \frac{\underline{c}}{w_{F,g}}\right) \cdot \frac{d}{dt}\left(\frac{w_h}{w_{F,g}}\right)}{\left(\frac{w_h}{w_{F,g}} - 1\right)^2} \tag{A.3}$$

In order to analyze this expression, we obtain $dw_{F,g}/dt$ from (10) and (15), and $d(w_h/w_{F,g})/dt$ from (16).

$$\begin{aligned} \frac{dw_{F,g}}{dt} &= (1-\alpha_g)\frac{\alpha_h}{\alpha_g}\frac{l_h}{t_h}w_{F,g} \cdot \frac{d}{dt}\left(\frac{t_h}{l_h}\right) > 0 \\ \frac{d}{dt}\left(\frac{w_h}{w_{F,g}}\right) &= \frac{\alpha_g - \alpha_h}{\alpha_g}\frac{l_h}{t_h}\frac{w_h}{w_{F,g}} \cdot \frac{d}{dt}\left(\frac{t_h}{l_h}\right) > 0 \end{aligned} \tag{A.4}$$

Both derivatives are positive because of Proposition 1 and Corollary 1. Throughout the proof, we use the notation $t_A \equiv \frac{T}{N}\big|_{w_h = w_{F,g}}$ (T/N at which horn becomes viable) and $t_B \equiv \frac{T}{N}\big|_{I_p(\bar{l}_h) = \underline{c}}$ (T/N at which consumption exceeds subsistence). Because the horn technology does not operate below t_A, it is sufficient to focus on $t \geq t_A$.

We now turn to the first part of the proof – the "if" part of the proposition, showing that $Z(t)$ is increasing over some range of t if $t_A < t_B$, and that b is below its maximum level. The upper panel of Figure 8 illustrates the underlying intuition: We show that $Z(t) = -\bar{l}_h$ in point B, is increasing for all t up to (and in some range beyond) point C, and that $Z(t)$ eventually becomes decreasing and converges to zero as t grows large.[54] Following (A.2), this means that $b = \underline{b}$ in B, and then increases over some range (beyond C) – this reflects EMP. Eventually, b becomes decreasing in t and converges to $\underline{b} + \mu\bar{l}_h$.

[Insert Figure 8 here]

[52]Note that $w_M + w_{F,g} = ((1+\rho)/\rho)w_{F,g}$.

[53]Peasant household income grows hand-in-hand with t over the range where horn is economically viable ($w_h > w_{F,g}$).

[54]Note that B lies to the left of C because $I_p(\bar{l}_h) = ((1+\rho)/\rho)w_{F,g} + \bar{l}_h(w_h - w_{F,g}) > ((1+\rho)/\rho)w_{F,g}$ for all $t > t_A$.

In point B, we have $I_p(\bar{l}_h) = ((1+\rho)/\rho)w_{F,g} + \bar{l}_h(w_h - w_{F,g}) = \underline{c}$. Re-arranging this expression yields $Z(t_B) = -\bar{l}_h$. For land-labor ratios up to point C, $\frac{1+\rho}{\rho} w_{F,g} \leq \underline{c}$. Therefore, $\left(\frac{1+\rho}{\rho} - \frac{\underline{c}}{w_{F,g}}\right) \cdot \frac{d}{dt}\left(\frac{w_h}{w_{F,g}}\right) \leq 0$ in (A.3). The remaining term in the denominator in (A.3) is positive because $t_B > t_A$. Consequently, Z is strictly increasing in t for $t \leq t_C$. In addition, since $Z(t)$ and $Z'(t)$ are continuous, and since $Z'(t_C) > 0$, there exists a $\delta > 0$ s.t. $\forall \tilde{t} \in (t_C, t_C + \delta)$, $Z(\tilde{t}) > 0$ and $Z'(\tilde{t}) > 0$. That is, $Z(t)$ is positive and increasing over some range to the right of C. Next, we show that $Z'(t)$ becomes negative, and $Z(t)$ converges to zero for large t. Substituting (A.4) into (A.3) and re-arranging yields:

$$\frac{dZ}{dt} = \frac{(1-\alpha_h)\underline{c} \; - \; (1-\alpha_g)\frac{\alpha_h}{\alpha_g}\frac{w_{F,g}}{w_h}\underline{c} \; - \; \frac{\alpha_g - \alpha_h}{\alpha_g}\frac{1+\rho}{\rho} w_{F,g}}{w_{F,g}\frac{w_{F,g}}{w_h}\left(\frac{w_h}{w_{F,g}} - 1\right)^2} \cdot \frac{l_h}{t_h} \cdot \frac{d}{dt}\left(\frac{t_h}{l_h}\right) \tag{A.5}$$

The denominator of this expression is positive, and so is $d(t_h/l_h)/dt$ by Proposition 1. Thus, we can focus on the sign of the numerator in (A.5). The first term in the numerator is constant, the second term converges to zero as t grows large, and the third term increases, following (A.4). Thus, for large enough t the numerator becomes negative such that $Z' < 0$.[55] Finally, we show that $\lim_{t\to\infty}(Z(t)) = 0$. This follows from (A.1): As $t \to \infty$, the denominator of Z becomes large while $\underline{c}/w_{F,g}$ goes to zero (both because of (A.4)). Altogether, this delivers the shape of $Z(t)$ shown in the upper panel of Figure 8. Finally, we show that $b < \bar{b}$ over some range that also involves $b'(t) > 0$ (that is, there exists a range of t over which both criteria for EMP are fulfilled). The latter holds unambiguously for $t_B \leq t \leq t_C$. In addition, in the vicinity of point B, birth rates b are close to $\underline{b} < \pi$, such that $b < \pi$. Formally, $\exists\, \epsilon > 0$ s.t. $\forall t_B \leq \tilde{t} < t_B + \epsilon : \; b < \pi$. This completes the "if" part of the proof.

We now turn to the "only if" part of the proof. It suffices to show that for all $t_A > t_B$, $Z'(t) < 0, \forall t > t_A$, such that birth rates b are never upward sloping in t, i.e., EMP never emerges. The lower panel of Figure 8 illustrates the functional form of Z. We begin by showing that $Z'(t)$ becomes large and negative as t converges to t_A from above. If $t \downarrow t_A$, $w_h \downarrow w_{F,g}$. Since $w_{F,g}/w_h \to 1$, (A.5) simplifies and we can derive the limit of $Z'(t)$:

$$\lim_{w_h \downarrow w_{F,g}} \left(\frac{dZ}{dt}\right) = \lim_{w_h \downarrow w_{F,g}} \frac{-\frac{\alpha_g - \alpha_h}{\alpha_g}\left(\frac{1+\rho}{\rho} w_{F,g} - \underline{c}\right)}{w_{F,g} \cdot 1 \cdot \left(\frac{w_h}{w_{F,g}} - 1\right)^2} \cdot \frac{l_h}{t_h} \cdot \frac{d}{dt}\left(\frac{t_h}{l_h}\right) = -\infty \tag{A.6}$$

This result follows because (i) the numerator in (A.6) is negative and finite. To see this, note that $\alpha_g > \alpha_h$ and $((1+\rho)/\rho)w_{F,g} > \underline{c}$.[56] Using the latter in (A.1) also implies that $\lim_{w_h \downarrow w_{F,g}} Z(t) = \infty$, as shown in the lower panel of Figure 8. (ii) The denominator converges to zero from above, and (iii), l_h/t_h and $d(t_h/l_h)/dt$

[55] Taking the limit of each term divided by the denominator, it is straightforward to show that $Z'(t)$ converges to zero from below as $t \to \infty$. For this step, note that $\frac{d}{dt}\left(\frac{t_h}{l_h}\right)$ is positive and finite: Because of Prop. 1, $\frac{d}{dt}\left(\frac{t_h}{l_h}\right) < \frac{d}{dt}\left(\frac{t}{l_h}\right) = \frac{1}{l_h} - \frac{t}{l_h^2}\frac{dl_h}{dt} < \frac{1}{l_h}$. The last inequality follows because $Z' < 0$ for large t, such that (A.1) implies $dl_h/dt > 0$. Finally, $1/l_h$ is finite: As we show below, $\lim_{t\to\infty}(Z(t)) = 0$, such that following (A.1), $\lim_{t\to\infty}(l_h(t)) = (1-\mu)\bar{l}_h > 0$.

[56] The latter holds because for all $t > t_B$: $I_p(\bar{l}_h) > \underline{c}$, and $\lim_{w_h \downarrow w_{F,g}} I_p(\bar{l}_h) = \lim_{w_h \downarrow w_{F,g}} ((1+\rho)/\rho)w_{F,g} + \bar{l}_h(w_h - w_{F,g}) = ((1+\rho)/\rho)w_{F,g}$.

are both positive and finite (see footnote 55 for the latter).

Next, we show that $Z'(t)$ is negative for all $t > t_A$ (and thus $w_h > w_{F,g}$). Since the denominator in (A.5) is positive and finite ($t > t_A \Rightarrow w_h > w_{F,g}$), it is sufficient to show that the numerator remains negative as t increases beyond t_A. To demonstrate this, we label the numerator in (A.5) $NUM(t)$ and show that $NUM'(t) < 0,\ \forall t > t_A$. In other words, the numerator becomes more negative as t increases. Using (A.4) and taking into account that $d(w_{F,g}/w_h)/dt = -(w_{F,g}/w_h)^2\, d(w_h/w_{F,g})/dt$, we obtain:

$$\frac{dNUM}{dt} = -\frac{\alpha_g - \alpha_h}{\alpha_g}(1-\alpha_g)\frac{\alpha_h}{\alpha_g}\left(\frac{1+\rho}{\rho}w_{F,g} - \frac{w_{F,g}}{w_h}\underline{c}\right)\cdot\frac{l_h}{t_h}\cdot\frac{d}{dt}\left(\frac{t_h}{l_h}\right) < 0 \tag{A.7}$$

The inequality holds because $d(t_h/l_h)/dt > 0$ and $((1+\rho)/\rho)w_{F,g} > \underline{c} > (w_{F,g}/w_h)\underline{c}$ for all $t > t_A$.[57] Finally, we have already shown that $\lim_{t\to\infty}(Z(t)) = 0$ (this holds irrespective of $t_A \lesseqgtr t_B$). Altogether, the second part of the proof shows that Z' is negative and large for $t \downarrow t_A$, remains negative for all $t > t_A$, and converges to zero from below as $t \to \infty$. $\square$

A.2. Proof of Corollary 2

Point A in Figure 3 lies to the left of B if $(I_p(\bar{l}_h)/\underline{c})\big|_{t=t_A} < 1$, i.e., if $I_p(\bar{l}_h) < \underline{c}$ in point A. Horn becomes feasible at this point: $w_h = w_{F,g}$. Using this in (16), we can solve for the land-labor ratio in horn: $\frac{t_h}{l_h} = \left[\rho\frac{\alpha_g}{\alpha_h}\left(\frac{A_g}{A_h}\right)^{\frac{1}{\alpha_g}}\left(\frac{1-\alpha_g}{1-\alpha_h}\right)^{\frac{1-\alpha_g}{\alpha_g}}\right]^{\frac{\alpha_g}{\alpha_g-\alpha_h}}$, where $\alpha_g > \alpha_h$. Next, (3) simplifies to $I_p = w_{M,g} + w_{F,g}$ at point A. Using (10) and (15) yields: $I_p = (1+\rho)\alpha_g A_g\left(\frac{A_g}{A_h}\frac{1-\alpha_g}{1-\alpha_h}\right)^{\frac{1-\alpha_g}{\alpha_g}}\left(\frac{t_h}{l_h}\right)^{\frac{\alpha_h}{\alpha_g}(1-\alpha_g)}$. Consequently, $I_p = (1+\rho)\alpha_g A_g\left[\left(\rho\frac{\alpha_g}{\alpha_h}\right)^{\alpha_h}\left(\frac{1-\alpha_g}{1-\alpha_h}\right)^{1-\alpha_h}\left(\frac{A_g}{A_h}\right)\right]^{\frac{1-\alpha_g}{\alpha_g-\alpha_h}}$ at point A, which is increasing in ρ and A_g, and is decreasing in A_h. Therefore, conditions (i)-(iii) make $(I_p(\bar{l}_h)/\underline{c})\big|_{t=t_A} < 1$ more likely to hold. $\square$

[57] From footnote 56 we know that $((1+\rho)/\rho)w_{F,g} > \underline{c}$ at $t = t_A$, and (A.4) shows that $w_{F,g}$ is increasing in t. In addition, for $t > t_A$, $w_{F,g}/w_h < 1$.

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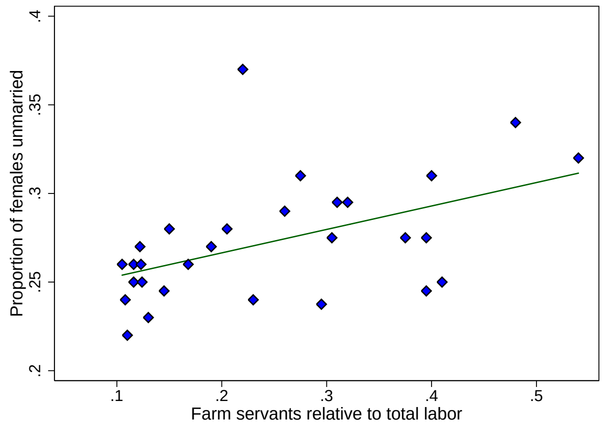
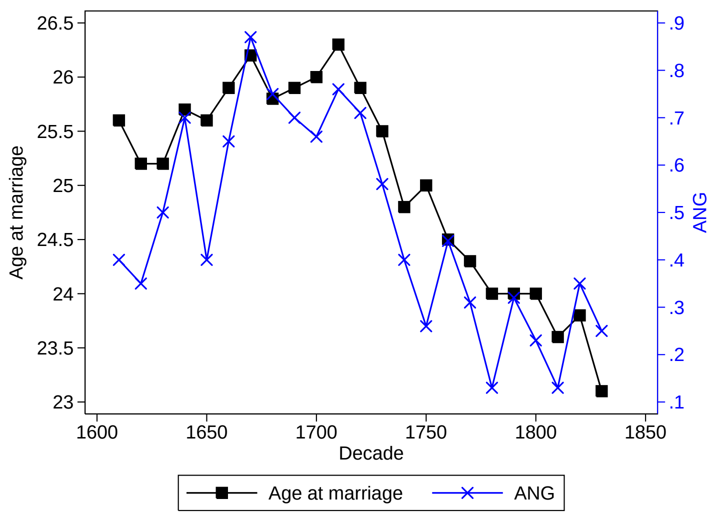
Figure 1: Husbandry and proportion of unmarried women: Cross-section



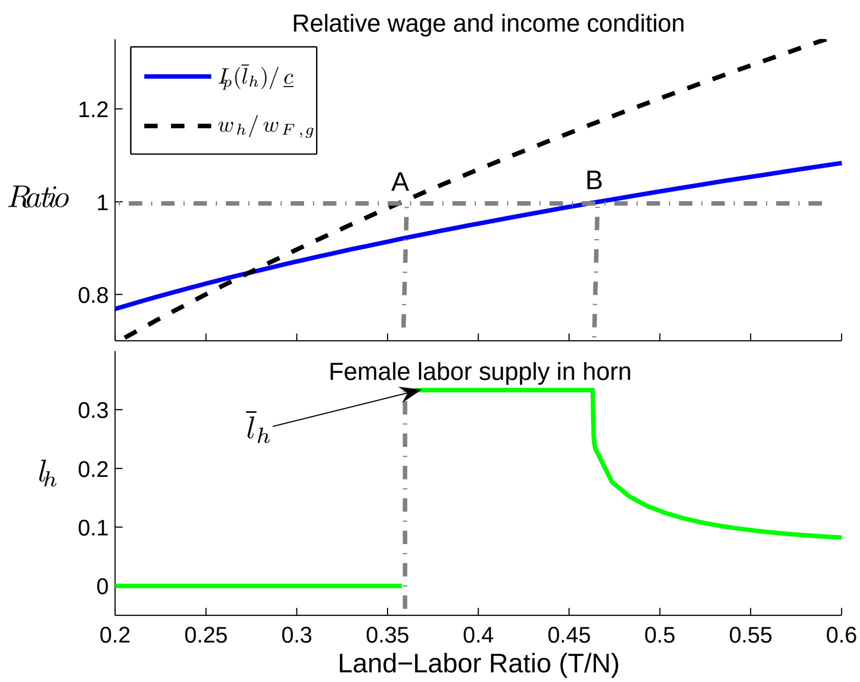
Source: Data from Kussmaul (1981). Females unmarried: Population aged twenty and over who are not married. Total labor force: All hired labor in agriculture (male and female). The sample reflects predominantly agricultural registration districts in England. Cross-sectional variation is by county, 1851. The regression line has a slope of .13 and is highly significant (t-stat 3.56).

Figure 2: Age at First Marriage and Marriage Seasonality



Source: Kussmaul (1981). ANG measures the relative strength of spring-to-fall marriage seasonality. Servants in pastoral agriculture typically married after the lambing season – in spring. Workers in grain production married after the harvest in fall. Thus, ANG shows the extent to which a marriage pattern is pastoral; high ANG means many servants working in the animal-producing sector. As employment in pastoral agriculture in England declined, the age at first marriage for women also fell sharply.

Figure 3: Land-labor ratio and female labor in horn production



Note: For land-labor ratios below point A, the horn technology does not operate, such that female labor in horn is zero. At point A, the horn technology becomes economically viable ($w_h > w_{F,g}$). Between A and B, household income is below subsistence ($I_p \leq \underline{c}$), implying large marginal returns to consumption and thus maximum female labor in horn ($l_h = \bar{l}_h$). To the right of B, the subsistence effect becomes less important as T/N increases, and l_h falls.

Figure 4: Female labor and fertility

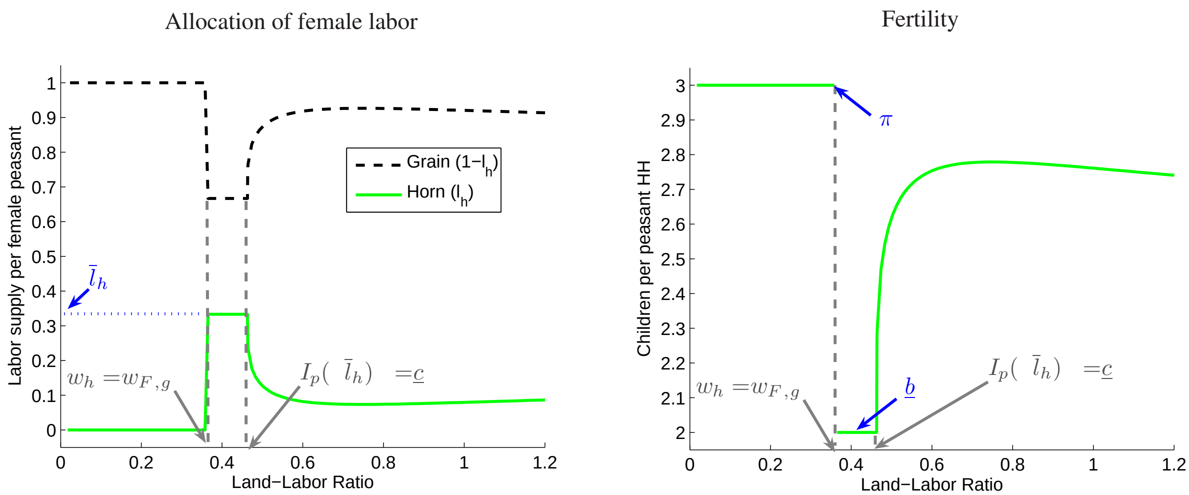


Figure 5: Land allocation and income shares

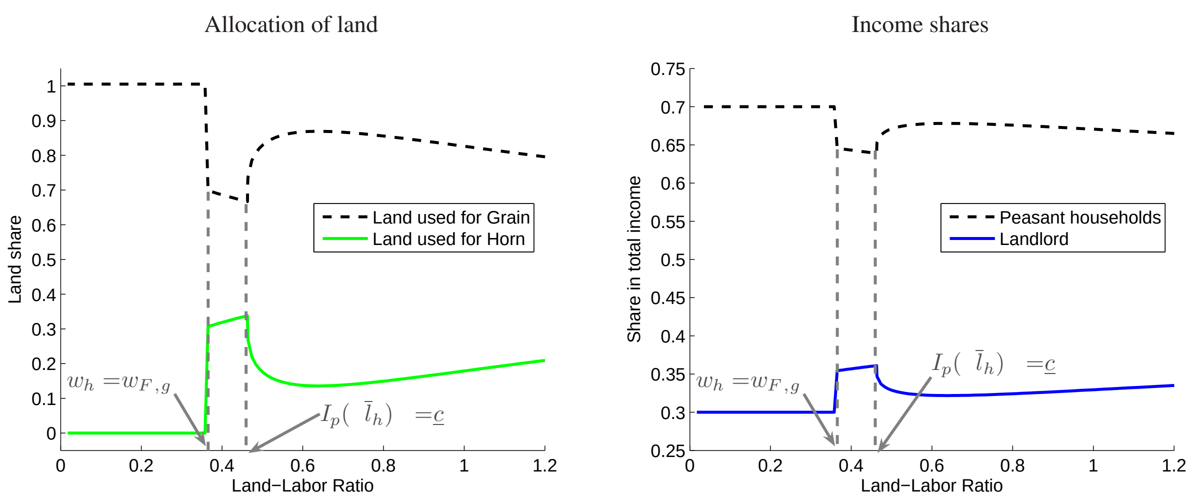


Figure 6: Steady states and EMP's impact on p.c. income

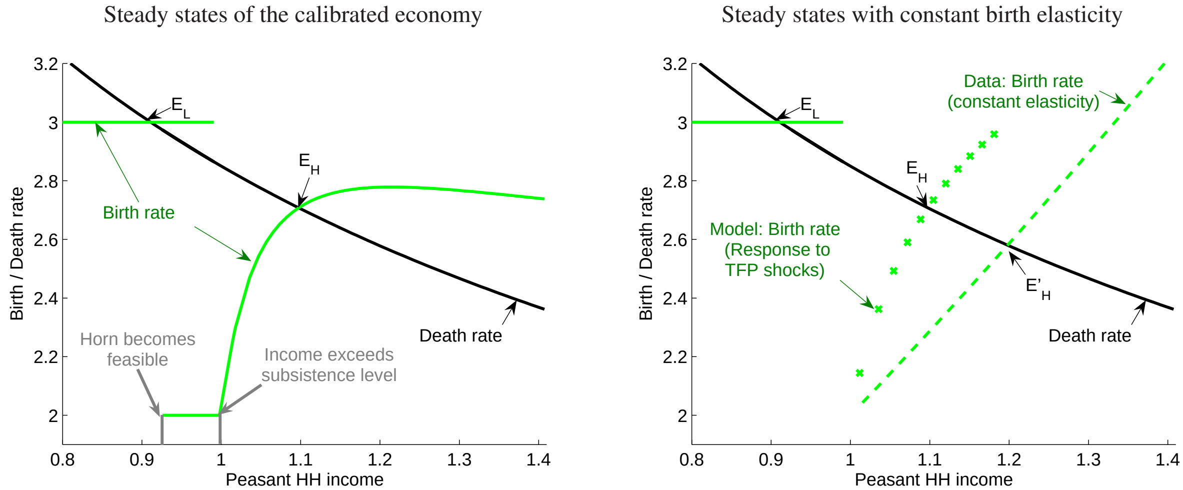


Figure 7: Long-run equilibria in England and China

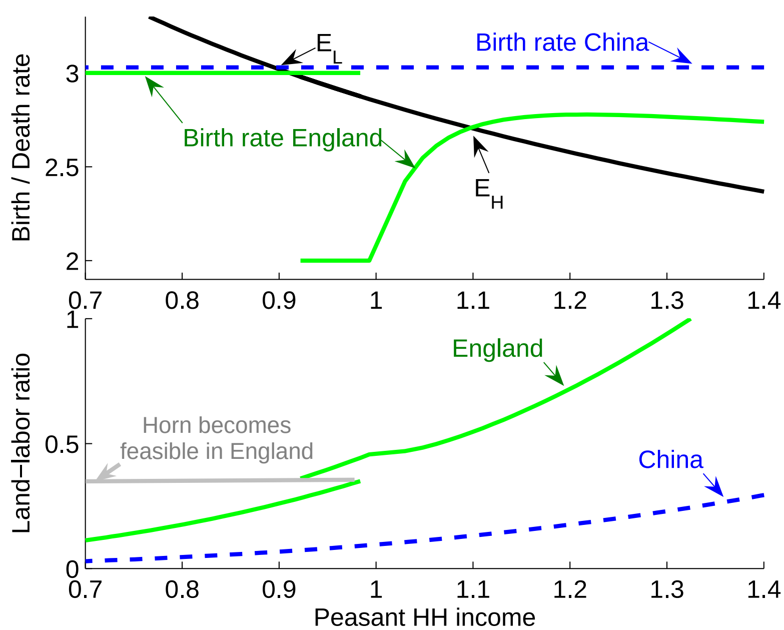


Figure 8: Functional form of $Z(t)$ in the proof of Proposition 1

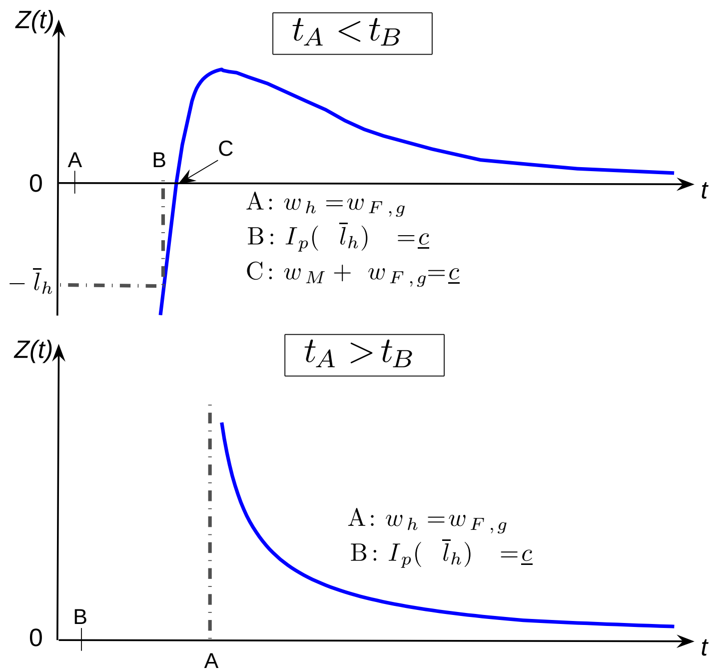


Table 1: Age of marriage and marital fertility in seventeenth century Europe

	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

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

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

Age	Hutterites	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: Agricultural output before and after the Black Death

	Output per head of population					
	Milk (gallons)	Beef (lb)	Veal (lb)	Mutton (lb)	Pork (lb)	Wool (lb)
1265	77	29	3	62	32	17
1348	55	20	3	98	13	24
1550	137	46	7	141	50	26
1700	281	89	16	189	98	40
Ratio 1550/1348	2.5	2.3	2.8	1.4	3.8	1.1

Source: Apostolides et al. (2008)

Table 4: 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).