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### **ABSTRACT**

Europeans restricted their fertility long before the 'Demographic Transition.' 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% between the 14th and 18th century. In a Malthusian environment, this translated into lower population pressure, raising average wages significantly, which in turn laid the foundation for industrialization. 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 in 1348-50. The land-intensive production of meat, wool, and dairy (pastoral products) increased, while labor-intensive 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. The emergence of EMP enabled Europe to shift from a high-fertility, low income to a low-fertility, high income Malthusian steady state. We demonstrate the importance of this effect in a calibration of our model and show why the same shock to population did not have similar consequences in China.

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# 1 Introduction

Technology advanced for millennia before economic growth became rapid and per capita incomes increased significantly. What allowed the transition from "Malthus to Solow" was fertility control. In many models of long-run growth, the demographic transition is a necessary ingredient for self-sustaining growth. It allows productivity increases to translate into higher incomes instead of a larger population (Kremer, 1993; Galor and Weil, 2000; Hansen and Prescott, 2002). Historically, European incomes per capita only began to grow once fertility had fallen significantly. The same is true in the 20th century: No developing country (except for oil producers) has attained medium income levels without going through a demographic transition beforehand.

In contrast to the rest of the world, Europeans began to limit their fertility long before the onset of modern growth. As early as the 14th century, a "European Marriage Pattern" (Hajnal, 1965) had emerged which combined late marriage for women with a significant share of women never marrying. West of a line from St Petersburg to Trieste, where the European Marriage Pattern (EMP) was prevalent, Europeans avoided 25-40% of all possible births.<sup>1</sup> The average female age at first marriage was 25 and 26.4 in England and Germany, respectively, in the 17th century. Similarly late marriages have only been registered again from the 1990s onwards, when the respective figures were 25.1 and 26.5 (UK-ONS, 2011; Flinn, 1981).

Fertility limitation in Europe went hand-in-hand with the "First Divergence" – European per capita incomes increased to levels far above subsistence (and ahead of other regions of the world) long before the Industrial Revolution. Reproduction rates were no longer determined by biological fertility alone; they became a socio-economic choice variable. Figure 1 illustrates how income and fertility interact in a Malthusian setting. Death rates decline in p.c. income. Fertility depends on the demographic regime. Without EMP (rest of the world – ROW), fertility is constant and high. In Europe, it is lower on average but responds to economic conditions. The intersection of birth and death schedules defines the steady state(s), where population and income are constant. In the absence of fertility restriction, the economy is in a low-income steady state ( $S^{ROW}$ ). EMP allowed Europe to transition to a more benign steady state ( $S^{Europe}$ ), combining high incomes with low fertility. The cross-sectional evidence also suggests that fertility limitation mattered for subsequent performance – within Europe, areas with strong fertility limitation were first to transition into rapid growth.

*[Insert Figure 1 here]*

How did such a unique, early, and strong form of fertility limitation arise? In this paper, we focus on the interaction of a strong, exogenous shock to land-labor ratios (the Black Death) with specific European characteristics. Economic changes after the Black Death favored the emergence of fertility limitation. In parallel with the rise in incomes after 1348-50, consumption of meat and dairy products surged. Agricultural production switched from "corn to horn" – from arable agriculture to livestock production (Campbell,

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<sup>1</sup>In the absence of effective contraception, and given a strong stigmatization of premarital sex, delayed marriage was the only effective way to reduce childbearing.

2000). Here, women had a comparative advantage. While men could work equally well in arable production as in pastoral farming, women were better suited to tasks requiring dexterity, not strength and stamina. Crucially, female servants in animal husbandry had to remain celibate. The rise in animal husbandry after 1350 thus increased female labor demand, lowering fertility. In this way, the Black Death also contributed to permanently higher European p.c. incomes.

Our model explains the emergence of EMP in a simple Malthusian two-sector model with endogenous marriage decisions. There are two types of output, "horn" (pastoral) and grain (arable). Both are produced with Cobb-Douglas technology using land and labor as inputs. The only difference is in the factor intensity of production: Horn uses land more intensively, while grain is more labor-intensive. We model the output of both sectors as perfect substitutes.<sup>2</sup> Men can work in arable and in pastoral production. Women can also work in both, but are less suited to tasks requiring physical strength (Alesina, Giuliano, and Nunn, 2011). If there is pastoral production, optimal allocation across sectors implies that only female labor will be used.<sup>3</sup> Land is owned by the lord, and either rented out to farmers (for grain production) or operated directly (for livestock farming). When hiring female workers for horn production, the lord requires them to be unmarried. Lord and farmers have the same consumption preferences, but only the latter care about children.

Land is in fixed supply; as population increases, incomes decline. Before the Black Death, land-labor ratios are low; land is relatively dear, and labor is cheap. Grain cultivation provides most of the food. Women marry early and work alongside men in family-operated arable agriculture. This changes after the plague. Land-labor ratios increase. Because of the different factor intensities in production, this favors the horn sector; the employment of women increases. Women trade off the opportunity to earn an income in pastoral farming against postponing marriage. This reduces childbearing; female servants in husbandry had to remain celibate. Low fertility keeps land-labor ratios relatively high. In a Malthusian economy, this produces higher incomes on average. Thus, as an indirect consequence of the Black Death, Europeans find themselves in a new steady state with greater female employment, late marriage, lower fertility, and higher per capita incomes.

The model also creates an economic "shock absorber" mechanism. When incomes are low, and consumption is close to subsistence, the relative appeal of earnings is greater – marriages are postponed. Nuptiality thus fluctuates in response to economic conditions: Hard times spell late marriages.<sup>4</sup> This helps to stabilize incomes.

The theory can account for key cross-sectional differences in fertility limitation. We predict that where women were employed in large numbers in agriculture, milking cows and tending sheep, marriage should occur late; where arable agriculture dominated, marriage ages should be markedly lower. This is what the data show across different counties in England. Our model also has implications for differences within Europe. Where the production of horn was feasible using female labor, such as in Northern Europe, fertility

<sup>2</sup>This simplifies our setup, but similar results can be obtained if meat and grain have a lower elasticity of substitution.

<sup>3</sup>This is, of course, a simplification of reality – men did work on pastoral farms. Capturing this would require the assumption of heterogeneous male labor, but would not change our results. Since we try to offer the simplest model of the emergence of EMP, we decided to abstract from this aspect.

<sup>4</sup>Jones and Schoonbroodt (2011) provide a dynastic model that explains pro-cyclical fertility in the 20th century.

limitation was effective, and incomes were higher; in Eastern Europe, where grain production was highly efficient and the Black Death had a smaller impact, EMP did not emerge.

Finally, our model helps to explain Europe's precocious rise to riches in the centuries before technological change became rapid. We first quantify the income gains arising from fertility limitation in Europe. Second, we focus on the contrast with China, and argue that land and labor productivity differences are key for explaining when fertility limitation will emerge. Our model predicts that in areas where the productivity of the grain sector is *high*, EMP will not emerge. This is true even in the presence of large mortality shocks reducing population size. China, because of its high grain productivity, did not evolve EMP despite suffering from the Black Death as well.

We proceed as follows: Section 2 discusses the related literature. Section 3 presents our model, and section 4 describes the historical context in more detail. In section 5, we examine several international comparisons. Section 6 concludes.

## 2 Related Literature

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.<sup>5</sup> 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 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 animal husbandry, who in turn delayed marriage. Doepke, Hazan, and Maoz (2007) argue that one-off negative shocks to the value of female labor can lead to large increases in fertility.<sup>6</sup>

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 (Doepke, 2004; Puerta, 2009). Recently, Greenwood, Seshadri, and Vandenbroucke (2005) have explored the impact of labor-saving household technology on fertility. Fernández-Villaverde, Greenwood, and Guner (2010) show how the availability of effective contraception technology leads to a de-stigmatization of premarital sex in the 20th century. Before 1800, effective contraception was not available. Delayed marriage – together with the stigmatization of pre-marital sex – was the only effective birth control 'technology.'

Relative to this literature, we make several contributions. We present the first rigorous model explaining the emergence of the European Marriage Pattern as a result of utility-maximizing behavior, following a large positive shock to income. In our model, fertility restriction arises without a role for human capital, in

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<sup>5</sup>Recent work using disaggregated data for Bavaria and for France has questioned this conclusion (Brown and Guinnane, 2001; Murphy, 2006).

<sup>6</sup>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.

contrast to models in the spirit of Barro and Becker (1989). Also, heterogeneity in wages or tastes (Jones, Schoonbroodt, and Tertilt, 2008) plays no role. Our approach emphasizes women's opportunity cost, as determined by changes in the structure of agricultural production following the Black Death. The 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). 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).<sup>7</sup> The unit of analysis is typically the world as a whole, not individual countries. Instead, we focus on cross-sectional differences, examining factors that led to Europe's precocious rise to riches.<sup>8</sup> 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.

The nature of the Malthusian world before 1800 is examined *inter alia* in Clark (2007) and Wrigley, Davies, Oeppen, and Schofield (1997).<sup>9</sup> 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 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.

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. De Moor and van Zanden (2005) 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, encouraged women to 'take time to choose' their marriage partners. Because many parents were landless, they could not entice their children to stay on the land. Thus, children

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<sup>7</sup>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.

<sup>8</sup>Vollrath's (2011) model also has cross-sectional implications. He shows that high labor intensity in agriculture can lead to higher fertility and therefore lower p.c. income. This is compatible with our argument, where pastoral agriculture (with low labor intensity) was central for Europe's fertility restriction.

<sup>9</sup>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).

sought out outside earnings opportunities, especially when wages were high (such as after the Black Death).

### 3 Model

This section presents a simple Malthusian model with labor supply and marriage decisions. The economy is composed of  $N$  female and  $N$  male peasants who work, consume, and procreate.<sup>10</sup> People live for two periods, childhood and adulthood. Children do not work or consume. At the beginning of each period, male and female peasants form  $N$  identical couples that make joint decisions to maximize household utility. For simplicity, we assume that adulthood and childhood are of equal length and that wages are the only source of income for peasants.

Before marriage, women do not have children. During marriage, there is no birth control and children arrive with frequency  $\pi$ . Delaying marriage is the only 'contraceptive technology.' Fertility is endogenously determined by the age at marriage.<sup>11</sup> We define the European Marriage Pattern as follows:

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

The economy is Malthusian – the steady state income level depends on mortality and fertility schedules. The former declines in consumption, while the latter rises with income in the presence of EMP. In the absence of EMP, the fertility schedule is flat, as shown in Figure 1. A steady state in our model is characterized by zero population growth, i.e., where birth rates equal death rates. This is the standard Malthusian result in the absence of technological progress. Our model economy is initially in a steady state with high, constant birth rates and low per-capita income ( $S^{\text{ROW}}$  in Figure 1). EMP can emerge as a consequence of major population losses following the Black Death. Because of later marriage, the birth schedule shifts downward (property (i) of EMP). In addition, a subsistence effect causes birth rates to increase with 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 in Europe. We also analyze productivity characteristics that favor the emergence of EMP in Europe as compared to China.

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<sup>10</sup>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.'

<sup>11</sup>Our model explains delayed marriage, but not the fact that a significant proportion of women remained unmarried. However, our mechanism can lead to lifetime celibacy as a corner solution if women have heterogeneous preferences over children.

### 3.1 Peasant Families: Preferences, Labor Supply, and Fertility

Adult peasants live for one period. Independent of whether or not they live in the same location, they make decisions jointly, maximizing household utility:

$$u(C_p, b) = (1 - \mu)v(C_p) + \mu \ln(b - \underline{b}), \quad (1)$$

where  $v(C_p)$  denotes utility from a consumption composite,  $b$  is the number of children (with a lower bound  $\underline{b}$ ), and  $\mu$  represents the relative importance of children vs. consumption in household utility. The lower bound on fertility is not crucial for our mechanism, but it proves useful in the calibration. There is no investment or bequests to children – all income is spent on consumption during an adult's life. Consumption utility is given by

$$v(C_p) = \begin{cases} \ln(C_p - \underline{c} + \epsilon) & \text{if } C_p > \underline{c} \\ (C_p - \underline{c})/\epsilon + \ln(\epsilon) & \text{if } C_p \leq \underline{c} \end{cases} \quad (2)$$

where  $\epsilon$  is a positive number close to zero. This specification ensures that  $v$  and  $v'$  are continuous and that the marginal utility is a large positive number.<sup>12</sup> Whether or not income is above the subsistence level  $\underline{c}$  plays a central role in our model. This setup is similar to Galor and Weil (1996) and is a special case of Jones' (2001) model.<sup>13</sup> Peasants draw consumption utility from 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.<sup>14</sup>

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, spending a share  $l_h$  of their time in horn production, earning  $w_h$ , and the remainder  $1 - l_h$  in grain production for the wage  $w_{F,g}$ .<sup>15</sup> When married and living together with their spouse, women also work in grain production on

<sup>12</sup>We use  $\underline{c} = 1$ , so that  $\lim_{C_p \rightarrow \underline{c}} v(C_p) = \ln(\epsilon)$  and  $\lim_{C_p \rightarrow \underline{c}} v'(C_p) = 1/\epsilon$  for convergence to  $\underline{c}$  from above and below.

<sup>13</sup>In a more general setup, rising income in a rich economy ( $C_p \gg \underline{c}$ ) 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  $C_p$  is close to  $\underline{c}$ .

<sup>14</sup>Of course, perfect substitutability between two types of food is a strong assumption. However, evidence suggests a high elasticity. In section 4 we discuss 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).

<sup>15</sup>Because only women work in horn production, we do not need extra subscripts for male or female peasants; the subscript  $h$  is sufficient.



the rented land. Peasant household income is thus given by

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

Female labor supply in horn production,  $l_h$ , is determined by the trade-off between a (potential) female wage premium in horn production and child rearing during marriage. When working in horn, female peasants are required to dwell away from home at the landlord's location. Marriage is not allowed, and women live separated from their fiancé. The fraction  $l_h$  of adult lifetime can therefore be interpreted as the celibate period for both men and women. The probability of childbearing is zero during this period. After marrying, husband and wife move in together, and women work in grain production at home. The share of lifetime married thus corresponds to female labor supply in the grain sector,  $l_{F,g} = 1 - l_h$ .<sup>16</sup> There is no contraception, and married couples produce  $\pi$  births per unit of time.<sup>17</sup> Consequently, the number of offspring per couple is given by

$$b = \pi(1 - l_h) \quad (4)$$

Given  $w_{M,g}$ ,  $w_{F,g}$ , and  $w_h$ , peasant households maximize (1) subject to the consumption utility given by (2), the birth rate given by (4), and household income (3). In the absence of bequests and investments, the budget constraint holds with equality, i.e.,  $C_p = I_p$ . The household optimization problem is then

$$\begin{aligned} \max_{l_h} \{ & (1 - \mu) v(I_p(l_h)) + \mu \ln[\pi(1 - l_h) - b] \} \\ \text{s.t. } & 0 \leq l_h \leq 1 \quad \text{and} \quad w_h > w_{F,g} \end{aligned} \quad (5)$$

The second constraint ensures that the utility of consumption is increasing in  $l_h$ . If this does not hold ( $w_h \leq w_{F,g}$ ), households unambiguously lose welfare when women work in horn (both consumption and the number of children fall with  $l_h$ ). Thus, the horn technology does not operate when  $w_h \leq w_{F,g}$ , so that  $l_h = 0$  and  $b = \pi$ . Otherwise ( $w_h > w_{F,g}$ ), we obtain an interior solution with  $l_h > 0$ . This is described in more detail below.

Finally, we describe mortality in our model. Death rates among adults are zero until a given period is over. Overall mortality is thus driven exclusively by child mortality.<sup>18</sup> The survival of children depends on average peasant consumption. The number of children dying per family is given by

$$d = d_0 (C_p^A / \underline{c})^{\varphi_d} , \quad (6)$$

where  $\varphi_d < 0$  is the elasticity of child mortality with respect to average consumption of peasant households ( $C_p^A$ ), and  $d_0$  is the death rate at subsistence consumption  $\underline{c}$ .<sup>19</sup> Consequently, child mortality falls as p.c.

<sup>16</sup>We implicitly assume that working in grain production is compatible with raising children.

<sup>17</sup>For simplicity, we treat  $\pi$  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.

<sup>18</sup>Historically, child mortality was the main driver of overall life expectancy.

<sup>19</sup>A historical justification for child mortality depending on average (rather than individual) income is that its main cause were

income rises. Note that below subsistence consumption, individuals suffer from hunger, but do not necessarily die – mortality increases continuously as  $C_p^A$  falls below  $\underline{c}$ . At the end of each period, parents die and surviving offspring form the next adult generation.

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 (6) 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 The Landlord, Location of Production, and Technology

Both technologies – grain ( $g$ ) and horn ( $h$ ) – use land and peasant labor as inputs. 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 workers at their marginal product.<sup>20</sup> 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 produces horn. 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; peasants can only grow grain on the lots that they rent.

The landlord does not work and does not draw utility from children; for simplicity, we assume that he is infinitely-lived. Therefore, he does not influence fertility directly. The landlord has the same consumption preferences as peasants,  $C_k = c_{k,h} + c_{k,g}$ .<sup>21</sup> His only source of income are land rents, generated by charging the marginal product of land in the two sectors,  $r_g$  and  $r_h$ . The landlord’s budget constraint is thus given by  $C_k \leq I_k = r_g T_g + r_h T_h$ . As for peasants, we assume that the landlord consumes all his income in each period, so that  $C_k = I_k$ . His optimization problem thus consists of allocating land optimally between the two sectors:

$$\max_{T_g} \{r_g T_g + r_h (T - T_g)\} \quad (7)$$

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diseases like diarrhea and typhus, whose spread depends on hygienic conditions (and therefore income) in the community.

<sup>20</sup>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 remain celibate.

<sup>21</sup>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.

Grain is produced according to:

$$Y_g = A_g \hat{L}_g^{\alpha_g} T_g^{1-\alpha_g}, \quad (8)$$

where  $A_g$  and  $\alpha_g$  are TFP and the labor share in grain production, respectively;  $T_g$  is land dedicated to grain, and  $\hat{L}_g$  denotes effective peasant grain-labor supply. The latter is given by:

$$\hat{L}_g = L_{M,g} + \rho L_{F,g}. \quad (9)$$

where  $L_{M,g}$  and  $L_{F,g}$  denote male and female grain-labor input, respectively. The parameter  $\rho < 1$  captures lower female productivity in grain. While both types of labor are perfectly substitutable, men have a relative advantage compared to women because grain farming requires arduous physical labor, such as ploughing, threshing, and reaping. The fact that female peasants spent much of their married time caring for children is a further justification for their relatively lower productivity in grain production.

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

$$Y_h = A_h L_h^{\alpha_h} T_h^{1-\alpha_h}, \quad (10)$$

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  $L_h = N - L_{F,g}$ .

In the following, 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 in grain and horn per household, respectively.<sup>22</sup> 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

<sup>22</sup>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.

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 follows from (8) and is given by

$$w_{M,g} = \alpha_g A_g \left( \frac{T_g}{\widehat{L}_g} \right)^{1-\alpha_g} = \alpha_g A_g \left( \frac{t_g}{\widehat{l}_g} \right)^{1-\alpha_g}, \quad (11)$$

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

$$w_{F,g} = \rho w_{M,g} \quad (12)$$

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 (9), we can thus express effective labor in grain production per household as a function of the share of female lifetime spent working in horn,  $l_h$ :

$$\widehat{l}_g = 1 + \rho(1 - l_h). \quad (13)$$

Next, we turn to pastoral production. When the landlord produces horn goods, he pays a wage rate equal to the marginal product of labor in (10):

$$w_h = \alpha_h A_h \left( \frac{t_h}{l_h} \right)^{1-\alpha_h}. \quad (14)$$

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:

$$r_g = (1 - \alpha_g) A_g \left( \frac{\widehat{l}_g}{t_g} \right)^{\alpha_g}, \quad r_h = (1 - \alpha_h) A_h \left( \frac{l_h}{t_h} \right)^{\alpha_h} \quad (15)$$

The landlord's optimal allocation of land according to equation (7) yields  $r_g = r_h = r$ . This implies:

$$\frac{t_g}{\widehat{l}_g} = \left( \frac{A_g}{A_h} \frac{1 - \alpha_g}{1 - \alpha_h} \right)^{\frac{1}{\alpha_g}} \left( \frac{t_h}{l_h} \right)^{\frac{\alpha_h}{\alpha_g}}. \quad (16)$$

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 (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  $\alpha_g$  and  $\alpha_h$ . 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.,  $\frac{d(t_g/\hat{l}_g)}{dt} > 0$  and  $\frac{d(t_h/l_h)}{dt} > 0$ .*

PROOF. If both technologies operate and land per household  $t$  increases, factor market clearing implies that land-labor ratios must increase in at least one of the two sectors. Following (16),  $d(t_g/\hat{l}_g)/dt$  and  $d(t_h/l_h)/dt$  have the same sign. Consequently, both derivatives are positive.  $\square$

Next, we use (11), and (16) to derive the wage rate in grain as a function of the horn land-labor ratio:

$$w_{M,g} = \alpha_g A_g \left( \frac{A_g}{A_h} \frac{1 - \alpha_g}{1 - \alpha_h} \right)^{\frac{1 - \alpha_g}{\alpha_g}} \left( \frac{t_h}{l_h} \right)^{\frac{\alpha_h}{\alpha_g} (1 - \alpha_g)}. \quad (17)$$

We have now obtained all wage rates as functions of the land-labor ratio in horn,  $t_h/l_h$ . Finally, we derive the female wage premium in horn production. We divide (14) by the female marginal product in grain production (given by (12) and (17)) to obtain:

$$\frac{w_h}{w_{F,g}} = \frac{\alpha_h}{\rho \alpha_g} \left( \frac{A_h}{A_g} \right)^{\frac{1}{\alpha_g}} \left( \frac{1 - \alpha_h}{1 - \alpha_g} \right)^{\frac{1 - \alpha_g}{\alpha_g}} \left( \frac{t_h}{l_h} \right)^{\frac{\alpha_g - \alpha_h}{\alpha_g}}. \quad (18)$$

The return to female labor in horn vs. grain is therefore driven by three components in our model. First, if grain technology is highly productive relative to horn technology ( $A_h/A_g$  is small), female wages in horn are comparably low. Second, the same is true if women are relatively productive in grain ( $\rho$  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.<sup>23</sup>

**Corollary 1.** *Provided that both sectors operate, the female wage premium 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 (18) with respect to  $t$ .  $\square$

### 3.4 Fertility, Female Labor Supply, and Emergence of EMP

Female labor supply in horn production – and thus fertility – depends crucially on the female wage premium in horn, which in turn rises and falls with the abundance of farmland. We begin by discussing the case where land is relatively abundant, so that the wage premium in horn is positive, making the sector attractive for female peasants. In particular, we will first derive the solution when  $w_h - w_{F,g}$  is large relative to  $\epsilon$ . In the

<sup>23</sup>In a more general setup with imperfect substitutability between grain and horn products, there is a fourth 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.

following, we refer to this case as horn production being economically viable.<sup>24</sup> The household optimization problem (5) yields (for illustration, we substitute  $b$  and  $I_p$  back into the solution):

$$b - \underline{b} = \begin{cases} \pi \frac{\mu}{1-\mu} \frac{I_p - \underline{c} + \epsilon}{w_h - w_{F,g}} & \text{if } I_p > \underline{c} \\ \pi \frac{\mu}{1-\mu} \frac{\epsilon}{w_h - w_{F,g}} & \text{if } I_p \leq \underline{c} \end{cases} \quad (19)$$

To fix ideas, we begin with a high horn wage premium  $w_h \gg w_{F,g}$ , and then lower it. Equation (19) entails an income condition:  $I_p > \underline{c}$ , i.e., that peasant household income is sufficient to produce above-subsistence consumption. With income above the subsistence level, we obtain an internal solution, as given by the first line in (19). The birth rate  $b$  increases in income due to the subsistence effect, but  $b$  falls in the horn wage premium, because this makes celibate work time more profitable for women. Which of the two effects dominates depends on how close income is to subsistence, which we discuss in detail below. For below-subsistence income, the birth rate depends on the ratio of  $\epsilon$  to  $w_h - w_{F,g}$ . Since we assumed, for now, that the latter is large relative to the former, this ratio is very small. Thus,  $b \simeq \underline{b}$ . At the same time, female labor supply in horn is close to its maximum:  $l_h \simeq \bar{l}_h = 1 - \underline{b}/\pi$ .

Next, we turn to the case where the wage premium in horn becomes minuscule. For a given  $\epsilon > 0$ , let  $w_h - w_{F,g} \rightarrow 0$ . Then, we obtain a corner solution where the birth rate is at its maximum:  $b = \bar{b} = \pi$ . At this point, the constraint  $l_h \geq 0$  is binding. In words, the wage premium becomes so low that it does not justify giving up children for work in horn anymore. This creates a sharp transition from low to high birth rates as  $w_h - w_{F,g}$  approaches zero from above.<sup>25</sup> Similarly, (4) implies that female labor in horn drops from its maximum level  $\bar{l}_h = 1 - \underline{b}/\pi$  to  $l_h = 0$  as  $w_h - w_{F,g}$  converges to zero. Finally, consider the case where there is no female wage premium in horn:  $w_h \leq w_{F,g}$ . Then, increasing  $l_h$  unambiguously lowers household welfare because both income and birth rates fall according to (3) and (4), respectively. Thus, female workers do not supply labor in horn production, and the economy remains in the previously obtained corner solution with  $l_h = 0$  and  $b = \pi$ .

Summing up, we distinguish between three regimes for birth rates and female labor supply in horn. Equation (20) gives the results for  $l_h$ , beginning with low land-labor ratios such that horn is not economically viable ( $w_h \leq w_{F,g}$ ) and  $l_h = 0$ . When land-labor ratios rise and horn production becomes viable, the solution depends on whether or not peasant income  $I_p$  exceeds subsistence. If it does not, we are in the second regime of (20), and women work the maximum time in horn,  $l_h = \bar{l}_h$ . If income exceeds subsistence, we obtain the internal solution given by the third regime. There is a twist related to determining the cutoff point between the second and the third regime, i.e., the point where  $I_p = \underline{c}$ . Income  $I_p$  is itself a function of  $l_h$ , as given by (3). To resolve this issue, we use the fact that in the second regime  $l_h = \bar{l}_h$ , so that the

<sup>24</sup>Technically, for any  $w_h > w_{F,g}$  there is a sufficiently small  $\epsilon$  to grant that this condition holds. Intuitively, the smaller  $\epsilon$ , the larger is the marginal utility of consumption below subsistence. With a stronger need to consume, peasant households are more inclined towards female work in horn (earning the wage premium  $w_h > w_{F,g}$ ), as opposed to having children. As  $\epsilon \rightarrow 0$ , horn is viable even for very small wage premia. In the following, we thus use the terminology that horn is 'viable' whenever  $w_h > w_{F,g}$ .

<sup>25</sup>Note that the smaller  $\epsilon$  (i.e., the larger the marginal utility of consumption), the smaller the wage premium at which this 'tipping point' is reached.

corresponding household income is given by  $I_p(\bar{l}_h) = w_{M,g} + w_{F,g}(1 - \bar{l}_h) + w_h \bar{l}_h$ . This is the maximum income that can be earned when  $w_h > w_{F,g}$ , under the constraint  $b \geq \underline{b}$ . We can thus use the income condition  $I_p(\bar{l}_h) \leq \underline{c}$  to determine the cutoff point between the second and the third regime. Following this discussion, we use (3) to solve (19) for  $l_h$ .

$$l_h = \begin{cases} 0, & \text{if } w_h \leq w_{F,g} \\ \bar{l}_h, & \text{if } w_h > w_{F,g} \text{ and } I_p(\bar{l}_h) \leq \underline{c} \\ (1 - \mu)\bar{l}_h - \mu \frac{w_{M,g} + w_{F,g} - \underline{c} + \epsilon}{w_h - w_{F,g}}, & \text{if } w_h > w_{F,g} \text{ and } I_p(\bar{l}_h) > \underline{c} \end{cases} \quad (20)$$

Note that  $I_p(\bar{l}_h)$  is increasing in the land-labor ratio because all wage rates increase in  $T/N$ . In addition,  $w_h/w_{F,g}$  rises with  $T/N$  (Corollary 1). The transition from the first to the third regime can thus be illustrated as a function of  $T/N$ , as shown in Figure 2. The upper panel depicts both  $w_h/w_{F,g}$  and  $I_p(\bar{l}_h)/\underline{c}$  as functions of land available per peasant household. The lower panel in Figure 2 relates the two conditions with female labor supply in horn ( $l_h$ ). We begin with low  $T/N$  (regime 1). Because of the relative wage condition (dashed line), work in horn is viable 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. When  $T/N$  – and thus income – is low, i.e., if  $I_p(\bar{l}_h)/\underline{c} \leq 1$ , peasants are close to starvation (regime 2). 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.

[Insert Figure 2 here]

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 (regime 3), two effects govern female labor supply decisions. First, the relative wage effect leads to *more* work in horn when  $w_h$  increases relative to  $w_{F,g}$ . Second, the subsistence effect implies *less* female labor in horn production as income grows.<sup>26</sup> For our choice of parameters the subsistence effect dominates when income is small, while the relative wage effect eventually prevails when income is large.<sup>27</sup> Figure 2 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 still poor. Intuitively, poverty generates strong incentives for female peasants to work in horn for the wage premium  $w_h > w_{F,g}$ . The following proposition states the conditions under which EMP emerges as a consequence of major population losses.

<sup>26</sup>To understand the subsistence effect, suppose that  $I_p$  is close to, but larger than,  $\underline{c}$ . 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. As a result, 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. Consequently, the subsistence effect implies that income and female labor shares in horn move in opposite directions.

<sup>27</sup>For large  $T/N$ ,  $l_h$  becomes eventually upward sloping (not depicted in Figure 2).



**Proposition 2.** *EMP emerges over some range of  $T/N$  if and only if  $\frac{T}{N}|_{w_h=w_{F,g}} < \frac{T}{N}|_{I_p=\underline{c}}$ , 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, where we show that  $b < \bar{b}$  and that  $b$  is upward sloping in income over some range if the condition holds, while  $b$  is always downward sloping otherwise.

Proposition 2 implies that point A in Figure 2 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. In this case, the subsistence effect (making work in horn more necessary for *smaller*  $T/N$ ) is strong; it 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 subsistence effect is relatively weak when horn becomes viable. The relative wage effect more than offsets the subsistence effect, and birth rates are downward sloping in income. Thus, 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 at 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 ( $\rho$  is relatively small).*

PROOF: See Appendix A.2.

The mechanism in our model that creates fertility limitation is similar in spirit to Galor and Weil (1996). In their model, female labor is more complementary to capital than men’s labor; capital accumulation raises female wages and lowers fertility. In our model, land plays a similar role. Because women have a comparative advantage in the land-intensive horn sector, their wages rise with the abundance of land, and fertility falls. Our model is also related to Greenwood et al. (2005), who argue that technological advances in the household sector can explain the baby boom because they lowered the cost of children. In a similar vein, relatively high productivity in horn (compared to grain) production favors the emergence of fertility restriction in our setup, by raising the opportunity cost of family life and childbearing. However, in contrast to Greenwood et al., our mechanism works without sector-biased changes in productivity. Two other central features distinguish our model from existing ones. First, for very low land-labor ratios, the horn technology is not viable because women’s wages in horn are below their counterpart in grain production. Thus, the mechanism leading to fertility decline does not operate in a land-scarce economy. Second, married couples cannot control their fertility. Instead, the number of children results from a tradeoff between female work time away from home and married life with home production. This reflects the historical fact that effective contraception was unavailable in early modern times; delayed marriage (and fewer women marrying) was the only way to reduce fertility.



We show in section 5.5 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 and the simulation of our model, we provide some historical evidence that supports our mechanism.

## 4 Historical Context and Evidence

In this section, we discuss the history of EMP's emergence. The Black Death led to a rapid increase in the land-labor ratio. As predicted by our model, this shift in factor scarcities led to the emergence of large-scale pastoral production. This was followed by fertility limitation as young women postponed marriage. Our model also predicts a link between fertility behavior and the role of women working in agriculture. As we demonstrate below, this is what the cross-section of marriage ages in England during the early modern period bears out.

We first summarize changes in agricultural production and consumption after the Black Death, and then survey the available evidence about fertility limitation in Europe. 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.

### 4.1 Changes in Production and Consumption after the Black Death

Prior to the Black Death, European agriculture experienced declining marginal returns. Population was increasing, while land was in fixed supply – output per capita fell (Campbell, 2000; Apostolides, Broadberry, Campbell, Overton, and van Leeuwen, 2008). The Black Death killed one third to half of the population. Output per capita surged, and 1350 became a turning point for real wages. By 1450, real wages in England were 50% higher than they had been on the eve of the plague. Per capita consumption of food overall increased. As consumers grew richer, their consumption patterns shifted from 'corn to horn' (Campbell, 2000). More money was spent on 'luxury foods.' Meat and milk consumption increased markedly. For farm workers on large estates, we can quantify these changes: The percentage of calories from meat and fish rose from 7% in 1256 to 26% in 1424 (Dyer, 1988).

The Great Plague caused major changes in production (Apostolides et al., 2008):

"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 ..."

Campbell (2000) estimates that grain acreage declined by approximately 15 percent after 1349, while livestock reared for meat and milk increased by up to 90 percent. Sheep-farming husbandry expanded everywhere. The estimates of Apostolides et al. (2008) suggest that pastoral output (in constant prices) increased

rapidly between 1348 and 1555, while arable output only grew slowly (cf. Table 1). Milk production per head was up by 190%, beef by 170%, and pork by 350%.

*[Insert Table 1 here]*

Large landowners switched to pastoral farming for two reasons: First, it economized on labor input. Per acre, husbandry required 15-25% fewer hands than arable production. Second, cheap labor (in particular, of women) replaced that of adult males. Pastoralism and the processing of its products is 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. 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%. The switch from 'corn to horn' therefore involved a shift in demand from male to female labor.<sup>28</sup>

## 4.2 The Origins and Decline of the European Marriage Pattern

Two main factors curtail fertility under EMP – late female marriage, and a high percentage of women never marrying. We focus on late marriage. It is the single most striking feature of EMP, and more data is available on its emergence.<sup>29</sup> In the Roman Empire, age at first marriage was 12-15 for pagan girls, and somewhat higher for Christian girls. During the Middle Ages, this number was slightly 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 only after the Black Death (Hajnal, 1965, 1982). For women, the age at first marriage in the early modern period was 26 years; 17.5% never married. Scandinavians married even later. Table 2 gives an overview:

*[Insert Table 2 here]*

Within marriage, fertility was largely unconstrained. Table 3 shows marital fertility by age group, for Hutterites (a modern-day Canadian sect that rejects birth control), Western Europe before 1800, and China.

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<sup>28</sup>We use information on the composition of employment per acre from Allen (1991), who gives figures for England in 1770, for various farm sizes. For size, we use his values for 100 acres (small) and 250 acres (large farms), and employ the size distributions in Allen (1988) to obtain aggregate numbers. In addition, average farm size increased after the 14th century. 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 reinforced the switch to horn production.

<sup>29</sup>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. 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).

Western European marital fertility was only slightly below contemporaneous levels of Hutterites and therefore probably close to the biological maximum.<sup>30</sup> Chinese fertility within marriage was low largely as a result of infanticide. In 18th century Germany, some 20% of women married for the first time aged 30 and higher (Knodel, 1988).

*[Insert Table 3 here]*

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, fertility declined. 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). This helped to reduce the downward pressure on living standards.

Fertility restriction through late marriage was probably 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 at 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 hoped to raise age at marriage – through apprenticeships, for example – there were many ways to ignore or circumvent restrictions, especially in the larger towns (Ingram, 1985; Clark, 2007).<sup>31</sup>

EMP declined in the second half of the eighteenth century; English fertility increased rapidly. The way this change occurred highlights the role of economic factors in the operation of EMP. 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). 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, economic change undermined the institution of farm service for young women. Cottage shop manufacturing offered a chance to earn a living, while already having children. Female earnings opportunities outside of animal husbandry improved; thus women could marry earlier, and still earn the same. The decline of England's low fertility regime was probably 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.

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<sup>30</sup>The remaining minor difference is at least partially explained by the better nutrition and general health of Hutterites.

<sup>31</sup>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). Greenwood and Guner (2010) provide a more detailed account of the history of premarital sex.

### 4.3 Farm Service and Fertility Restriction

Apprenticeships and service in agriculture were a standard part of an English adolescent's life. After 1349, landlords increasingly hired agricultural servants to work on the larger farms (Kussmaul, 1981). 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.<sup>32</sup> Celibacy was both a convention and a technological requirement. 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. 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. Servants were entitled to room and board in exchange for labor services. Housing married maids and their offspring would have involved a heavy additional expense for the landlord. The system also had advantages for the servants. 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."

The predictions of our model are borne out in the cross-section of counties in England. Areas with high rates of service in husbandry also had higher proportions of females unmarried (Kussmaul, 1981). The left panel of Figure 3 shows the relationship.<sup>33</sup> The larger the proportion of farm servants in the labor force, the higher the share of females unmarried. Kussmaul (1988) also shows that areas dominated by pastoral production had more people working as agricultural servants.

[Insert Figure 3 here]

In addition, and also in line with our model, there is evidence that areas with large pastoral production registered higher ages at first marriage. As Kussmaul (1988) shows, the overall marriage age and the proportion of typically "pastoral" marriages moved in tandem (right panel of Figure 3).<sup>34</sup> In other words, in periods when horn production was dominant, marriages occurred later. In combination, the evidence strongly suggests that husbandry was linked to late marriage and fertility restriction through the institution of farm service.

### 4.4 Chinese Demography

In contrast to Europe, marriage in China occurred early and was near-universal for women. 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, 1999). The age at first marriage for women was also low. Amongst members of the Imperial

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<sup>32</sup>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.

<sup>33</sup>Most of the women counted as unmarried would have found spouses later – the proportion of women unmarried represents snapshot data, not the marriage experience by cohort.

<sup>34</sup>She uses the timing of marriages to show this – marriages of servants in husbandry typically occurred when their contracts ended in spring, after the lambing season.

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).<sup>35</sup>

The extent to which Chinese demography resulted in higher fertility and greater pressure on living standards is debated. As Lee and Feng (1999) and Feng, Lee, and Campbell (1995) have argued, infanticide and lower fertility limitation within marriage reduced population growth rates. However, what matters for population pressure is the total fertility rate – the combined effect of marriage rates and fertility within marriage. There is no question that this rate was markedly higher in China than in Europe – by 20-40% (Smith, 2011). In line with this, 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 one third faster than in Europe.

## 5 Simulation and International Comparisons

In this section, we solve, calibrate, and simulate our model. We also examine the effects of relatively low grain productivity in Western Europe, compared with other parts of the world.

### 5.1 Solving the Model for Given Land-Labor Ratios

We begin by solving the model 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, corresponding to (20): (a) an economy with very small land-labor ratios where the horn technology does not operate; (b) a more land-abundant economy with both technologies in use but binding subsistence constraint, and (c) a land-abundant one, where both technologies operate and household income is above subsistence.

#### *Case a: Only grain production*

For low land-labor ratios, Corollary 1 implies that women's (shadow) wages in horn fall below their counterpart in grain ( $w_h \leq w_{F,g}$ ), corresponding to the first case in (20). This pushes women out of horn labor – it is more profitable for them to contribute to grain production in the peasant household. Consequently,  $l_h = 0$  and horn goods are not produced; (13) simplifies to  $\hat{l}_g = 1 + \rho$ . 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 (11) and (12). Women marry immediately when they become 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.

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<sup>35</sup>While irrelevant for fertility, the same was not true in the case of men. 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).

### *Case b: Grain and horn production, income below subsistence*

With rising land-labor ratios, labor in horn becomes viable ( $w_h > w_{F,g}$ ), but peasant consumption is initially still below the subsistence level ( $I_p(\bar{l}_h) \leq \underline{c}$ ). The marginal utility of consumption is large, boosting female labor supply in the more rewarding horn sector. The female labor supply constraint is thus binding:  $l_h = \bar{l}_h$ , representing the second case in (20). With  $l_h$  known, we have to solve for  $w_{M,g}$ ,  $w_{F,g}$ ,  $w_h$ , and  $t_h$ .

Market clearing requires that total income (peasant households' wages and the landlord's rents) is spent on grain and horn consumption:

$$N(w_{M,g} + w_{F,g}(1 - l_h) + w_h l_h) + rT = Y_g + Y_h. \quad (21)$$

Because land is optimally allocated between the two technologies, rental rates in horn and grain production equalize. Thus,  $r$  is given by (15). Substituting for  $r$ , using (8) and (10), dividing by the number of households in (21), and substituting for  $\hat{l}_g$  from (13), we obtain:

$$w_{M,g} + w_{F,g}(1 - l_h) + w_h l_h + (1 - \alpha_h) A_h \left( \frac{l_h}{t_h} \right)^{\alpha_h} t = A_g (1 + \rho(1 - l_h))^{\alpha_g} (t - t_h)^{1 - \alpha_g} + A_h l_h^{\alpha_h} (t_h)^{1 - \alpha_h} \quad (22)$$

We now have a system of 4 equations: (12), (14), (17), and (22), which we solve for the 4 unknowns numerically.

### *Case c: Grain and horn production, income above subsistence*

Finally, we solve the model when both technologies operate ( $w_h > w_{F,g}$ ) and peasant consumption exceeds subsistence ( $I_p > \underline{c}$ ). Since both technologies operate, all equations are the same as in case b). In addition,  $l_h$  is now also unknown, and we add the equation from the third case of (20). We solve the resulting system of 5 equations with 5 unknowns numerically.

## 5.2 Calibration

To calibrate our model parameters for Western Europe, we focus on England, where data is relatively abundant, and 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  $\alpha_h = 0.4$ .<sup>36</sup> 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

<sup>36</sup>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:  $0.32 \times 0.7 + 0.68 \times 0.4 = 0.496$ .

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  $\pi$  when reaching its maximum level. We normalize land to  $T = 1$ ; population in the pre-plague steady state is derived endogenously, as described below. Next, we choose TFP in grain and horn,  $A_g = 1.45$  and  $A_h = 1.50$ . Together with  $\alpha_g$ ,  $\alpha_h$ , and  $\rho$ , this ensures that the horn technology becomes feasible before consumption reaches the subsistence level, allowing EMP to emerge. These parameters also imply that  $w_{M,g} > w_h$  for the relevant range of  $T/N$ , which ensures that men only work in grain production.<sup>37</sup> We refer to subsistence income in England as the level during the early 14th century famine, when few horn products were consumed (see Table 1), 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 (6). This implies that the pre-plague steady state involves close-to-subsistence income, as shown below.

### 5.3 Simulation results for given $T/N$

In the following, 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 (4). 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 (20).

*[Insert Figure 4 here]*

For very low land-labor-ratios, the horn technology does not operate because  $w_h \leq w_{F,g}$ ; no land is allocated to horn production. Birth rates are high because couples marry early; 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 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

<sup>37</sup>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  $T/N < 0.85$ .



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.

#### 5.4 Steady States, Elasticity of Birth Rates, 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.<sup>38</sup> The first steady state ( $E_L$ ) has high population pressure and low p.c. income, while 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,  $\varphi_b$ . 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).<sup>39</sup> 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 – 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 Kelly's (2005) estimates (dashed line). In our model structure,  $\varphi_b$  is not constant. In a final comparative exercise, we show the magnitude of EMP's impact under the assumption that  $\varphi_b$  is constant at the rate estimated by Kelly (2005), 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

<sup>38</sup>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.

<sup>39</sup>Similar to (6), the equation  $b = b_0 (\bar{C}_p/\underline{c})^{\varphi_b}$  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 (Clark, 2007).



include a different mortality regime, as well as (to a limited extent) technological change. We examine the contributions of these two additional factors in Voigtländer and Voth (2008) in detail.

## 5.5 International Comparisons

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.

### *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.<sup>40</sup> Rapid recovery of Southern European populations also reversed post-plague wage gains. Changes in agriculture were less pronounced there. 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. 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.<sup>41</sup> 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

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<sup>40</sup>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).

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

remained low.<sup>42</sup>

In Eastern Europe, grain productivity was very 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.

### *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.<sup>43</sup> Chinese land productivity was 700% of English land productivity in grain, and labor productivity was 86%. This implies a factor-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]*

Chinese grain production was efficient because it used numerous techniques to raise output per unit of land. All of them required the use of 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 agriculture 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.<sup>44</sup> In contrast, grain accounted for almost all of China's agricultural production.

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,"<sup>45</sup> the use of draft animals declined in the Ming (1368-1644) and

<sup>42</sup>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.

<sup>43</sup>From his figures, we derive an estimate of output per acre in arable farming in the midlands of 3.5 pounds per acre.

<sup>44</sup>Allen (2009) implies a somewhat higher figure of 44%

<sup>45</sup>Cited after Brenner and Isett (2002).

Qing (1644-1911) period. By the mid-Qing period, animal use had disappeared almost entirely, except for the most arduous tasks.<sup>46</sup> The land needed to feed an ox was dear, and farms were typically too small for keeping an ox.

Ever smaller farm sizes in China also meant that there was 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, 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).<sup>47</sup> This offers important empirical support for the predictions of our model - in Europe, female labor was relatively more valuable, partly because technology, soil, and climate favored the pastoralism, where women could make more of a contribution.

An additional factor was adverse to the emergence of EMP in China. When plowing with oxen disappeared, the strength requirements of grain and rice production were lower. This eroded the relative male advantage in the grain (rice) sector. Therefore, the relative female productivity in grain,  $\rho$ , 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  $\rho$  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  $\frac{T}{N}|_{w_h=w_{F,g}} > \frac{T}{N}|_{I_p=c}$ .<sup>48</sup> 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 a mortality shock, wages converge back to the only steady state  $E_L$ . 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.<sup>49</sup> This result

<sup>46</sup>The view is controversial. Wider availability of bean cake may have helped the increased use of oxen after 1620 (Allen, 2009).

<sup>47</sup>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).

<sup>48</sup> $A_g^{\text{China}} > A_g^{\text{England}}$  has two effects on China relative to England: First, it decreases  $w_h/w_{F,g}$ , shifting point A in Figure 2 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. If we additionally use  $\rho^{\text{China}} > \rho^{\text{England}}$ , point A shifts even further to the right, making the emergence of EMP in China yet more unlikely.

<sup>49</sup>The kink in English peasant household income results from the higher average land intensity of production when the horn

is in line with the findings in Allen (2009), who shows that English agriculture operated with land-labor ratios that were 9.5 times higher than Chinese ones.

*[Insert Figure 7 here]*

Paradoxically, China's high land productivity, as emphasized by the revisionist 'California School' (Pomeranz, 2000; Goldstone, 2003), undermined its chances of developing fertility limitation. In sum, our model 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.

## 6 Conclusion

Why did Europe evolve a system of delayed marriage that reduced fertility centuries before the demographic transition? We argue that the Black Death was key. Fertility restriction emerged as an indirect consequence of the abundance of land after 1348-50. The Black Death reduced population by between one third and half. Land-labor ratios rose markedly. This favored the agricultural sector that used land more intensively – 'horn' production (Campbell, 2000). Cattle were kept for meat and milk, and many more sheep for mutton and wool. The rise of large-scale livestock farming translated into a greater economic role for women. Female labor is better suited to shepherding and milking than to ploughing or threshing (Alesina et al., 2011). 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.

Working as a servant involved moving 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 force incomes back to the *same* equilibrium point.<sup>50</sup> Lower fertility in Europe as a result of EMP was an important factor for the persistence of unusually high per capita incomes long before the Industrial Revolution. In models in the spirit of Acemoglu and Zilibotti (1997) and Greif and Sasson (2009), higher incomes facilitate the transition to self-sustaining growth. 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.

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sector starts operating. This redistributes total income in favor of the landlord (see the right panel of Figure 5).

<sup>50</sup>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.'

Our model can also account for the divergent fortunes of Europe compared with China, and the rest of the world. China was subject to similar mortality shocks 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 arable 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 in grain – facilitated the emergence of a low fertility regime after the Black Death because it encouraged the employment of women, laying an important part of the foundation for Europe’s precocious rise to riches.

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## Tables

Table 1: Agricultural output before and after the Black Death

	Output per head of population						
	Wheat (bushel)	Milk (gallons)	Beef (lb)	Veal (lb)	Mutton (lb)	Pork (lb)	Wool (lb)
1265	4.4	19	7	1	15	8	4
1348	3.8	18	7	1	32	4	8
1550	4.9	52	18	3	54	19	10
1700	4.9	53	17	3	36	19	8
Ratio 1550/1348	1.3	2.9	2.7	3.3	1.7	4.5	1.3

Source: Apostolides et al. (2008)

Table 2: 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 3: 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 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 \(1992\)](#).

## Figures

Figure 1: Steady States with and without EMP (Europe vs. China)

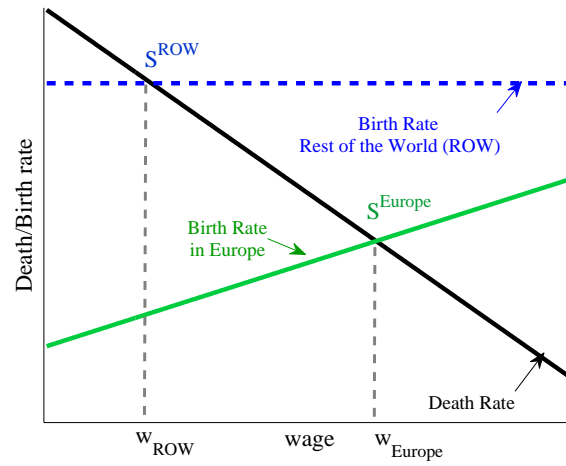
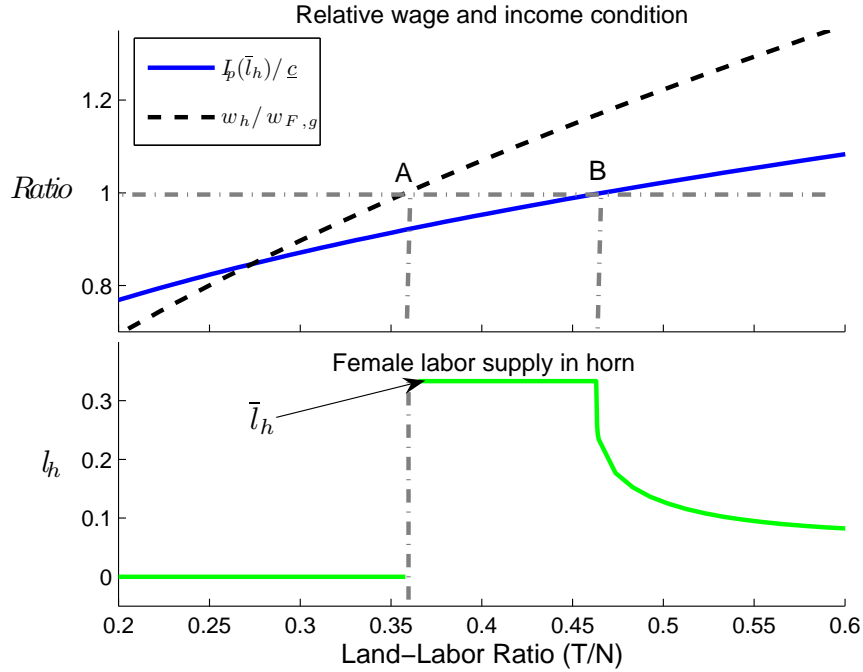
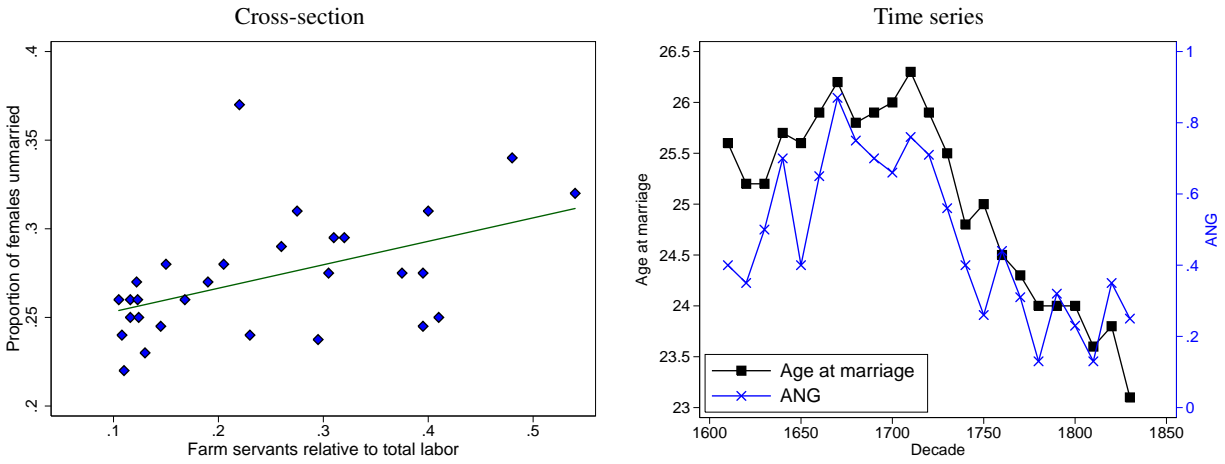


Figure 2: Land-labor ratio and female labor in horn production



*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 3: Farm service and fertility restriction



Source: Data from Kussmaul (1981).

Left panel: Cross-section of husbandry and proportion of unmarried women. Females unmarried represents the 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).

Right panel: Age at First Marriage and Marriage Seasonality. 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 4: Female labor and fertility

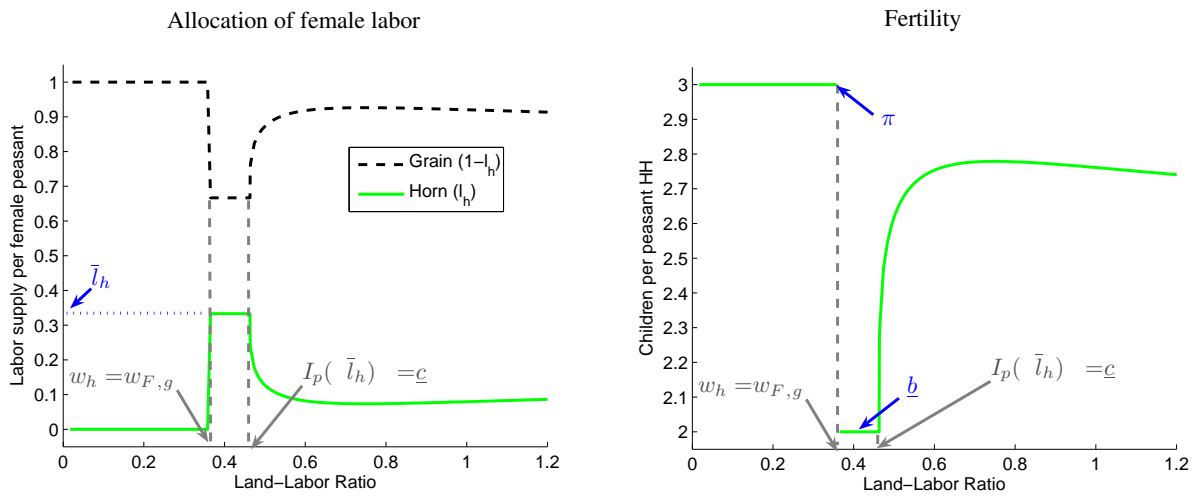


Figure 5: Land allocation and income shares

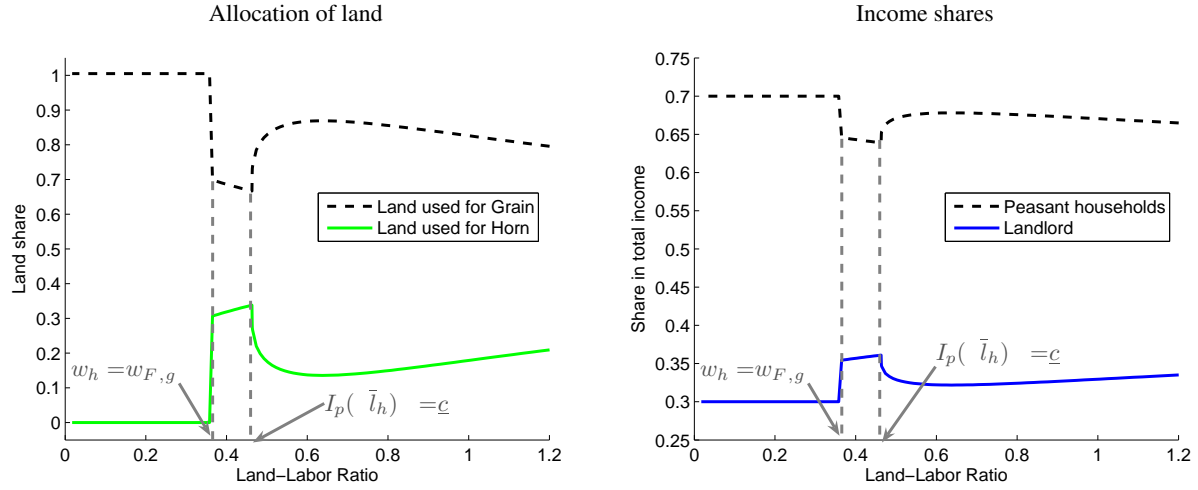


Figure 6: Steady states and EMP's impact on p.c. income

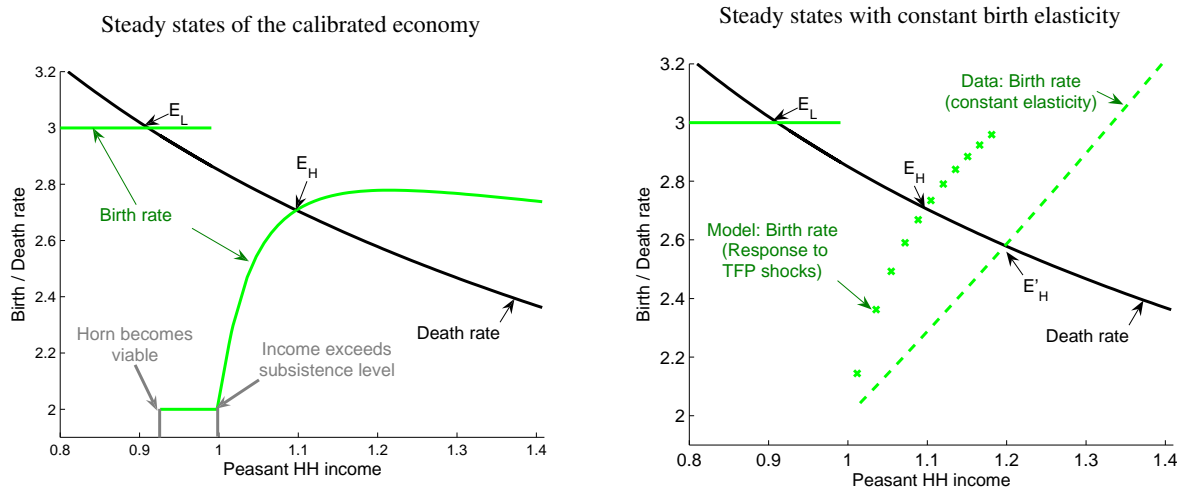
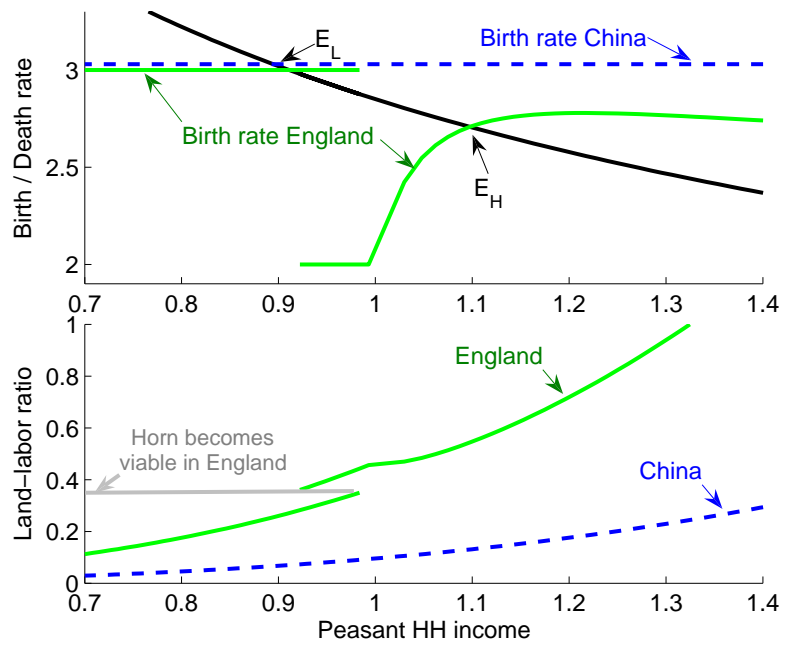


Figure 7: Steady states in England and China





## Online Appendix

### A.1. Proof of Proposition 2

By definition, EMP requires (i)  $b < \bar{b}$  and (ii),  $b$  to be increasing over some range of  $t = T/N$ . We show that the first condition holds when horn becomes viable ( $T/N > \frac{T}{N}|_{w_h=w_{F,g}}$ ), irrespective of whether or not income exceeds subsistence at this point. The crucial part of the proof is thus condition (ii), which requires that  $l_h$  in equation (20) be decreasing in household income over some range of  $t = T/N$ , such that birth rates are increasing. We focus on the third regime in (20), because  $l_h$  and  $b$  are constant in the other two regimes. As a first step, we re-arrange the third line of (20) using (12):<sup>51</sup>

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

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

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

EMP therefore requires (i)  $Z(t)$  to be increasing in  $t$  over some range.<sup>52</sup> Throughout the proof, we thus focus on the derivative of  $Z$  with respect to  $t$ :

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

In order to analyze this expression, we obtain  $dw_{F,g}/dt$  from (12) and (17), and  $d(w_h/w_{F,g})/dt$  from (18).

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

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

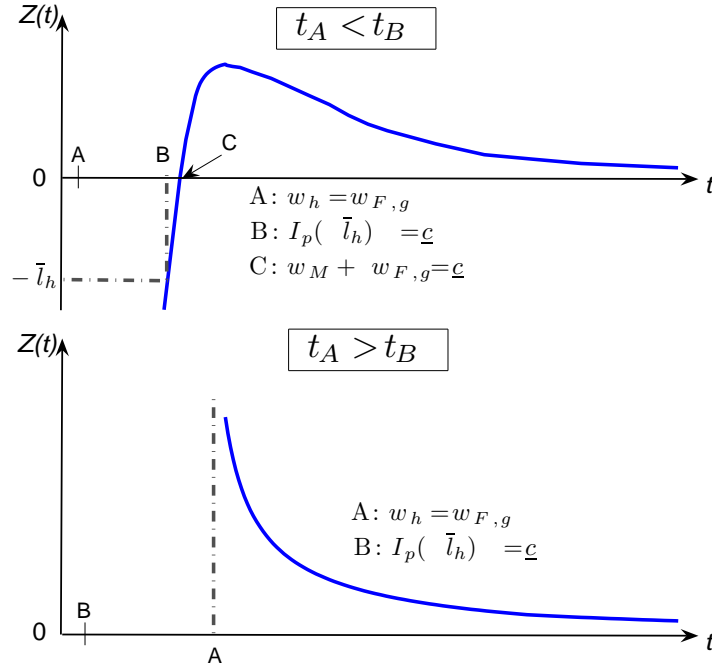
We now turn to the first part of the proof – the "if" part of the proposition, showing that  $Z(t)$  is increasing over some range of  $t$  if  $t_A < t_B$ , and that  $b$  is below its maximum level. Before turning to the formal proof, the upper panel of Figure A.1 illustrates the underlying intuition: We show that  $Z(t) = -\bar{l}_h$  in point B, is

<sup>51</sup>Note that  $w_M + w_{F,g} = ((1 + \rho)/\rho)w_{F,g}$ . For simplicity, but without loss of generality, we ignore the small positive parameter  $\epsilon$ . Leaving  $\epsilon$  in the equation and considering the case  $\epsilon \rightarrow 0$  yields identical results.

<sup>52</sup>Peasant household income grows hand-in-hand with  $t$  over the range where horn is economically viable ( $w_h > w_{F,g}$ ).

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.<sup>53</sup> Following (A.2), this means that  $b = \underline{b}$  in B, and then  $b$  increases over some range (beyond C) – this increasing part reflects EMP. Eventually,  $b$  becomes decreasing in  $t$  and converges to  $\underline{b} + \mu \bar{l}_h$ .

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



We now show this line of argument formally. 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:

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

<sup>53</sup>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  $t > t_A$ .

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  $Z' < 0$ .<sup>54</sup> Finally, we show that  $\lim_{t \rightarrow \infty} (Z(t)) = 0$ . This follows from (A.1): As  $t \rightarrow \infty$ , 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 A.1, which establishes property (ii) of EMP over some range of  $T/N$ .

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  $\underline{b} < \pi = \bar{b}$ , such that  $b < \bar{b}$ . Formally,  $\exists \epsilon > 0$  s.t.  $\forall t_B \leq \tilde{t} < t_B + \epsilon : b < \pi$ . This establishes property (i) of EMP and 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 A.1 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  $w_{F,g}/w_h \rightarrow 1$ , (A.5) simplifies and we can derive the limit of  $Z'(t)$ :

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

This result follows because (i) the numerator in (A.6) is negative and finite. To see this, note that  $\alpha_g > \alpha_h$  and  $((1+\rho)/\rho)w_{F,g} > \underline{c}$ .<sup>55</sup> 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 A.1. (ii) The denominator converges to zero from above, and (iii),  $l_h/t_h$  and  $d(t_h/l_h)/dt$  are both positive and finite (see footnote 54 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:

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

<sup>54</sup>Taking the limit of each term divided by the denominator, it is straightforward to show that  $Z'(t)$  converges to zero from below as  $t \rightarrow \infty$ . 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,  $\lim_{t \rightarrow \infty} (Z(t)) = 0$ , such that following (A.1),  $\lim_{t \rightarrow \infty} (l_h(t)) = (1 - \mu)\bar{l}_h > 0$ .

<sup>55</sup>The latter holds because for all  $t > t_B$ :  $I_p(\bar{l}_h) > \underline{c}$ , and  $\lim_{w_h \downarrow w_{F,g}} I_p(\bar{l}_h) = \lim_{w_h \downarrow w_{F,g}} ((1+\rho)/\rho)w_{F,g} + \bar{l}_h(w_h - w_{F,g}) = ((1+\rho)/\rho)w_{F,g}$ .

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  $t > t_A$ .<sup>56</sup> Finally, we have already shown that  $\lim_{t \rightarrow \infty} (Z(t)) = 0$  (this holds irrespective of  $t_A \leq t_B$ ). 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  $t \rightarrow \infty$ .  $\square$

## A.2. Proof of Corollary 2

Point A in Figure 2 lies to the left of B if  $(I_p(\bar{l}_h)/\underline{c})|_{t=t_A} < 1$ , 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 (18), we can solve for the land-labor ratio in horn:

$$\frac{t_h}{l_h} = \left[ \rho \frac{\alpha_g}{\alpha_h} \left( \frac{A_g}{A_h} \right)^{\frac{1}{\alpha_g}} \left( \frac{1-\alpha_g}{1-\alpha_h} \right)^{\frac{1-\alpha_g}{\alpha_g}} \right]^{\frac{\alpha_g}{\alpha_g - \alpha_h}}, \text{ where } \alpha_g > \alpha_h. \text{ Next, (3) simplifies to } I_p = w_{M,g} + w_{F,g}$$

at point A. Using (12) and (17) 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  $\rho$  and  $A_g$ , and is decreasing in  $A_h$ . Therefore, conditions (i)-(iii) make  $(I_p(\bar{l}_h)/\underline{c})|_{t=t_A} < 1$  more likely to hold.  $\square$

<sup>56</sup>From footnote 55 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  $t > t_A$ ,  $w_{F,g}/w_h < 1$ .