The Three Horsemen of Growth: Plague, War and Urbanization in Early Modern Europe*

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Abstract

We construct a simple Malthusian model with two sectors, and use it to explain how Western Europe overtook China in terms of incomes and urbanization rates in the early modern period. That living standards could exceed subsistence levels in a Malthusian setting at all should be surprising. Rising fertility and falling mortality ought to have reversed any gains. In our setup, population fell following the Black Death; wages surged. Because of Engel's Law, demand for urban products increased. European cities were particularly unhealthy; urbanization pushed up death rates. This effect was reinforced by more frequent wars, fed by city wealth, and disease spread by trade. Thus, higher wages themselves reduced population pressure. Without technological change, our model can account for income increases that lead to levels far above subsistence, as well as the sharp rise in European urbanization.

JEL: E27, N13, N33, O14, O41

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1 Introduction

In 1400, Europe's chances for rapid economic development seemed small. The continent was politically fragmented, torn by frequent military conflict, and dominated by feudal elites. Literacy was low. Other regions, such as China, appeared more promising. It had a track record of useful inventions, from ocean-going ships to gunpowder and advanced clocks (Moykr 1990). The country was politically unified, and governed by a career bureaucracy chosen by competitive exam (Pomeranz 2000). Few if any of the important variables analyzed in modern growth studies suggest that Europe looked promising.[1]

By 1700 however, and long before it industrialized, Europe had pulled ahead decisively - a first "Great Divergence" had occurred (Broadberry and Gupta 2006, Diamond 1997).[2] England's per capita income was more than twice that of China, European silver wages were often markedly higher, and European urbanization rates were more than double those in China (Broadberry and Gupta 2006, Maddison 2003). This early divergence matters in its own right. It laid the foundations for the European conquest of vast parts of the globe (Diamond 1997). More importantly, it may have contributed to the even greater differences in per capita incomes that followed. In many unified growth models, a gradual or temporary rise of per capita income is crucial for starting the transition to self-sustaining growth (Galor and Weil 2000, Hansen and Prescott 2002). Also, higher starting incomes may increase a country's industrialization probabilities (Voigtländer and Voth 2006). If we are to understand why Europe achieved the transition from "Malthus to Solow" before other regions of the world, it is necessary to explain this initial divergence of incomes.

In this paper, we identify a new puzzle, and argue that its solution can help explain why the most advanced parts of Europe were far ahead of the rest of the world by 1700 already. The early modern divergence in per capita incomes represents a major puzzle for Malthusian models because per capita incomes should not be able to rise substantially above subsistence for an extended period. Before industrialization, the 'fertility of wombs' was necessarily greater than the 'fertility of minds.' Galor (2006) estimates that TFP grew by no more than 0.05-0.15% p.a. in the pre-industrial era. Over a century, productivity could increase by 5-16%. Maximum fertility rates per female, by contrast, are around 7. Even with only 3 surviving children, a human population growing unconstrained would quadruple after 100

[1] For a recent overview, see Bosworth and Collins (2003) and Sala-i-Martin et al. (2004).

[2] Pomeranz (2000), comparing the Yangtze Delta with England, argues the opposite. The consensus now is that his revisionist arguments to do no stand up to scrutiny (Allen 2004; Allen, Bengtsson, and Dribe 2005; Broadberry and Gupta 2006).

years.[3] This is why, in a Malthusian regime, past generations should have always, in HG Well's words, "spent the great gifts of science as rapidly as it got them in a mere insensate multiplication of the common life."[4]

Nonetheless, living standards in many European countries increased throughout the early modern period. Maddison (2007) estimates that Western European per capita incomes increased by more than 30%, and aggregate incomes still more between 1500 and 1700.[5] His figures are imperfect, but knowledgeable observers such as Adam Smith detected the same trend: "the annual produce of the land and labour of England... is certainly much greater than it was a little more than a century ago at the restoration of Charles II (1660)... and [it] was certainly much greater at the restoration than we can suppose it to have been a hundred years before."[6] How could such a marked rise be sustained over such a long period, despite the potential for rapid population growth to erode all gains quickly?

We argue that the impact of the Black Death in Europe was crucial. Western Europe's unique set of geographical and political starting conditions interacted with the plague shock to make higher per capita living standards sustainable. In a Malthusian regime, lower population spells higher wages. Because the shock was very large, with up to half of the population dying, land-labor ratios improved, and wages increased substantially. These real wage gains were so large, and concentrated in such a brief period of time, that they could not be undermined quickly by population growth. Wages remained high for more than one or two generations, and were partly spent on manufactured goods. Their production required a higher percentage of the labor force in the urban sector. Because early modern European cities were deathtraps with mortality far exceeding fertility rates, they would have disappeared had it not been for steady in-migration from the countryside. Thus, the extra demand for manufactures pushed up average death rates, making higher incomes sustainable. We capture these key elements in a simple two-sector model. Effectively, Engel's law ensured that the plague's positive effect on wages did not wear off entirely as a result of higher fertility and lower mortality. Because changes in the composition of demand increased urbanization rates, average death rates became permanently higher, making the wage gains sustainable.

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[3] Assuming a generation length of 25 years.

[4] Wells 1905. Galor and Weil (2000) assume that the response of fertility to incomes is delayed. Hence, a one-period acceleration in technological change can generate higher incomes in the subsequent period, and a sequence of positive shocks can lead to sustained growth. While this solves the problem in a technical sense, it is unlikely to explain why fertility responses did not erode real wage gains over hundreds of years.

[5] Maddison estimates that total real GDP doubled in the same period.

[6] Smith, 1776 (1976), pp. 365-66.

This benign effect was reinforced because city wealth fueled early modern Europe's endemic warfare. Between 1500 and 1800, the continent's great powers were fighting each other on average for nine years out of every ten (Tilly 1990). Cities also acted as nuclei for long-distance trading networks. Both war and trade spread epidemics. The more effectively they did so, the higher death rates overall were, and the more readily a rise in incomes and in the urban share of the population could be sustained. In this way, three "Horsemen of Death" - plague, war, and urbanization - led to higher incomes. The combination of these three factors is what we call the European Mortality Pattern. In contrast to numerous papers identifying a negative (short-run) effect of wars, civil wars, disease, and epidemics on growth in economies today,[7] we argue that they acted as "Horsemen of Growth".

The great 13th century plague also affected China, as well as other parts of the world (McNeill 1977). Why did it not have the same effects? We argue that two factors were crucial. Chinese cities were far healthier than European ones, for a number of reasons involving cultural practices and political conditions. Also, political fragmentation in Europe ensured that greater wealth in cities helped to finance almost continuous warfare after 1500. Since China was politically unified, there was no link between city growth and the frequency of armed conflict. Hence, a very similar shock did not lead to permanently higher death rates; per capita incomes could not rise.[8]

The mechanism presented in this paper is not the only one that can deliver a divergence in per capita incomes without technological change. In addition to high death rates, Europeans curtailed birth rates. In contrast to many other regions of the world, socio-economic factors, and not biological fertility, determined the age at first marriage for women. This is what Hajnal (1965) termed the European Marriage Pattern. In our calibrations, we find that fertility restriction can explain part of the European advantage, but that the mortality effects identified in our model account for more than half of the "Great Divergence".

We are not the first to argue that higher death rates can have beneficial economic effects. Young (2005) concludes that Aids in Africa has a silver lining because it reduces fertility rates, increasing the scarcity of labor and thereby boosting future consumption. Lagerlöf (2003) also examines the interplay of growth and epidemics, but argues for the opposite causal mechanism. He concludes that a decline in the severity of epidemics can stimulate growth if they stimulate population growth and human capital acquisition. Brainard and Siegler (2003) study the outbreak of "Spanish flu" in the US, and conclude

[7] Murdoch and Sandler 2002, Hoeffler and Querol-Reynal 2003, Hess 2003.

[8] Hui (2005) compares the Warring States period in China (656-221 BC) with early modern Europe, and argues that flawed strategy is largely to blame for Europe's failure to unify politically.

that the states worst-hit in 1918 grew markedly faster subsequently. Compared to these papers, we make two contributions. We are the first to construct a consistent model demonstrating how specific European characteristics - political and geographical - interacted with a mortality shock to drive up living standards over the long run. Also, we calibrate our model to show that it can account for a large part of the ”Great Divergence” in the early modern period.

Other related literature includes the unified growth models of Galor and Weil (2000), and Galor and Moav (2003). In both, before fertility limitation sets in and growth becomes rapid, a state variable gradually changes over time during the Malthusian regime, making the final escape from stagnation more and more likely. In Galor and Weil (2000) and in Jones (2001), the rise in population which in turn produces more ideas is a key factor; in Galor and Moav (2003), it is the quality of the population.[9] Hansen and Prescott (2002) assume that productivity in the manufacturing sector increases exogenously, until part of the workforce switches out of agriculture. Our model abstracts from technological change during the Malthusian era, and emphasizes changes in death rates as a key determinant of living standards. One of the key advantages is that it can be applied to the cross-section of growth. In contrast, the majority of unified growth papers implicitly uses the world as their unit of observation.

We proceed as follows. The next section provides a detailed discussion of the historical context. Section 3 introduces a simple two-sector model that highlights the main mechanisms. In Section 4, we calibrate our model and show that it captures the salient features of the ”Great Divergence”, compare the effect of the European Mortality Pattern to the consequences of fertility restriction, and compare the model predictions with actual data. The final section summarizes our findings and puts them in the context of explanations of the transition to self-sustaining growth.

2 Historical context and background

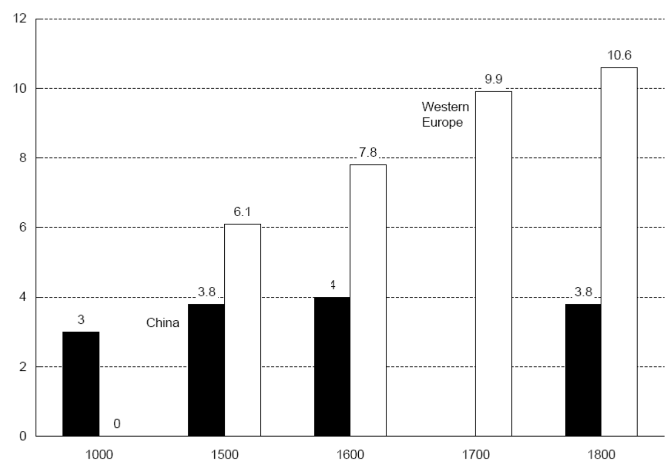
Our story emphasizes three elements that can explain the first ”Great Divergence”: the impact of the plague, the peculiarities of European cities, and interaction effects with the political environment. In this section, we first assemble some of the evidence suggesting that European growth during the early modern period was unusually rapid, and then discuss the three central elements in our model in turn.

[9] Clark (2007) finds some evidence in favor of the Galor-Moav hypothesis, with the rich having more surviving offspring.

The Great Divergence

That Europe pulled ahead of the rest of the world in terms of per capita living standards is now a widely accepted fact. While Pomeranz (2000) argued that farmers in the Yangtze delta in China earned the same wage in terms of calories as English farmers, there is now a broad consensus that overturns this argument. First, better data strongly suggest that English wages expressed as units of grain or rice were markedly higher. Broadberry and Gupta (2006) calculate Chinese grain-equivalent wages were 87% of English ones in 1550-1649, and fell to 38% in 1750-1849. Second, since foodstuffs were largely non-traded goods, they are a poor basis for comparison. Silver wages were much higher in Europe than in China. According to Broadberry and Gupta, they fell from 39% of the English wage to a mere 15%.[10] Finally, urbanization rates have been widely used as an indicator of economic development (Acemoglu, Johnson and Robinson 2005). They strongly suggest that Europe overtook China at some point between 1300 and 1500, and then continued to extend its lead (figure 1).

Figure 1: Urbanization rates in China and Europe, 1000-1800. Source: Maddison 2003



The beneficial effect of the Black Death on real wages is well-documented. The wage figures for England by Phelps-Brown and by Clark (2005) suggest that wages broadly doubled after 1350. If and when these gains were reversed, and to what extent, is less clear. The older Phelps-Brown series suggests a strong reversal. Clark (2005) shows that wages fell back from their peak somewhat, but except for crisis years around the English Civil War, they remained about fifty percent above their 1300 level.[11] In this

[10]While Broadberry and Gupta's figures for the second period are partly influenced by values from the early 19th century, when industrialization was already under way, it is clear that observations for the 18th century alone would also show a marked advantage.

[11]What matters for the predictions of the Malthusian model is per capita output, not wages as such. National income in the

sense, they offer some indirect support to the optimistic GDP figures provided by Maddison (2003).

Changes in Europe were not uniform. Allen (2001) found that the real wage gains for craftsmen after the Black Death were only maintained in Northwestern Europe. In Southern Europe - especially Italy, but also Spain - stagnation and decline after 1500 are more noticeable. Yet for every single European country with the exception of Italy, Maddison estimates that per capita GDP was higher by 1700 than it had been in 1500. This indirectly suggests that standard Malthusian predictions did not hold during the period. Maddison argues that subsistence is equivalent to ca. $400 US-Geary Khamy dollars. Even relatively poor countries like Spain and Portugal had per capita incomes more than twice as high in 1700. At this stage, every single European country had been above the threshold for centuries, often by 50 percent or more. This is the puzzle that we seek to explain.

The Plague

The plague arrived in Europe from the Crimea in December 1347. Besieging Tartar troops suffered from the disease. In an early example of biological warfare, they used catapults to throw bodies of the deceased over the city wall of Caffa, a Genoese trading outpost. Soon, the city population caught the disease. It spread via the shipping routes, first to Constantinople, then to Sicily and Marseille, then mainland Italy, and finally the rest of Europe. By December 1350, it had spread to the North of England and the Baltic (McNeill 1977).

Mortality rates amongst those infected varied from 30 to 95%. Bubonic and pneumonic forms of the plague both contributed to surging mortality. The bubonic form was transmitted by fleas and rats carrying the plague bacterium (Yersinia pestis). Infected fleas would spread the disease from one host to the next. When rats died, fleas tried to feast on humans, infecting them in the process. In contrast, pneumonic plague spread person to person, by coughing of the infected. Transmission and mortality rates were particularly high for this form of the plague.

There appear to have been few differences in mortality rates between social classes, or between rural and urban areas. Some city-dwellers tried to escape the plague, by withdrawing to country residences, as described in Decamerone. It is unclear how often these efforts succeeded. Only a handful of areas in the Low Countries, in Southwest France and in Eastern Europe were spared the effects of the Black Death.

aggregate will be equivalent to the sum of wages, rents, and capital payments. Since English population surpassed its 1300 level in the eighteenth century, it is likely that rental payments were higher, too.

We do not have good estimates of aggregate mortality for medieval Europe. Most estimates put population losses at 15 - 25 mio., out of a total population of approximately 40 mio. people. Approximately half of the English clergy died, and in Florence and Venice, death rates have been estimated as high as 60-75%.

City Mortality

European cities were deadly places. In 1841, when large inflows of labor put particular pressure on urban infrastructures, life expectancy in Manchester was a mere 25 years. At the same time, the national average was 42, and in rural Surrey, 45 years. Early modern cities were often equally unhealthy. Life expectancy in London, 1580-1799, fluctuated between 27 and 28 years (Landers 1993). Nor were provincial towns much more fortunate. York had similar rates of infant mortality.[12] In France, the practice of wet-nursing (sending children from cities for breast-feeding to the countryside) complicates comparisons. A comprehensive survey of rural-urban mortality differences estimates that in early modern Europe, life expectancy was 1.5 times higher in the countryside (Woods 2003).

Mortality figures for China have been reconstructed based on the family trees of clans (Tsui-Jung 1990). Infant mortality rates were lower in cities than in rural areas, and life expectancy was higher. While the data is not necessarily representative, other evidence lends indirect support. For example, life expectancy in Beijing in the 1920s and 1930s was higher than in the countryside. Members of Beijing's elite in the 18th century experienced infant mortality rates that were half those in France or England (Woods 2003). Given that, in Europe at least, class differences in mortality were not common in cities, there is a good chance that mortality rates in general might have been low.

In Japan, where some data for 18$^{\text{th}}$ century Nakahara and some rural villages survives, city dwellers lived as long as their cousins in the countryside. Some recent evidence (Hayami 2001) on adult mortality questions if cities were indeed healthier than the countryside, as some scholars have argued (Hanley 1997; Macfarlane 1997). What is clear is that on balance, the evidence favors the hypothesis that there was no large urban penalty in the Far East. The main reasons probably include the transfer of ”night soil” (i.e., human excrement) out of the city and onto the surrounding fields for fertilization, high standards of personal hygiene, and a diet that emphasized vegetarian food. Since the proximity of animals is a major

[12]Galley 1998. There is not enough data to derive life expectancy. Since infant mortality is a prime determinant, it was probably in the same range.

cause of disease, all these factors probably combined to reduce the urban mortality burden.

In the view of one prominent urban historian, in "1600, just as in 1300, Europe was full of cities girded by walls and moats, bristling with the towers of churches." (DeVries 1976). In China, city walls were widely used throughout the early modern period, partly because of their symbolic value for administrative centers of the Empire. However, since the country was unified under the Qin Dynasty, the defensive function of city walls declined. With relative ease, houses and markets spread outside the city walls.[13] Because Far Eastern cities could easily expand beyond the old fortifications, city growth did not push up population densities in the same way as in Europe.[14]

In many European countries, regulations further ensured that manufacturing activities and market exchange was largely a monopoly of the cities.[15] In China, periodic markets in the countryside served the same function, reducing relative urbanization rates (Rozman 1973). Finally, European cities offered a unique benefit not found in other parts of the world - the chance to escape servitude. The general rule of staying within the city walls for one year and one day made free men out of peasants bound to the land and their lord. In contrast, "Chinese air made nobody free".[16]

Wars, Trade and Disease

The available data on deaths caused by military operations in the early modern period is sketchy.[17] What is clear is that diseases spread by armies were far more important than battlefield casualties and the deaths of siege victims in determining mortality rates. While individual campaigns could be deadly, armies were too small, and their members too old, to influence aggregate mortality rates significantly.[18] The plague of 1347-48 was not the last to strike Europe. In the period 1347-1536, there were outbreaks every 7 years.

[13]In some cases, the new suburbs would also be enclosed by city walls (Chang 1970).

[14]Barcelona is one extreme example. After the 1713 uprising, the Bourbon kings did not allow the city to expand beyond its existing walls until 1854. As industrial growth led to an inflow of migrants, living conditions deteriorated considerably (Hughes 1992).

[15]Some scholars have argued that "proto-industrialization", i.e. early forms of home-based manufacturing, often located in the countryside, were an important feature of early modern European growth (Ogilvy and Cerman 1996). This view is not widely accepted (Coleman 1983).

[16]Mark Elvin, cited in Bairoch (1991).

[17]Landers (2003) offers an overview of battle-field deaths.

[18]Since infant mortality was high, by the time men could join the army, many male children had died already. This makes it less likely for military deaths to matter in the aggregate. Lindegren (2000) finds that military deaths only raised Sweden's death rates by 2-3/1000 in most decades between 1620 and 1719, a rise of no more than 5%. Castilian military deaths were 1.3/1000, equivalent to 10 percent of adult male deaths but no more than 3-4% of overall deaths.

Until the 1670s, frequency declined by half. The last incidents in Western Europe were plague outbreaks in Austria (1710) and Marseille (1720). Warfare and the outbreak of diseases were closely linked. The Black Death had originally arrived with a besieging Tartar army in the Crimea. Early modern armies killed many more Europeans by the germs they spread than through warfare. Isolated communities in the countryside would suddenly be exposed to new germs as soldiers foraged or were billeted in farmhouses. The effect could be as deadly as it had been in the New World, where European diseases killed millions. In one famous example, it has been estimated that a single army of 6,000 men, dispatched from La Rochelle to deal with the Mantuan Succession, spread plague that killed over a million people (Landers 2003). Population losses in the aggregate could be heavy. The Holy Roman Empire lost 5-6 mio. out of 15 mio. inhabitants during the Thirty Years War; France lost 20% of its population in the late 16th century as a result of civil war. As late as in the Napoleonic wars, typhus, smallpox and other diseases spread by armies marauding across Europe proved far deadlier than guns and swords.

For the early and mid-nineteenth century, we have data that allows some gauging of the orders of magnitude involved. In the Swedish-Russian war of 1808-09, mortality rates in Sweden doubled, almost exclusively through disease. In isolated islands, the presence of Russian troops led to a tripling of death rates. During the Franco-Prussian and the Austro-Prussian wars later in the 19th century, non-violent death rates increased countrywide by 40-50% (Landes 2003). Both background mortality and the impact of war were probably lower than in the early modern period. Warfare was less likely to spread new germs, since in areas touched by troop movements were now integrated by extensive railway networks. The figures for the Thirty Years War and for 16th century France similarly suggest increases in mortality above their normal rate by 50 to 100%.

Early modern warfare, with its need for professional, drilled troops, Italian-style fortifications, ships, muskets and cannons were particularly expensive – money formed the sinews of power (Brewer 1990, Landers 2003). To fight wars, princes needed access to liquid wealth. Philip II's silver allowed him to fight a war in every year of his reign except one. Elsewhere, the growth of cities provided the kind of easily mobilized wealth that could be spent on mercenary armies - either directly, through taxation, or through sovereign lending. With the growth of urbanization in early modern Europe, the financial means for fighting more, fighting longer, and in more deadly fashion became more easily accessible.

China in the early modern period saw markedly less warfare than Europe. We calculate that even on the most generous definition, wars and armed uprisings only occurred in one year out of five, no more than a quarter of the European frequency. Not only were wars fewer in number. They also produced less of a spike in epidemics. Europe is geographically subdivided by rugged mountain ranges and large rivers, with considerable variation in climatic conditions. China overall is more homogenous in geographical terms. While rugged in many parts, major population centers were not separated by geographical barriers in the same way as in Europe. Since linking semi-independent disease pools through migratory movements pushes up death rates in a particularly effective way, it may also be that in every armed conflict, similar troop movements produced less of a surge in Chinese death rates than in Europe.[19]

Compared to warfare, trade in early modern Europe was a less effective, but more frequent cause of disease spreading. This is why quarantine measures became frequent throughout the continent. The last outbreak of the plague in Europe occurred in Marseille in 1720. A plague ship from the Levant, with numerous sufferers on board, was first quarantined, only to have the restriction lifted as a result of commercial pressure. It is estimated that 50,000 out of 90,000 inhabitants died in the subsequent outbreak (Mullett 1936). Since trade increases with per capita incomes, the positive, indirect effect of the initial plague on wages created knock-on effects. These combined to raise mortality rates yet further. In addition, there were interaction effects between the channels we have highlighted. The effectiveness of quarantine controls, for example, often declined when wars disrupted administrative procedure (Slack 1981).

3 The Model

This section presents a simple two-sector model that captures the basic mechanisms determining pre-industrial living standards. The economy is composed of N identical individuals who work, consume, and procreate. N_A individuals work in agriculture (A) and live in the countryside, while N_M agents live in cities producing manufacturing output (M), both under perfect competition.[20] For simplicity, we assume that wages are the only source of income. Agents choose their workplace in order to maximize expected utility, trading greater risks of death in the city for a higher wage. Agricultural output is produced using

[19]We are indebted to David Weil for this point. Weil (2004) shows the marked similarity of agricultural conditions in large parts of modern-day China.

[20]During the early modern period, a substantial share of manufacturing took place outside cities – a process called "protoindustrialization" by some. We abstract from it since cities still grew, and our key mechanism remains intact, even if some of the additional demand translated into growth for non-urban manufactured goods.

labor and a fixed land area. This implies decreasing returns in food production. Manufacturing uses labor only and is subject to constant returns to scale. Preferences over the two goods are non-homothetic and reflect Engel's law: The share of manufacturing expenditures (and thus the urbanization rate N_M/N) grows with income.

Population growth responds to per-capita income. Higher wages translate into more births and lower mortality. Therefore, the economy is Malthusian – per capita income stagnates close to the subsistence level, keeping most people at the edge of starvation (”positive” Malthusian check). With stagnating technology, death rates equal birth rates, and N is constant in equilibrium. Technological progress temporarily relieves Malthusian constraints; population can grow. In the absence of ongoing productivity gains, however, the falling land-labor ratio drives wages back to their original equilibrium level. Per-capita income is therefore self-equilibrating.

An epidemic like the plague has an economic effect akin to technological progress: it causes land-labor ratios to rise dramatically. This leaves the remaining population with greater per-capita income, which translates into more demand for manufactured goods. As a consequence, urbanization rates have to rise. In the absence of productivity growth and shifts in the birth or death schedules, subsequent population growth pulls the economy back to its earlier equilibrium – there is no escape from Malthusian stagnation. However, after the plague, the 'Horsemen of Death' start to ride high: Wars become more frequent. City mortality is high. Increasing trade, linking the urban nuclei, spreads disease, as do wars. As these become a permanent feature of the early modern European economy, the death schedule shifts upwards. We argue that this mechanism captures an important element of the European experience in the centuries between the Black Death and the Industrial Revolution. The new long-run equilibrium has higher birth and death rates, but also increased per capita incomes and a higher share of the population living in cities.

3.1 Consumption

Each individual supplies one unit of labor inelastically in every period. There is no investment – individuals i use all their income to consume homogenous agricultural goods ($c_{A,i}$) and manufactured goods ($c_{M,i}$). At the beginning of each period, agents choose their workplace in order to maximize expected utility. Agents' optimization therefore involves two stages: The choice of their workplace and the optimal spending of the corresponding income. We consider the latter first.

In the intra-temporal optimization, each individual takes workplace-specific wages $w_i,\ i = \{A, M\}$ as given and maximizes instantaneous utility.[21] The corresponding budget constraint is $c_{A,i} + p_M c_{M,i} \leq w_i$, where p_M is the price of the manufactured good. The agricultural good serves as the numeraire. Before they begin to demand manufactured goods, individuals need to consume a minimum quantity of food, $\underline{c}$. In the following, we refer to this number as the subsistence level, meaning that individuals satisfy their basic needs for calories at $\underline{c}$. Below $\underline{c}$, individuals suffer from hunger, but do not necessarily die – mortality increases continuously as c_A falls. Preferences take the Stone-Geary form and imply the composite consumption index:

$$u(c_A, c_M) = \begin{cases} (c_A - \underline{c})^{\alpha} c_M^{1-\alpha}, & \text{if } w_i > \underline{c} \\ \beta(c_A - \underline{c}), & \text{if } w_i \leq \underline{c} \end{cases} \tag{1}$$

Where $\beta > 0$ is a parameter specified below. Given w_i, consumers maximize (1) subject to their budget constraint. In a poor economy, where income is not enough to ensure subsistence consumption $\underline{c}$, equation (2) does not apply. In this case, the starving peasants are unwilling to trade food for manufactured goods such that the relative price p_M and rural wages w_M are zero. Thus, there are no cities and all individuals work in the countryside: $N_A = N$, while $c_A = w_A < \underline{c}$.

When agricultural productivity is large enough to provide above-subsistence consumption $w_A > \underline{c}$, expenditure shares on agricultural and manufacturing products are:

$$\begin{aligned} \frac{c_{A,i}}{w_i} &= \alpha + (1-\alpha)\left(\frac{\underline{c}}{w_i}\right) \\ \frac{p_M c_{M,i}}{w_i} &= (1-\alpha) - (1-\alpha)\left(\frac{\underline{c}}{w_i}\right) \end{aligned} \tag{2}$$

Once consumption passes the subsistence level, peasants start to demand manufacturing products, which leads to the formation of cities. If income grows further, the share of spending on manufactured goods grows in line with Engel's law, and cities grow in size. The relationship between income and urbanization is governed by the parameter α. A larger α implies more food expenditures and thus less urbanization at any given income level.

[21] In the following, the subscripts A and M not only represent agricultural and manufacturing goods, but also the locations of production, i.e., countryside and cities, respectively.

3.2 Production

Agricultural and manufactured goods are homogenous, and are produced under constant returns and perfect competition. In the countryside, peasants use labor N_A and land L to produce food. The agricultural production function is

$$Y_A = A_A N_A^{\gamma} L^{1-\gamma} \tag{3}$$

where A_A is a productivity parameter and γ is the labor income share in agriculture. Suppose that there are no property rights over land. Thus, the return to land is zero and agricultural wages are equal to the average product of labor:

$$w_A = A_A \left(\frac{L}{N_A}\right)^{1-\gamma} = A_A \left(\frac{l}{n_A}\right)^{1-\gamma} \tag{4}$$

where $l = L/N$ is the land-labor ratio and $n_A = N_A/N$ is the labor share in agriculture, or rural population share. Since land supply is fixed, increases in population result in a falling land-labor ratio and ceteris paribus in declining agricultural wages. Manufacturing goods are produced in cities using the technology

$$Y_M = A_M N_M \tag{5}$$

where A_M is a productivity parameter. Manufacturing firms maximize profits and pay wages $w_M = p_M A_M$. The manufacturing labor share n_M is identical to the urban population share.

3.3 Migration

The optimal workplace choice determines migration in our model. We suppose that migration occurs at the beginning of every period t, such that migrating individuals arrive at their workplace before production starts in t. In early modern Europe, death rates were substantially higher in cities as compared to rural areas $(d_M > d_A)$. Higher mortality rates in the cities were compensated by higher average wages. In order to set up the corresponding optimization problem, we first derive the indirect utility of consumers from (1) and (2):

$$\widetilde{u}(w_i, p_M) = \left(\frac{1}{p_M}\right)^{1-\alpha} \alpha^{\alpha} (1-\alpha)^{1-\alpha} (w_i - \underline{c}) \tag{6}$$

Note that this equation is valid only if ($w_i > \underline{c}$), which is the more interesting case on which we concentrate from now on. Individuals maximize expected utility in each period, where $(1 - d_i)$ is the survival probability when working at place $i = \{A, M\}$. We define the (hypothetical) utility associated with death as the one corresponding to zero consumption: $\widetilde{u}(0,p_M) = -\beta\underline{c}$, as implied by (1).[22] For the following steps it is convenient to define $\beta \equiv (1/p_M)^{1-\alpha}\,\alpha^{\alpha}\,(1-\alpha)^{1-\alpha}$. The optimization problem is then:

$$\max_{i=\{A,M\}} \{(1-d_i)\,\widetilde{u}(w_i,p_M) \;+ d_i\,\widetilde{u}(0,p_{M,t})\} \tag{7}$$

This setup implies that the city and countryside expected utility levels are equal whenever no migration is desired. In this case, (7) yields:

$$(w_M - \underline{c}) = \frac{(1-d_A)}{(1-d_M)}(w_A - \underline{c}) + \frac{d_M - d_A}{1-d_M}\,\underline{c} \tag{8}$$

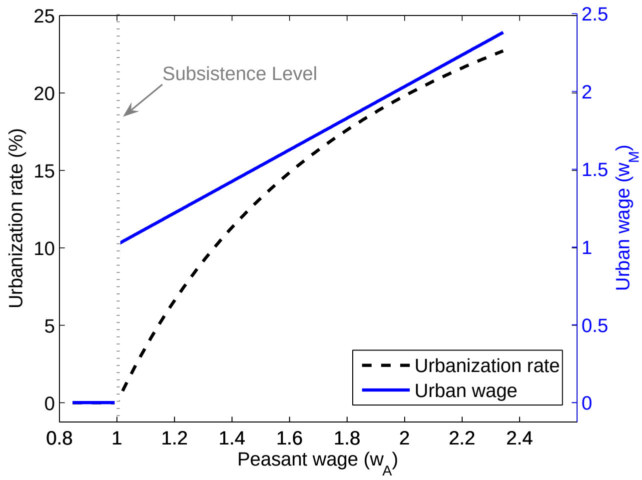
Since $d_M > d_A$, wages in the city are higher than in the countryside.[23] If (8) holds with equality, no migration occurs. When the LHS is larger than the RHS, the urban wage premium outweighs the excess mortality in cities, attracting rural workers. The rising urban labor supply then causes the relative wage to drop until equality is re-established. The opposite workplace decisions restore the equilibrium when the RHS is larger than the LHS. These dynamics can immediately correct minor shocks to relative productivity or population N_A and N_M. If shocks are large, like the plague, migration must be large to re-establish equality in (8). In this case, cities grow less than would be predicted by the baseline model as it takes time to build urban infrastructure – Rome was not built in a day. We discuss this case in detail in section 3.5.

Figure 2 illustrates the basic income-demand-urbanization mechanism of our model. If the rural wage (horizontal axis) is below subsistence, the starving population does not demand any manufacturing goods and cities do not exist (zero urbanization, left axis). Correspondingly, there are no manufacturing workers (zero urban wages, right axis). Cities emerge once peasants' productivity is large enough to provide above-subsistence consumption, such that agents also demand manufacturing goods. At the same time, urban consumption becomes important, driven by city workers who produce manufacturing output. As productivity grows further, urbanization and consumption (both urban and rural) grow in tandem.

[22]Any negative number associated with the utility level of death serves to obtain a positive city wage premium – the more negative, the higher the premium.

[23]If rural income is too small to ensure consumption above subsistence ($w_A \leq \underline{c}$), equation (8) does not hold and there is no migration, since all agent work in agriculture.

Figure 2: Wages and urbanization



3.4 Population Dynamics

Birth and death rates depend on real p.c. income. Since there is no investment, units of consumption serve as a measure of real income: $c_{\bullet,i} = c_{A,i} + c_{M,i}$ for $i = \{A, M\}$.[24] Substituting from (2) into this expression yields:

$$c_{\bullet,i} = \alpha w_i + (1-\alpha)\underline{c} + \frac{(1-\alpha)}{p_M}(w_i - \underline{c}) \tag{9}$$

Individuals at location i procreate at the birth rate

$$b_i = b_0 \cdot (c_{\bullet,i})^{\varphi_b} \tag{10}$$

where $\varphi_b > 0$ is the elasticity of the birth rate with respect to real income. Note that $c_{\bullet,i} = \underline{c}$ if $w_i = \underline{c}$. We choose $\underline{c} = 1$, so that b_0 represents the birth rate at subsistence income. Before the Black Death, location-specific death rates fall with income and are given by

$$\begin{aligned} d_A &= \min\{1,\ d_0 \cdot (c_{\bullet,A})^{\varphi_d}\} \\ d_M &= \min\{1,\ d_0 \cdot (c_{\bullet,M})^{\varphi_d} + \triangle d_M\} \end{aligned} \tag{11}$$

where $\varphi_d < 0$ is the elasticity of the death rate with respect to real income and $\triangle d_M$ represents city excess mortality; d_0 is the countryside death rate at subsistence income.

[24] A simplified approach would have birth and death rate as functions of nominal income w_i, not taking into account changes in the relative price p_M. Because the latter changes substantially with the land-labor ratio, we choose the real income approach.

Higher p.c. income and urbanization after the plague spur trade and wars. Military casualties mount. Armies as well as merchants continuously spread pathogenic germs across cities and countryside. These factors raise background mortality. In combination, this is what we call the 'Horsemen effect', h. Because it is driven by growing income and urbanization, we use the urbanization rate n_M as a proxy for its strength. To capture the positive relationship between urbanization and Horsemen mortality, we calculate h as:

$$h(n_M) = \begin{cases} 0, & \text{if } n_M \leq n_M^h \\ \min\{\delta\, n_M,\ h_{max}\}, & \text{if } n_M > n_M^h \end{cases} \tag{12}$$

where $\delta > 0$ is a slope parameter, h_{max} represents the maximum additional mortality due to the Horsemen effect, and n_M^h is the threshold urbanization rate where the effect sets in. A poor economy with little urbanization has neither long-range mobility due to trade nor means for warfare; germ pools remain isolated and mortality is only driven by individual rural income as given by (11).[25] The role of the plague in our model is to introduce germs and to push p.c. income to levels where $n_M > n_M^h$. Neither germs nor higher income (and thus mobility) alone have an effect on long-run income levels. Only if higher mobility spreads epidemics, background mortality increases and alleviates the population pressure.

The last step before analyzing equilibria is to derive population growth from economy-wide fertility and mortality rates. We derive average fertility from (10), using the workforce shares n_A and n_M as weights:

$$b = n_A b_A + n_M b_M \tag{13}$$

The same method yields average death rates from (11) and (12), depending on whether or not the Horsemen are at work.

$$d = \begin{cases} n_A d_A + n_M d_M, & \text{if } n_M \leq n_M^h \\ n_A d_A + n_M d_M + h, & \text{if } n_M > n_M^h \end{cases} \tag{14}$$

Note that increasing real income has an ambiguous effect on mortality: Larger $c_{\bullet,i}$ translates into smaller death rates in (11). On the other hand, manufacturing demand rises with income, driving more people into cities where mortality is higher. Moreover, in the presence of the Horsemen effect, urbanization (proxying for the spread of epidemics through trade and wars) also implies larger overall background

[25] A more detailed justification for $n_M^h > 0$ is that it indicates a minimum income level that cannot be expropriated, containing food for elementary nutrition as well as basic cloth and tools produced in city manufacturing. Once this threshold is passed, taxation yields the means for warfare and arouses the Horsemen.

mortality. The aggregate impact of productivity on mortality depends on the model parameters (as shown in section 4.1).

Population growth equals the difference between the average birth and death rate: $\gamma_{N,t} = b_t - d_t$. The law of motion for aggregate population N is thus

$$N_{t+1} = (1 + b_t - d_t)N_t \tag{15}$$

Births and deaths occur at the end of a period, such that all individuals N_t enter the workforce in period t.

3.5 Equilibria

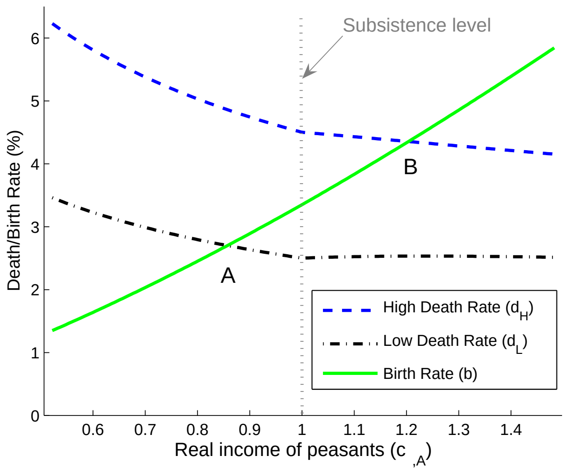
Equilibrium in our model is a sequence of factor prices, goods prices, and quantities that satisfies the intra-temporal and workplace optimization problems for consumers and firms. In this section, we analyze the economy without technological progress. The long-run equilibrium is characterized by stagnant population, labor shares, wages, prices, and consumption. All depend on how the birth and death schedule respond to income. Figure 3 visualizes this relationship. Real peasants' income $c_{\bullet,A}$ is shown on the horizontal axis.[26] Relatively low death rates lead to equilibrium A: a poor economy with below-subsistence income ($c_{\bullet,A} \leq \underline{c}$) where all individuals work in agriculture. The long-run level of consumption is independent of productivity parameters; it only depends on the intersection of b and d_L. For purposes of illustration, assume that there is a one-time major innovation in agriculture, augmenting A_A in equation (4). The rising wage shifts $c_{\bullet,A}$ to the right of point A, such that population grows ($b > d_L$). Consequently, the land-labor ratio l declines. So do wages, which eventually drives the economy back to equilibrium A. Land per worker is therefore endogenously determined in the long-run equilibrium.

In the absence of ongoing technological progress, there are two ways for achieving a permanent rise in per-capita income.[27] First, a permanent drop in birth rates, for example due to the emergence of the European Marriage Pattern. And second, a permanent increase in mortality – the main focus of this paper.

[26] Provided that there is demand for manufacturing products, urban income is proportional to its rural counterpart, as shown in Figure 2.

[27] Continuous technological progress constantly pushes consumption to the right of point A, with increasing population and falling l always pulling it back. The equilibrium is thus located to the right of the intersection of b and d and is characterized by consumption stagnating at a higher level. Consumption can grow continuously only if technological change outpaces the falling land-labor ratio – a highly unrealistic scenario given the observed productivity growth of about 0.1% p.a. before the Industrial Revolution.

Figure 3: Population dynamics and equilibria



Permanently higher death rates (d_H) imply lower population in equilibrium and therefore higher income, as represented by point B in Figure 3.[28] While total population is constant in point B, there must be perpetual migration from the countryside to cities in order to compensate city excess mortality.

Points A and B in Figure 3 are long-run equilibria with endogenous population size. For given technology A_A, productivity is fixed in the long-run, given by the endogenously determined land-labor ratio. During the transition to long-run equilibria, population dynamics change land per worker and thus productivity. In the following, we analyze these short-run equilibria. We first concentrate on the economy with below-subsistence consumption where individuals struggle for survival and produce only food in the countryside. Next, we turn to the economy with consumption above $\underline{c}$, accounting for constraints to migration due to city congestion during the transition process.

The Economy with Below-Subsistence Consumption

In order to check whether overall productivity (determined by A_A and the land-labor ratio) is sufficient to ensure above-subsistence consumption, we construct the indicator $\widehat{w}$, supposing that all individuals work in agriculture. Equation (3) then gives the corresponding per-capita income:

$$\widehat{w} \equiv \frac{Y_A(N)}{N} = A_A \left(\frac{L}{N}\right)^{1-\gamma} \tag{16}$$

[28] Note that the death schedules d_L and d_H become flatter when consumption passes the subsistence level. This is because richer agents also demand manufacturing products such that part of the population lives in cities, where mortality is higher ($\triangle d_M > 0$).

If $\widehat{w} \leq \underline{c}$, all individuals work in agriculture ($N_A = N$) and spend their complete income on food. Since there is no demand for manufacturing goods, the manufacturing price is zero, implying zero urban wages and population. Economy-average fertility and mortality are thus equal to the rural levels given by equations (10) and (11).[29] Finally, there is no migration. In order to derive the long-run equilibrium, we calculate birth and death rates according to the equations in section 3.4. The intersection of the two schedules (point A in Figure 3) determines equilibrium income, which we can use to derive the corresponding population size N from (16).

Above-Subsistence Consumption and Unconstrained Migration

If $\widehat{w} > \underline{c}$, agricultural productivity is large enough to provide above-subsistence consumption. Following (2), the well-nourished individuals spend part of their income for manufacturing goods. Thus, a share n_M of the population lives and works in cities. In each period, individuals choose their profession and workplace based on their observation of income and mortality in cities and the countryside. Productivity increases lead to more manufacturing demand and spur migration, which occurs until (8) holds with equality. For small productivity changes, migration is minor and cities can absorb sufficiently many migrants to establish this equality immediately. We refer to this case as equilibrium with unconstrained migration. Goods market clearing together with equations (2), (3), and (5) implies

$$A_A N_A^{\gamma} L^{1-\gamma} = \alpha \left[(w_A - \underline{c}) N_A + (w_M - \underline{c}) N_M \right] + \underline{c} N \tag{17}$$

$$p_M A_M N_M = (1 - \alpha) \left[(w_A - \underline{c}) N_A + (w_M - \underline{c}) N_M \right] \tag{18}$$

Solving for the expression in brackets in (18), plugging it into (17), and substituting $w_M = p_M A_M$ yields

$$\alpha w_M (1 - n_A) + (1 - \alpha) \underline{c} = (1 - \alpha) A_A n_A^{\gamma} l^{1-\gamma} \tag{E1}$$

This equation contains two unknowns: n_A and w_M. We find an expression for the latter by using the equality in (8), as implied by unconstrained migration. Substituting (4) into (8) and rearranging gives:

$$(w_M - \underline{c}) = \frac{(1 - d_A)}{(1 - d_M)} \left[A_A \left(\frac{l}{n_A} \right)^{1-\gamma} - \underline{c} \right] + \frac{d_M - d_A}{1 - d_M} \, \underline{c} \tag{E2}$$

[29]Note that the Horsemen effect is zero because $n_M = 0$.

We now need d_A and d_M as functions of n_A and w_M. Plugging (9) into (11), with w_A substituted from (4) and $p_M = w_M/A_M$, we obtain:

$$d_A = d_0 \left[\alpha A_A \left(\frac{l}{n_A} \right)^{1-\gamma} + \frac{1-\alpha}{w_M} A_M \left(A_A \left(\frac{l}{n_A} \right)^{1-\gamma} - \underline{c} \right) + (1-\alpha)\underline{c} \right]^{\varphi_d} + h(1-n_A) \quad \text{(E3)}$$

$$d_M = d_0 \left[\alpha w_M + \frac{1-\alpha}{w_M} A_M (w_M - \underline{c}) + (1-\alpha)\underline{c} \right]^{\varphi_d} + \triangle d_M + h(1-n_A) \quad \text{(E4)}$$

The last term in (E3) and (E4) represents the Horsemen effect as a function of the urbanization rate $n_M = 1 - n_A$. For a given population size N we now have a system of 4 equations [(E1)-(E4)] and 4 unknowns (n_A, w_M, d_A, and d_M) that we solve numerically. Given these variables, it is straightforward to calculate the urbanization rate n_M, rural wages w_A from (4), and workplace-specific real income (or consumption) $c_{\bullet,i}$ from (9). Finally, workplace-specific birth rates are given by (10).

All calculations up to now have been for a given N. For small initial population, births outweigh deaths and N grows until diminishing returns bring down p.c. income enough for $b = d$ to hold. The opposite is true for large initial N. To find the long-run equilibrium with constant population, we derive b and d from (13) and (14). We then iterate the above system of equations, deriving N_t in each period t from (15), until the birth and death schedules intersect (point B in Figure 3). The long-run equilibrium level of population depends on the productivity parameters A_A and A_M, and on the available arable surface, L.

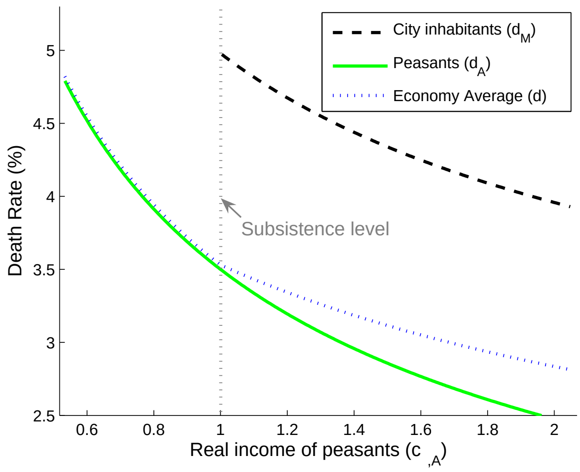
Under unconstrained migration, expected utility in each period is identical for peasants and manufacturing workers. Rural and urban population is given by $N_A = n_A N$ and $N_M = n_M N$, respectively. But is there migration in the long-run equilibrium? To answer this question, Figure 4 shows the workplace-specific death rates as a function of real income.[30] We calibrate city excess mortality including the effects of war and trade as $\triangle d_M = 1.5\%$. Equilibrium death rates in cities are higher than in the countryside.[31] Birth rates, on the other hand, are similar in both workplaces.[32] With stagnant total population and no migration, N_M would therefore decline continuously. This implication of our model is in line with the finding in the historical overview section that early modern European cities would have disappeared without a constant inflow of population.

[30] As in Figure 2, we use peasants' consumption to represent real income. Urban income is a multiple of rural income, as implied by (8). Each point on the horizontal axis therefore corresponds to an urban real income level $c_{\bullet,M} > c_{\bullet,A}$. Note that for $c_{\bullet,A} < \underline{c}$, urban death rates are not defined since all individuals work in the countryside.

[31] The higher real income of manufacturing workers drives down d_M according to (11). However, this income effect is overcompensated by the higher background mortality in cities $\triangle d_M$.

[32] With an urban wage premium (relative to subsistence) in the range of 30% and birth rate elasticity $\varphi_b = 1.41$, as in our baseline calibration, b_M and b_A deviate by less than 0.05%.

Figure 4: Death rates by workplace and average death rate



Congestion and Constrained Migration

Major changes in the urban-rural income differential provide substantial incentives for migration. However, the short-term capacity of cities to absorb migrants is limited because new dwellings and infrastructure must be provided. Building new dwellings and urban infrastructure was one of the costliest undertakings in the early modern economy. Too many migrants caused congestion, making further movement to cities unattractive. In the interest of simplicity, we capture congestions effects with an upper limit to the growth rate of cities, $\overline{\nu}$.[33] When shocks are large, implying large wage differentials, the migration constraint becomes binding. It then takes time until the population shares reach their long-run equilibrium levels n_A^{LR} and n_M^{LR}.

Let $N_{A,t}^{\star}$ and $N_{M,t}^{\star}$ be the number of individuals living in the countryside and cities, respectively, at the beginning of period t *before* migration occurs. This 'native' population is determined by workplace-specific fertility and mortality in the previous period:

$$N_{i,t}^{\star} = (1 + b_{i,t-1} - d_{i,t-1})\, N_{i,t-1} \tag{19}$$

where $N_{i,t-1}$ is the number of agents that live at workplace $i = \{A, M\}$ during period $t-1$, *after* migration has taken place. Let M_t^u be the level of migration necessary to (immediately) establish long-run population levels $N_i^{LR} = n_i^{LR} N$ in period t, i.e., the migration that would take place if it were

[33]Migration in the opposite direction plays no role in our model because any income increase (following the Plague or technological progress) makes cities more attractive than the countryside via the manufacturing demand channel.

unconstrained:

$$M_t^u = N_{A,t}^\star - N_A^{LR} = N_M^{LR} - N_{M,t}^\star \quad (20)$$

There are two ways to calculate M_t^u, since migration out of agriculture (first term in (20)) must equal migration into cities (second term). M_t^u is positive if migration goes from the countryside to cities, i.e., if the number of native peasants is larger than the optimal long-run rural population, and negative if migration takes the opposite direction. Next we derive the growth of city population that occurs when migration is unconstrained, reaching the long-run equilibrium instantaneously.

$$\nu_t \equiv \frac{M_t^u}{N_{M,t}^\star} = \frac{N_M^{LR} - N_{M,t}^\star}{N_{M,t}^\star} = \frac{n_M^{LR} - n_{M,t}^\star}{n_{M,t}^\star} \quad (21)$$

As this equation shows, the growth rate of city population is equal to the growth of the urbanization rate – a fact that we will use to calibrate $\overline{\nu}$. The magnitude of M_t^u, and thus the likelihood that congestion constrains migration, is the larger the more the long-run population distribution deviates from actual values. If ν_t exceeds the upper bound for into-city migration, the constraint $\overline{\nu}$ becomes binding. The number of migrants under this constraint is given by $M_t^c = \overline{\nu} N_{M,t}^\star$, that is, urban population grows at the rate $\overline{\nu}$. Together with (19), this gives the law of motion for workplace-specific population under constrained migration.

$$\begin{aligned} N_{A,t} &= N_{A,t}^\star - \overline{\nu} N_{M,t}^\star \\ N_{M,t} &= N_{M,t}^\star + \overline{\nu} N_{M,t}^\star \end{aligned} \quad (22)$$

The agricultural workforce in period t is thus composed of rural offspring and surviving peasants from $t-1$, less the ones migrating to cities (until congestion makes these places unattractive). The city population consists of surviving manufacturing workers and urban offsprings, augmented by the migrants from the countryside.

The equilibrium values of wages, prices, and income under constrained migration are derived from the location-specific workforce given by (22). Rural wages are obtained directly from (4), while (E1) can be re-arranged to recover urban wages:

$$w_M = \frac{1-\alpha}{\alpha(1-n_A)} \left[A_A n_A^\gamma l^{1-\gamma} - \underline{c} \right] \quad (23)$$

Manufacturing products are sold at $p_M = w_M / A_M$. Workplace specific real income, fertility, and mortality are then calculated from (9), (10), and (11), respectively.

4 Calibration and Simulation Results

In this section we explain the calibration of our model and simulate it with and without the Horsemen effect. We choose parameters in order to match historically observed fertility, mortality, and urbanization rates in early modern Europe. We then simulate the impact of the plague and derive the long-run levels of p.c. income and urbanization in the centuries following the Black Death. Finally, we add to our model the alleviating effect on birth rates that the European Marriage Pattern provided.

4.1 Calibration

In order to calibrate our model, we follow the procedure outlined in section 3.5: The intersection of birth and death schedule determines per-capita income and equilibrium population size. Urbanization rates in Europe before the Black Death were about 2.5%.[34] For cities to exist in our model, we need above-subsistence real income (and consumption) $c_{\bullet,i} > \underline{c}$ in the long-run pre-plague equilibrium. For the intersection of b and d to lie to the right of $\underline{c}$, we must have death rates higher than birth rates at the subsistence level, i.e., $d_0 > b_0$ in equations (10) and (11). Kelly (2005) estimates the elasticity of death rates with respect to income, using weather shocks as exogenous variation. We use his estimate for England over the period 1541-1700, $\varphi_b = -0.55$, as a best-guess for Europe. Regarding the elasticity of birth rates with respect to real income, we use his estimate of $\varphi_b = 1.41$ for Europe.[35] Regarding the level of birth and death rates, we use 3.5% in the pre-plague equilibrium, corresponding to the cumulative birth rates reported by Anderson and Lee (2002). This, together with the elasticities and the equilibrium urbanization rate of 2.5%, implies $b_0 = 3.2\%$ and $d_0 = 3.5\%$. As discussed in the historical overview section, we estimate that death rates in European cities were approximately 50% higher than in the countryside. This implies a (conservative) value of $\triangle d_M = 1.5\%$.

Scale does not matter in our model. Solely the productivity parameters A_A and A_M, together with the land-labor ratio l determine individual income. Thus, for any equilibrium p.c. income derived from

[34] Maddison (2003) reports 0% in 1000 and 6.1% in 1500; DeVries (1984) documents 5.6% in 1500. Our 2.5% for the 14th century is at the upper end of what we expect, given that wages stagnated throughout the millenium before the plague. We deliberately make this conservative choice, leaving less urbanization to be explained by our story.

[35] This number is bigger than the estimates in, say, Crafts and Mills 2007, or in Lee and Anderson 2002. Because of the important endogeneity issues in deriving any slope coefficient, the IV-approach by Kelly is more likely to pin down approximate magnitudes than identification through VARs or through Kalman filtering techniques.

the intersection of b and d, we can recover the corresponding population N.[36] We choose parameters such that initial population is unity ($N_0 = 1$). This involves $A_A = 0.460$, $A_M = 0.535$, and $L = 8$, where land is fixed such that its hypothetical rental rate is 5%.[37] Our calibration also implies the desired urbanization rate $n_{M,0} = 2.5\%$ and a price of manufacturing goods that is double the price of agriculture products, i.e., $p_M = 2$.[38]

For the baseline model, we calibrate the parameters γ to fit the average historical labor share in agriculture, using data for England over the period 1700-1850, which implies $\gamma = 0.6$. This corresponds to the land income share of 40% suggested by Crafts (1985), and is almost identical with the average in Stokey's (2001) two calibrations. We normalize the minimum food consumption $\underline{c}$ to unity. For low income levels, all expenditure goes to agriculture. With higher productivity, manufacturing expenditure share and urbanization grow in tandem. To derive this relationship, we pair income data from Maddison (2007) with urbanization rates from DeVries (1984). In the model, the responsiveness of urbanization to income is governed by the parameter α. The data for Europe show that the urbanization rate rose from 5 to 10 percent between 1500 and 1800, while p.c. income grew by 50%. The corresponding model parameter that approximately reflects this relationship is $\alpha = 0.6$. Figure 2 is derived using this value.

In the centuries before 1700, labor productivity grew at an average rate of roughly 0.05-0.15% per year (Galor 2005). We use an exogenous growth rate of agricultural and manufacturing TFP, A_A and A_M, of $\tau = 0.1\%$ in our simulations with technological progress. In order to quantify the upper bound for city growth, reflecting congestion in our model, we use DeVries' (1984) urbanization data for 1500-1800. The largest observed growth rate of urbanization in Europe over this period is $\overline{\nu} = 0.38\%$ between 1550 and 1600.

After the Black Death, the Horsemen effect comes into play. Means for warfare and trade grow with p.c. income, and the increased mobility leads to an ongoing dispersion of germs. According to equation (12), the Horsemen are at work when the urbanization rate n_M is larger than the threshold level n_M^h. We choose $n_M^h = 2.5\%$, corresponding to the pre-plague urbanization rate. Therefore, the Horsemen effect begins to work its wonders immediately after the Black Death, though not yet with full force. The

[36] For example, rural population is implicitly given by (4), and is the larger (for a given wage w_A) the more land is available. We calculate the long-run equilibrium by solving the system (E1)-(E4) and iterating over population until $b = d$. This procedure gives the long-run stable population as a function of fertility and mortality parameters, productivity, and land area.

[37] Recall that we assume no property rights to land. The size of L is therefore not important for our results – it could also be normalized to one and included in A_A. We leave L in the equations for the sake of arguments involving the land-labor ratio.

[38] Other values of this parameter, resulting from different A_M relative to A_A, do not change our results.

effect is linearly increasing in the urbanization rate until reaching its maximum. In order to calibrate the maximum impact of the Horsemen channel on mortality, we use data on war-related deaths and epidemics from Levy (1983). His data show that, in a typical year, more than one European war was in progress – there were 443 war years during the period 1500-1800, normally involving three or more powers. Since it is the movement of armies, and not just military engagements that caused death, we count the territories of combatant nations as affected if they were the locus of troop movements. The weighted average produces a war-related effect of an additional 0.75% deaths per annum. To this we add a guestimate of 0.25%. This is motivated by the spread of disease through additional trade, also facilitated and encouraged by the wealth of cities – few of the goods on the plague ship in Marseille harbor in 1720 would have carried goods for the consumption of peasants. Overall, our best guess for the maximum size of the Horsemen effect is thus $h_{\text{max}} = 1\%$. This value is reached in the first half of the 17th century. War frequency was almost double what it had been a century before, and the devastation wrought by the Thirties Years War was the most severe in any armed conflict until the 20th century (Levy 1982). Urbanization rates reached 8% at this time (De Vries, 1984). The implied slope parameter of the Horsemen function is therefore $\delta = h_{\text{max}}/(0.08 - n^h_M) = 1.82$. Table 1 summarizes the calibration parameters.

4.2 Plague and Equilibrium without Horsemen Effect

The left panel of figure 5 shows the pre-plague long-run equilibrium corresponding to our baseline calibration. The fertility and mortality schedule intersect at 3.5%, while 2.5% of the population live in cities. The economy is trapped in Malthusian stagnation in point E. One-time increases in productivity lead to higher income and therefore population growth. As a consequence, the land-labor ratio falls and drives per-capita income back to its long-run equilibrium value.

The effect of a one-time technological improvement on p.c. income is very similar to the impact of the plague in our model: While the former raises TFP, the latter increases the land-labor ratio; both result in higher wages, according to (4). The right panel of figure 4 shows the effect of the Black Death when all model parameters are unchanged. Before the plague, population and urbanization rate stagnate in the absence of technological progress. The Black Death kills one third of the population, similar to the devastation documented in 14^{th} century Europe. As an immediate consequence, wages, p.c. consumption, and urbanization rates rise. In the aftermath of the plague, population grows because the economy is now situated to the right of the long-run equilibrium in point E, such that fertility outweighs mortality. The

Table 1: Baseline Calibration

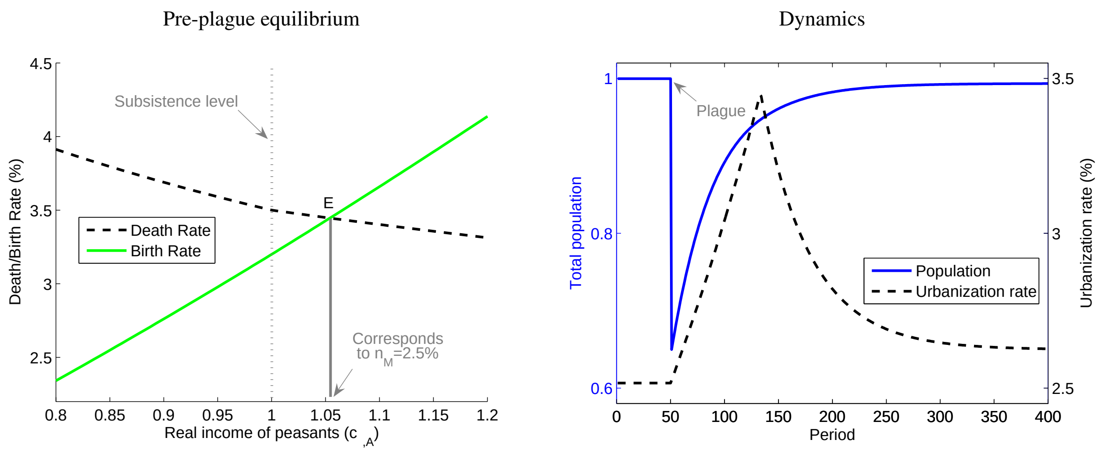
Symbol	Interpretation	Value
Parameters		
α	Food expenditure share (as income $\rightarrow \infty$)	0.6
γ	Labor share in agriculture	0.6
$\underline{c}$	Subsistence food consumption	1
L	Land	8
A_A	Agriculture technology parameter	0.460
A_M	Manufacturing technology parameter	0.535
τ	Rate of technological progress	0.1%
b_0	Birth rate at $c = \underline{c}$	0.032
d_0	Death rate at $c = \underline{c}$	0.035
φ_b	Elasticity of birth rates wrt. income	1.41
φ_d	Elasticity of death rates wrt. income	-0.55
$\triangle d_M$	City excess mortality	0.015
h_{max}	Maximum Horsemen effect	0.01
n_M^h	Threshold for Horsemen effect	0.025
δ	Slope parameter for Horsemen effect	1.82
$\overline{\nu}$	Upper bound on city growth due to congestion	0.0038
Resulting values in long-run equilibrium before Black Death		
N_0	Population	1.00
$n_{A,0}$	Urbanization rate	2.5%
$b_0 = d_0$	Economy-average birth and death rate	3.5%
$p_{M,0}$	Relative price of manufacturing goods	2.00

falling land-labor ratio then drives the economy back to E, where all variables are back at their pre-plague values. Things look different in the presence of the Horsemen effect.

4.3 Long-run Equilibrium with Horsemen Effect

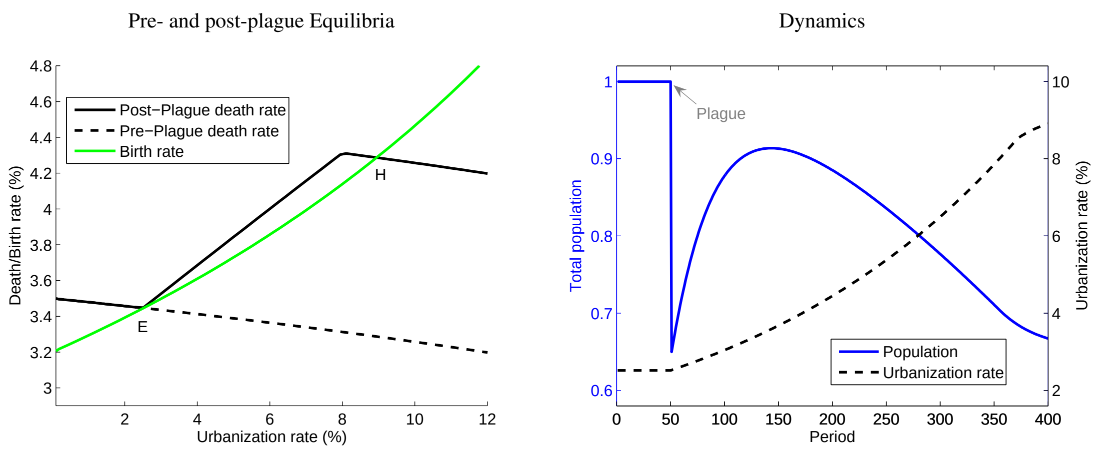
Following the plague in Europe, higher p.c. income increases trade, but also means for warfare. The enhanced mobility constantly spreads epidemics and therefore raises country-wide mortality. The size of this Horsemen effect grows with urbanization, as given in (12). The left panel of figure 5 shows that the equilibrium with the Horsemen effect (point H) involves higher birth and death rates (about 4%), more p.c. consumption, and higher urbanization. Point H is a unique and stable equilibrium where all variables are in a stalemate in the absence of technological progress. The economy converges to this equilibrium in the aftermath of the Black Death (right panel of figure 5). Surviving individuals and their descendants

Figure 5: Long-run impact of the plague, ceteris paribus



are therefore better off then their ancestors before the plague. Famously, it took until the 19th century for wages to recover the level last seen at the post-plague peak (Clark 2005).

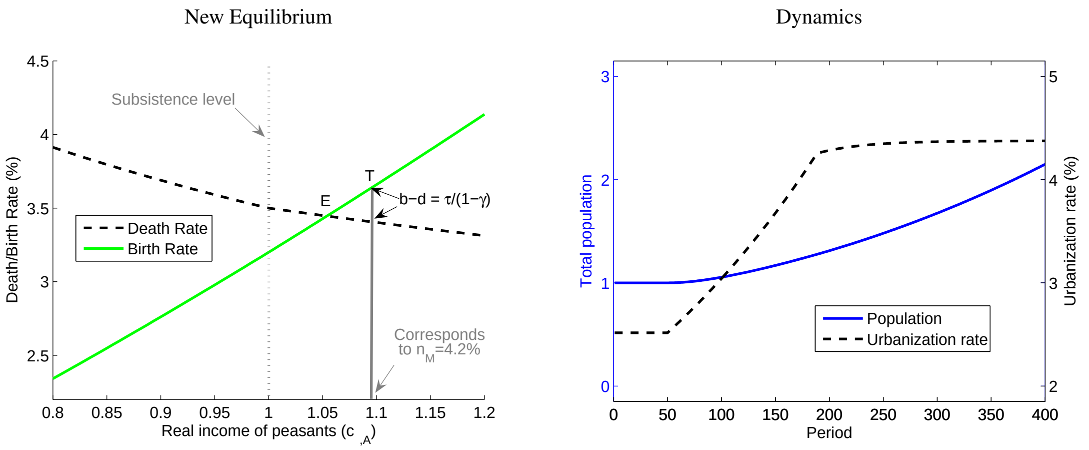
Figure 6: Impact of the plague with Horsemen effect



4.4 Technological Progress and Model Fit

Technological progress in premodern times alone is not enough to escape from the Malthusian trap. While the growing population completely eats up the fruits of one-time inventions, *ongoing* progress implies higher, but still stagnating, long-run p.c. income. Technology constantly improves p.c. income in this case, and population growth responds, offsetting any gains. This corresponds to a long-run equilibrium in point T in figure 7, where the birth rate exceeds the death rate and technological progress is exactly offset by the falling land-labor ratio.[39] The right panel of figure 7 illustrates the orders of magnitude involved. The rate of technological change before the Industrial Revolution was low, approximately 0.1% (Galor 2005). For purposes of illustration, progress is assumed to set in after 50 periods of stagnating technology. As the figure shows, this raises the urbanization rate by less than 2%. Note that this is an extreme scenario where the economy jumps from complete stagnation to continuous inventions. The corresponding increase of urbanization is thus an upper bound for the impact of technology on individual income. Therefore, technological progress cannot be a candidate to explain the rise of Europe in the early modern period.

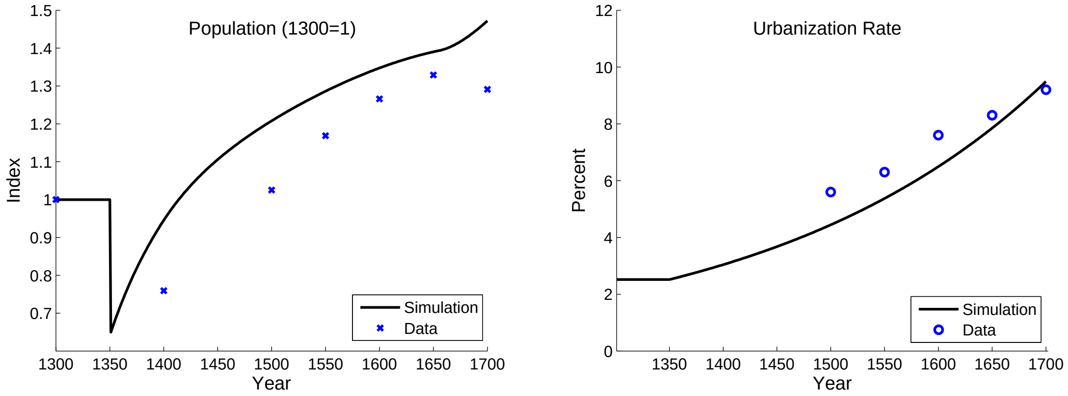
Figure 7: Effect of ongoing technological progress



Next, we investigate the fit of our model, including the Horsemen effect and the observed rate of technological progress. While the former alone can account for almost all the observed increase in European urbanization (see figure 4.3), the latter helps to explain the growing population. Figure 8 shows the corresponding simulation results together with the data. Our model performs well in reproducing both population growth and urbanization.

[39] Equation (3) with constant p.c. income (and thus constant agricultural labor share) implies that the population grows at the rate $\tau/(1-\gamma)$ in the long-run equilibrium.

Figure 8: Europe: Simulation Results vs. Data



Data sources: Population from Kremer (1993). Urbanization rates from DeVries (1984).

5 Extensions

5.1 The European Marriage Pattern

Europe curtailed fertility in an important way. In a normal Malthusian setting, fertility should have eroded all gains in living standards quickly. Lower birth rates for a given income have a similar effect as higher background mortality: both alleviate population pressure on the land-labor ratio. Average realized fertility rates in early modern Europe were approximately equal to those in China, despite markedly higher living standards (Clark 2007). At Chinese levels of per capita income, European fertility would be much lower because of fertility restriction. In figure 9, 17$^{\text{th}}$ century China would be close to point E, implying that English fertility with the EMP would have been 0.75% below the corresponding value for China. We do not know when the European marriage pattern emerged. Some authors have argued that the plague was critical (Van Zanden and deMoor 2007). If so, then some of the increase in European incomes after 1350 has to be attributed to the plague's impact on fertility.

Births in England were probably unusually responsive to economic conditions (Lee 1981, Wrigley and Schofield 1981). England was also ahead of the European average in terms of its income and city growth: p.c. income grew by 75% between 1500 and 1700 (50% in Europe), and urbanization rates more than quadrupled from 3% to over 13% (and 20% in 1800) (Maddison 2007, DeVries 1984). We now turn to investigating the contribution of the EMP to income and city growth in our model. We suppose that birth rates are not responding to income before the Black Death, so that $\varphi_b^{\text{before}} = 0$. After the plague the EMP emerges, shifting the birth schedule downwards by 1% (corresponding to $0.3 \times 3.5\%$) and making it responsive to income such that $\varphi_b^{after} = 1.4$, as in the baseline calibration.[40]

Figure 9: England: Pre-and post-plague equilibria with EMP and Horsemen

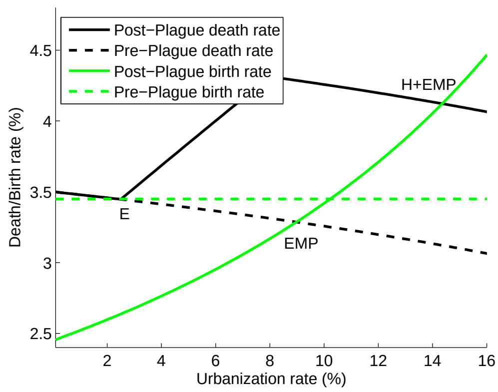


Figure 9 shows the EMP simulation results. In the absence of the Horsemen effect, the shift and turn of the birth schedule move the economy from the pre-plague equilibrium E to the EMP equilibrium. Part of the downward-shift is compensated by the positive response of birth rates to growing income after the plague. The Horsemen effect creates an additional rise in urbanization (equilibrium H+EMP). Instead of an urbanization rate of 2.5%, we predict a rate of 9% based on the rotated fertility schedule. The rise from 9 to 15% is due to the Horsemen effect. Both effects appear to be equally important, and together they match the observed increase in England's urbanization rate. This underlines the importance of the Horsemen effect for increasing living standards in early modern Europe – in continental Europe, where the EMP was weaker, the Horsemen contribution was likely even more significant.

The fact that the outward shift of the death schedule did not lead to a much sharper decline in population is also a result of the European Marriage Pattern. Had it not been for the sharp response of fertility due to higher living standards, the reduction in population pressure after 1350 would have been even stronger.

6 Concluding Remarks

Standard accounts of the transition from "Malthus to Solow" emphasize the near-stability of incomes before 1800 (Hansen and Prescott 2002). While sensible compared to modern rates of growth, it is

[40]The corresponding parameter values are $b_0^{before} = 0.0345$ and $b_0^{after} = 0.0245$. With all other parameters unchanged, this implies an equilibrium urbanization rate of 2.5% before the plague.

incorrect by historical standards. The Dutch Republic and England in 1700 had per capita incomes that were extraordinary compared to all ages that came before, and contemporaries saw them as such (DeVries 1976). This precocious rise in incomes long before industrialization may have been an important factor contributing to the ultimate economic, military and political ascendancy of Western Europe from the 19th century onwards.

In this paper, we argue that a simple two-sector extension of the standard Malthusian model can shed new light on the puzzling rise of European per capita incomes. Many interpretations of the ”rise of Europe” emphasize high rates of innovation, compared to Asia (Mokyr 1990), or fertility restriction (Wrigley 1988). We argue that, in a Malthusian setting, better technology cannot explain the ”Great Divergence”, and we also show that fertility restriction alone is insufficient. Instead, we build a model in which per capita living standards can rise markedly without technological change or fertility decline. Many unified growth models generate the early transition from stagnation to sustained growth by means of a delayed response of fertility to wages. This allows per capita incomes to rise slowly but steadily in tandem with population. We argue that this cannot be realistic in most settings, because fertility responds ”too rapidly” to permit anything other than a short-lived increase in living standards. In a micro-founded model, we show that only very large, negative shocks can be followed by a marked delay between rising incomes and return to earlier population levels. We argue that the Black Death hitting Europe in the 14th century was precisely such a shock, lifting wages and per capita incomes for several generations. Richer individuals began to demand more urban goods, and because early modern European cities were ”graveyards” (Bairoch 1991), incomes could permanently exceed conventionally-measured subsistence levels. This is particularly true because city growth acted as a catalyst for European belligerence and the spread of disease through trade – a link we call the ”Horsemen of Growth”.

One implication of our results is that urbanization is not simply an indicator of higher levels of development, as assumed in some recent work (Acemoglu, Johnson and Robinson 2005). City growth also provided a mechanism that made higher per capita incomes sustainable in a Malthusian setting. Our paper has emphasized the contrast between early modern Europe and the rest of the world. Future research should examine if the model developed in this paper can also explain the growing differences between Northwestern and Southern Europe. Did differences in political structure allow the self-sustaining rises in incomes to persist for longer in the North? Did greater preferences for urban goods, or differences in sanitary practices drive up mortality rates differently? While many histories of the ”rise of the West” have been written from a technological perspective, we argue that differences in mortality (and also, fertility) were far more potent determinants of pre-industrial living standards.

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