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

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Abstract

How did Europe overtake China? We construct a simple Malthusian model with two sectors, and use it to explain how European per capita incomes and urbanization rates could surge ahead of Chinese ones. That living standards could exceed subsistence levels at all in a Malthusian setting should be surprising. Rising fertility and falling mortality ought to have reversed any gains. We show that productivity growth in Europe can only explain a small fraction of rising living standards. Population dynamics – changes of the birth and death schedules – were far more important drivers of the long-run Malthusian equilibrium. The Black Death raised wages substantially, creating important knock-on effects. Because of Engel's Law, demand for urban products increased, raising urban wages and attracting migrants from rural areas. European cities were unhealthy, especially compared to Far Eastern ones. Urbanization pushed up aggregate 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 the sharp rise in European urbanization as well as permanently higher per capita incomes. We complement our calibration exercise with a detailed analysis of intra-European growth in the early modern period. Using a panel of European states in the period 1300-1700, we show that war frequency can explain a good share of the divergent fortunes within Europe.

JEL: E27, N13, N33, O14, O41

Keywords: Malthus to Solow, Long-run Growth, Great Divergence, Epidemics, Demographic Regime

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1 Introduction

In 1400, Europe's potential for growth must have seemed limited. The continent was politically fragmented, torn by 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 variables that predict growth in modern-day data would suggest that Europe's starting position was favorable.[1]

By 1700 however, and long before it industrialized, Europe had pulled ahead decisively in terms of per capita income – an early divergence preceded the "Great Divergence" that emerged with the Industrial Revolution (Broadberry and Gupta 2006, Diamond 1997).[2] By this date, England's per capita income was more than twice that of China or India, European silver wages were often markedly higher, and Western European urbanization rates were more than double those in China (Broadberry and Gupta 2006, Maddison 2001). 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). There is growing evidence that a country's development in the more distant past is a powerful predictor of its current income position (Comin, Easterly and Gong 2006). Voigtländer and Voth (2006) develop a model in which greater industrialization probabilities are the direct consequence of higher starting incomes.[3] If we are to understand why Europe achieved the transition from "Malthus to Solow" before other regions of the world, understanding the initial divergence of incomes is crucial.

In this paper, we identify the early divergence a new puzzle, and argue that its solution can help explain why the most advanced parts of Europe in terms of income 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 (2005) 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 per woman, a human population growing unconstrained would quadruple after 100 years.[4] In a Malthusian regime, past generations should have always "spent the great gifts of science as rapidly as it got them in a mere insensate multiplication of the common life" (in the words HG Wells).[5]

[1] For a recent overview, see Barro (1997), Bosworth and Collins (2003), and Sala-i-Martin, Doppelhofer and Miller (2004).

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

[3] Allen (2006) has argued that high wages of artisans in Britain before 1800 were responsible for skill-replacing technological change during the Industrial Revolution.

[4] Assuming a generation length of 25 years.

[5] 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.

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Nonetheless, living standards in many European countries increased markedly during the early modern period. Maddison (2007) estimates that Western European per capita incomes grew by more than 30%, and aggregate incomes still more between 1500 and 1700.[6] His data are imperfect, but knowledgeable contemporary 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."[7] 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 key. 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 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 reversed quickly by population growth. Wages remained high for more than one or two generations, and were partly spent on manufactured goods. Most of this production took place in cities. Because early modern European cities were death-traps, with mortality far exceeding fertility rates, they would have disappeared without 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, implying lower population pressure. Welfare may not have increased, but wages reached a permanently higher level.

This 'benign' direct effect of urbanization 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, the Horsemen of the Apocalypse jointly produced higher incomes. In contrast to numerous papers identifying a negative (short-run) effect of wars, civil wars, disease, and epidemics on growth in economies today,[8] we argue that these factors effectively acted as 'Horsemen of Growth.'

The great 14th century plague also affected China, as well as other parts of the world (McNeill 1977). Why did it not have the same effects there? 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. We examine these in more detail below. Also, political fragmentation in Europe ensured continuous warfare once the growing wealth of cities could be tapped by belligerent princes. This was the case after 1400. China, on the other hand, was politically unified, except for brief spells of turmoil. There was no link between city growth and the frequency of armed conflict. Hence, a very similar shock

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

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

[8] Murdoch and Sandler (2002), Hoeffler and Reynal-Querol (2003), Hess (2003).

did not lead to permanently higher death rates; per capita incomes could not rise.

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 most of the "First Divergence".

We are not the first to argue that higher death rates can have beneficial economic effects. Clark (2007) highlighted the benign effect of higher death rates on living standards. He also concluded that Englishmen in 1800 lived no better than ancestors on African savannah.[9] 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 foster 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 that the states worst-hit in 1918 grew markedly faster subsequently. Compared to these papers, we make three contributions. First, we use the Malthusian model to explain rising wages, not stagnation. Second, we are the first to demonstrate how specific European characteristics – political and geographical – interacted with a large mortality shock to drive up incomes over the long run. Also, we calibrate our model to show that it can account for a large part of the "First Divergence" in the early modern period. Finally, we use a panel dataset on urbanization, incomes, and wars in Europe to explain divergent fortunes within Europe itself.

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 evolves 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.[10] Cervellati and Sunde (2007) argue that mortality *decline* from the 19th century onwards was an important element in the transition to self-sustaining growth, by reducing fertility and increasing human capital formation. 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 outcomes. In contrast, the majority of existing unified growth papers implicitly use 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 "First Divergence". We also compare the effect of the European Mortality Pattern to the consequences of fertility restriction. In section 5, we provide empirical evidence for our hypothesis. We show that increasingly frequent military conflict can explain much of the growing income differences within Europe. The final section summarizes our

[9] This point does not stand up to scrutiny. On all traditional measures English wages by 1800 were unusually high, compared to both Britain's own history and those in other countries (Allen 2001).

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

findings.

2 Historical context and background

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

The First Divergence

That Europe pulled ahead of the rest of the world in terms of per capita living standards is now widely accepted. 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 by 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%.[11] Finally, urbanization rates have been widely used as an indicator of economic development (Acemoglu, Johnson and Robinson [subsequently AJR] 2005). This indicator shows that Europe overtook China at some point between 1300 and 1500, and then continued to extend its lead (figure 1).

[Insert Figure 1 here]

The beneficial effect of the Black Death on real wages is well-documented. The wage figures for England by Phelps-Brown and Hopkins (1981) and by Clark (2005) suggest that wages broadly doubled after 1350. When these gains were reversed, and how much, is less clear. The older Phelps-Brown and Hopkins series suggests a strong decline. 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.[12] In this sense, the existing wage series offer qualified support to the optimistic GDP figures provided by Maddison (2007).

Not all of Europe did equally well. Allen (2001) found that 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. Described as the 'Rise of Atlantic Europe' by AJR (2005), the North-West overtook Southern Europe in terms of urbanization rates and output. Yet for every single European country with the exception of Italy, Maddison estimates that per capita

[11] 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.

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

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 assumes that subsistence is equivalent to approximately $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. And yet, population growth did not reverse these real wage gains. This is the puzzle that we seek to explain. We do so in a way that allows us to capture the main reasons for intra-European divergence.

The Plague

The plague arrived in Europe from the Crimea in December 1347. Tartar troops besieging the Genoese trading outpost of Caffa suffered from the disease. In an early example of biological warfare, the Tartars used trebuchets to throw disease-infected corpses over the city wall. Soon, the defenders caught the disease. It spread with the fleeing Genoese along the main trading routes, first to Constantinople, then to Sicily and Marseille, then mainland Italy, and finally the rest of Europe. By December 1350, it had reached 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 from person to person, via the tiny droplets transmitted by the coughing of the infected. Transmission and mortality rates were particularly high for the pneumonic 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 Boccaccio's 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.

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% (Ziegler 1969).

City Mortality

European cities were deadly places. In 1841, when large inflows of labor had 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. While available figures are not as precise, early modern cities were probably just as 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.[13] 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

[13] 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.

differences estimates that in early modern Europe, life expectancy was approximately 50 percent higher in the countryside than in cities (Woods 2003).

No such differential probably existed in China. Some mortality estimates have been derived from the family trees of clans (Tsui-Jung 1990), using data from the 15th to the 19th century. Chinese 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).

In Japan, where some data for 18th 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 Far Eastern 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 China and Japan. Principal reasons probably include the transfer of "night soil" (i.e., human excrement) out of the city and onto the surrounding fields for fertilization, relatively high standards of personal hygiene, and a diet rich in vegetarian food. Since the proximity of animals is a major cause of disease, all these factors probably combined to reduce the urban mortality burden in the Far East.

Differences in the way cities were built also added to relatively high urban mortality in Europe. In the words 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. Since the country's unification under the Qin Dynasty in the third century BC, the defensive function of city walls declined. With relative ease, houses and markets spread outside the city walls.[14] 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.[15] This is likely to have reduced overcrowding and kept mortality rates low.

In many European countries, regulations further ensured that manufacturing activities and market exchange was largely a monopoly of the cities.[16] In China, periodic markets in the countryside served the same function. This reduced relative urbanization rates (Rozman 1973). Finally, European cities offered a unique benefit not found in other parts of the world – a chance to escape servitude. As a general rule, 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, as one leading historian put it, "Chinese air made nobody free".[17]

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

[15] 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).

[16] 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).

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

Wars, Trade and Disease

The available data on deaths caused by military operations in the early modern period is sketchy.[18] 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.[19]

The "Great Plague" of 1347-48 was not the last to strike Europe. Less well-known is the fact that the Black Death of Middle Ages was followed by a wave of deadly outbreaks that only peaked in the early modern period. As shown in figure 2, the number of plague epidemics more than quadrupled between the 14th and the 17th century – from about 150 outbreaks per decade after the "Great Plague" to a peak of 705 in 1630-40. The frequency of outbreaks declined only in the late 17th century and dropped below 50 outbreaks per decade in the 18th century, which occurred mostly in Eastern Europe. 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 (Diamond 1999). 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 may have killed up to one 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 during the Napoleonic wars, typhus, smallpox and other diseases spread by armies marauding across Europe proved far deadlier than guns and swords.

[Insert Figure 2 here]

For the early and mid-nineteenth century, we have data that allows us to gauge the orders of magnitude involved. In the Swedish-Russian war of 1808-09, mortality rates in all of Sweden doubled, almost exclusively through disease. In isolated islands, the presence of Russian troops – without any fighting – 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% (Landers 2003). Both background mortality and the impact of war were probably lower at this late stage than during the early modern period. Warfare was less likely to spread new germs, since in areas touched by troop movements were now integrated by extensive road, canal, and railway networks. The figures for the Thirty Years War and for 16th century France however also imply that mortality rates rose 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 was particularly expensive – money formed the sinews of power (Brewer 1991,

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

[19] 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.

Landers 2003, Tilly 1990). To make war, princes needed access to liquid wealth. Silver from the Indies allowed Philip II of Spain to fight 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 borrowing. With the growth of urbanization in early modern Europe, the financial means for fighting more, fighting longer, and in more a 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 as many geographical barriers as in Europe. The Yangtze River's climate is markedly different to that of the Yellow River, and early settlers migrating from the North experienced high mortality rates in the South. Yet differences within Europe, from the North of Finland to the shores of Sicily and Ionia, were substantially greater. Also, average distances between population centres were large, and travellers had to traverse more mountainous terrain. The history of epidemics in China suggests that by 1000 AD, disease pools had become largely integrated (McNeill 1976). 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.[20]

Compared to warfare, trade in early modern Europe was a less effective, but more frequent cause of disease. 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 pressure by merchants. 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 additional knock-on effects. These combined to raise mortality rates yet further. Finally, 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). All these factors in combination ensured that, after the Black Death, European death rates increased, and stayed high, in a way that is unlikely to have occurred in China.

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.[21] For simplicity, we assume

[20] 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.

[21] 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

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 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 (the "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 thus self-equilibrating.

An epidemic like the plague has an economic effect akin to technological progress: it causes land-labor ratios to rise dramatically. This leaves the remaining population with greater per-capita income, 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, in our model, the "Horsemen of Death" start to ride high after the plague: 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 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.[22] 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 individuals buy manufactured goods, they need to consume a minimum quantity of food, $\underline{c}$. We refer to $\underline{c}$ as the subsistence level. Below it, individuals suffer from hunger, but do not necessarily die

demand translated into growth for non-urban manufactured goods.

[22] 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.

– mortality increases continuously as c_A falls below $\underline{c}$. While consumption is below $\underline{c}$, any increase in income is spent on food. 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 $\beta > 0$, as 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 $\underline{c}$, the starving peasants are unwilling to trade food for manufactured goods at any price. Thus, the demand for urban labor is zero and there are no cities. 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 spend on manufacturing products. These are produced in cities, which grow as a result. If income increases further, the share of spending on manufactured goods grows in line with Engel's law, and cities expand. The relationship between income and urbanization is governed by the parameter α. A higher α implies more food expenditures and thus less urbanization at any given income level.

3.2 Production

All agricultural goods are homogenous, and are produced under constant returns and perfect competition. The same is true of manufactured goods. 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 output per rural worker:

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

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

Migration decisions reflect utility maximization of individuals. We suppose that they move (if at all) at the beginning of every period t, such that migrating individuals arrive at their workplace before production starts at time t. In early modern Europe, death rates in cities were substantially higher than in the countryside ($d_M > d_A$). High urban wages compensated for the elevated mortality risk. 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). For the following steps it is convenient to define $\beta \equiv (1/p_M)^{1-\alpha} \alpha^{\alpha} (1-\alpha)^{1-\alpha}$.[23] The optimization problem is then:

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

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.[24] 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, thus 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 construct urban infrastructure – Rome was not built in a day. We discuss this case in detail in section 3.5.

Figure 3 illustrates the basic income-demand-urbanization mechanism of our model. If the rural wage (horizontal axis) is below subsistence (normalized to $\underline{c} = 1$), the starving population does not consume any manufacturing goods. Cities do not exist (zero urbanization, left axis), and there are no workers employed in manufacturing (zero urban wages, right axis). Cities emerge once peasants' productivity is high enough for consumption to rise above subsistence. At this stage, urban consumption also becomes important, driven by city workers who produce manufacturing output. As productivity increases further, urbanization and consumption (both urban and rural) grow in tandem.

[23] This definition is made without loss of generality. 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. Our choice of β ensures that the relative price of urban goods does not directly influence the location decision. This simplifies the subsequent analysis.

[24] 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.

[Insert Figure 3 here]

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 $i = \{A, M\}$.[25] 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.

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). Higher p.c. income after the plague simultaneously spur trade and wars. Liquid wealth in cities funds wars and attracts traders. Military casualties mount. Armies as well as merchants continuously spread pathogenic germs to 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 the 'Horsemen effect', we calculate h as:

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

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.[26] The role of the plague in our model is to introduce germs and to push p.c. income to levels where $n_M > n_M^h$. To kill, germs need to be spread. This is why the plague can produce a long-term effect. It combines a new disease with higher incomes, which translates into greater mobility (through both warfare and more trade). Only if higher mobility spreads epidemics, background mortality increases and alleviates the population pressure.

[25] We calibrate our model such that the initial relative price is $p_{M,0} = 1$. Thus, $w_{i,0} = c_{A,i,0} + c_{M,i,0}$. Real income in period t is therefore given in terms of the prices in period 0. A simplified approach would have birth and death rate as functions of nominal income $w_{it} = c_{A,it} + p_{M,t}\, c_{M,it}$, 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.

[26] 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.

Before we analyze equilibria, we derive population growth from economy-wide fertility and mortality rates. Average fertility evolves according to (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 ride.

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

Increasing real income has an ambiguous effect on mortality: Larger $c_{\bullet,i}$ translates into lower 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 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 rates respond to income. Figure 4 visualizes the schedules. Peasants' real income $c_{\bullet,A}$ is shown on the horizontal axis.[27] Relatively low death rates give rise 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.

[Insert Figure 4 here]

In the absence of continuous technological progress, there are two ways for achieving a permanent rise in per-capita income.[28] First, a permanent decline in birth rates. The European Marriage Pattern had

[27] Provided that there is demand for manufacturing products, urban income is proportional to its rural counterpart, as shown in Figure 3.

[28] 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

such an effect, with delayed marriage for some women and permanent celibacy for others. Alternatively, a permanent rise in mortality can boost incomes. This is the channel we focus on. Higher death rates (d_H) imply lower population in equilibrium and therefore higher income, as represented by point B in Figure 4.[29] While total population is constant in point B, there must be perpetual migration from the countryside to cities in order to compensate for city excess mortality.

Points A and B in Figure 4 are long-run equilibria with endogenous population size. For a given technology A_A, productivity is fixed in the long-run. At any one point in time, output per capita is driven by the endogenously determined land-labor ratio. During the transition to long-run equilibrium, population dynamics influence the land-labor ratio and thus output per worker. In the following, we analyze these dynamics. 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 $\widehat{w}$, assuming that all individuals work in agriculture. Equation (3) then gives the corresponding per-capita income:

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

If $\widehat{w} \leq \underline{c}$, all individuals work in agriculture ($N_A = N$) and spend their entire income on food. Since there is no demand for manufacturing goods, the manufacturing price is zero. This implies zero urban wages and zero population. Economy-wide fertility and mortality are thus equal to the rural levels given by equations (10) and (11).[30] 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 4) 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 high enough for consumption levels to rise above subsistence. Following (2), well-nourished individuals spend part of their income on manufacturing goods. To produce them, 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 enough

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.

[29] 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 ($\triangle d_M > 0$).

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

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:

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

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:

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

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

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 4). 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 5 shows the workplace-specific death rates as a function of real income.[31] 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.[32] Birth rates, on the other hand, are similar in both workplaces.[33] With stagnant total population and no

[31] As in Figure 3, 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.

[32] 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 $\triangle d_M$.

[33] 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%.

migration, N_M would therefore decline continuously. This implication of our model is in line with the widely-established historical finding that early modern European cities would have disappeared without a constant inflow of population.

[Insert Figure 5 here]

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 houses and enlarging cities was one of the costliest undertakings in the early modern economy. Too many migrants caused over-crowding, making further migration to the cities unattractive. In the interest of simplicity, we capture congestion effects with an upper limit to the growth rate of cities, $\overline{\nu}$.[34] When shocks are large, and wage differentials are substantial, this constraint becomes binding. It then takes time until 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 unconstrained:

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

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 instantly.[35]

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

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 migration to the urban centers, the constraint $\overline{\nu}$ becomes binding. The number of migrants under this

[34] 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.

[35] More precisely, this is the growth rate of city population due to migration only. We implicitly assume that urban offsprings do not contribute to congestion because they live with their parents, at least in the short run. In this specification, the growth rate of ν is equal to the growth of the urbanization rate – a fact that we will use to calibrate $\overline{\nu}$.

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 with constrained migration:

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

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 offspring, augmented by 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 follow from (4), while (E1) can be re-arranged to recover urban wages:

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

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 calibrate our model and simulate it with and without the additional mortality that comes from urbanization, trade, and war. 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 approximately 3%.[36] For cities to exist in our model, real incomes have to be above subsistence, i.e., $c_{\bullet,i} > \underline{c}$ 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, that is, $d_0 > b_0$ 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.[37] Regarding the level of birth and death

[36] Maddison (2001) reports 0% in 1000 and 6.1% in 1500; DeVries (1984) documents 5.6% in 1500. Our 3% 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.

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

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 3.0%, implies $b_0 = 3.11\%$ and $d_0 = 3.53\%$. 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 $A_{A,t}$ and $A_{M,t}$, together with the land-labor ratio l_t, determine individual income. Thus, for any equilibrium p.c. income derived from the intersection of b and d, we can calculate the corresponding population N.[38] We choose parameters such that initial population is unity $(N_0 = 1)$. This involves the initial productivity parameters $A_{A,0} = 0.462$, $A_{M,0} = 1.080$, and $L = 8$, where land is fixed such that its hypothetical rental rate is 5%.[39] Our calibration also implies the desired urbanization rate $n_{M,0} = 3.0\%$ and a price of manufacturing goods that is equal to the price of agricultural products, i.e., $p_{M,0} = 1$.[40]

For the baseline model, we use the labor income share in agriculture $\gamma = 0.6$. This is similar to the value implied by Crafts (1985), and it is almost identical with the average in Stokey's (2001) 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 parallel. 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. Figure 6 plots urbanization rates in England in the early modern period against per capita income. The latter is normalized to unity for the pre-plague period. Note that at this point $n_M = 3\%$ in the model, as calibrated above. Rising incomes went hand-in-hand with higher urbanization rates. Our calibration, derived with a model parameter of $\alpha = 0.55$, traces out a similar increase. The simulation consistently shows slightly higher urbanization rates for a given income level. This is deliberate – urbanization is an imperfect proxy for the production of non-agricultural goods, as many authors have emphasized (Wrigley 1985).

[Insert Figure 6 here]

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 greater 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

[38] 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.

[39] 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.

[40] Other values of this variable, resulting from different $A_{M,0}$ relative to $A_{A,0}$, do not change our results.

$n_M^h = 3.5\%$, which is above the pre-plague urbanization rate. The 'Horsemen effect' begins to play a role only if city wealth becomes large enough to support the cost of warfare. Below n_M^h, city income is too low to be taxed or expropriated, serving merely to provide elementary nutrition and basic manufacturing goods.[41] Once the threshold is passed, the 'Horsemen effect' increases linearly in the urbanization rate until it reaches its maximum.[42] 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. Combined with demographic data in Maddison (2007), we obtain the percentage of European population affected by war between 1500 and 1700.[43] Figure 7 shows that this measure grows from about 12% in 1500 to roughly 50% around 1700, and decreases in the 18th century.[44] The population share affected by wars mirrors the trend in the number of plague outbreaks shown in figure 2, as it should if wars were one of the main factors spreading disease in early modern Europe. In times of war, death rates nationwide could rise by a factor of 1.5 to 2 (see the discussion in section 2). Given equilibrium death rates of over 3%, this implies an additional 1.5-3 percent under warfare. With more than one third of the European population affected by warfare throughout the 17th century, we derive a war-related 'Horsemen effect' of 0.5-1 percent, and use the mid-point of this interval, 0.75 in the calibration. To this we add a guestimate of 0.25%. This is motivated by the spread of disease through additional trade, which was also facilitated and encouraged by the wealth of cities. Overall, our best guess for the maximum size of the 'Horsemen effect' is therefore $h_{\text{max}} = 1\%$. This value is reached in the first half of the 17th century. The Thirty Years War was particularly savage, and saw troop movement from many countries, over a very wide area, and for an extended period (Levy 1983). Urbanization rates reached 8% in the 17th century (DeVries, 1984). The implied slope parameter of the Horsemen function is therefore $\delta = h_{\text{max}}/(0.08 - n_M^h) = 0.222$. Table 1 summarizes the calibrated parameters.

[Insert Figure 7 here]

[Insert Table 1 here]

4.2 Plague and Equilibrium without 'Horsemen Effect'

The left panel of figure 8 shows the pre-plague long-run equilibrium according to our baseline calibration. The fertility and mortality schedules intersect at a rate of 3.5% for each, while 3% of the population live

[41] Recall that city wages and urbanization rates grow in tandem (figure 3) such that one serves as an indicator for the other. Total taxable surplus income (above subsistence) may not have increased as much as per capita income due to population losses. However, what matters for the ability to fight wars is the relative position of powers. If population losses are symmetric, higher per capita incomes can translate into greater war-fighting ability.

[42] Our long-run results would be the same if the 'Horsemen effect' reached its full strength immediately after the plague. However, our modeling choice provides more historical realism during the transition – warfare and death rates increased only gradually with urbanization in early modern Europe.

[43] Linear interpolation is used for the years where no population data are available.

[44] The AJR (2005) dataset shows a similar if less pronounced trend over time. For the calibration, we use the more precise measure of population affected by warfare derived from the Levy data. Where comparability of results is key, as in the regression analysis below, we use the AJR data instead.

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.

[Insert Figure 8 here]

The effect of a one-time technological improvement on p.c. income is 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 8 shows the effect of the Black Death when all model parameters are unchanged. Before the plague, population and urbanization stagnate in the absence of technological progress. The Black Death in our calibration reduces population by 40%. As an immediate consequence, wages and p.c. consumption rise. Urbanization rates increase more slowly because cities cannot immediately grow to their new equilibrium size. 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, with fertility higher than mortality. The falling land-labor ratio eventually drives the economy back to E, with all variables returning to their pre-plague values. We argue that this describes the Chinese experience. Things look different in the presence of the 'Horsemen effect', which is unique to Europe.

4.3 Long-run Equilibria with 'Horsemen Effect'

If the shock is large enough, like the Great Plague, city wealth generates more trade and provides the means for more wars. The economy can converge to a new equilibrium with higher mortality, but also larger p.c. income and urbanization. The left panel of figure 9 shows the two stable equilibria, E and H, and an unstable equilibrium, U. Initially, the economy is in E, and all variables remain unchanged in the absence of technological progress. In order to initiate the transition from E to H, a shock to population (or productivity) must be large enough to push the economy beyond U, where Horsemen-augmented death rates exceed birth rates.[45] We argue that early modern Europe underwent such a transition.

Following the plague, p.c. incomes surged. Surviving individuals and their descendants were substantially better off than their ancestors before the plague. This is in line with historical evidence: It took until the 19th century for wages to recover their post-plague peak (Clark 2005). The demand for urban goods made cities grow, fostering trade and providing the means for warfare. Enhanced mobility constantly spread epidemics and therefore raised mortality. The size of this 'Horsemen effect' grew together with urbanization until the 17th century, as shown in figures 2 and 7, and captured by (12) in our model. The economy converges to the Horsemen equilibrium (point H) in the aftermath of the Great Plague. This equilibrium is characterized by higher birth and death rates (about 4.2%) and higher urbanization (8.5%). The corresponding dynamics are shown in the right panel of figure 9. Our story can explain the rising urbanization rates in early modern Europe in the absence of technological change. However, in this reduced form it predicts falling population, which contradicts the observed trend. Next, we allow for slowly growing productivity. We find that technological progress can explain rising population, but cannot account for increasing urbanization. The latter is explained largely by the 'Horsemen effect.'

[45] With ongoing technological progress the argument is similar. Continuous technological progress implies rising population at stagnant p.c. income. If death rates rise sufficiently because of the Horsemen, income grows while population can grow or fall. We analyze this case below.

[Insert Figure 9 here]

4.4 Technological Progress and Model Fit

Technological progress in premodern times alone is not enough to escape from the Malthusian trap. While a growing population eventually reverses the benefits of one-time inventions, *ongoing* progress implies higher, but still stagnating, long-run p.c. income. Its effects are thus similar to a permanent outward shift of the death schedule. Our calibrations also suggest that the effect in early modern Europe was markedly smaller than the effect of death rates. Technology pushes p.c. income up, and population growth responds, offsetting any gains. This corresponds to a long-run equilibrium in point T in the left panel of figure 10, where the birth rate exceeds the death rate and technological progress is exactly offset by the falling land-labor ratio.[46] The right panel of figure 10 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.

[Insert Figure 10 here]

Next, we investigate the fit of our model, including the 'Horsemen effect' and the observed rate of technological progress.[47] We begin simulations in 1000 AD in order to show both the pre- and post-plague fit of the model. While the 'Horsemen effect' alone can account for almost all the observed increase in European urbanization (see figure 9), technological progress is responsible for the growth in population. Figure 11 shows the simulation results together with the data. Our model performs well in reproducing both population growth and urbanization.

[Insert Figure 11 here]

4.5 The European Marriage Pattern

Europeans curtailed fertility in an important way - by delaying marriage for most women, and ensuring that a high proportion never married.[48] This pattern is known as the European Marriage Pattern (EMP), and only evolved West of a line from Triest to St. Petersburg. In a normal Malthusian setting, increasing fertility should have eroded all gains in living standards quickly. Lower birth rates for a given income have

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

[47] We allow technology to grow at $\tau = 0.1\%$ throughout the simulation. The model is calibrated to yield the same initial values as above for population, urbanization, fertility, mortality, and relative prices (as given in the lower part of table 1). Intuitively, this technology-progress adjusted calibration corresponds to shifting the death schedule downwards by $\tau/(1-\gamma)$ in figure 10. The new equilibrium T is then the same as the previous E.

[48] This went hand in hand with very low rates of bastardy.

a similar effect to higher background mortality: both alleviate population pressure and reduce the land-labor ratio in equilibrium. Average realized fertility rates in early modern Europe were approximately equal to those in China, despite markedly higher living standards (Clark 2007). At Chinese income levels, European fertility would have been much lower because of fertility restriction. In figure 12, 17th century China would be close to point E. This suggests that English fertility, because of the EMP, would have been 0.75% below the corresponding value for China - with equal incomes. 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 incomes and city growth: p.c. income grew by 75% between 1500 and 1700, and urbanization rates more than quadrupled from 3% to over 13% (and 20% in 1800) (Maddison 2007, DeVries 1984). We now investigate the EMP's contribution to income and city growth in our model. We assume that birth rates are not responsive to income before the Black Death, so that $\varphi_b^{\text{before}} = 0$. After the plague the EMP emerges, it shifts the birth schedule downwards by 1%. This corresponds to a 30% drop relative to the pre-plague equilibrium. We deliberately assign a potentially large role to the EMP, as to ensure that we do not exaggerate the role of the 'Horsemen effect.' The EMP also makes birth rates responsive to income such that $\varphi_b^{\text{after}} = 1.4$, as in the baseline calibration.[49]

[Insert Figure 12 here]

Figure 12 shows the EMP simulation results. In the absence of the 'Horsemen effect', the shift and tilt 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 3%, we predict a rate of 8.5% based on the rotated fertility schedule. The rise from 8.5 to 14 percent 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 possibly even more significant.

5 Empirical Evidence

In this section we provide empirical evidence that underlines the importance of the 'Horsemen of Growth'– the rise in mortality that results from more wars, more cities, and more trade. We demonstrate that this mechanism can help us explain divergence within Europe, between a dynamic North-Western region and a stagnant Southern one. While urbanization rates and wages declined in the latter, they rose in the former after 1500. The "Rise of Atlantic Europe", emphasized by AJR (2005) is captured by our model, but it is

[49] The corresponding parameter values are $b_0^{\text{before}} = 0.0344$ and $b_0^{\text{after}} = 0.0244$. With all other parameters unchanged, this implies again an equilibrium urbanization rate of 3% before the plague.

observationally equivalent to the rise of the most belligerent and war-torn parts of Europe.[50] We extend the dataset used by AJR (2005), who show that Atlantic trade was a driver of European growth, both directly, and indirectly through its effect on institutional quality. Our results suggest that warfare was also a key determinant of income levels in Europe until 1700. Since war itself killed few people, we argue that this effect is driven by the epidemics that fighting and the movement of armies spread. We also show that the effect is causal, by pinning down the part of variation in war frequency driven by geographical factors. In the following, we quickly describe our data sources and then turn to the regressions – first using a cross-section and then panel data for early modern Europe.

5.1 Data

We use two indicators for European development: urbanization and per capita GDP. Both measures generally go hand in hand. AJR (2002b) present time-series and cross-section evidence for a close association between urbanization and per capita income before as well as after industrialization. [51] Urbanization can therefore be used as a proxy for GDP per capita. AJR (2005) derive urbanization rates by dividing the urban population numbers of Bairoch et al. (1988) by the population estimates of McEvedy and Jones (1978).[52] The former dataset includes information on all 2,200 European cities which had 5,000 or more inhabitants at some time between 800 and 1800. From 800 until 1700 there are estimates for every 100 years, and then for every 50 years through 1850. Since Bairoch et al. (1988) emphasize that estimates before 1300 are rough and unreliable, we do not include these figures in our sample. We use the data between 1300 and 1700 to derive our baseline results. In addition, as a consistency check, we use urbanization data from DeVries (1984). His data cover all cities with at least 10,000 inhabitants. As a result, DeVries' urbanization estimates are generally lower, but the pattern over time is similar. The higher reliability of these data comes at a cost: DeVries' data only start in 1500 and cover primarily Western Europe. Following AJR (2005), we use estimates of GDP per capita from Maddison (2001). His estimates start in 1500 and are available for 1600, 1700, and 1820. Especially before 1820, the figures are more akin to educated guesses. We therefore think of the GDP data as an additional robustness check. Our main results use urbanization data between 1300 and 1700 from Bairoch et al. (1988).

War frequency is also adopted from AJR (2005) who derive the number of years of war in the preceding 50 or 100 years from Kohn (1999). These data exclude civil wars and colonial wars outside Europe. Using the average war frequency over the preceding period allows for a new equilibrium to emerge, after the short-term upheaval of warfare itself. We use two geographical variables as instruments for war frequency in early modern Europe. First, the average aerial distance of a country's capital to the capitals of the great powers: Spain, France, England, Austria, the Ottoman Empire, and Russia.[53] Our second

[50] We think of the data exercise as an indirect test of our hypothesis regarding the origins of European ascendancy. Since a simple empirical analysis of Europe vs. China would essentially leave us with a regression based on N=2, we use a panel on intra-European divergence to demonstrate the importance of the channels we identify.

[51] One reason for this finding is that only areas with high agricultural productivity and a developed transportation network could support large urban populations (Bairoch, Batou and Chèvre, 1988, Ch. 1; DeVries, 1976, p. 164).

[52] All country-level data are derived for borders as of 2001.

[53] What constitutes a great power can be debated. Great powers according Kennedy (1988) also include Sweden and the United Provinces. For our purposes, the country in question has to be a major military player for the entire period. Prussia, which emerges as a great power after 1700, is not part of the set for this reason. Sweden declines as a major power after the Thirty Years War. The United Provinces are not politically independent before the 17th century. To calculate distance, we use aerial distances between

instrument is the altitude of capitals. Both variables reflect geographically-determined protection against potential aggressors – the first through distance and the second through a natural defense against foreign powers. Since our instruments capture the geographically determined part of the variation in war frequency, they are particularly appropriate for our argument – geographical ease of access will also benefit the third of our Horsemen, trade. The data confirm the prediction that low-lying countries close to the major powers suffered many more wars – both our instrumental variables are negatively correlated with war frequency (see below).

5.2 Estimation Strategy

We have argued that in a Malthusian setup, the 'Horsemen of Growth' drive up death rates and therefore lead to higher steady state income and urbanization rates. The calibration of the 'Horsemen effect' implied that diseases, spread mainly by warfare, provide the largest contribution to rising death rates. Trade is another factor raising mobility and spreading disease. While we cannot account directly for the flow of goods across early modern Europe, our geography-based instruments for warfare will capture part of the mobility channel. Consequently, warfare together with its geography-based instruments should account for the main impact of the 'Horsemen of Growth' on urbanization and per capita income in early modern Europe. We test this idea using regressions of the following form:[54]

$$u_{j,t} = \beta\, war_{j,t} + d_t + \delta_j + \gamma\, X_{j,t} + \varepsilon_{j,t} \tag{24}$$

where $u_{j,t}$ is the urbanization rate in country j at time t (or alternatively log per capita income), $war_{j,t}$ denotes war frequency, the d_t's are year effects and the δ_j's denote country effects. $X_{j,t}$ is a vector of other covariates, including Western Europe dummies, measures of Atlantic trade and institutions, religion, latitude and Roman heritage. Finally, $\varepsilon_{j,t}$ is a disturbance term.

Ideally, we would also want to check the channel through which the 'Horsemen of Growth' work their wonders – population. However, this is hard to identify. On the one hand, more wars and mobility increase living standards in a Malthusian setup by spreading diseases and reducing population. On the other hand, this direct negative effect on population is at least partially offset by the positive response of birth rates to income. In addition, higher income leads to more demand for manufacturing goods, which in turn can raise productivity, supporting greater populations.[55] Consequently, while the 'Horsemen effect' on living standards is positive (figure 9), its impact on population is ambiguous. We therefore restrict our analysis to the former.

5.3 Cross-Section

We begin by analyzing a cross-section of growth in early modern Europe, where the dependent variable in (24) is the change in urbanization or per-capita income, and the explanatory variables are averaged

capitals (in kilometers) are obtained from http://www.indo.com/distance/. Just like country borders, country capital are as of 2001, with the exception of Turkey, where Istanbul is used instead of Ankara since the capital at the time, Edirne, was closer to Istanbul.

[54] Urbanization plays an ambiguous role in our estimation strategy. It is the dependent variable, capturing per capita income levels. It is also one of the factors driving up death rates. Fortunately, the bias arising from this is small. Our calibration has shown that excess city mortality has a negligible effect on aggregate death rates.

[55] While technological progress alone is not enough to significantly increase incomes, it can substantially affect population growth (see figure 10).

over the corresponding period.[56]

OLS Regressions

First, we examine simple correlations. Figure 13 shows that a higher war frequency between 1300 and 1700 is associated with a larger increase in urbanization. The same holds for per capita income, which is available from 1500 on.[57] Columns 1-4 of table 5 show that the correlation is highly significant and robust to excluding the great powers themselves, or the Netherlands which are unusually rich and afflicted by numerous conflicts. The same pattern emerges when we run the regression without population weights or when including Atlantic coast-to-area as a measure for the potential for Atlantic trade, as suggested by AJR (2005).

[Insert Figure 13 here]

[Insert Table 2 here]

IV Regressions

Wars and urbanization growth could be related for reasons other than the mortality channel. For example, fast growing countries may have the means (and incentives) for warfare, implying a reverse causality. We therefore need instruments that explain a country's war frequency but do not influence growth through channels other than the spreading of diseases. We use geographical variables such as the average distance to great powers and the altitude of a country's capital. We expect both variables to lower the probability of warfare, and to make long-distance trade more difficult. While distance to great powers offers protection from conflict through distance to potential aggressors, altitude of a country's capital proxies for ruggedness. This directly lowers the risk of invasion. Two examples illustrate this point. Both Switzerland and the Netherlands are on average about 1,200 km away from great powers. However, Switzerland is protected by mountains – a protection that the Netherlands lack because of their sea-level altitude. This is reflected in the war frequencies of both countries between 1300 and 1700: 0.14 vs. 0.56 wars per year on average. Table 3 shows that this relationship holds, on average, for the entire sample.[58] War frequency between 1300 and 1700 is highest for countries that are close to great powers and have relatively low-lying capitals, and it is smallest for countries with the opposite characteristics. War frequency is intermediate for the two mixed cases close/high and distant/low. In order to allow for non-linearity in the distance-altitude relationship, we include the interaction between both variables. Finally, we also use a dummy variable for the five great powers in the first stage regressions.[59]

[Insert Table 3 here]

[56]This also has the advantage of indirectly serving as a check on our data for the biases identified by Bertrand, Duflo, and Mullainathan (2004), who argue that difference-in-difference estimators tend to understate standard errors. Since our fixed effects regressions below are open to this criticism, we use the cross-sectional evidence – as suggested by Bertrand et al. – to check how sensitive our results potentially are.

[57]Maddison (2001) provides data also for 1200, but these are rough guestimates – the reported p.c. income is the same for all European countries (400 international Geary-Khamis dollars).

[58]Results are very similar when using the median.

[59]This captures the effect of the great power status itself on warfare. Including these dummies improves the fit at the first stage. However, all cross-sectional and panel results are robust to excluding the dummies.

Columns 6 and 7 of table 2 report the results of our IV estimation.[60] The first-stage results reported in the lower part of the table confirm our choice of instruments: both distance to great powers and altitude lower the frequency of war, while great power status itself has the opposite effect. The interaction term is positive and significant, which is also intuitive. Note that from column 6 the marginal effect of distance to great powers on war frequency is given by $d(war)/d(distance) = -.566 + .0018\ altitude$. Therefore, distance is the more decisive as a protection against warfare the lower a country's capital. Neither instrument endogeneity nor weak instruments appear to be a concern: While the p-values of the overidentifying restriction are far from the level at which one would reject instrument endogeneity, the F-statistic for the instruments is well above 10, which is often used as a rule-of-thumb for instrument quality.[61]

The second-stage results in columns 6 and 7 represent the causal impact of war frequency on urbanization over the period 1300-1700. The coefficients are highly significant and positive, but slightly lower than in the OLS specifications. This is what we would expect, given that warfare may in part respond positively to greater riches. AJR (2005) argue that access to the Atlantic was an important determinant of growth in Western Europe relative to Eastern Europe. We confirm their finding, obtaining a large coefficient for coastline. In order to compare the importance of warfare and Atlantic trade for European urbanization *on average*, we multiply the coefficients in column 7 with the corresponding explanatory variable's population-weighted average. Average European urbanization grew by 3.3 percent between 1300 and 1700.[62] About 3/4 of this increase is due to war frequency (weighted average .55), while less than 1/5 is due to Atlantic trade, proxied by the coastline-to-area ratio (weighted average .005). However, Atlantic trade is as important as warfare for explaining *cross-country* variation within Europe: A one standard deviation increase in Atlantic coastline (0.011) is associated with a 1.5% increase in the urbanization rate between 1300 and 1700. Similarly, a one standard deviation increase in war frequency (0.304) implies a 1.4% rise in urbanization over the same period. Taken at face value, the 'Horsemen of Growth' can account for a good deal of Europe's rise, while Atlantic trade explains some of the rise of its North-Western part.

All results presented so far have used the urbanization rates calculated by AJR (2005) for the period 1300-1700. In Appendix 1 we show that our results are robust to using urbanization rates from DeVries (1984) for the period 1500-1700.

GDP as dependent variable

In order to check the robustness of our cross-section results to alternative development indicators, we also use per capita income. Since these figures are only available from 1500 on, we use the change in

[60] Throughout the empirical section we use the kernel-based heteroskedastic and autocorrelation-consistent (HAC) 2-step GMM estimation technique, and follow Newey and West (1994) to select the bandwidth. This approach is more efficient than traditional 2-stage least square estimation. When using the latter, the magnitude of our results does not change, but standard errors are generally larger – although the high significance of the warfare variable remains mostly unaffected. There is an argument in the literature that the continuous updating estimator (CUE) due to Hansen, Heaton, and Yaron (1996) can gain further efficiency. We check our main results using the CUE and find very similar magnitudes and standard errors.

[61] The quality of our instruments, as indicated by Stock and Yogo's (2002) test, is very close to the highest level, indicating 5% maximal IV relative bias.

[62] This relatively small increase results from the high initial urbanization rates in 1300 in the AJR (2005) dataset, which counts cities from 5,000 inhabitants on. According to the urbanization data from DeVries (1984) – counting only cities with more then 10,000 inhabitants – average European urbanization grew by about 4% over half the time span, between 1500 and 1700. For North-Western Europe this figure is even larger – about 7 percent.

log GDP per capita between 1500 and 1700 as the dependent variable. The results presented in table 4 confirm the ones found above for urbanization.[63] War frequency correlates positively with per capita GDP growth, and the IV regressions indicate a positive causal relationship. While the sign is 'right' in all specifications, standard errors are relatively larger, such that the results for GDP per capita are less significant than the ones for urbanization. This is likely driven by the more noisy data on per capita income.

Average per capita GDP in Europe grew by 0.26 log points (or about 30%) between 1500 and 1700. Based on the coefficients in column 7 of table 4, warfare can explain 27 percent of this increase over time, and Atlantic coastline another 15 percent. Finally, both variables are important drivers of cross-sectional variation: If war frequency (Atlantic coastline) increases by one standard deviation, per capita income growth goes up by .05 (.09) log points.

[Insert Table 4 here]

5.4 Panel

One concern in the cross-sectional analysis is that country-specific characteristics could drive both warfare and development. We now address this issue by turning to a panel, which allows us to control for country fixed effects. As for the cross-section, we start with urbanization as the dependent variable, and then turn to GDP per capita to check the robustness of our results.

Urbanization as dependent variable

Table 5 presents the panel regressions for country-level urbanization. Data are available in 100 year intervals between 1300 and 1700. The pooled OLS regression in the first column shows a strong positive correlation between war frequency and urbanization. All remaining specifications use instruments for warfare. The panel structure requires an extension of the set of instruments. The ones used so far – distance to great powers, altitude, distance x altitude, and great power dummies – are time-invariant. The warfare variable in the panel, on the other hand, varies over time and across countries. In order to capture these two dimensions, we multiply the previous instruments by time dummies.[64] One concern is that the instrument-time interactions capture trends that are common to both warfare and urbanization (or income). To address this concern we include time dummies in most specifications. Since the number of instruments is large, we only report summary statistics for the first stage results. However, the corresponding individual coefficients are similar to those presented in the cross-section in table 2. As shown in the bottom of table 5, instruments used in the panel are of high quality. The rule-of-thumb threshold for an F-statistic of 10 is exceeded in all specifications. Moreover, the p-values of the overidentification restrictions suggest that instrument endogeneity is no serious concern, with the exception of column 6, where it can be rejected at the 10% level.

[Insert Table 5 here]

[63] The first-stage coefficients and statistics are not reported. They are almost identical to the ones shown in table 2.

[64] This is similar in spirit to AJR. (2005), who use time interactions of several regressors that only vary across countries, e.g., Atlantic coastline, Western Europe dummies, and latitude.

The second column in table 5 uses instruments for warfare, and the third adds time and country fixed effects. The fourth column repeats this regression but does not use population weights. All three specifications imply a highly significant positive impact of war frequency on urbanization. Columns 5-7 show that our results hold when we control for Atlantic trade. Our results confirm the AJR (2005) finding of its importance, but also underline the influence of warfare on European development. For example, the coefficients in column 6 indicate for the period 1300-1700 approximately 4.2 percentage points more urbanization growth in the Netherlands than in Switzerland due to warfare (war frequency grows from 0 to 2.22 in the former and from 0 to 0.01 in the latter), and 2.4 percentage points more urbanization growth due to Atlantic coastline (using the coefficient 1.805; the Atlantic coastline-to-area ratio is 0.013 in the former and 0 in the latter). According to these numbers, warfare explains about 1/5 and Atlantic coastline about 1/8 of the differential 22 percentage point actual urbanization growth between the Netherlands and Switzerland between 1300 and 1700.[65] Column 7 extends the panel until 1800 but excludes England, where the Industrial Revolution was on its way from the mid-18th century onward. The corresponding results are very similar to the previous ones (the same holds if we include England or further extend the sample to 1850). Appendix 1 shows that our findings are robust to using urbanization rates from DeVries (1984).

GDP as dependent variable

Table 6 provides regression evidence using log GDP per capita as the dependent variable, keeping the same specifications as in table 5. Maddison's (2001) estimates of GDP per capita are available for 1500, 1600, 1700, and 1820. Since output numbers in the 19th century are influenced by differential industrialization across Europe, we restrict the sample to 1500-1700 and include 1820 only in column 7. All results confirm our previous finding: War frequency has a highly significant positive impact on development in early modern Europe.

[Insert Table 6 here]

5.5 Robustness

There is no shortage of alternative explanatory variables that have variously been used to explain differential economic success. We try adding a number of them to our basic setup, and demonstrate that the effect of warfare remains highly significant in all specifications.

The dependent variable, as before, is either urbanization (panel A) or per capita income (panel B). The explanatory variable is war frequency, instrumented by geographical factors. All specifications use the log volume of Atlantic trade, interacted with the Atlantic trader dummy. This is a variation described in the AJR (2005) paper to account for the importance of Atlantic trade. We also use dummies for Western Europe from 1300 onwards. This setup differs from AJR's, who use these dummies from 1600 onwards. They are trying to capture the growth in trade that follows the discovery of the New World. We are interested in controlling for other factors that drive up urbanization in Western Europe, including in the period before 1500. We also add information on initial institutions, Protestant religion, Roman heritage,

[65] The contribution of Atlantic trade is larger for later periods. For example, in 1850 Atlantic coastline can explain up to half of the differential. However, our argument refers to the period 1300-1700.

and latitude. These variables have been proposed as explanations of differential development by various authors.[66]

[Insert Table 7 here]

Column 1 shows our baseline specification, but with the Atlantic trader - volume of trade interaction added. The size and significance of the war variable remains unaffected. Column 2 controls for initial institutions, interacted with year dummies for 1600 and 1700.[67] To replicate the full range of specifications pioneered in AJR (2005), columns 3 and 4 add a triple interaction between the Atlantic trader dummy, trade volume, and initial institutions. Whether we use the data weighted by population or in its basic form, our results are never affected in a substantial way. We also find that using war frequency in this way does not undermine the significance of the AJR result. Positive coefficients on the triple interaction support the argument that Atlantic trade promoted development where initial institutions were good: Urbanization and p.c. income in Atlantic trader countries with less restrictive initial institutions grew faster than in Atlantic trader countries with worse initial institutions. Columns 5-7 control for other potential determinants of European development, such as Protestantism, Roman heritage, and latitude. These variables have a positive effect on urbanization and per capita incomes. Protestantism seems to have been positively associated with growth, but the effect is only significant when we use income as the dependent variable. Controlling for this factor also does not change our results for war frequency. Having formed part of the Roman Empire has a positive and jointly significant impact on both urbanization and p.c. income. The war variable remains unaffected. Finally, columns 7 adds latitude-year interactions for all dates in the panel, where latitude enters as the distance of a country's capital from the equator. This controls for the shift of economic activity away from Southern towards Northern Europe in early modern times. While being jointly significant, the latitude variables do not alter our results on warfare.

Overall, the war variable (instrumented by geographical determinants) emerges as highly significant in all of our robustness checks. This is true of both dependent variables. We find some influence for Roman heritage and for latitude (and in the log GDP specification, for the influence of Protestantism). We note in passing that the Atlantic trader variable does not appear as robust as the war measure. From 1700 onwards, Atlantic trade becomes a crucial driver of European development according to our specification: If we run the regressions from 1700 to 1850 (not reported in the table), Atlantic trade is highly significant and positive, while war frequency turns out to be insignificant. War frequency declined after 1815, while growth accelerated. With the Industrial Revolution spreading, other factors such as technological change probably started to matter. The opportunities offered by new manufacturing processes were likely captured more readily in countries with good institutions (AJR, 2002a). Our results therefore suggest a more nuanced interpretation of the 'Rise of Europe.' In the first two centuries after the discovery of America, Atlantic trade rose relatively slowly (see AJR, 2005), while warfare surged. In a Malthusian setup, the

[66] Weber (1905) is often interpreted as having argued for a direct influence of Protestantism on economic performance, even if his original argument was much more subtle - cf. Landes (1998). The influence of Roman heritage is discussed in Anderson (1974), Jones (1981), and Landes (1998), inter alia. Latitude is used to analyze the relationship between geography and development in a variety of studies following Gallup et al. (1998).

[67] Initial institutions are the average constraint on the executive in 1400-1500, as coded by AJR (2005). This variable ranges from 1 to 7, with a higher score indicating more constraints. Since Atlantic trade began only in the 16th century, year-interactions are included from 1600 onwards.

latter led to rising p.c. income and urbanization. It was only when Atlantic trade grew rapidly after 1700 that we can document its important role in European development clearly.

6 Conclusion

Epidemics and wars frequently ravaged Europe between 1350 and 1700. We argue that death and destruction spelled riches and power in the early modern period. Europe's precocious rise may owe more to these scourges of mankind than to technological innovation. We build a simple two-sector extension of the standard Malthusian model that can shed new light on the puzzling rise of European per capita incomes. Many interpretations of the "rise of Europe" have emphasized technological creativity and high rates of innovation, compared to Asia (Mokyr 1990). We argue that, in a Malthusian setting, better technology cannot explain the "First 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. Some long-run 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 subsistence levels. This is particularly true because city growth acted as a catalyst for European belligerence. It also spread disease through trade – links that we call the 'Horsemen of Growth.'

We demonstrate that permanently higher mortality rates, driven by greater urbanization after the Black Death, were empirically important. In our calibrations, the mortality channel consistently emerges as accounting for at least half of the increase in per capita incomes. Fertility restriction is probably responsible for the remainder. We complement the calibration exercise with a detailed analysis of the intra-European growth record after 1300. Using a panel of European states in the period up to 1700, we find that war frequency – our preferred proxy for the 'Horsemen of Growth' – can explain a good share of the divergent fortunes within Europe. In particular, we find that we can explain a good deal of the rise of North-Western Europe compared to the rest of the continent. The effect of war, trade, and urbanization is broadly similar – if not stronger – than Atlantic trade (as suggested by AJR 2005). While war emerges consistently as a driver of higher incomes in early modern Europe, there is little reason to assume that the same will be true today. Non-reproducible factors of production, such as land, only play a small role in most economies. Even where they matter a great deal, such as in parts of Africa, modern wars may not yield the same effect. Military technology has become markedly more destructive, of both people and capital equipment. This checks the positive effect of rising land-labor ratios.

One implication of our findings is that urbanization is not simply an indicator for development. City growth also 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. In the final analysis, Europe's

political fragmentation and geographical heterogeneity interacted with the negative shock of the Black Death in a unique way. In combination, urbanization, warfare, and trade ensured a mortality regime that was different from the one prevailing in Asia. Future work should focus on the other factor contributing to Europe's precociously rising incomes – the emergence of the European Marriage Pattern.

Appendix

A.1 Sensitivity to Alternative Urbanization Data

We examine the sensitivity of our results to an alternative choice of dependent variable. DeVries' (1984) figures are often considered superior to the Bairoch et al. (1988) dataset. DeVries' definition of what makes a city is slightly different, and the data is only available after 1500. Geographical coverage also declines, from 22 countries (Bairoch et al.) to 16 (DeVries). In tables A.1 and A.2, we use DeVries' figures as the dependent variable. Results are largely unchanged, with the war frequency measure emerging as large and highly significant in almost all cross-section regressions and in all panel specifications.

[Insert Table A.1 here]

[Insert Table A.2 here]

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Figure 1: Urbanization rates in China and Europe, 1000-1800. Source: Maddison (2001)

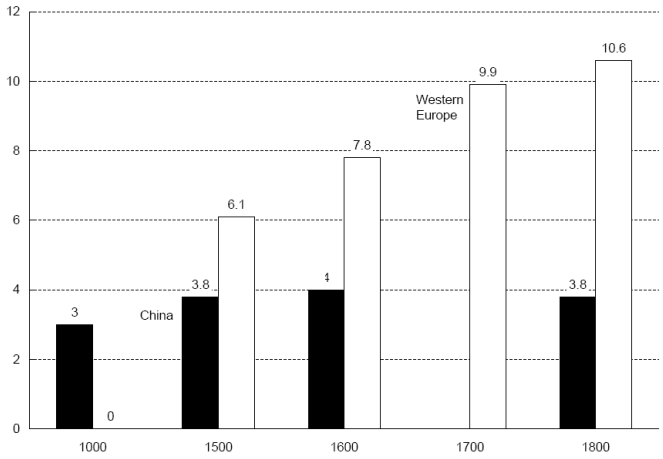
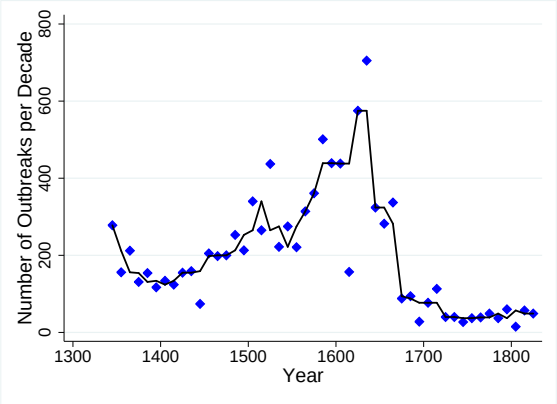


Figure 2: Plague outbreaks in Europe



Data source: Biraben (1975). Data points represent the number of outbreaks over 10 year periods. The solid line is the median of each data point and the two adjacent ones.

Figure 3: Wages and urbanization

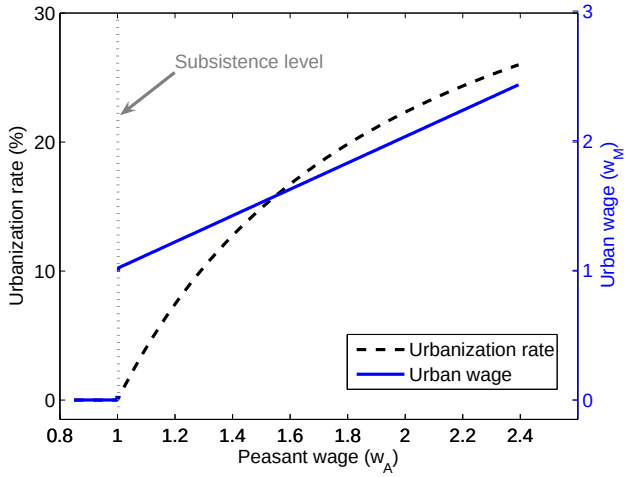


Figure 4: Population dynamics and equilibria

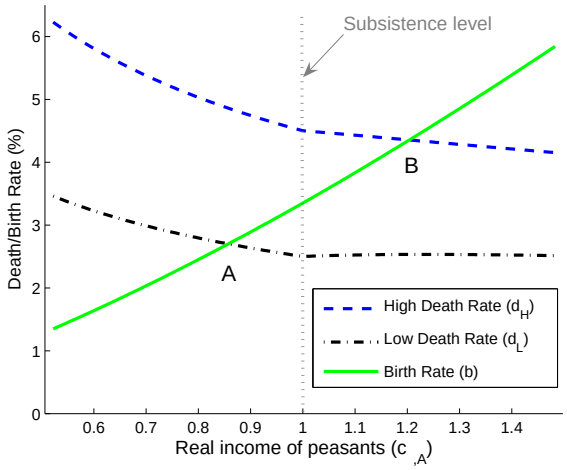


Figure 5: Death rates by workplace and average death rate

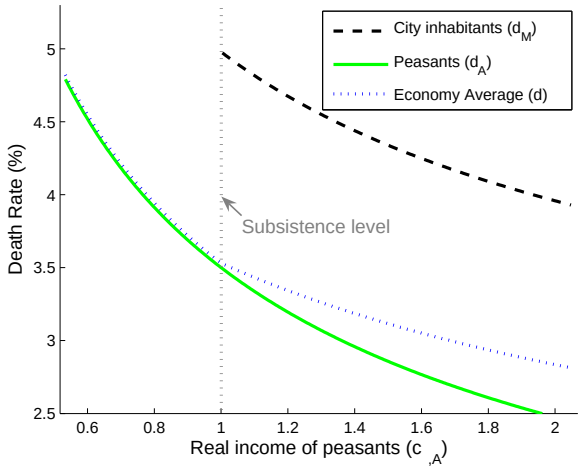
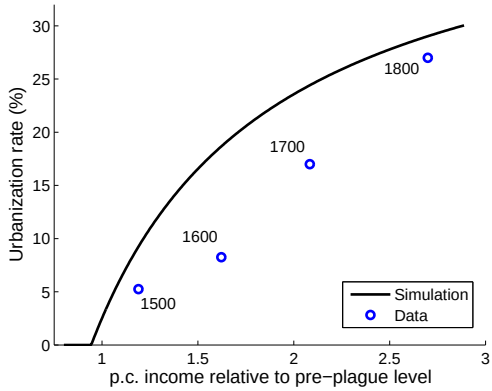
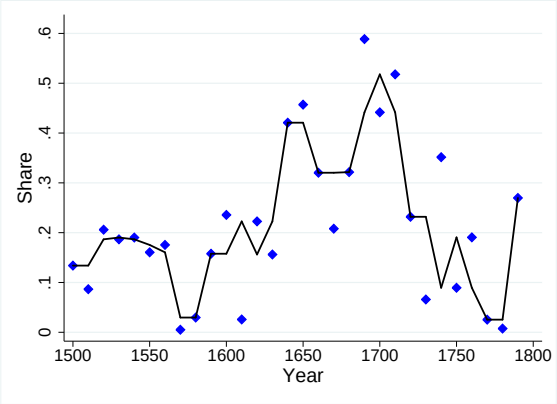


Figure 6: Urbanization vs. p.c. income in England



Data sources: p.c. income from Maddison (2001) is relative to the 1350 level. Urbanization rates from Wrigley (1985).

Figure 7: Percentage of European population affected by war



Data sources: War data from Levy (1983); population from Maddison (2007). Data points represent 10-year averages. The solid line is the median of each data point and the two adjacent ones.

Figure 8: Long-run impact of the plague, ceteris paribus

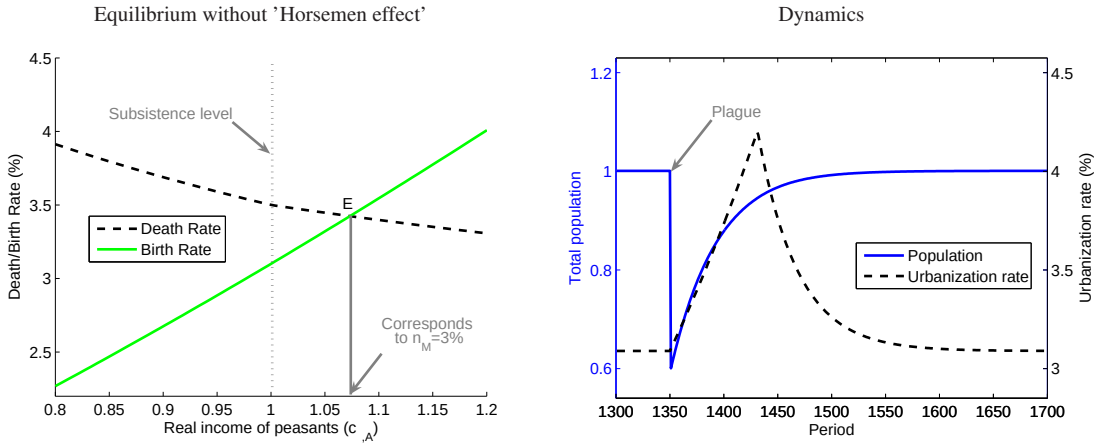


Figure 9: Long-run impact of the plague with 'Horsemen effect'

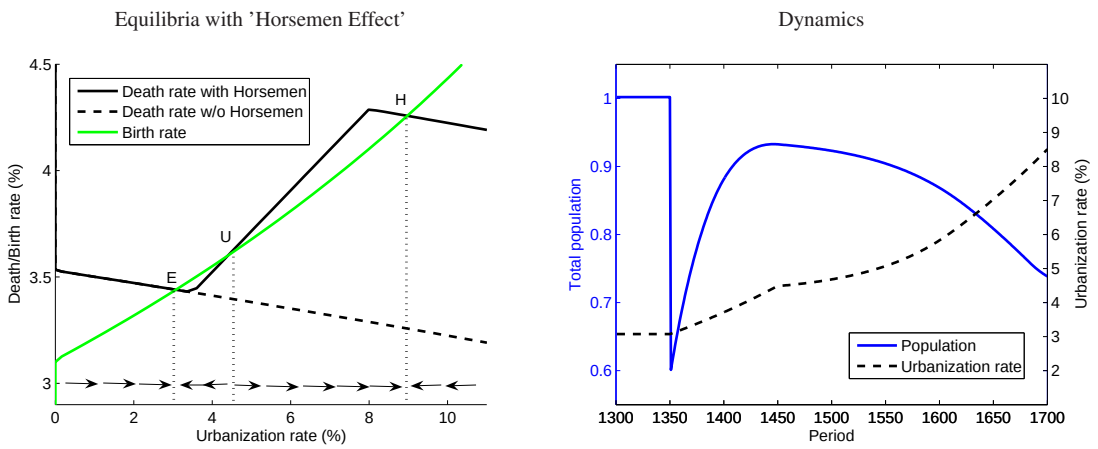


Figure 10: Effect of ongoing technological progress

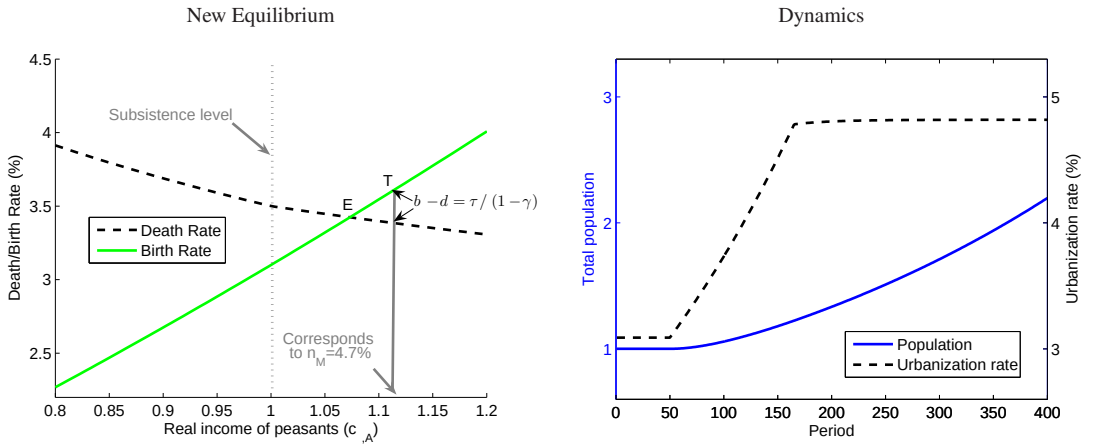
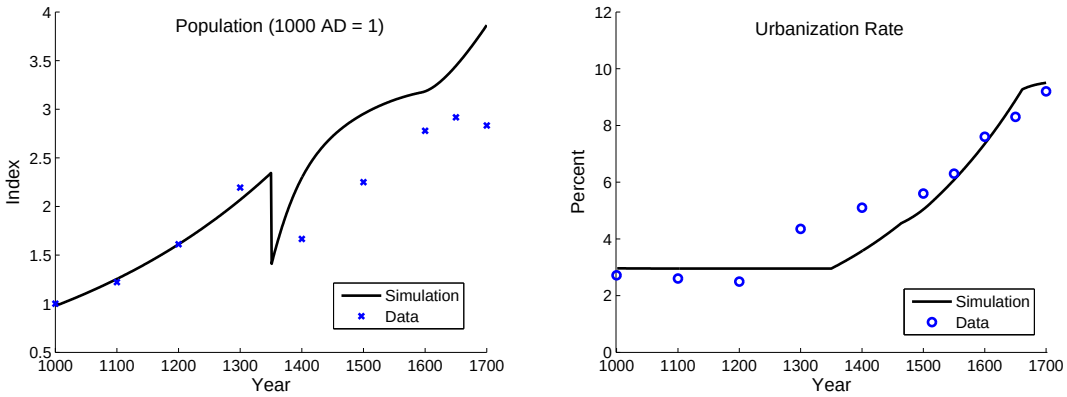


Figure 11: Europe: Simulation Results vs. Data



Data sources: Population from Kremer (1993). Urbanization rates: for 1500-1700 from DeVries (1984); 1000-1400 use De Vries's figures extrapolated backwards with AJR (2005). See section 5.1 for a description of both datasets.

Figure 12: Pre-and post-plague equilibria with EMP and Horsemen

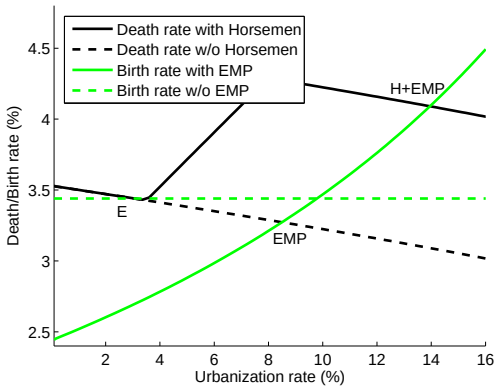


Figure 13: Warfare and European development

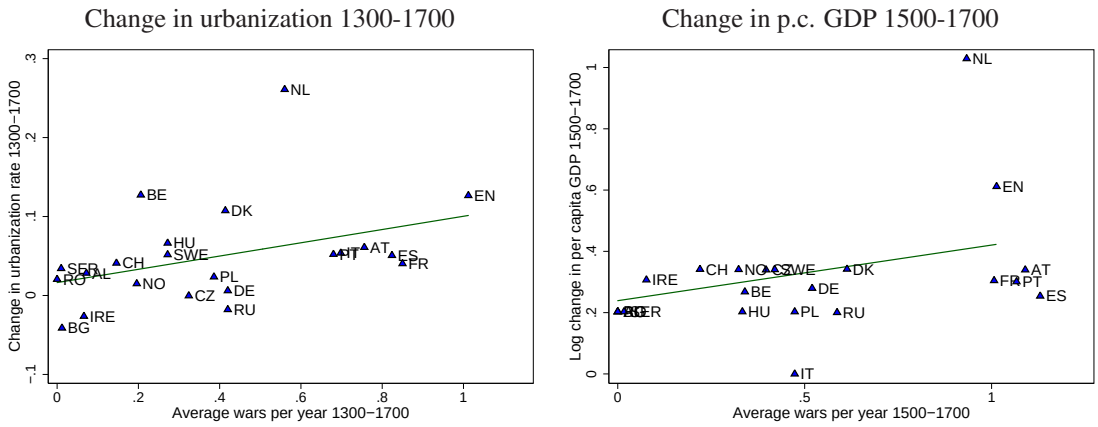


Table 1: Baseline Calibration

Symbol	Interpretation	Value
Parameters		
α	Food expenditure share (as income $\to \infty$)	0.55
γ	Labor share in agriculture	0.6
$\underline{c}$	Subsistence food consumption	1
L	Land	8
$A_{A,0}$	Initial TFP in agriculture	0.462
$A_{M,0}$	Initial TFP in manufacturing	1.080
τ	Rate of technological progress	0.1%
b_0	Birth rate at $c = \underline{c}$	0.0311
d_0	Death rate at $c = \underline{c}$	0.0353
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'	0.035
δ	Slope parameter for 'Horsemen effect'	0.22
$\overline{\nu}$	Upper bound on city growth due to congestion	0.0038
Resulting values in long-run equilibrium before the Great Plague		
N_0	Population	1.0
$n_{A,0}$	Urbanization rate	3.0%
$b_0 = d_0$	Economy-average birth and death rate	3.5%
$p_{M,0}$	Relative price of manufacturing goods	1.0

Table 2: Cross section: Change in urbanization vs. average wars per year, 1300-1700

	Dependent variable is change in urbanization 1300-1700						
	OLS	OLS w/o Netherl.	OLS w/o Gr. Pow.	OLS unweighted	OLS	IV	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Wars per year	.0755**	.0755**	.0670**	.0840**	.0477*	.0466***	.0459***
(Avg. 1300-1700)	(.0298)	(.0296)	(.0290)	(.0312)	(.0242)	(.0145)	(.0173)
Atlantic coast-to-area					1.659***		1.298***
					(.4570)		(.301)
Observations	22	21	17	22	22	22	22
R^2	.20	.30	.10	.16	.34	-	-
FIRST STAGE REGRESSIONS							
						Dependent variable is avg. wars per year 1300-1700	
Instruments‡							
Avg. Distance to great powers						-.566***	-.539***
(in 1000 km)						(.1900)	(.1650)
Altitude of capital						-.00332**	-.00316**
(in m)						(.0012)	(.0012)
Interaction distance x altitude						.00180**	.00175**
						(.0006)	(.0006)
Dummy for Great Power						.427***	.388***
						(.1170)	(.1170)
R^2						0.60	0.64
Tests for Instruments:							
p-value overidentifying restrictions						.39	.46
Weak identification F-statistic						14.8	12.6

Notes: All regressions except (4) are weighted by countries' average population 1300-1700. Standard errors (in parentheses) are robust to arbitrary heteroskedasticity. Key: *** significant at 1%; ** 5%; * 10%. Regressions (6) and (7) are estimated using two-step feasible efficient GMM. See text for details on variables.

‡ Controls used in the second stage (above) are also included in the first stage regression, but only coefficients for instruments are reported.

Table 3: War frequency and instruments

		Altitude	
		low (below mean)	high (above mean)
Dist. great powers	close (below mean)	.45	.38
	distant (above mean)	.37	.33

Note: War frequency is the average for 1300-1700.

Table 4: Cross section: Change in p.c. GDP vs. average wars per year, 1500-1700

	Dependent variable is change in country-level log GDP per capita 1500-1700						
	OLS	OLS w/o Netherl.	OLS w/o Gr. Pow.	OLS unweighted	OLS	IV‡	IV‡
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Wars per year	.189**	.163*	.212	.212*	.0972	.143*	.128**
(Avg. 1300-1700)	(.0892)	(.0823)	(.2150)	(.1120)	(.0580)	(.0867)	(.0623)
Atlantic coast-to-area					7.696***		7.849***
					(1.1730)		(1.2360)
Observations	22	21	17	22	22	22	22
R^2	.15	.17	.07	.18	.42	-	-

Notes: All regressions except (4) are weighted by countries' average population 1300-1700. Standard errors (in parentheses) are robust to arbitrary heteroskedasticity. Key: *** significant at 1%; ** 5%; * 10%. Regressions (6) and (7) are estimated using two-step feasible efficient GMM. See text for details on variables.

‡ Instruments for wars per year are the same as used in table 2; first stage coefficients and statistics are very similar to those reported in this table.

Table 5: Panel: Urbanization and wars per year in early modern Europe

	Dependent variable is country-level urbanization						
	1300-1700	1300-1700	1300-1700	1300-1700	1300-1700	1300-1700	1300-1800
	OLS	IV	IV	IV unweighted	IV	IV	IV w/o Britain
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
					Potential for Atlantic Trade measured by		
					dummy	Atlantic coast-to-area	
Wars per year	.0446***	.0435***	.0270***	.0313***	.0345***	.0211***	.0192***
	(.0156)	(.0126)	(.0094)	(.0102)	(.0117)	(.0074)	(.0055)
p-value for Western Europe x year dummies			[.01] (1300-1700)	[.19] (1300-1700)	[.11] (1600-1700)	[.16] (1600-1700)	[.01] (1600-1800)
Potential for Atlantic Trade x 1500					.0257***	.177	1.051
					(.0079)	(.3420)	(1.1930)
Potential for Atlantic Trade x 1600					.00107	.511	-1.815
					(.0157)	(.3430)	(1.2420)
Potential for Atlantic Trade x 1700					.0137	1.805***	- .0092
					(.0129)	(.2540)	(1.1490)
Potential for Atlantic Trade x 1750							2.458**
							(1.0260)
Potential for Atlantic Trade x 1800							1.481
							(.9830)
Country and Year dummies	no	no	yes	yes	yes	yes	yes
Observations	110	110	110	110	110	110	147
R^2	.10	.07	.86	.77	.87	.89	.91
FIRST STAGE STATISTICS‡							
p-value overidentifying restrictions		.16	.17	.22	.16	.09	.43
Weak identification F-statistic		113.6	31.0	16.1	16.4	35.7	30.0

Notes: All regressions except (4) are weighted by countries' population in each year. Standard errors (in parentheses) are robust to arbitrary heteroskedasticity. Key: *** significant at 1%; ** 5%; * 10%. Regressions (2) - (7) are estimated using two-step feasible efficient GMM. See text for details on variables.

‡ Instruments for wars per year are average distance to great powers, altitude of capital, distance x altitude, and the great power dummy; all instruments are interacted with year dummies. Controls used in the second stage (above) are also included in the first stage regression.

Table 6: Panel: Per capita income and wars per year in early modern Europe

	Dependent variable is country-level log GDP per capita						
	1500-1700	1500-1700	1500-1700	1500-1700	1500-1700	1500-1700	1500-1820
	OLS	IV	IV	IV unweighted	IV	IV	IV w/o Britain
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
					Potential for Atlantic Trade measured by		
					dummy	Atlantic coast-to-area	
Wars per year	.243***	.277***	.0960***	.0430**	.0779***	.0738**	.0691***
	(.0631)	(.0616)	(.0220)	(.0218)	(.0259)	(.0344)	(.0199)
p-value for Western Europe x year dummies			[.00] (1500-1700)	[.00] (1500-1700)	[.89] (1600-1700)	[.17] (1600-1700)	[.11] (1600-1800)
Potential for Atlantic Trade x 1500					.219***	9.002***	-2.369
					(.0409)	(2.3730)	(6.1380)
Potential for Atlantic Trade x 1600					.258***	13.59***	3.962
					(.0626)	(2.4440)	(2.9740)
Potential for Atlantic Trade x 1700					.281***	16.95***	6.537**
					(.0724)	(2.4030)	(2.9270)
Potential for Atlantic Trade x 1800							5.495*
							(2.8610)
Country and Year dummies	no	no	yes	yes	yes	yes	yes
Observations	66	66	66	66	66	66	84
R^2	.18	.17	.86	.95	.94	.87	.94
FIRST STAGE STATISTICS‡							
p-value overidentifying restrictions		.04	.79	.22	.31	.14	.27
Weak identification F-statistic		114.9	32.5	17.1	15.2	53.2	39.7

Notes: All regressions except (4) are weighted by countries' population in each year. Standard errors (in parentheses) are robust to arbitrary heteroskedasticity. Key: *** significant at 1%; ** 5%; * 10%. Regressions (2) - (7) are estimated using two-step feasible efficient GMM. See text for details on variables.

‡ Instruments for wars per year are average distance to great powers, altitude of capital, distance x altitude, and the great power dummy; all instruments are interacted with year dummies. Controls used in the second stage (above) are also included in the first stage regression.

Table 7: Robustness checks

	Baseline	Control for institutions	Control for institutions	Control for institutions, unweighted	Control for religion	Control for Roman heritage	Control for latitude
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	PANEL A: Dependent variable is country-level urbanization; panel 1300-1700						
Wars per year (IV)	.0305***	.0339***	.0337***	.0289**	.0363***	.0269**	.0277***
	(.0102)	(.0095)	(.0103)	(.0126)	(.0107)	(.0112)	(.0065)
p-value for Western Europe x year dummies, 1300-1700	[.22]	[.04]	[.04]	[.32]	[.07]	[.21]	[.21]
Atlantic trader dummy x volume of Atlantic trade	.000882	- .000847	- .00993*	- .0162***	.0012	- .00689**	- .00245
	(.0027)	(.0026)	(.0058)	(.0049)	(.0029)	(.0034)	(.0029)
p-value for initial institutions x year dummies, 1600-1700		[.00]	[.00]	[.74]			
Atlantic trader dummy x volume of Atlantic trade x initial institutions			.00846	.0267***			
			(.0055)	(.0037)			
p-value for Protestant x year dummies, 1600-1700					[.15]		
p-value for Roman heritage x year dummies, 1300-1700						[.00]	
p-value for Latitude x year dummies, 1300-1700							[.00]
Country and year dummies	yes	yes	yes	yes	yes	yes	yes
Observations	110	110	110	110	110	110	110
R^2	.86	.88	.88	.79	.86	.88	.87
FIRST STAGE STATISTICS							
p-value over-id restrictions	.16	.27	.21	.31	.22	.13	.17
Weak IV F-statistic	20.8	22.4	22.2	9.6	21.4	16.7	20.6
	PANEL B: Dependent variable is country-level log GDP per capita; panel 1500-1700						
Wars per year (IV)	.0788**	.0927***	.0786***	.101***	.0985***	.0905***	.0868***
	(.0364)	(.0154)	(.0160)	(.0160)	(.0133)	(.0187)	(.0149)
p-value for Western Europe x year dummies, 1500-1700	[.00]	[.00]	[.00]	[.00]	[.00]	[.00]	[.00]
Atlantic trader dummy x volume of Atlantic trade	.0401	.0231	- .146***	- .179***	.0713***	.0880***	.0453*
	(.0390)	(.0292)	(.0391)	(.0227)	(.0145)	(.0274)	(.0248)
p-value for initial institutions x year dummies, 1600-1700		[.20]	[.00]	[.18]			
Atlantic trader dummy x volume of Atlantic trade x initial institutions			.213***	.222***			
			(.0369)	(.0175)			
p-value for Protestant x year dummies, 1600-1700					[.00]		
p-value for Roman heritage x year dummies, 1500-1700						[.00]	
p-value for Latitude x year dummies, 1500-1700							[.00]
Country and year dummies	yes	yes	yes	yes	yes	yes	yes
Observations	66	66	66	66	66	66	66
R^2	.86	.96	.98	.98	.94	.97	.96
FIRST STAGE STATISTICS							
p-value over-id restrictions	.75	.36	.11	.30	.22	.14	.05
Weak IV F-statistic	23.8	27.4	26.9	5.1	15.4	17.7	15.9

Notes: All regressions except (4) are weighted by countries' population in each year. Standard errors (in parentheses) are robust to arbitrary heteroskedasticity. Key: *** significant at 1%; ** 5%; * 10%. All regressions use instrumental variables for wars per year, and are estimated using two-step feasible efficient GMM. Instruments for wars per year are average distance to great powers, altitude of capital, distance x altitude, and the great power dummy; all instruments are interacted with year dummies. The reported weak IV F-statistic is the Kleibergen-Paap Wald rk F statistic.

Table A.1: Cross section: Using urbanization rates from DeVries (1984)

	Dependent variable is change in urbanization from DeVries, 1500-1700						
	OLS	OLS w/o Netherl.	OLS w/o Gr. Pow.	OLS unweighted	OLS	IV‡	IV‡
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Wars per year	.0573**	.0521**	.119*	.0613*	.0394**	.0544***	.0233
(Avg. 1500-1700)	(.0212)	(.0196)	(.0620)	(.0304)	(.0154)	(.0188)	(.0153)
Atlantic coast-to-area					1.464***		1.618***
					(.2570)		(.2690)
Observations	16	15	12	16	16	16	16
R^2	.30	.39	.40	.24	.60	-	-
FIRST STAGE REGRESSIONS							
p-value overidentifying restrictions						.37	.70
Weak identification F-statistic						270.3	204.8

Notes: All regressions except (4) are weighted by countries' average population 1300-1700. Standard errors (in parentheses) are robust to arbitrary heteroskedasticity. Key: *** significant at 1%; ** 5%; * 10%. Regressions (6) and (7) are estimated using two-step feasible efficient GMM. See text for details on variables.

‡ Instruments for wars per year are the same as used in table 2; first stage coefficients and statistics are very similar to those reported in this table.

Table A.2: Panel: Using urbanization rates from DeVries (1984)

	Dependent variable is country-level urbanization from de Vries (1984)						
	1500-1700	1500-1700	1500-1700	1500-1700	1500-1700	1500-1700	1500-1820
	OLS	IV	IV	IV unweighted	IV	IV	IV w/o Britain
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
					Potential for Atlantic Trade measured by		
					dummy	Atlantic coast-to-area	
Wars per year	.0311**	.0391***	.0288***	.0513***	.0315***	.0235***	.0213***
	(.0152)	(.0056)	(.0046)	(.0033)	(.0060)	(.0029)	(.0024)
p-value for Western Europe x year dummies			[.27] (1500-1700)	[.03] (1500-1700)	[.37] (1600-1700)	[.59] (1600-1700)	[.00] (1600-1800)
Potential for Atlantic Trade x 1500					.0557***	-1.066***	-2.496***
					(.0196)	(.4020)	(.6700)
Potential for Atlantic Trade x 1600					.0490**	- .778*	- .369
					(.0199)	(.4050)	(.8530)
Potential for Atlantic Trade x 1700					.0609***	.542	- .243
					(.0197)	(.4080)	(.4580)
Potential for Atlantic Trade x 1750							.505
							(.4430)
Potential for Atlantic Trade x 1800							1.039**
							(.4400)
Country and Year dummies	no	no	yes	yes	yes	yes	yes
Observations	48	48	48	48	48	48	75
R^2	.09	.07	.94	.92	.94	.97	.96
FIRST STAGE STATISTICS							
p-value overidentifying restrictions		.25	.40	.78	.28	.18	.21
Weak identification F-statistic		840.6	28.8	181.6	14.6	37.9	53.7

Notes: All regressions except (4) are weighted by countries' population in each year. Standard errors (in parentheses) are robust to arbitrary heteroskedasticity. Key: *** significant at 1%; ** 5%; * 10%. Regressions (2) - (7) are estimated using two-step feasible efficient GMM. See text for details on variables.

‡ Instruments for wars per year are average distance to great powers, altitude of capital, distance x altitude, and the great power dummy; all instruments are interacted with year dummies. Controls used in the second stage (above) are also included in the first stage regression.