

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

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First draft: September 2007

This draft: January 2009

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 surged ahead of Chinese ones. Productivity growth 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. We show in a calibration exercise that our model can account for the sharp rise in European urbanization as well as permanently higher per capita incomes in 1700, without technological change. Wars contributed importantly to the rise of Europe, even if they had negative short-run effects. We also examine intra-European growth, using a panel of European states in the period 1300-1700. Estimation results suggest that war frequency can explain a good share of divergent fortunes within Europe as well.

JEL: E27, N13, N33, O14, O41

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

*We would like to thank Steve Broadberry, Greg Clark, Nick Crafts, Angus Deaton, Matthias Doepke, Oded Galor, Bob Hall, Nobu Kiyotaki, Kiminori Matsuyama, Joel Mokyr, Rachel Ngai, Ron Lee, Ed Prescott, Diego Puga, Michèle Tertilt, Jaume Ventura, David Weil, and Fabrizio Zilibotti for helpful comments and suggestions. Seminar audiences at Brown University, Humboldt University, the Minnesota Macro Workshop, Northwestern University, Pompeu Fabra, UC Berkeley, UCLA, Princeton, and Zürich University offered helpful advice. Morgan Kelly shared unpublished results; Mrdjan Mladjan provided outstanding research assistance. Financial support by the Centre for International Economics at UPF (CREI) is gratefully acknowledged.

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1 Introduction

In 1400, Europe's potential to overtake the rest of the world 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 (Mokyr, 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, an initial 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 as 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 the fertility transition, 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 the words of HG Wells, earlier 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

Nonetheless, incomes in many European countries increased markedly during the early modern pe-

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

²Pomeranz (2000), comparing the Yangtze Delta with England, argues the opposite. The consensus now is that his revisionist arguments do not stand up to scrutiny (Allen, 2004; Allen, Bengtsson, and Dribe, 2005; Broadberry and Gupta, 2006).

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

⁴Assuming a generation length of 25 years.

⁵Wells (1905). This is the intuition behind Ashraf and Galor (2008), who test for long-term stagnation of incomes despite variation in soil fertility and agricultural technology.

riod. Maddison (2007) estimates that Western European per capita incomes on average grew by 30%. In the most successful economies, they more than doubled. His data are imperfect, but knowledgeable contemporary observers detected the same trend. In 1750s England, Henry Fielding saw a "torrent of luxury which of late years hath poured itself into this nation ..." (Fielding, 1751, p. 6). Overall, and despite the logic of the Malthusian world, 58% of Europe's gain in total income, 1500-1700, was due to larger population, while 42% came from higher p.c. incomes (Maddison (2007)). How could marked rises in living standards 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. It created a new mortality regime with permanently higher death rates. Malthus (1826) argued that a number of factors can keep population pressure in check: "vicious customs with respect to women, great cities, unwholesome manufactures, luxury, pestilence, and war." We focus on three – great cities, pestilence, and war. In a Malthusian regime, lower population spells higher wages. In this way, Western Europe's unique set of geographical and political starting conditions interacted with the plague shock to make higher per capita living standards sustainable. Growth in this context implied a transition to a higher equilibrium level of income; it was not an open-ended process. Because the plague shock was large, with up to half of the population dying, land-labor ratios and wages increased substantially. These real wage gains were so large that population growth could not reverse them quickly. Wages remained high for more than a generation or two. They were partly spent on manufactured goods, which were mostly produced in towns. Early modern European urban centers were death-traps, with mortality far exceeding fertility rates. Had it not been for steady in-migration from the countryside, they would have disappeared entirely. Thus, new demand for manufactures pushed up average death rates, which in turn made 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 rose, resulting in lower population pressure.

This 'benign' direct effect of urbanization was reinforced by two factors – war and trade. Between 1500 and 1800, the continent's great powers were fighting each other on average for nine years out of every ten (Tilly, 1992). City wealth fueled early modern Europe's endemic warfare. Growing urban centers could be taxed more easily than farmers in the countryside - the urban economy was highly monetized. Cities also offered a chance to tap credit markets. Many early modern wars were fought with the funds provided by Genoese banking families, Amsterdam financiers, the Fuggers, and the Medici. In contrast to numerous papers identifying a negative effect of wars, civil wars, disease, and epidemics on income levels in economies today,⁶ we argue that these factors raised wages in early modern times – the Horsemen of the Apocalypse effectively acted as Horsemen of Growth. This is because the effects of early modern warfare were similar to a neutron bomb – it primarily killed people, by spreading disease. Economic devastation was limited. Cities also acted as centers for long-distance trade. 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 initial rise in incomes after the Black Death was made permanent by the 'Horsemen effect,' which

⁶Murdoch and Sandler (2002); Hoeffler and Reynal-Querol (2003); Hess (2003).

pushed up mortality rates and produced higher per capita incomes. In a calibration exercise, we show that the direct effect of city mortality mattered, but that it was markedly smaller than the effects of war and trade.

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 did not lead to permanently higher death rates; per capita incomes could not be sustained at higher levels.

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 Voigtländer and Voth (2009), we examine its contribution to high European wages. While its effect is substantial, we conclude that it can account for no more than half of the increase in output per head after 1400.

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 their distant ancestors on the African savannah.⁷ Young (2005) concludes that HIV 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 (2002). 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), Jones (2001), and Kremer (1993), the rise in population which in turn produces more ideas is a key factor; in Galor and Moav (2002), it is the quality of the population.⁸ Cervellati and Sunde (2005) argue that the 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

⁷This 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).

⁸Clark (2007) finds some evidence in favor of the Galor-Moav hypothesis, with the rich having more surviving offspring.

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 shows that technological change cannot explain rising p.c. income in early modern times, and emphasizes changes in death rates as a key determinant of output per head. 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." In section 5, we provide empirical evidence for our hypothesis. We show that increasingly frequent military conflict can explain a fair share of growing income differences within Europe. The final section summarizes our findings.

2 Historical Context and Background

Our story emphasizes three elements that contributed to the "First Divergence" under Malthusian conditions: the impact of the plague, the peculiarities of European geography and 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 by 1700 had reached unusually high levels, 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%.⁹ Finally, urbanization rates have been widely used as an indicator of economic development (Acemoglu, Johnson, and Robinson (2005) [subsequently AJR, 2005]). This indicator shows that Europe overtook China at some point between 1300 and 1500, extending its lead thereafter (figure 1).

[Insert Figure 1 here]

The beneficial effect of the Black Death on real wages is well-documented. It ushered in a "golden age of labor" (Postan, 1972). After 1350, wages approximately doubled (Phelps-Brown and Hopkins, 1981; Clark, 2005). Afterwards, the older Phelps-Brown and Hopkins series suggested a strong decline. Clark (2005) shows that wages fell back from their peak somewhat, but except for crisis years around the

⁹While 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.

English Civil War, they remained about fifty percent above their 1300 level.¹⁰ 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 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. And yet, population growth did not fully 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.¹¹

There appear to have been few differences in mortality rates between social classes, age groups, 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 roughly 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).

¹⁰What 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.

¹¹The exact nature of the disease that erupted in 1347 is still debated. For a summary of some of the arguments, cf. Herlihy (1997).

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.¹² Clark (2009) finds that early modern English urban mortality rates may have been up to 1.8 times the level in the countryside. For France, the practice of wet-nursing (sending children from cities for breast-feeding to the countryside) complicates comparisons. A comprehensive survey of rural-urban mortality differences estimates that in early modern Europe, life expectancy was approximately 50 percent higher in the countryside than in cities (Woods, 2003). Thomas Malthus emphasized that city life was a potent force for curtailing population pressure, and that infant mortality responded to the pressures of city life quickly: "There certainly seems to be something in great towns, and even moderate towns, peculiarly unfavourable to the very early stages of life."¹³

No such differential 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. Members of Beijing's elite in the 18th century experienced infant mortality rates that were half those in France or England (Woods, 2003). 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.

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.

High urban mortality in Europe also reflected the way in which cities were built. 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" (de Vries, 1976). In China, too, city walls were widely used throughout the early modern period, partly because of their symbolic value for administrative centers of the Empire. However, since the country'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 expand beyond the old fortifications, city growth did not push

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

¹³Malthus (1973, p. 242). In the first edition, he had remarked: "These facts seem to show that population increases exactly in the proportion that the two great checks to it, misery and vice, are removed... The unwholesomeness of towns, to which some persons are necessarily driven from the nature of their trades, must be considered as a species of misery" (Malthus, 1798, p. 34).

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

up population densities in the same way as in Europe.¹⁵ This reduced overcrowding and kept mortality rates low.

In many European countries, regulations further ensured that manufacturing activities and market exchange took largely place in the cities. Even if some manufacturing activity was performed in the countryside ("proto-industrialization," cf. Ogilvie and Cerman, 1996), urbanization is a useful proxy for the rise of non-agricultural output (Wrigley, 1985).¹⁶ In China, periodic markets in the countryside served a function monopolized by European cities. 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" (Mark Elvin, cited in Bairoch, 1991).

Wars, Trade and Disease

Early modern armies killed many more Europeans by the germs they spread than through warfare. The Black Death had originally arrived with a besieging Tartar army in the Crimea. As a result of troop movements, 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, 1997). 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). 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. In contrast, battlefield casualties were generally low, compared to aggregate death rates.¹⁷ While individual campaigns could be deadly, armies were too small, and their members too old, to influence aggregate mortality rates significantly.¹⁸

Civilian population losses in wartime 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. The figures for early 17th century Germany and 16th century France imply that aggregate mortality rates rose by 50 to 100%, and that these rates were sustained for decades. For the early and mid-nineteenth century, we have additional data on the indirect, country-wide rise in mortality from warfare. 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). These numbers are a

¹⁵Barcelona 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).

¹⁶The importance of proto-industrialization has been disputed (Coleman, 1983).

¹⁷Data on deaths caused by military operations in the early modern period is sketchy. Landers (2003) offers an overview of battlefield deaths. 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.

¹⁸Since 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.

lower bound for the impact of warfare on aggregate death rates before 1700. In the 19th century, warfare was less likely to spread new germs, since areas touched by troop movements were now integrated by extensive road, canal, and railway networks. In our calibrations, we are going to work with conservative assumptions – a rise in death rates by between 40% and 100% during wartime.

The "Great Plague" of 1347-48 was devastating. Less well-known is the fact that the Black Death of Middle Ages was followed by a wave of outbreaks. These only peaked during the early modern period. Many of them were linked to warfare, such as the outbreaks in Germany during the Thirty Years War. 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).

[Insert Figure 2 here]

Warfare is expensive, and it became ever more so during the early modern period. Money formed the sinews of power (Brewer, 1991; Landers, 2003; Tilly, 1992). The "military revolution" produced a need for professional, drilled troops, Italian-style fortifications, ships, muskets, and cannons. 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. Less fortunate princes tapped cities for 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, and fighting longer, became more readily accessible.

Compared to warfare, trade in early modern Europe was probably a less effective, but more frequent cause of disease. The Black Death in the 14th century spread along trade routes (Herlihy, 1997). The close link between trade and infectious disease is the reason why quarantine measures became increasingly common as time wore on. The last outbreak in Europe occurred in Marseille in 1720, and is also linked to long-distance trade. A plague ship from the Levant, with 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 effect of the Black Death on wages created knock-on effects. These raised mortality rates yet further. Finally, there were interaction effects between the channels we have highlighted. The effectiveness of quarantine measures, 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 other parts of the world.

The Destructiveness of War

Early modern war could be deadly (mostly because of disease), and it could destroy farms, infrastructure, and capital. The siege and sack of a city, for example, could inflict major damage to civilian property. Since many houses before the 18th century were constructed out of wood, they burnt easily. In the countryside, cattle and horses were regularly stolen by the raiding parties of advancing armies. Where seed

grain was taken, famine in the following year became likely. Murder and rape were common. Long-distance trade became hazardous, and often declined markedly. Mercenary armies, often undisciplined, were particularly feared. Where fighting continued for prolonged periods – such as along the Rhine in Germany during the Thirty Years War, and in Northern Italy – large population losses could coincide with severe economic dislocation (Landers, 2003).

Despite all this, de Vries (1976) concluded in *Europe in an Age of Crisis* that “it is hard to prove that military action checked the growth of the European economy’s aggregate output.” For all its horrors, the economic losses induced by early modern warfare were often limited, and they did not last long. Malthus himself, in his *Essay on Population*, noted the remarkable ability of early modern economies to bounce back from war-induced destruction (Malthus, 1798):

The fertile province of Flanders, which has been so often the seat of the most destructive wars, after a respite of a few years, has appeared always as fruitful and as populous as ever. Even the Palatinate lifted up its head again after the execrable ravages of Louis the Fourteenth.

A variety of compensating factors mitigated economic losses. In areas of frequent troop movement, peasants developed sophisticated early warning systems. By 1645, a Franconian official informed the prince that all of his subjects had fled to town in the area, taking every moveable good with them (Parker, 1987). Since advancing troops relied on food and fodder from the countryside, in areas with regular troop movement, plunder and extortion was quickly transformed into a system of tax-like contributions. Destruction of capital mattered less where it could be rebuilt quickly. Houses were often made of timber. These were easy to reconstruct. For example, after the Turkish siege of Vienna in 1683, the Venetian ambassador marvelled at the fact that “the suburbs as well as the neighbouring countryside have been completely rebuilt in a short space of time” (Tallett, 1992). A detailed study of the military conflict and rural life in the war-torn Basse-Meuse region in France found that the regional impact was largely mitigated by local adaptation (Gutmann, 1980).

Where fields went untended, fertility subsequently increased – a form of involuntary fallowing facilitated nitrogen fixation in the soil. Farm animals have high fertility rates, and losses of livestock can be made up quickly. Where food production fell, prices soared. This provided a windfall for surviving farmers. Well-disciplined troops also spent funds. Supplying them represented a business opportunity. While the taxes and debts that supported wartime expenditure may have been distortionary, it is not clear how much of it was ‘wasted.’ Pay constituted the single largest expenditure item, and was recycled in the local economy. Armies were generally small, recruiting no more than 0.5-1.5 percent of total population until the end of the 18th century. Moreover, men serving in the field were rarely drawn from the productive segments of society. Finally, war-induced mortality, where it resulted from poor nutrition, was probably concentrated amongst the more vulnerable groups – the young and the elderly (Tallett, 1992). Thus, war reduced the dependency burden.

Early modern states tried to limit the destructiveness of wars. The Thirty Years War was devastating, but it was not the norm. Italian condottieri leading mercenary armies often avoided pitched battles, reducing the loss of valuable fighting men. As armies grew in size after 1500, they became more disciplined. Articles of war became more common, and were enforced more rigorously. The use of mercenaries declined. Where the armies of Wallenstein and Tilly during the Thirty Years War had often plundered and

killed indiscriminately, the well-trained troops of the eighteenth century often lived on food supplies from strategically positioned magazines (Parker, 1988). Attrition became less important as a way to subdue the enemy; manoeuvre warfare gained in relative importance.

None of this is to say that war had lost its destructiveness by the end of the early modern period. Yet its impact cannot be compared with that of modern-day conflict. Military technology was too primitive to cause widespread destruction of capital stock. Where conflict was frequent, local economic structures adapted. Negative effects were thus primarily short-run, reflecting the local destruction of livestock, capital, and the disruption of communications. Once hostilities ceased, compensating factors – such as the boost to land productivity from fallowing – made good many of the losses. In our modeling, we will assume that war shifted the mortality schedule, and may have reduced TFP in the short term, but that it did not affect productivity in the long run.

China in the early modern period saw markedly less warfare than Europe. 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.¹⁹ The history of epidemics in China suggests that by 1000 AD, disease pools had become largely integrated (McNeill, 1977). 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

3 The Model

This section presents a simple two-sector model that shows how shifting mortality determined 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 that wages are the only source of income. Mobility of the workforce ensures that rural and urban wages equalize. 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 nutrition. Higher wages, and thus higher food consumption, translate

¹⁹While 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 centers were large, and travelers had to traverse more mountainous terrain.

²⁰We are indebted to David Weil for this point. Weil (2004) shows the marked similarity of agricultural conditions in large parts of modern-day China.

²¹During the early modern period, a substantial share of manufacturing took place outside cities – a process called "proto-industrialization" by some. We abstract from it since cities still grew, and our key mechanism remains intact, even if some of the additional demand translated into growth for non-urban manufactured goods.

into more births and lower mortality. The economy is Malthusian – per capita income stagnates and depends on the location of the fertility and mortality schedules. In the absence of technological progress, death rates equal birth rates, and N is constant in equilibrium. An increase in productivity temporarily relieves Malthusian constraints; population can grow. Without *ongoing* productivity gains, however, the falling land-labor ratio drives wages back to their original equilibrium level. Per-capita income is thus self-equilibrating.

An epidemic like the plague has an economic effect akin to technological progress: it causes land-labor ratios to rise dramatically. This leaves the remaining population with greater per-capita income, which translates into more demand for manufactured goods. As a consequence, urbanization rates have to rise. In the absence of ongoing 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 Growth' start to ride after the plague: Wars become more frequent. Cities grow, and raise aggregate mortality. Increasing trade, linking the urban nuclei, spreads disease, as do wars. As these three factors grow in importance, the aggregate death schedule shifts up. 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. It is important to note that our model does not deliver ongoing growth of per capita incomes. Rather, it describes the transition from one long-run equilibrium to another. We argue that these changes capture an important dimension of the European experience in the centuries between the Black Death and the Industrial Revolution.

3.1 Consumption

Each individual supplies one unit of labor inelastically in every period. There is no investment – all income is spent to consume agricultural goods (c_A) and manufactured goods (c_M). Agents choose their workplace in order to maximize income. When migration is unconstrained, this equalizes urban and rural wages: $w_A = w_M = w$.²² The resulting budget constraint is $c_A + p_M c_M \leq w$, 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 – mortality increases continuously as c_A falls below \underline{c} . While the wage rate is below \underline{c} , any increase in income is spent on food. Preferences take the Stone-Geary form and imply the composite consumption index:

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

Where $\phi > 0$ is a constant. Given w , 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 $c_A = w_A < \underline{c}$.

²²In 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.

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

$$\begin{aligned}\frac{c_A}{w} &= \alpha + (1 - \alpha) \left(\frac{\underline{c}}{w} \right) \\ \frac{p_M c_M}{w} &= (1 - \alpha) - (1 - \alpha) \left(\frac{\underline{c}}{w} \right)\end{aligned}\quad (2)$$

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

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

$$Y_A = A_A N_A^\beta L^{1-\beta} \quad (3)$$

where A_A is a productivity parameter and β 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:

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

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

$$Y_M = A_M N_M \quad (5)$$

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.

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; manufacturing production starts. Under unconstrained migration, which we assume for now, urban and rural wages equalize. As productivity increases further, urbanization and wages grow in tandem. Appendix A.1 describes the model with constrained migration.

[Insert Figure 3 here]

3.3 Population Dynamics

Birth and death rates depend on nutrition, measured by food consumption c_A .²³ Individuals procreate at the rate

$$b = b_0 \cdot (c_A/\underline{c})^{\varphi_b} \quad (6)$$

where $\varphi_b > 0$ is the elasticity of the birth rate with respect to nutrition, and b_0 represents the birth rate at subsistence consumption. In the absence of the 'Horsemen effect,' the aggregate death rate falls with income and is given by

$$d = \min\{1, d_0 \cdot (c_A/\underline{c})^{\varphi_d}\} \quad (7)$$

where $\varphi_d < 0$ is the elasticity of mortality with respect to food consumption and d_0 is the death rate at subsistence income.

Next, we introduce the Horsemen in our model. These raise mortality. Higher city death rates contribute to this directly. Thus, increasing urbanization led to higher average mortality. The corresponding impact on aggregate death rates is given by $n_M \Delta d_M$, where Δd_M represents city excess mortality.²⁴ In addition to this direct effect, growing income and urbanization also indirectly increased mortality – by fostering wars and trade, spreading diseases. A poor economy with little urbanization has few funds for warfare, nor demand for goods traded over long distances; germ pools remain largely isolated. 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 with Δd_M , 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:

$$h(n_M) = \Delta d_M n_M + \begin{cases} 0, & \text{if } n_M \leq \underline{n}_M \\ \min\{\delta (n_M - \underline{n}_M), \bar{h}\}, & \text{if } n_M > \underline{n}_M \end{cases} \quad (8)$$

The first term is the direct impact of urbanization on aggregate death rates, while the second term represents the indirect effect following from the spreading of diseases through increased warfare and trade. The maximum additional mortality due to trade and warfare is given by \bar{h} ; $\delta > 0$ is a slope parameter, and \underline{n}_M is the threshold urbanization rate where the indirect effect sets in.²⁵ The role of the plague in our model is to introduce germs and to push p.c. income to levels where $n_M > \underline{n}_M$. 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

²³In the working paper (Voigtländer and Voth, 2008) we present an alternative modeling strategy, where fertility and mortality depend on a measure of real income. The results are very similar to the ones presented here.

²⁴Higher city mortality arguably lowers the utility of urban workers. In the working paper version (Voigtländer and Voth, 2008) we take this fact into account for endogenous individual workplace decisions. As a result, urban wages are above their rural counterparts, compensating for higher city mortality. While adding historical realism, this more complicated setup does not affect our main results. In addition, the calibration below shows that the direct contribution of city excess mortality to aggregate death rates is the least important of the three Horsemen. To keep the model simple, we therefore abstain from explicitly modeling the impact of Δd_M on workplace decisions.

²⁵A more detailed justification for $\underline{n}_M > 0$ 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.

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.

In the presence of the 'Horsemen effect,' aggregate mortality is given by

$$d^h = d + h(n_M) \tag{9}$$

When the Horsemen ride, increasing income has an ambiguous effect on mortality. On the one hand, larger food consumption translates into lower death rates in (7). On the other hand, manufacturing demand rises with income, driving more people into cities where mortality is higher. In addition, urbanization (proxying for the spread of epidemics through trade and wars) also implies larger overall background mortality. The aggregate impact of income on mortality depends on the model parameters. Our calibration in section 4.1 shows that death rates increase in income over some range.

Population growth equals the difference between the average birth and death rate, $\gamma_{N,t} = b_t - d_t^{(h)}$, where the latter can include the 'Horsemen effect,' as indicated by the superscript (h). The law of motion for aggregate population N is thus

$$N_{t+1} = (1 + b_t - d_t^{(h)})N_t \tag{10}$$

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

3.4 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. Food consumption c_A is shown on the horizontal axis. We choose $\underline{c} = 1$. Relatively low death rates give rise to equilibrium A: a poor economy with below-subsistence consumption ($c_A \leq \underline{c}$) 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_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. For a given technology, land per worker is therefore endogenously determined in the long-run equilibrium.

[Insert Figure 4 here]

In the absence of ongoing technological progress, there are two ways to achieve a permanent rise in per-capita income.²⁶ First, a permanent decline in birth rates. The European Marriage Pattern had 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 here. Higher death rates

²⁶We discuss the effect of continuous technological progress in detail below.

(d_H) imply lower population in equilibrium and therefore higher individual income, as represented by point B in figure 4.

Points A and B in figure 4 are long-run equilibria with endogenous population size. For a given technology A_A , output per worker is fixed in the long-run. 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

To check if overall productivity (determined by A_A and the land-labor ratio) is sufficient to ensure above-subsistence consumption, we construct the indicator \hat{w} , assuming that all individuals work in agriculture. Equation (3) with $N_A = N$ gives the corresponding per-capita income:

$$\hat{w} \equiv \frac{Y_A(N)}{N} = A_A \left(\frac{L}{N} \right)^{1-\beta} \quad (11)$$

If $\hat{w} \leq \underline{c}$, all individuals work in agriculture 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 city population. In order to derive the long-run equilibrium, we calculate birth and death rates according to equations (6) and (7).²⁷ 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 (11).

Above-Subsistence Consumption

If $\hat{w} > \underline{c}$, 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 in cities and the countryside. Productivity increases lead to more manufacturing demand and spur migration to cities, which occurs until $w_M = w_A$. For small productivity changes, migration is minor and cities can absorb enough migrants to establish this equality immediately. We refer to this case as equilibrium with unconstrained city growth. Goods market clearing together with equations (2), (3), and (5) implies

$$A_A N_A^\beta L^{1-\beta} = [\alpha w + (1 - \alpha)\underline{c}] N \quad (12)$$

$$p_M A_M N_M = [(1 - \alpha)(w - \underline{c})] N, \text{ if } \hat{w} > \underline{c} \quad (13)$$

Substituting $w_M = p_M A_M$ into (13) and using $(1 - n_A) = N_M/N$ yields the employment share in agriculture:

$$n_A = \alpha + \frac{(1 - \alpha)\underline{c}}{w}, \text{ if } \hat{w} > \underline{c} \quad (14)$$

Consequently, the share of agricultural employment decreases in wages, while urbanization $n_M = 1 - n_A$ increases. The responsiveness of urbanization to wages is the stronger the smaller α – a result that we

²⁷Note that the 'Horsemen effect' is zero because $n_M = 0$.

use to calibrate this parameter. The missing piece to solve the model is the wage rate. To obtain w , we divide (12) by N . This yields

$$\alpha w + (1 - \alpha)\underline{c} = A_A [n_A(w)]^\beta \left(\frac{L}{N}\right)^{1-\beta}, \quad (15)$$

which says that per-capita food demand (LHS) equals per-capita production in agriculture (RHS), with the rural employment share n_A depending on wages as given in (14). This equation implicitly determines the wage rate for a given population size N . It has a unique solution, and w increases in A_A and L/N . Given w and $p_M = w/A_M$, food and manufacturing consumption follow from (2), labor shares from (14), and demographic variables from (6)-(8).

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 for given N . We then iterate the above system of equations, deriving N_{i+1} in each iteration i from (10), 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 . Wages in the long run, however, depend only on the intersection of the b and d schedules, and are independent of the levels of A_A , A_M , or L .

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.

4.1 Calibration

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%.²⁸ For cities to exist in our model, food consumption has to be above subsistence, i.e., $c_A > \underline{c}$ in the long-run pre-plague equilibrium. For the intersection of b and d to lie to the right of \underline{c} , death rates must be higher than birth rates at the subsistence level, $d_0 > b_0$. The exact parameter values depend on the slope of the birth and death schedules. Kelly and Ó Grada (2008) estimate the elasticity of birth rates with respect to income before the Black Death (1263-1348). We use the average of their results, $\varphi_d = -0.55$. This is very similar to the figures estimated by Kelly (2005), who derives figures for the period 1541-1700.²⁹ For the elasticity of birth rates with respect to real income, we use the estimate in Kelly (2005) of $\varphi_b = 1.41$. Both φ_d and φ_b rely on estimates for England as a best-guess for Europe. This is a conservative assumption for our

²⁸Maddison (2001) reports 0% in 1000 and 6.1% in 1500; de Vries (1984) documents 5.6% in 1500. Our 3% for the 14th century is at the upper end of what we expect, given that living standards were under severe downward pressure before the plague (Herlihy, 1997). We deliberately make this conservative choice, leaving less urbanization to be explained by our story.

²⁹Kelly and Ó Grada (2008) find $\varphi_d = -0.59$ for 20 large manors and -0.49 for the full sample of 66 manors. These numbers coincide with the one estimated by Kelly (2005), who finds $\varphi_d = -0.55$ using weather shocks as a source of exogenous variation.

purposes, since the operation of the Poor Law is likely to have dented the operation of Malthus' "positive check" in England. Without the buffer of income support, death rates elsewhere are likely to have spiked more quickly in response to nutritional deficiencies.³⁰ Regarding the level of birth and death rates, we use b and $d = 3.0\%$ in the pre-plague equilibrium, which is in line with the rates reported by Anderson and Lee (2002). This, together with the elasticities and the pre-plague urbanization rate of 3.0%, implies $d_0 = 3.07\%$ and $b_0 = 2.72\%$.

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 level derived from the intersection of b and d , we can calculate the corresponding population N .³¹ We choose parameters such that initial population is unity ($N_0 = 1$). This involves the initial productivity parameters $A_{A,0} = 0.472$, $A_{M,0} = 1.102$, and $L = 8$, where land is fixed such that its hypothetical rental rate is 5%.³² 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., $p_{M,0} = 1$.³³ Since our baseline calibration refers to Europe, we take city excess mortality into account when deriving aggregate death rates in the pre-plague equilibrium.

For the baseline model, we use the labor income share in agriculture $\beta = 0.6$. This is similar to the value implied by Crafts (1985), and is almost identical with the average in Stokey's (2001) calibrations. We normalize the minimum food consumption \underline{c} to unity. For low wage levels, all expenditure goes to agriculture. With higher p.c. income, manufacturing expenditure share and urbanization grow in parallel. To derive this relationship, we pair income data from Maddison (2007) with urbanization rates from de Vries (1984). In the model, the responsiveness of urbanization to income is governed by the parameter α . Figure 5 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 individual income went hand-in-hand with higher urbanization rates. Our calibration, derived with a model parameter of $\alpha = 0.68$, traces out the pattern in the data.

[Insert Figure 5 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 $\gamma_A = 0.1\%$ in our simulations with technological progress.

In Europe, the 'Horsemen effect' raises background mortality. The first Horseman, urbanization, comes into play as soon as people start dwelling in cities, where death rates are high. As discussed in the historical overview section, death rates in European cities were approximately 50% higher than in the

³⁰These elasticities are bigger than the estimates in, say, Crafts and Mills (2008), or in Anderson and Lee (2002). Because of endogeneity issues in deriving a slope coefficient in a Malthusian setup, 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. For the same reason, we are not convinced that Malthusian forces weakened substantially in the early modern period, as argued by Nicolini (2007), Crafts and Mills (2008), and Galloway (1988).

³¹For example, rural population is implicitly given by (4), and is the larger (for a given wage) the more land is available. We calculate the long-run equilibrium by solving for birth and death rates for given N , and then iterate 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.

³²Recall 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 unity and included in A_A . We leave L in the equations for the sake of arguments involving the land-labor ratio.

³³Other values of the relative price, resulting from different $A_{M,0}$ relative to $A_{A,0}$, do not change our results.

countryside. This implies a value of $\Delta d_M = 1.5\%$. The first term in equation (8) captures the direct effect of urbanization on background mortality. It is, however, not the biggest contributor to higher average death rates. On average, European urbanization grew from approximately 3 to 9.2 percent between 1300 and 1700. This implies that in 1300, average death rates were boosted by 0.05% - 0.07%; by 1700, this had risen to 0.14%-0.22%. This suggests a boost of between 0.09% and 0.15% from urbanization itself. If the smaller, and less crowded cities of medieval Europe did not generate a large urban mortality penalty, the boost coming from urbanization may have been even higher (with a maximum of 0.22% if the medieval penalty was zero, and by 1700, it had reached 0.22%). To err on the side of caution, we will use 0.09% as the most likely value for the contribution of urbanization to higher death rates.

After the Black Death, this direct effect is reinforced by rising mobility and the spreading of diseases. Warfare and trade grow with p.c. income, and greater mobility leads to an ongoing dispersion of germs. According to equation (8), these indirect Horsemen are at work when the urbanization rate n_M is larger than the threshold level \underline{n}_M . We choose $\underline{n}_M = 3.5\%$, which is above the pre-plague urbanization rate. The indirect 'Horsemen effect' begins to play a role only if city wealth becomes large enough to support the cost of warfare. Below \underline{n}_M , city income is too low to be taxed or expropriated, serving merely to provide elementary nutrition and basic manufacturing goods. This implies an important non-linearity – even in the face of massive population losses, expropriable surplus may rise considerably. This will be especially true if starting levels are close to subsistence, as they probably were in Europe before the plague.³⁴ Effectively, war is a "luxury good" for rulers, as a function of per capita income of their subjects. Once cities are large enough, the 'Horsemen effect' increases steadily in the urbanization rate until it reaches its maximum.³⁵

In order to calibrate the maximum impact of warfare 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 1700.³⁶ Figure 6 shows that this measure grows from about 12% in 1500 to roughly 50% around 1700, and decreases in the 18th century.³⁷ 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 40 to 100% (see section 2). The impact of war was local, but we focus on nationwide effects to match the construction of the war frequency variable, which also uses nations as the unit of analysis. Given

³⁴Kelly and Ó Grada (2008) offer evidence on how close to the minimum large parts of the English population were before 1350.

³⁵Our 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.

³⁶Linear interpolation is used for the years where no population data are available. To avoid the confounding effects of shifting borders, we keep these constant. We count all countries at war as affected because troop movements also occur within countries even when there is no fighting on their own soil.

³⁷The 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.

equilibrium death rates of 3%, this implies an additional 1.2-3 percent under warfare. Throughout the second half of the 17th century, on average 38% of the European population were affected by wars. Based on the period with the largest war frequency in early modern times, we derive the maximum war-related mortality increase:

$$\text{Excess death under warfare} \times \text{max. share of population affected} = [0.46 - 1.14\%]$$

In the baseline calibration, we use a point estimate close to the center of this interval – a maximum war-related ‘Horsemen effect’ of 0.75%.

To this we add an estimate of 0.25%, caused by epidemics spread via trade. We do not know with certainty how many extra deaths were caused by the growth in trade that followed from higher per capita incomes. Modern data can help to gauge the broad effects. Oster (2009) argues that in the case of HIV in Africa, a doubling of trade leads to between a doubling and a quadrupling of infections. If infectious disease in the pre-plague equilibrium accounted for only one death out of eight, an increase in the death rate by 0.25% via this factor is plausible.³⁸ This probably constitutes a lower bound on death by diseases spread via trade routes – plague, typhoid, smallpox and influenza are more infectious than HIV, and they cause rapid death. Overall, our best guess for the sum of the two indirect ‘Horsemen effects’ – due to warfare and trade – is $\bar{h} = 1\%$. This value is reached during the 17th century, which saw particularly savage warfare, with troop movements over a very wide area, and for extended periods (Levy, 1983). Urbanization rates reached 8% in the mid-17th century (de Vries, 1984). The implied slope parameter of the Horsemen function is therefore $\delta = \bar{h}/(0.08 - \underline{n}_M) = 0.222$.

[Insert Figure 6 here]

Migration from the countryside to cities was not immediate. Cities could not absorb migrants overnight. In the case of larger inflows, new dwellings and infrastructure had to be provided. Building new houses and enlarging cities was one of the costliest undertakings in the early modern economy. The arrival of numerous migrants caused over-crowding, making further migration to the cities less attractive. To capture these difficulties during the transition phase, we assume that city growth was constrained. We explain this extension to the baseline model in Appendix A.1. While none of the long-run results depend on this assumption, we gain historical realism and can compare predicted transitional dynamics to the data. We set maximum urban growth to the highest growth rate observed over the period 1500-1800, equivalent to $\bar{v} = 0.4\%$.³⁹ Table 1 summarizes the calibrated parameters.

[Insert Table 1 here]

³⁸To gauge magnitudes, we calculate as follows: Trade grows with elasticities of 0.8 and 0.65 with respect to income of country A and B, as in the gravity model estimated by Bergstrand (1985, table 1, column 1). This implies that as overall income doubles, trade rises by 145%. We focus on the period 1500-1700, where income data are available. In order to provide a conservative estimate, we consider only the per capita component of overall income growth. That is, we do not take into account the contribution of population growth to aggregate income increases, because growing population might reflect the return to long-run levels after the Black Death. Using Bergstrand’s elasticity, combined with the fact that p.c. incomes grew by approximately 30%, suggests that trade may have grown by 44% during our period. Using the average elasticity of 1.5 from Oster (2009), infectious disease should have increased by 65%. For the aggregate death rate to increase by 0.25% as a result of more trade after the plague, an annual 0.38% of the population must have fallen victim to infectious diseases before the plague. This corresponds to approximately one out of every 8 deaths in the pre-plague equilibrium.

³⁹This was observed during the period 1550 to 1600, according to de Vries’ (1984) data.

4.2 Plague and Equilibrium without 'Horsemen Effect'

The left panel of figure 7 shows the pre-plague equilibrium without the 'Horsemen effect.' This reflects conditions in China, where urbanization did not raise background mortality. The fertility and mortality schedules intersect at a rate of approximately 3% for each, while 2.7% of the population live in cities. The economy is trapped in Malthusian stagnation in point C .⁴⁰ 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 7 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 7 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 C , with fertility higher than mortality. The falling land-labor ratio eventually drives the economy back to C , 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'

Three Horsemen of Growth – urbanization, trade and war – increased per capita incomes in early modern Europe. Figure 8 shows their respective contributions. City mortality alone would have raised urbanization by over one percent. Trade's effect is similar, but slightly larger. The single biggest contributor to rising incomes, according to our baseline calibration, is war. It alone raises urbanization rates by approximately 4%. In combination, our "three Horsemen" can account for an increase in the percentage of Europeans living in towns and cities from 2.7% in C to approximately 9% in E_H .

[Insert Figure 8 here]

Compared to China, Europe was highly fragmented. Geography threw up greater barriers to political, economic and trade integration. These factors produced a knock-on effect of one-time increases in p.c. income. If the shock was large enough, like the Great Plague, higher incomes generated more trade and provided the means for more wars. The economy can converge to a new equilibrium with higher mortality, but also higher p.c. income and urbanization. The left panel of figure 9 shows the two stable equilibria, E_0 and E_H , and an unstable equilibrium, E_U . Initially, the economy is in E_0 , and all variables remain unchanged in the absence of technological progress. In order to initiate the transition from E_0 to E_H ,

⁴⁰Note that the urbanization rate in equilibrium C is below the pre-plague level of 3% for Europe. The reason is that the direct 'Horsemen effect' – excess city mortality – is not at work in China, so that average mortality is slightly lower than in Europe, implying lower equilibrium urbanization. This difference becomes apparent when comparing C and E_0 in figure 9.

a shock to population (or productivity) must be large enough to push the economy beyond E_U , where Horsemen-augmented death rates exceed birth rates.⁴¹ We argue that early modern Europe underwent such a transition.

Following the Black Death, 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 6, and captured by (8) in our model. The economy converges to the 'Horsemen equilibrium' (point E_H in figure 9) in the aftermath of the Great Plague. This equilibrium is characterized by higher birth and death rates (about 3.8%) and higher urbanization (9%). 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.'

[Insert Figure 9 here]

4.4 The Role of Technological Progress

Technological progress in pre-modern 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. The new long-run equilibrium can be derived from equation (3). Constant p.c. income (and thus a constant agricultural labor share) implies $\gamma_N = \gamma_A / (1 - \beta)$, with γ_A representing TFP growth. Thus, in the long-run equilibrium population growth is proportional to the rate of technological progress, and this relationship is the stronger the larger the labor share β in agricultural production. Intuitively, if β is small the fixed factor land is important – when technology pushes p.c. income up and N responds, decreasing returns quickly offset any technological gains and keep population in check.

The setup with ongoing technological progress 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. 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

⁴¹With 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.

income. Our calibrated model therefore suggests that the effect of technological progress in early modern Europe was markedly smaller than the impact of rising death rates.

[Insert Figure 10 here]

How fast would technology have to improve to explain the rise of early modern Europe? Based on Maddison's (2007) figures we derive a lower bound, focusing on the period 1500-1700. Over these two centuries, European p.c. income increased by 30%. If technological improvements were the sole cause for this rise, the rate of population growth in 1700 would be at least 1.7%.⁴² To sustain per capita incomes at 30% above the 1500 level, technological progress would have to offset the rapid population growth, which implies TFP growth rates of $\gamma_A = (1 - \beta)\gamma_N \simeq 0.7\%$. TFP increases of this magnitude were not observed before the second half of the 19th century (Crafts and Harley, 1992; Antràs and Voth, 2003). If we assessed the strength of Malthusian responses accurately, technological progress cannot be a candidate to explain the rise of Europe in the early modern period.

4.5 Model Fit

How well does the model fit the data? We begin simulations in 1000 AD in order to show both the pre- and post-plague fit of the model.⁴³ 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. In other words, technological progress alone, without the Horsemen, translates into rapid population increases, while per capita income stagnates. On the other hand, the Horsemen alone, without TFP growth, deliver higher *per capita* income (figure 9), but *aggregate* income decreases because of the substantial population decline. Both mechanisms together deliver growing population and per capita income, and therefore also rising aggregate income.⁴⁴ A simple calculation sheds light on the relative importance of the two components. Using Maddison's (2007) numbers for Europe in 1500 and 1700, we find that rising per capital income accounts for 42 percent of aggregate GDP increases over this period, and population growth explains the remaining 58 percent.⁴⁵ Finally, figure 11 shows our simulation results together with the data. Our model performs well in reproducing both population growth and urbanization.

[Insert Figure 11 here]

⁴²To derive this number, we normalize p.c. income to unity in 1500, $y^{1500} = 1$, and set $b_0 = d_0 = 3\%$. Together with (6) and (7) this setup implies $\gamma_N^{1500} = 0$. We then use a linear approximation to derive the population growth rate, γ_N^{1700} , corresponding to the higher level of p.c. income in 1700. This yields $\gamma_N^{1700} = (\varphi_b - \varphi_d)b_0(y^{1700} - y^{1500}) = (1.41 + 0.5) \cdot 3\% \cdot 0.3 = 1.72\%$.

⁴³We allow technology to grow at $\gamma_A = 0.1\%$ throughout the simulation. The model is calibrated to yield the same pre-plague (1350) 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 $\gamma_A/(1 - \beta)$ in figure 10. The new equilibrium T then involves the same urbanization rate as the previous E_0 .

⁴⁴In our calibration, the rate of TFP growth $\gamma_A = 0.1\%$ is sufficiently large for productivity-driven population increases to overcompensate population losses due to the Horsemen.

⁴⁵Aggregate European GDP grew at rate of 0.31% p.a. between 1500 and 1700, with p.c. income and population growing at 0.13% and 0.18%, respectively.

4.6 Robustness of Calibration Results

Next, we examine the robustness of our calibration results. We test how stable our quantitative findings are if alternative parameter values are used, and explore the impact of adding negative short-run effects of wars on output.

Magnitude of Effects and Sensitivity of Main Results

The size of the 'Horsemen effect' is of central importance for our results. To shed light on the margin of error of the overall effect, we discuss the contribution of individual components. Data on excess city mortality are relatively reliable. Table 2 shows the corresponding magnitudes in 1300 and 1700 for various countries and two different city mortality penalties – one corresponding to our baseline calibration and the other representing an upper bound, 80%. The upper bound is derived from the ratio of Northern town mortality and the rural Sussex death rate in 1841 (Szreter and Mooney, 1998). Clark (2009) finds a similar differential between the offspring of urban and rural testators in early modern England.⁴⁶ From one country to the next, the magnitude of the direct 'Horsemen effect' varies substantially depending on overall urbanization rates. In England it is initially close to zero. As urban centers grow, it increases to 0.2-0.32 percent. In the most urbanized countries in Europe, such as the Netherlands, the direct effect can be as large as 0.5-0.8%. This is the same order of magnitude as the contribution of warfare in our baseline calibration.

[Insert Table 2 here]

On average in Europe, city mortality contributed 0.07 to 0.22% to overall death rates. We use a value of 0.14%. Figure 8 shows the effect. Compared to the equilibrium at point C, with no contribution of excess city mortality, this factor alone can account for 1.2% higher urbanization rates, or one fifth of the total.⁴⁷

Next, we turn to the indirect 'Horsemen effects' due to warfare and trade. In section 4.1 we argued that war related deaths added 0.5-1.0%, based on the war frequency in the second half of the 17th century. For trade we base our estimate of 0.25 percent on an analogy with the trade and HIV in modern-day Africa (Oster, 2009). Even if we use the lower bound of the warfare effect (0.5%), and assume zero for trade, we find substantially higher urbanization rates. Under these conservative assumptions, the two remaining effects (city death and warfare) raise urbanization rates to about 7 percent.

The responsiveness of population growth to p.c. income changes is also important for our findings. This variable is governed by the elasticity of birth and death rates to nutrition, based on Kelly's (2005) estimates for early modern Britain. More recent work by Kelly and Ó Grada (2008) confirms the orders of magnitude involved. If the *b* and *d* schedules are flatter than in our baseline calibration, population growth reacts more slowly to income increases. Consequently, there is more scope for technological progress to

⁴⁶The life expectancy at birth on farms in his sample is 41.8; in cities and towns, it falls from 32 to 29. The latter is derived from the weighted average of London mortality and that in other urban centers.

⁴⁷With 9.2 percent of the population living in cities in 1700, excess urban mortality add 0.14% to aggregate death rates (see table 2). Because of lower population pressure, urbanization rates rise by 1.2% above the initial level in *C*. However, without additional forces contributing to urbanization, the economy would eventually converge back to *C*. The direct effect alone can therefore not generate a sustainable increase in p.c. income and urbanization.

improve living standards. On the other hand, the model also becomes more sensitive to an increase in background mortality, which increases the power of the Horsemen. More precisely, if both b and d have only half the slope that we used in the baseline calibration, technological progress at 0.1% p.a. delivers a 9% increase in p.c. income (corresponding to roughly 4% increase in urbanization).⁴⁸ This leaves ample scope for the Horsemen of Growth to contribute to the rise of Europe.

Negative Impact of Warfare on Productivity

As discussed in section 2, early modern warfare was destructive, but on a limited scale. Productivity suffered in the short-run, as a result of the destruction of physical capital, slaughter of livestock, and the disruption of communications. These adverse effects normally disappeared quickly once armies moved on.⁴⁹ We now incorporate this negative impact into our model. In the modified setup, each country will be at war for four consecutive years in each decade. This is equivalent to the highest average observed for a fifty-year period in early modern Europe (see figure 6). Under warfare, TFP decreases by 1% (5%), and returns to the baseline level when hostilities cease. Death rates increase by Δd . To isolate effects, we assume that neither city mortality nor trade add to background mortality in this exercise. The remainder of the decade is peaceful, and death rates are at their baseline level. During wars, we use conservative values, $\Delta d = 1\%$ and 2% , and simulate the model without migration constraints and without technological progress.⁵⁰ Figure 12 shows the results.

[Insert Figure 12 here]

Initially, the economy is in equilibrium C (see e.g. figure 9). Periodic warfare sets in after 50 years. The left panel shows the effect of negative TFP shocks of 1% during wars; the right one, 5%. In both cases, p.c. income rises and population falls in the long-run. Per capita income fluctuates more strongly when warfare is assumed to have a large negative effect on TFP, but overall development patterns are unaffected. With $\Delta d = 1\%$, p.c. income fluctuates around 1.23, which corresponds to an urbanization rate of 6%. For the case of larger mortality rates due to warfare ($\Delta d = 2\%$), it fluctuates around 1.37, which implies urbanization rates of 8.5%. The latter value is very similar to the main result in the baseline calibration.

This modified analysis shows that our results are robust to relaxing two implicit assumptions. First, even with lower productivity under warfare, long-term p.c. income and urbanization rise. This is explained by the quick return of TFP to its pre-war level in early modern times, while population growth takes time to replace the deceased. Second, periodic warfare (with a large mortality increase during wars and zero additional mortality otherwise) delivers the similar results as continuous warfare (with a constant average impact on mortality).

⁴⁸To derive this result, we follow the approximation shown in footnote 42, using the fact that population must grow at $\gamma_N = \gamma_A / (1 - \beta)$ in steady state.

⁴⁹Even if warfare had a negative long-run impact on productivity, our main result would not change. Following the Malthusian logic, with lower productivity levels, population would be lower in equilibrium. But p.c. incomes would still rise with mortality.

⁵⁰These figures compare to the previous calibration as follows: With a maximum 38% of the European population affected by wars, 1 and 2 percent excess mortality during warfare translate into a 0.38 and 0.76 percent maximum war-related 'Horsemen effect,' respectively. The second value is therefore similar in magnitude to our baseline calibration.

5 Empirical Evidence

In this section, we argue that the 'Horsemen of Growth' can help us understand divergence within Europe – between a dynamic North-Western region and a stagnant Southern one. We focus on one of our horsemen: war. While urbanization rates and wages declined in the South, they rose in the North-West after 1500. AJR (2005) have emphasized growing constraints on the executive as a cause for the "Rise of Atlantic Europe". Extending their dataset, we show that this rise is observationally equivalent to increasing urbanization in the most belligerent and war-torn parts of Europe.⁵¹ Our results suggest that warfare was an additional determinant of income levels in Europe until 1700. Because war itself killed few people, we argue that this effect is driven by the epidemics that the movement of armies spread. We also argue that the effect is causal, by exploiting 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. Acemoglu, Johnson, and Robinson (2002b) present time-series and cross-section evidence for a close association between urbanization and per capita income before as well as after industrialization.⁵² 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).⁵³ 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 de Vries (1984). His data cover all cities with at least 10,000 inhabitants. As a result, de Vries' urbanization estimates are generally lower, but the pattern over time is similar. The higher reliability of these data comes at a cost: De Vries' 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, af-

⁵¹We 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 $N=2$, and data availability is poor, we use a panel on intra-European divergence to demonstrate the importance of one key channel – war.

⁵²One 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; de Vries, 1976, p. 164).

⁵³All country-level data are derived for borders as of 2001.

ter 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.⁵⁴ Our second 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 implied that disease, spread by warfare, was the largest single contributor 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:⁵⁵

$$u_{j,t} = \beta \text{war}_{j,t} + d_t + \delta_j + \gamma X_{j,t} + \varepsilon_{j,t} \quad (16)$$

where $u_{j,t}$ is the urbanization rate in country j at time t (or alternatively log per capita income), $\text{war}_{j,t}$ 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 individual income 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.⁵⁶ Consequently, while the ‘Horsemen effect’

⁵⁴What 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 capitals (in kilometers) that are obtained from <http://www.indo.com/distance/>. Just like country borders, country capitals 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.

⁵⁵Urbanization 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 minor effect on aggregate death rates.

⁵⁶While technological progress alone is not enough to significantly increase incomes, it can substantially affect population growth

on per capita income 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 (16) is the change in urbanization or per-capita income, and the explanatory variables are averaged over the corresponding period.⁵⁷

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.⁵⁸ Columns 1-4 of table 3 show that the correlation is highly significant and robust to excluding the great powers, 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 14 here]

[Insert Table 3 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 reverse causation. 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 4 shows that this relationship holds, on average, for the entire sample.⁵⁹ 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 (see figure 10).

⁵⁷This 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.

⁵⁸Maddison (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).

⁵⁹Results are very similar when using the median.

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.⁶⁰

[Insert Table 4 here]

Columns 6 and 7 of table 3 report the results of our IV estimation.⁶¹ 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 $d(war)/d(distance) = -.566 + .0018 \text{ altitude}$. 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.⁶²

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 1700.⁶³ 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.

⁶⁰This 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.

⁶¹Throughout 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.

⁶²The quality of our instruments, as indicated by Stock and Yogo (2002) test, is very close to the highest level, indicating 5% maximal IV relative bias.

⁶³This 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 de Vries (1984) – counting only cities with more than 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.

All results presented so far have used the urbanization rates calculated by AJR (2005) for the period 1300-1700. In Appendix A.2 we show that our results are robust to using urbanization rates from de Vries (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 log GDP per capita between 1500 and 1700 as the dependent variable. The results presented in table 5 confirm the ones found above for urbanization.⁶⁴ 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 5, 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 5 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 6 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 \times 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.⁶⁵ 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 3. As shown

⁶⁴The first-stage coefficients and statistics are not reported. They are almost identical to the ones shown in table 3.

⁶⁵This 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.

in the bottom of table 6, 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 exogeneity can be rejected at the 10% level.

[Insert Table 6 here]

The second column in table 6 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 1700.⁶⁶ 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 A.2 shows that our findings are robust to using urbanization rates from de Vries (1984).

GDP as dependent variable

Table 7 provides regression evidence using log GDP per capita as the dependent variable, keeping the same specifications as in table 6. 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 7 here]

5.5 Robustness of Empirical Results

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 main 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

⁶⁶The 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.

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, and latitude. These variables have been proposed as explanations of differential development by various authors.⁶⁷

[Insert Table 8 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 1700.⁶⁸ 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 more initial constraints on the executive 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, column 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 before 1700, the Atlantic trader variable does not appear as robust as the war measure. Only 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

⁶⁷Weber (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, Sachs, and Mellinger (1998).

⁶⁸Initial 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.

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 (Acemoglu, Johnson, and Robinson, 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 former 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. Far from undermining the growth of the European economy, we argue that they were important contributors to its economic ascendancy: Death and destruction spelled riches and power in the early modern period. We use a simple two-sector Malthusian model in which higher population implies lower incomes due to strongly declining marginal returns to labor. The Black Death marked a turning point for economic fortunes in early modern Europe. It killed between a third and half of the European population. In a normal Malthusian setting, a boost to incomes following an epidemic should have been transitory. Yet the plague shock was so big that subsequent changes effectively produced a "ratchet effect." Even high rates of fertility could not reverse the substantial wage gains for several generations. A set of changes in economic and political conditions helped to preserve wage gains. Europe's "golden age of labor" after 1350 saw richer individuals demanding more urban goods. Cities grew in response. Because early modern European cities were "graveyards" (Bairoch, 1991), this helped to stabilize incomes, by helping to reduce downward pressure on land-labor ratios. This is particularly true because city growth acted as a catalyst for European belligerence. With more money available for taxation and borrowing as a consequence of greater urban riches, princes fought more often, and for longer. Urban growth also spread disease through trade. These indirect repercussions of the Black Death we call the 'Horsemen of Growth' because they jointly increased mortality, thus helping to preserve post-plague wage gains.

We demonstrate that permanently higher mortality rates, driven by greater urbanization after the Black Death, were empirically important. In our calibrations, the mortality channel alone can account for at least half of the increase in per capita incomes in early modern Europe. Of this increase, the largest component comes from more frequent warfare. Trade and urbanization make smaller contributions. Elsewhere, we argue that fertility restriction may have been responsible for much of the remainder (Voigtländer and Voth, 2009). Shifting mortality schedules are also important for explaining divergence within Europe 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 this way, we can explain a good deal of the rise of North-Western Europe compared to the rest of the continent. The effect of war (and indirectly, trade) is broadly similar – if not stronger – than other leading explanations, such as Atlantic trade (AJR, 2005).

Non-reproducible factors of production, such as land, probably play a significant role in production in today's Third World (Weil and Wilde, 2009). That is why epidemics that boost death rates, such as AIDS, have the potential to raise per capita incomes (Young, 2005). Oster (2009) showed that HIV in

Africa spreads along trade routes. Since trade is linked to incomes, a similar feedback mechanism to the one we identified in early modern Europe may operate in developing countries. Urbanization and war, on the other hand, are unlikely to have similar effects. Military technology has become markedly more destructive. This limits the benign effects of rising land-labor ratios. In addition, cities are no longer notably less healthy than rural areas.

Why did war, disease, and urbanization not yield similarly advantageous results elsewhere? Neither plagues, war, nor cities were unique to Europe. However, European cities were remarkably unhealthy, for a variety of cultural reasons. The plague in China could not produce a similar, self-reinforcing cycle of higher incomes and rising mortality because one-off increases in wages did not produce a permanent increase in death rates via higher urbanization, and more war. Similarly, the Justinian Plague that hit Imperial Rome – possibly just as devastating at its 14th century counterpart – occurred at a time when Roman cities had ample supplies of clean water. Without city walls, they were also not as overcrowded as early modern European cities. The latter kept concentrating ever larger numbers of people in the same area, protected by fortifications. In both 14th century China and in Justinian Rome, another crucial ‘Horseman of Growth’ was also not available. Both regions were politically unified, and a rise in city wealth did not translate into more frequent warfare.⁶⁹

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 produced a mortality regime that was different from the one prevailing in other parts of the world.

Appendix

A.1. Congestion and Constrained City Growth

Income increases raise the demand for urban goods and thus manufacturing wages, attracting migration to cities. However, in the short-run migration is constrained because new dwellings and infrastructure must be provided. Too many migrants therefore lead to over-crowding, making further migration to urban centers unattractive. In the interest of simplicity, we capture congestion effects with an upper limit to the growth rate of cities, $\bar{\nu}$. When shocks are large, and urban-rural wage differentials are substantial, this constraint becomes binding. It then takes time until population shares reach their long-run equilibrium levels n_M^{LR} and n_A^{LR} , as given by the equation for unconstrained migration, (14).

Let $N_{A,t}^*$ and $N_{M,t}^*$ be the number of individuals living in the countryside and cities, respectively, at the beginning of period t . $N_M^{LR} = n_M^{LR}N$ denotes long-run urban population, i.e., the number of city inhabitants that would be established under unconstrained city growth if overall population is N . Next, we derive the growth of city population that occurs when migration is unconstrained, reaching the

⁶⁹Political fragmentation was also much lower in the Middle East, which was hard-hit by the 14th century plague. Much of it was quickly unified under first the Mamluks, then the Ottomans. This limited the potential for death rates to be driven up by continued fighting. In addition, the destruction of irrigation systems in the Middle East by the Mongols did much to undermine the economic viability of ‘hydraulic empires’(in Wittfogel’s phrase). Europe did not have similarly centralized, vulnerable infrastructure.

long-run equilibrium instantly.⁷⁰

$$\nu_t \equiv \frac{N_M^{LR} - N_{M,t}^*}{N_{M,t}^*} = \frac{n_M^{LR} - n_{M,t}^*}{n_{M,t}^*} \quad (\text{A.1})$$

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 the growth rate of urban centers, the constraint $\bar{\nu}$ becomes binding. In this case, replacing ν with $\bar{\nu}$ in (A.1) gives the law of motion for city population:

$$N_{M,t} = (1 + \bar{\nu})N_{M,t}^* \quad (\text{A.2})$$

The remainder of the population works in agriculture: $N_{A,t} = N_t - N_{M,t}$. Equilibrium wages, production, and relative prices under constrained city growth can be derived from the known location-specific employment. Note that urban and rural wages differ in this case. Agricultural wages are given by (4). The manufacturing wage depends on the relative demand for urban goods. Introducing location-specific wages in (2) together with market clearing yields an explicit solution for urban wages:⁷¹

$$w_M = \frac{1}{n_M} \frac{1 - \alpha}{\alpha} [w_A n_A - \underline{c}] \quad (\text{A.3})$$

Manufacturing products are sold at $p_M = w_M/A_M$. Workplace-specific food consumption follows from the corresponding wages and (2). Accordingly, fertility and mortality also vary by location, following from (6) and (7), respectively. Aggregate birth and death rates are weighted averages of the rural and urban rates. The 'Horsemen effect' is calculated as in the unrestricted case. While non of the long-run (or qualitative) results in this paper depend on the assumption of congestion and limited city growth, it is important for historical realism in the transitional dynamics.

A.2. Sensitivity to Alternative Urbanization Data

We examine the sensitivity of our results to an alternative choice of the dependent variable. De Vries' (1984) figures are often considered superior to the Bairoch et al. (1988) dataset. De Vries' 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 (de Vries). In tables A.1 and A.2, we use de Vries' 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]

⁷⁰More precisely, this is the growth rate of city population due to migration only. We implicitly assume that urban offspring 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 use to calibrate $\bar{\nu}$.

⁷¹A detailed solution of the model with location-specific wages and demand is provided in the working paper Voigtländer and Voth (2008).

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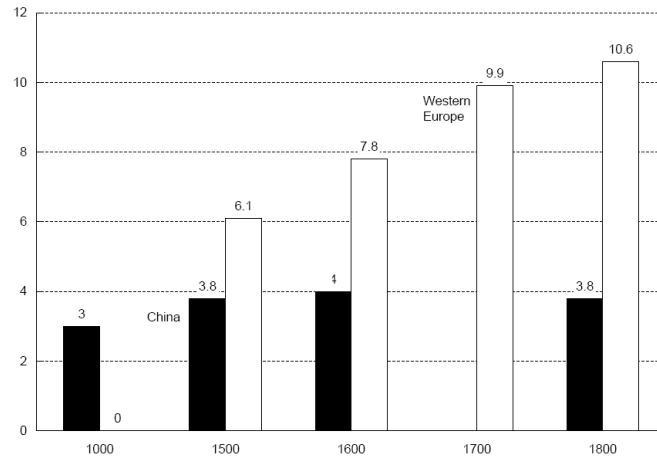
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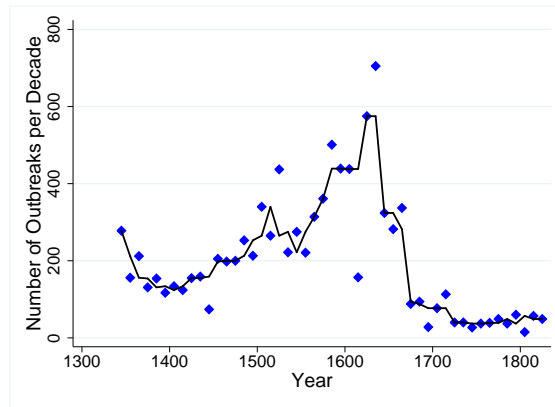
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Figure 1: Urbanization rates in China and Europe, 1000-1800.



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

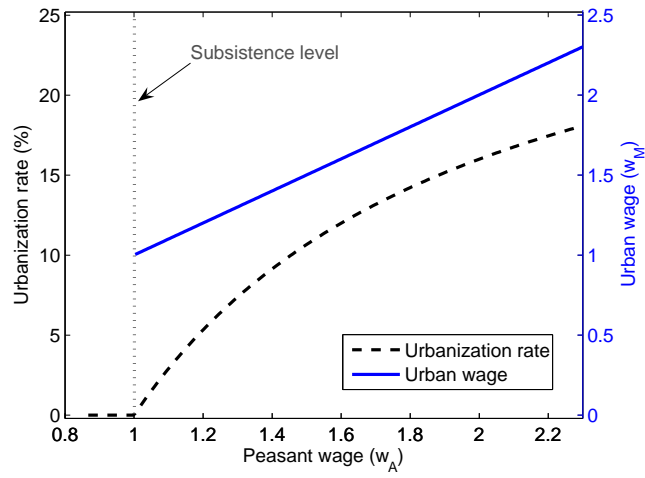


Figure 4: Population dynamics and equilibria

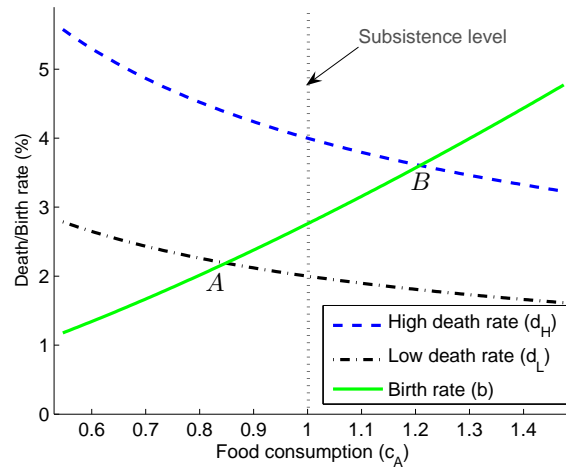
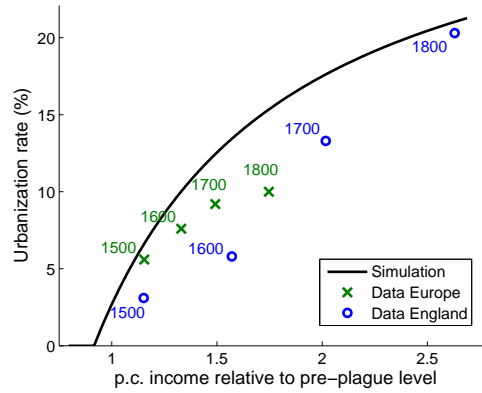
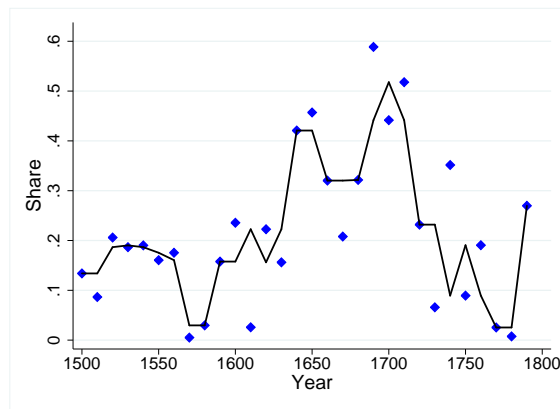


Figure 5: Urbanization and p.c. income – model vs. data



Data sources: p.c. income from Maddison (2007) is relative to the 1350 level (obtained with linear interpolation). Urbanization rates from de Vries (1984).

Figure 6: 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 7: Long-run impact of the plague, ceteris paribus

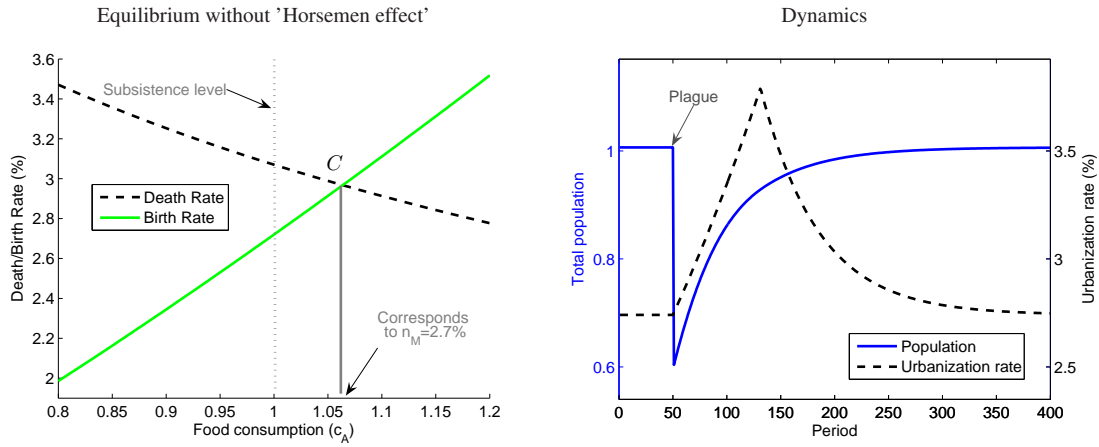


Figure 8: Contributions to overall 'Horsemen effect'

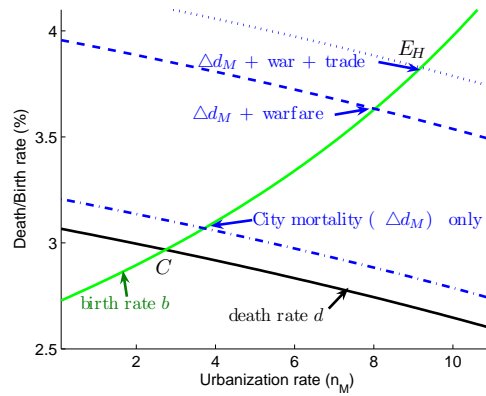


Figure 9: Long-run impact of the plague with 'Horsemen effect'

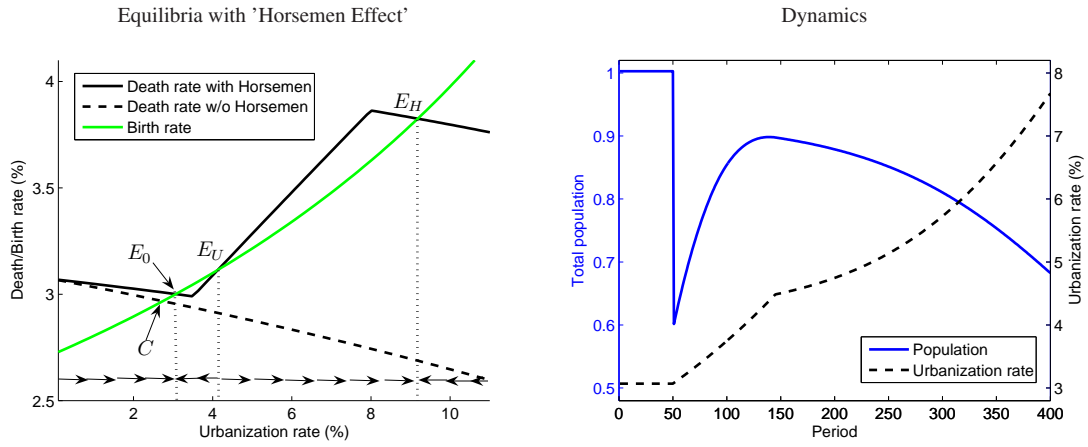


Figure 10: Effect of ongoing technological progress

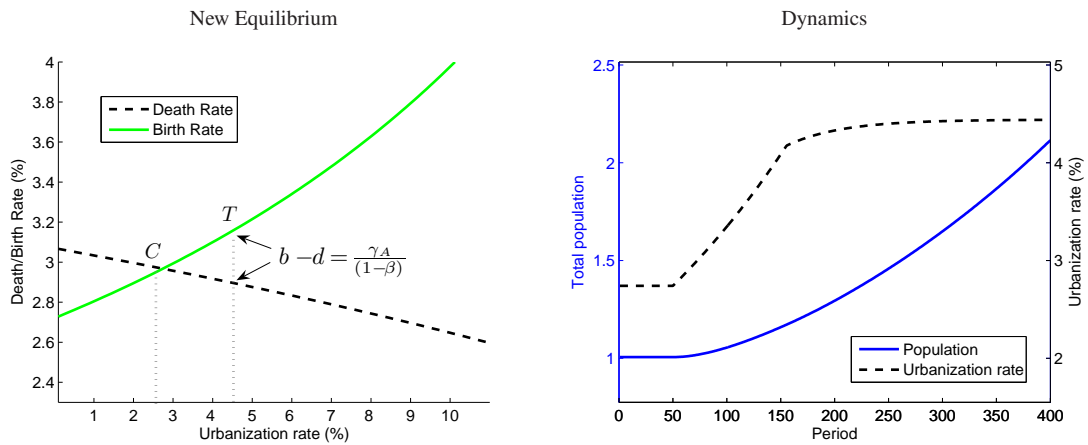
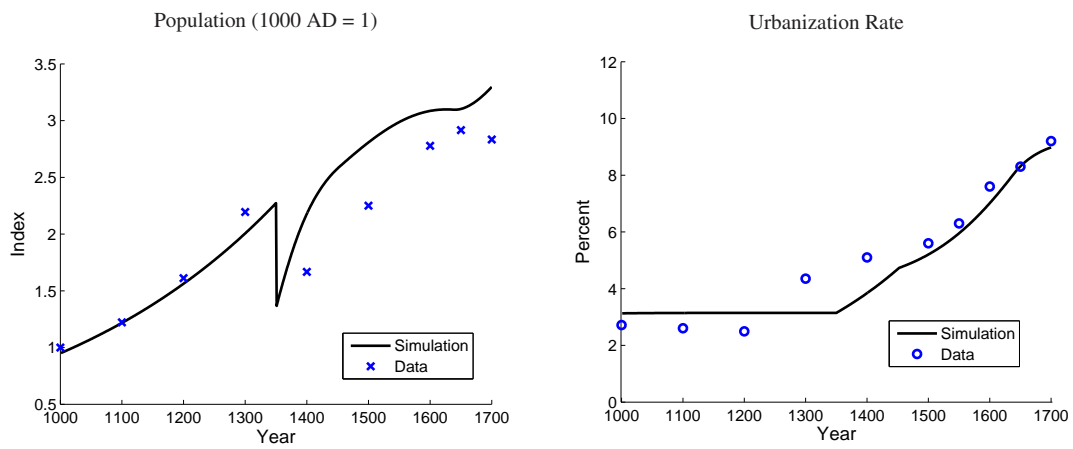


Figure 11: Europe: Simulation results vs. data



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

Figure 12: Robustness of Results: Negative impact of warfare on TFP

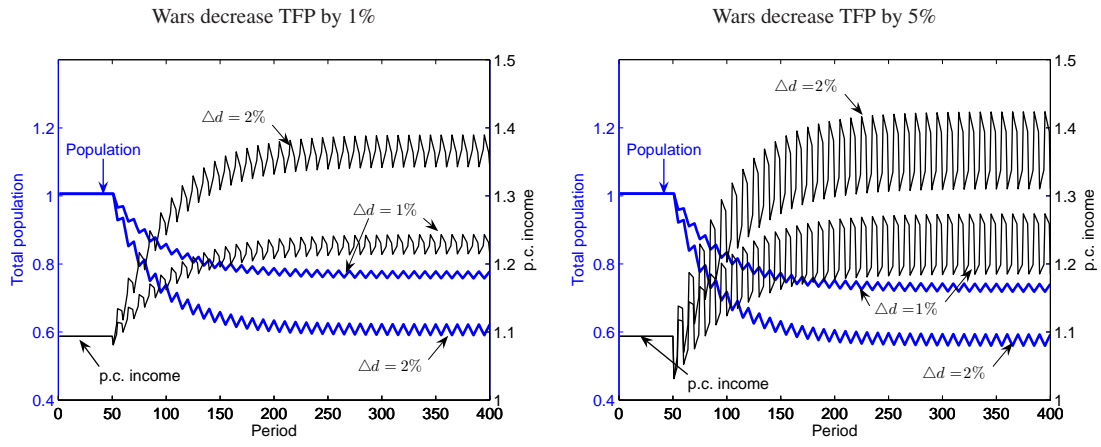


Figure 13: Warfare and European development

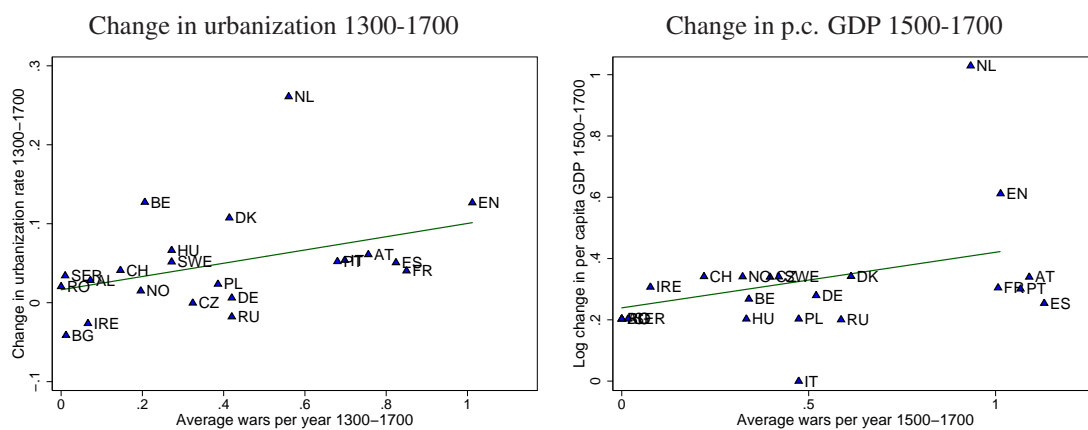


Table 1: Baseline Calibration

Symbol	Interpretation	Value
<i>Parameters</i>		
α	Responsiveness of urbanization to income	0.68
β	Labor share in agriculture	0.6
\underline{c}	Subsistence food consumption	1
L	Land	8
$A_{A,0}$	Initial TFP in agriculture	0.472
$A_{M,0}$	Initial TFP in manufacturing	1.102
γ_A	Rate of technological progress	0.1%
b_0	Birth rate at $c = \underline{c}$	2.72%
d_0	Death rate at $c = \underline{c}$	3.07%
φ_b	Elasticity of birth rates wrt. income	1.41
φ_d	Elasticity of death rates wrt. income	-0.55
Δd_M	City excess mortality	1.5%
\bar{h}	Maximum trade and war effect	0.01
\underline{n}_M	Threshold for trade and war effect	0.035
δ	Slope parameter for trade and war effect	0.22
\bar{v}	Upper bound on city growth due to congestion	0.4%
<i>Resulting values in long-run equilibrium before the Great Plague</i>		
N_0	Population	1.0
$n_{M,0}$	Pre-plague urbanization rate	3.0%
$b_0 = d_0$	Economy-average birth and death rate	3.0%
$p_{M,0}$	Relative price of manufacturing goods	1.0

Table 2: Urbanization and its contribution to average mortality

		Europe	NL	Italy	England
Year		<i>Urbanization rate (n_M)</i>			
1300		3.0	6.6	12.7	2.2
1700		9.2	33.6	13.4	13.3
	<i>City penalty</i>	<i>Mortality due to n_M (%)</i>			
1300	$\Delta d_M = 50\%$	.05	.10	.19	.03
1300	$\Delta d_M = 80\%$	.07	.16	.30	.05
1700	$\Delta d_M = 50\%$	.14	.50	.20	.20
1700	$\Delta d_M = 80\%$	.22	.81	.32	.32

Data sources: Urbanization rates in 1700 from de Vries (1984); in 1300 using de Vries' figures extrapolated backwards with the country-specific trend from AJR (2005). See section 5.1 for a description of both datasets. Urbanization for 1300 Europe derived as in footnote 28.

Table 3: Cross section: Change in urbanization vs. average wars per year, 1300-1700

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

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

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

Table 5: Cross section: Change in p.c. GDP vs. average wars per year, 1500-1700

	<i>Dependent variable is change in country-level log GDP per capita 1500-1700</i>						
	OLS (1)	OLS w/o Netherl. (2)	OLS w/o Gr. Pow. (3)	OLS unweighted (4)	OLS (5)	IV [‡] (6)	IV [‡] (7)
Wars per year (Avg. 1300-1700)	.189** (.0892)	.163* (.0823)	.212 (.2150)	.212* (.1120)	.0972 (.0580)	.143* (.0867)	.128** (.0623)
Atlantic coast-to-area					7.696*** (1.1730)		7.849*** (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 3; first stage coefficients and statistics are very similar to those reported in this table.

Table 6: Panel: Urbanization and wars per year in early modern Europe

	<i>Dependent variable is country-level urbanization</i>						
	1300-1700 OLS (1)	1300-1700 IV (2)	1300-1700 IV (3)	1300-1700 IV unweighted (4)	1300-1700 IV (5)	1300-1700 IV (6)	1300-1800 IV w/o Britain (7)
					Potential for Atlantic Trade measured by dummy Atlantic coast-to-area		
Wars per year	.0446*** (.0156)	.0435*** (.0126)	.0270*** (.0094)	.0313*** (.0102)	.0345*** (.0117)	.0211*** (.0074)	.0192*** (.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*** (.0079)	.177 (.3420)	1.051 (1.1930)
Potential for Atlantic Trade x 1600					.00107 (.0157)	.511 (.3430)	-1.815 (1.2420)
Potential for Atlantic Trade x 1700					.0137 (.0129)	1.805*** (.2540)	-.0092 (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 7: Panel: Per capita income and wars per year in early modern Europe

<i>Dependent variable is country-level log GDP per capita</i>							
	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*** (.0631)	.277*** (.0616)	.0960*** (.0220)	.0430** (.0218)	.0779*** (.0259)	.0738** (.0344)	.0691*** (.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*** (.0409)	9.002*** (2.3730)	-2.369 (6.1380)
Potential for Atlantic Trade x 1600					.258*** (.0626)	13.59*** (2.4440)	3.962 (2.9740)
Potential for Atlantic Trade x 1700					.281*** (.0724)	16.95*** (2.4030)	6.537** (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 8: 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)
<i>PANEL A: Dependent variable is country-level urbanization; panel 1300-1700</i>							
Wars per year (IV)	.0305*** (.0102)	.0339*** (.0095)	.0337*** (.0103)	.0289** (.0126)	.0363*** (.0107)	.0269** (.0112)	.0277*** (.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 (.0027)	-.000847 (.0026)	-.00993* (.0058)	-.0162*** (.0049)	.0012 (.0029)	-.00689** (.0034)	-.00245 (.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 (.0055)	.0267*** (.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
<i>PANEL B: Dependent variable is country-level log GDP per capita; panel 1500-1700</i>							
Wars per year (IV)	.0788** (.0364)	.0927*** (.0154)	.0786*** (.0160)	.101*** (.0160)	.0985*** (.0133)	.0905*** (.0187)	.0868*** (.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 (.0390)	.0231 (.0292)	-.146*** (.0391)	-.179*** (.0227)	.0713*** (.0145)	.0880*** (.0274)	.0453* (.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*** (.0369)	.222*** (.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 de Vries (1984)

<i>Dependent variable is change in urbanization from de Vries, 1500-1700</i>							
	OLS	OLS	OLS	OLS	OLS	IV [‡]	IV [‡]
	(1)	w/o Netherl. (2)	w/o Gr. Pow. (3)	unweighted (4)	(5)	(6)	(7)
Wars per year (Avg. 1500-1700)	.0573** (.0212)	.0521** (.0196)	.119* (.0620)	.0613* (.0304)	.0394** (.0154)	.0544*** (.0188)	.0233 (.0153)
Atlantic coast-to-area					1.464*** (.2570)		1.618*** (.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 3; first stage coefficients and statistics are very similar to those reported in this table.

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

<i>Dependent variable is country-level urbanization from de Vries</i>							
	1500-1700	1500-1700	1500-1700	1500-1700	1500-1700	1500-1700	1500-1820
	OLS	IV	IV	IV	IV	IV	IV
	(1)	(2)	(3)	unweighted (4)	(5)	(6)	w/o Britain (7)
						Potential for Atlantic Trade measured by dummy	
						Atlantic coast-to-area	
Wars per year	.0311** (.0152)	.0391*** (.0056)	.0288*** (.0046)	.0513*** (.0033)	.0315*** (.0060)	.0235*** (.0029)	.0213*** (.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*** (.0196)	-1.066*** (.4020)	-2.496*** (.6700)
Potential for Atlantic Trade x 1600					.0490** (.0199)	-.778* (.4050)	-.369 (.8530)
Potential for Atlantic Trade x 1700					.0609*** (.0197)	.542 (.4080)	-.243 (.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.