Urbanization and the onset of modern economic growth*

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Abstract: We present a theory of the onset of the Industrial Revolution, inspired by recent developments in economic geography. The existing literature suggests that technological change and industrialization prompted urbanization. We maintain that causality ran the other way. England was unusually urban by the late 1700s. This triggered the creation and diffusion of knowledge within urban communities, thereby generating sustained and unprecedented technological change. More frequent interaction with neighbours allowed urbanites to imitate new ideas faster and innovate with higher probability. Resulting productivity gains induced more rural-urban migration, which further raised density in cities and hence the rate of technological change.

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1. Introduction

The 'new growth theories' that developed in the 1990s were initially concerned with growth in the short-run (that is, in already rich industrial economies) or in the medium-term (i.e., in economies that are today part of the so-called developing world). However, in recent years, a number of papers have started to examine the determinants of growth in the long-run. This line of research has focused on understanding the industrial revolution, or more precisely, the Second Industrial Revolution that occurred in the late 19th century. This was characterized by the move from an economy based on the accumulation of physical capital to one in which intentional technological change and human capital accumulation play an essential role. Examples of such research are Galor and Moav (2004, 2006), who examine how an economy moves from investing in physical capital to investing in human capital; and Jones (2005), who looks at the appearance of the knowledge-based economy.[1] Surprisingly, growth theorists have hardly examined the most significant growth episode in history: the First Industrial Revolution (FIR), which started in England in the mid-18th century and is generally recognized as the beginning of modern economic growth. [2]

This paper tries to understand what triggered the First Industrial Revolution and thereby cast light on two further questions. Why did the Industrial Revolution happen in England – rather than France or China or South America? And why did it start around 1760 – rather than 1360 or 1960 or 60BCE? There are two key elements in our analysis. The first is our concept of the First Industrial Revolution as a process of structural change. Specifically, we follow Crafts and define an 'industrial revolution' as a shift of labour resources from agriculture into industry. Growth will then be driven by the flow of labour from farming to industry, and can be measured by the increase in the consumption of manufactures. In doing so, we are going one step further back than existing work because the only inputs into production are individuals and land, whereas physical capital (that is, machines) is unavailable.

The second key element in our analysis is the idea that cities are 'special' because they create frequent human encounters that are the basic means for the diffusion and creation of knowledge. We follow Marshall, and the formalization of his ideas by Glaeser (1999), in supposing that cities allow for both the creation and transmission of ideas across agents, thus creating the mechanism that eventually leads to growth. Our theory makes urbanization (as opposed to industrialization) the key element in a theory of development. Thus we combine economic geography – defined as the idea

[1] Growth in the *very* long-run is studied by Galor and Moav (2002).

[2] The literature on the economics of the First Industrial Revolution is obviously extensive. For a recent discussion of the questions that economists have been raising on it see, for example, Mokyr (2008, 2009)

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that agglomeration results in productivity increases – with development, and argue that the First Industrial Revolution occurred because England was uniquely urbanized around 1760.

Our model is related to Hansen and Prescott (2002), who examine how an economy can move from a no-growth to a Solow-type growing economy and argue that this can help explain the onset of the Industrial Revolution. In their setting, industrial revolution occurs because productivity in manufacturing is sufficiently high, at some point, for workers to start moving into that sector. However, their model has a number of unsatisfactory features. First, technological change is exogenous, à la Solow. Second, there is technological change that increases manufacturing productivity *even if the manufacturing sector is not operational*; this raises the question of how the productivity of a sector can increase if the sector does not exist. Third, the agricultural sector disappears in the long-run, as the two sectors produce a single homogeneous good. We share three features with their analysis: there are two sectors (agriculture and manufacturing), land exhibits diminishing returns, and equilibrium at any point in time is driven by the allocation of labour across the two sectors. However, in our setting the industrial revolution starts from an increase in agricultural labour productivity, which drives labour away from agriculture and into manufacturing and (if the labour transfer is large enough) generates endogenous technological change in manufacturing.

There are three steps in our analysis. First, there is an increase in urbanization. There are several possible explanations for this event, such as the impact of the Black Death on relative wages and the structure of consumer demand (see Voigtländer and Voth, 2006, 2008). We believe that a more likely candidate is the increase in extractions (taxes and rents) from English farmers, which both permitted and caused rural-urban migration. By the end of the 18^{th} century, labour productivity was substantially higher in Europe – and particularly in England – than elsewhere in the world (Brunt and Fidalgo, 2009), and in the case of England this was associated with high agricultural taxation. At the same time, Europe – particularly England – was uniquely urbanized. We present evidence on these issues in section 2 below and in our model it is the extraction rate that generates the initial shock that sets structural change in motion.

Once cities reach a substantial size, all the mechanisms discussed by the recent literature on economic geography start to apply; see Combes, Mayer and Thisse (2008) for a survey. The key assumption is that high density creates more encounters and favours the creation and diffusion of knowledge. We suppose that there are two ways in which an individual may increase his productivity (that is, obtain ideas that make him more productive). First, agents in cities may acquire an idea by meeting someone with an idea. We follow Glaeser (1999) and suppose that the number of meetings is an increasing function of the number of individuals in the city, *i.e.* of the rate of urbanization. Higher density implies more meetings and hence more individuals with ideas. In contrast, the low density in rural areas implies that there are no meetings and hence no transmission of ideas. Note that this cannot generate continual growth; once all ideas are transmitted, growth will stop. Second, we follow Jovanovic and Rob (1989) and suppose that an individual can create new knowledge by observing the ideas or experience of others, thus endogenously creating new ways of production. For example, an agent meets someone who is using a "boat"; then he meets another agent using a "steam engine". He can then combine their ideas to create a "steamboat". This second aspect is crucial because it will be the driver of long-run growth. We make a key assumption concerning innovation, namely that an individual can innovate only if he has observed a sufficiently large number of ideas. We model this by supposing that only a fraction of meetings will potentially result in an innovation. As a result, the rate of growth of productivity in manufacturing will be a function of urban density.

In sum, we argue that an initial increase in urbanization took place in England in the 18th century. Cities created frequent encounters amongst individuals and became 'wells of knowledge' that raised productivity through imitation and innovation. The increase in manufacturing productivity induced further rural-urban migration that accelerated the process of knowledge diffusion and creation. Growth hence appeared endogenously.

Our paper is related to several strands of literature. The first are the recent developments in growth theory that explain how the world moved from stagnation to growth, best represented by Unified Growth Theory (UGT); see Galor (2005) for a survey. UGT is at the core of our understanding of the appearance of modern growth and of the close relationship between population dynamics and economic development, yet specific differences in the timing and speed of the transition are still not fully understood. We consider an additional aspect that would complement the UGT and which provides a possible explanation for why England was first.

Our analysis is closely related to Voigtländer and Voth (2006, 2008) who examine the factors that resulted in the Industrial Revolution happening in Europe, and particularly England, rather than elsewhere. Both models share with us an approach based on the migration of workers from agriculture into manufacturing. Voigtländer and Voth (2006) examine how weather shocks could have pulled some economies out of the Malthusian trap, while Voigtläder and Voth (2008) maintain, like we do, that cities played a crucial role in the Industrial Revolution. In their setup, the Black Death is the exogenous trigger that initially raises wages and results in migration towards cities, and cities then prevented a population increase due to their poor health environment. Our analysis complements theirs by maintaining that the frequent interactions occurring in cities not only resulted in the transmission of viruses but also of ideas.

The importance of ideas for the growth process has been recently emphasized by Lucas (2009). Lucas emphasizes that "all knowledge resides in the head of some individual person" and hence the productive capacity of an economy will be the sum of the knowledge of its members. This concept of knowledge has two important implications. The first is that intellectual activity results from social interactions hence meeting people is an essential aspect of the transmission and creation of knowledge. The second is the fact that heterogeneity in experiences and ideas is necessary in order to create new or better ideas, as argued by Jovanovic and Rob (1989). We incorporate these two aspects in our analysis and argue that urbanization is a key element in the process of creation of knowledge because it determines the frequency of social interactions and the number of different experiences that an individual can observe.

Lastly, the paper is also related to the literature on economic geography. Economic geography has examined how the increase in productivity and the reduction in transport costs that occurred during the Industrial Revolution led to urbanization and spatial concentration; see Combes, Mayer and Thisse (2008, chapter 1). In this context, changes in technology are treated as an exogenous shock that causes location choices. In contrast, we argue that it was an initial surge in urbanization that led to the process of innovation that lies at the root of the Industrial Revolution.

The rest of the paper is organised as follows. Section 2 discusses the historical evidence that supports our arguments. Section 3 presents the basic model and examines the determinants of urbanization. Section 4 discusses the creation and transmission of ideas, and obtains the dynamics of urbanization and knowledge. A numerical example is then provided. Section 6 concludes.

2. Historical evidence

Our model is founded on – and explains – the international and temporal variation in four key variables: urbanization levels, agricultural labour productivity, and agricultural extractions. In this section we describe the salient features of these variables across space and through time.

Differences and changes in urbanization

The trigger for the Industrial Revolution in our model is an increase in the urban population. Evidence on urbanization at the time of the FIR points to the unique position of Western Europe and, in particular, England. Figure 1 reveals that China, which is regarded by many historians as the most technologically advanced country in the Middle Ages, had much higher urbanization rates than

Europe around the year 1000. But Western Europe experienced a massive increase in urbanization rates over the next 700 years, reaching almost 10 per cent by the year 1700, whilst no substantial change took place in China. Amongst the western European nations, England (and, to a lesser extent, Scotland) had the highest urbanization rates, as can be seen from figure 2.

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

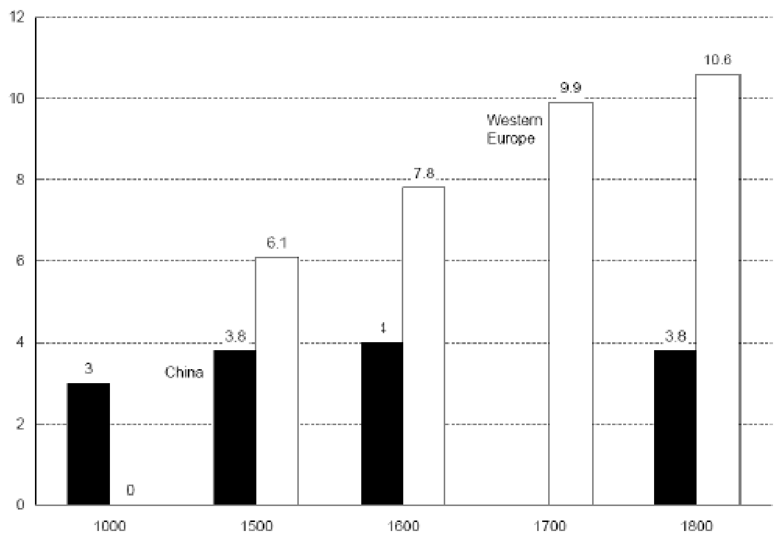
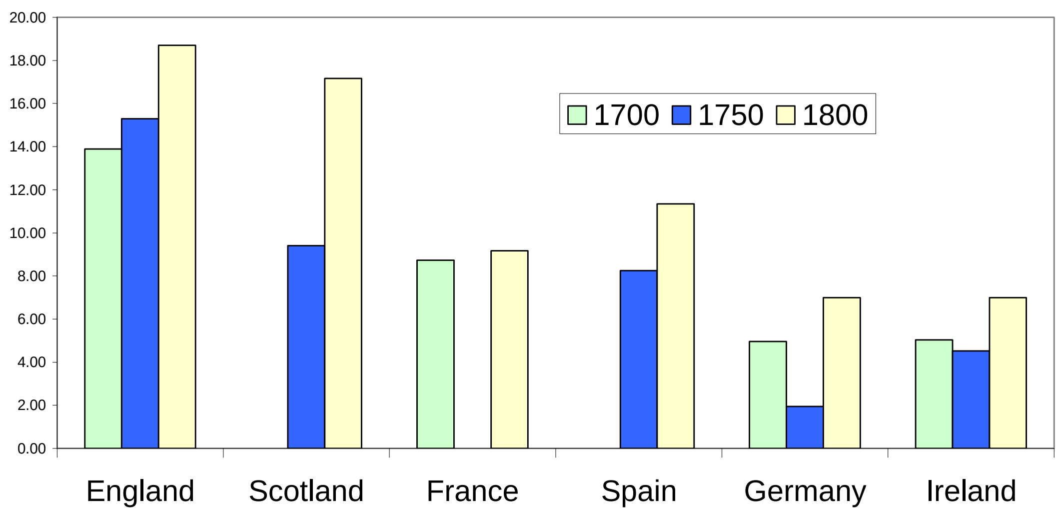


Figure 2:

Share of urban population



Source: Authors' calculations.

Why was the urbanization rate higher and rising in England and Scotland? The reason is simply that there were many more large cities. This is crucial because, in our model, it is not the urbanization rate of a country *per se* that matters but the absolute size of cities. [3] The frequency of meetings (and hence the diffusion and creation of ideas) is determined by the population of the city, so it is more effective to herd people into a small number of larger cities than a large number of small cities.[4] Table 1 reports the urban population living in the largest cities in the western European economies at benchmark dates.[5] England is more urbanized than the other European countries at the beginning of the century and pulls dramatically ahead of other countries between 1750 and 1800 and accelerates thereafter.

Table 1. Urban population living in the largest western European cities, 1750-1850.

	1750	**1800**	**1850**
Austria	0	247 000	431 000
France	570 000	550 000	1 053 000
Italy	339 000	430 000	618 000
Netherlands	210 000	217 000	225 000
Spain	0	0	501 000
England	***675 000***	***948 000***	***3 148 000***
Ireland	***0***	***200 000***	***262 000***
Scotland	***0***	***0***	***345 000***

Source: Bairoch *et al.* (1988).

Table 2 takes the largest western European cities in 1850 and tracks their expansion since 1700. Notice that England alone accounts for almost half of the urban population living in large cities in 1850. The rise of Birmingham, Liverpool and Manchester after 1750 is especially marked, as is the expansion of Dublin and Glasgow (both in the United Kingdom, but not England); by 1850 they were all larger than most European capital cities.

[3] Historical evidence on the geographical size of cities is scarce, and certainly as population size grew so did the physical size of cities. However, the latter is likely to have grown more slowly, and cities tended not to increase the size of 'public spaces' such as markets were commercial (and hence intellectual) exchanges took place.

[4] Consider the two extreme cases – a country with 5 million cities, each having one inhabitant, versus a country with one city having 5 million inhabitants. Frequency of meetings is clearly going to be much larger in the second case.

[5] We define "large" cities as having population of 200 000 or above. Of course, one could argue about the appropriate definition of "large" cities. But the result that England pulled rapidly ahead of other countries in the late eighteenth century is robust to alternative definitions and the data that we report here are broadly representative of the situation.

Table 2. Expansion over time of the largest European cities in 1850 (population in `000s).

City	1700	1750	1800	1850
Amsterdam	200	210	217	225
Barcelona	34	50	100	220
Berlin	55	113	172	437
Lisbon	180	185	195	240
Madrid	140	160	168	281
Milan	125	124	135	209
Naples	300	339	430	409
Paris	500	570	550	1 053
Vienna	114	175	247	431
London	***575***	***675***	***948***	***2 236***
Birmingham	***7***	***24***	***71***	***233***
Manchester	***8***	***18***	***84***	***303***
Liverpool	***6***	***22***	***83***	***376***
Dublin	***60***	***129***	***200***	***262***
Glasgow	***13***	***25***	***70***	***345***

Note: Includes all western European cities with population >200 000 in 1850.
Source: Bairoch *et al.* (1988).

Agricultural labour productivity

Urbanization was accompanied by – we argue that it was generated by – high agricultural output per worker. By the beginning of the 18th century, agricultural yields were higher in Western Europe (particularly England) than elsewhere in the world. Brunt and Fidalgo (2008) have collected new data on agricultural labour productivity that show massive differentials in output per agricultural worker around the world in 1700, 1775, 1845 and 1870; see Table 3. They try to find geographical units of similar sizes, so the data are mostly for countries but by province for India and China (for which we report the most and least productive regions here). The sizes of the differentials may seem surprising but note that very similar magnitudes are reported in Maddison (2000). We prefer the data reported here because they refer explicitly to agriculture, whereas Maddison constructs data for the whole economy of each country. However, since agriculture was by far the largest sector in each economy throughout this period, the two data sets inevitably turn out to be quite similar.

Table 3. Real output per worker in agriculture (England in 1870=100)

	1705	1775	1845	1870
England	59	84	71	100
Scotland	NA	57	109	157
Netherlands	NA	45	48	36
France	22	15	19	27
Prussia	1	2	23	50
USA	17	26	58	73
China (Hupei, most productive)	61	48	39	44
China (Kweichow, least productive)	1	2	2	1
India (Bengal, most productive)	17	18	19	19
India (Punjab, least productive)	4	4	4	6

Source: Brunt and Fidalgo (2009).

Another reason to prefer the Brunt-Fidalgo data is that they report the allocation of labour between agriculture and other sectors. So their agricultural labour productivity data are necessarily consistent with their measure of structural change towards non-agricultural production. This is useful because, except for England, there are basically no data on the size of the manufacturing workforce in each country.

Agricultural taxes in early modern times

We argue that the increase in urbanization was generated by an increase in agricultural labour productivity. But what caused the increase in agricultural labour productivity? We maintain that it was the increase in extractions from English farmers that was levied by landlords and the government. In table 4, we report the tax burden on agricultural workers in England and China in *c.* 1775; it was almost 100 times greater in England.[6] Since output per worker was around ten times higher in England than in the typical Chinese province, the tax *rate* was around ten times higher in England than China. How is this possible? In a Malthusian world the answer is straightforward. In equilibrium, output per worker at the margin will be equal to subsistence (by assumption). Now impose a tax equal to 50 per cent of output. Then the output of the marginal worker must double, so that he can pay the tax and still continue to subsist. Workers who are unable to meet this level of output will die (or never be born). So high-tax countries – such as England – will be characterized by

[6] In fact, land was mostly owner-occupied in China, so there was virtually no extraction through land rents.

low agricultural population densities, whereas low-tax countries – such as China – will be characterized by high agricultural population densities. This is confirmed in the last line of table 4.

Table 4. Extractions per adult male agricultural worker in *c.* 1775 (English d).

Extraction	England	*China (average)*
Land rent	3389	0
Tithe	471	0
Poor rate	272	0
Land tax	354	47
TOTAL	**4487**	**47**
Acres per ag. worker	***20***	***3***

Source: Brunt and Fidalgo (2010).

Of course, there could be many other factors – which are outside our model – driving the apparent relationship between taxes, land area and output per worker. Social, political, military and economic institutions were very different in England and China. To control for some of the possible confounding factors, it is interesting to see how taxes were related to agricultural population density across Chinese provinces. The results from a regression analysis are reported in table 5 below. They show that higher taxes in a province reduced the population density. We partially control for the possibility of endogeneity by regressing the population density in 1775 on taxation rates in 1753.

Table 5. Population densities and per capita tax burdens across Chinese provinces.

Dependent variable:	Population density in 1775
Constant	-1.00*
	(0.44)
Per capita tax burden in 1753	-1.18**
	(0.33)
r-squared	43.94
N	18

Notes and sources. All variables are in natural logarithms. Dependent variable is the population per acre in 1775, drawn from Brunt and Fidalgo (2010); independent variable is the tax burden per capita in 1753, drawn from Wang, *Land taxation*, table 4.1. ** denotes statistical significance at the one per cent level and * denotes statistical significance at the five per cent level.

The level of taxation in England by the late 18th century was hence particularly high. This was the result of a sustained increase in extraction from agriculture over the previous 250 years.

Figure 3 presents the evolution of an index for real wages and real taxes plus rents.[7] In 1550, taxes and rents paid by farmers represented only 7 percent of total output; by 1600 their share had increased to 19 percent. They fluctuated between 17 and 19 percent during the 17th century and then increased steadily over the next hundred years reaching 25 percent by 1800.

Figure 3: Wages and Rents plus Taxes in England (index 1550=100)

Source: Authors' calculations from Clark (2002) and Brunt (2000); see text.

We have now presented a considerable quantity of descriptive data, drawn from the world economy between 1700 and 1870, that is consistent with key elements of our model. Of course, this is not a coincidence: we constructed our model to explain the world, not vice versa. Thus none of the evidence that we have presented could plausibly constitute a "test" of the model – even if we could work out how to construct a rigorous test using the scattered data currently available – but it gives us confidence that our model can explain important aspects of economic development. So we now

[7] Clark (2002; table 1) provides an index of real wages and of the real value of taxes and rents. In order to get tax rates, we have used data from Brunt (2000) on the value of output per worker and rents and taxes for 1775. Output is 975d/acre, which with 20 acres per worker yields an output per worker of 19 500d. This generates an extraction rate from gross output of 23 per cent (=4 487/19 500).

develop a rigorous model of growth and industrialization and simulate it to reflect the salient features of historical experience.

3. A model of urbanization

We begin by setting out the components of the model. This section considers the determinants of urbanization, taking as given productivity in manufacturing. The endogenous evolution of this productivity is discussed in section 4.

3.1 Population and preferences

We consider an overlapping-generations setup. Agents live for two periods. In the first they are apprentices; in the second they work and have a single offspring so that the number of dynasties remains constant over time. There are N dynasties of workers and εN dynasties of landlords, with $\varepsilon < 1$. Landlords extract rents from the farmers to whom they let their land. Workers have two possible occupations, working as a farmer or in manufacturing. We suppose that these occupations require agents to live either in the countryside or in cities, respectively. Hence agents will live in one of two locations, cities or the countryside, depending on their occupational choice. Young agents are born in the location chosen by their parents and make their occupational/location choice in the first period of their life. That is, they migrate as young adults and the next period they work. During the first period of their life, they may or may not acquire "ideas" that make them more productive, according to a process defined below. [8]

We follow Voigtläder and Voth (2008) and suppose that preferences are identical for all agents and take the form

$$U(c_{at}, c_{mt}) = \begin{cases} \beta(c_{at} \text{-} \underline{c}) & \text{if} \quad c_{at} < \underline{c} \\ (c_{at} \text{-} \underline{c})^{\alpha} c_{mt}^{1-\alpha} & \text{if} \quad c_{at} \geq \underline{c} \end{cases} \tag{1}$$

where c_{at} and c_{mt} are respectively consumption of the agricultural and the manufacturing good in the second period of life, and $\underline{c}$ a minimum food requirement. This yields the demand functions

$$c_{at} = \alpha y_t + (1-\alpha)\underline{c} \tag{2a}$$

[8] The fact that individuals acquire skills when young, i.e. before they start working, fits well with a structure of apprenticeships whereby young individuals chose their 'trade' at a relatively early age and acquired specific skills.

$$c_{mt} = \frac{(1-\alpha)}{p_t}(y_t - \underline{c}) \tag{2b}$$

where y_t is the income of the individual, and the prices of the agricultural and the manufacturing good are, respectively, 1 and p_t. The resulting indirect utility function can be expressed as

$$U(y_t) = \begin{cases} \beta(y_t\text{-}\underline{c}) & \text{if} \quad y_t < \underline{c} \\ a(y_t\text{-}\underline{c})\, p_t^{\alpha-1} & \text{if} \quad y_t \geq \underline{c} \end{cases} \tag{3}$$

where $a \equiv \alpha^{\alpha}(1-\alpha)^{1-\alpha}$.

3.2 Technology and factor payments

Agriculture

Agricultural output is produced with a constant-returns-to-scale technology using labour and land, *T*,

$$Y_{at} = T^{1-\gamma}\left(AL_{at}\right)^{\gamma}, \tag{4}$$

where A denotes productivity in the agricultural sector, L_{at} agricultural labour, and $0 < \gamma \leq 1$. Farmers rent the land which is the property of landowners. The wage in the agricultural sector is supposed to be proportional to output per worker. That is,

$$w_{at} = \omega A^{\gamma}\left(\frac{T}{L_{at}}\right)^{1-\gamma} \tag{5}$$

where $\omega \leq 1$. The parameter ω is a distributional parameter that tells us what fraction of average agricultural output farmers keep. If farmers receive the marginal product of labour we have $w_{at} = (1-\alpha)A^{\gamma}\left(T / L_{at}\right)^{1-\gamma}$. We want to be more general and suppose that landlords and the authorities extract a fraction τ of the revenue, so that $\omega = 1-\tau$. In what follows we will term τ the tax rate, even if not all of it is reaped by the state. Define $A_a \equiv A^{\gamma}\left(T / N\right)^{1-\gamma}$ which is simply output per worker when the entire labour force works in agriculture. Then, the wage can be expressed as $w_{at} = (1-\tau)A_a n_{at}^{\gamma-1}$, where n_{at} is the share of population employed in farming. The wage in agriculture will be higher when the rents extracted by landlords and when employment in farming are lower.

Lastly, note that the presence of the a minimum food requirement, $\underline{c}$, can be interpreted as a Malthusian effect if we suppose that agricultural per capita output below this level would lead to death and hence a reduction in the population.[9] We can then define $\underline{n}_a \equiv \left(\underline{c}(1+\varepsilon)/A_a\right)^{1/\gamma}$ which is the level of agricultural employment required in order to provide the minimum food requirement, $\underline{c}$, to the entire population and assume that $\underline{c}(1+\varepsilon) < A_a$ so that $\underline{n}_a < 1$. This assumption simply says that agricultural TFP, *A*, and/or land per capita, *T/N*, have to be sufficiently high for the minimum food requirement to be produced. Otherwise there will be no demand for manufactures. Agricultural employment cannot fall below the lower bound $\underline{n}_a$, which in turn defines an upper bound for the share of manufacturing employment, namely $\overline{n}_m \equiv (1-\underline{n}_a)$. Lastly, the minimum food requirement also imposes a constraint on the tax rate, as the wage of farmers must be sufficiently high for them to consume at least $\underline{c}$. That is, $\tau < 1-\underline{c}n_{at}^{1-\gamma}/A_a$. A sufficient condition for this is $\tau < \overline{\tau} \equiv 1-\underline{c}/A_a$, as the lowest possible productivity per worker is obtained when all workers are employed in farming, i.e. $n_{at} = 1$. In what follows we suppose that this condition holds.

Manufacturing

Manufacturing takes place in cities. It is characterized by constant returns and the only input is labour. Artisans without an idea produce one unit of output, while those with *i* ideas produce $(1+hi)$. Aggregate manufacturing output is then

$$Y_{mt} = B_t L_{mt} \tag{6}$$

where L_{mt} is employment in manufacturing and B_t is average productivity in that sector, which depends on the average number of ideas that those who work in manufacturing have, denoted I_t. That is, $B_t = 1+hI_t$, where I_t will be endogenously determined in section 4.

We suppose that skills are sector specific. They are acquired when young and hence individuals will not move when old. Since the price of the manufacturing good is p_t, the wage in manufacturing will then be $(1+hi)p_t$ for those with ideas and p_t for those without. Hence the expected wage in manufacturing is simply $w_{mt} = p_t B_t$, and is independent of employment in the sector at time *t*.

There is a disutility associated with living in cities, denoted v_t, so that the expected utility of

[9] We do not consider the other element in Malthusian theories, namely that increases in agricultural output result in higher fertility and hence a larger population. See Galor (2005).

a worker living in the city and working in manufacturing is $EU_{mt} = a(w_{mt} - \underline{c})p_t^{\alpha-1} - v_t$. There are various possible justifications for this cost. Murphy, Shleifer and Vishny (1989) argue that manufacturing work itself generates a disutility for which workers have to be compensated. Voigtläder and Voth (2008) emphasize the health costs of living in cities, given that they had a worse disease environment than that found in rural areas. Although either interpretation is possible, we suppose that v_t captures the cost due to a higher probability of disease associated with city life. We further suppose that the cost takes the form $v_t = adp_t^{\alpha}$, where d is a positive constant. Assuming that the health cost is proportional to the price of manufactures will imply that, as this price falls over time due to technological improvements, the disutility associated with city life will fall (or equivalently, that the probability of disease falls). In other words, we are assuming that increases in manufacturing know-how will result in improvements in medical know-how that reduce the health cost associated with urban dwelling.

3.3. Static equilibrium

Employment in agriculture and manufacturing

Workers can freely move between agriculture and manufacturing, and will do so in order to equalize the expected utility in the two sectors. The decision to migrate is taken by young individuals at time *t*-1 on the basis of their (rational) expectations of the income they would get at *t* in each of the two sectors.[10]

Utility in farming is simply $U_{at} = a(w_{at} - \underline{c})p_t^{\alpha-1}$. Equating this to EU_{mt}, and using the expressions above for the wages in agriculture and manufacturing we obtain the following relation between the price of manufactures and employment in agriculture

$$p_t = \frac{(1-\tau)A_a n_{at}^{\gamma-1}}{B_t - d} \qquad (7)$$

This equation implies a negative relationship between p_t and n_{at} since a higher price increases the manufacturing wage and hence results in migration away from farming. Higher productivity, B_t, or

[10] Note that some of the young in the city get ideas and others do not. This means that ex post, those in the city who got a below-average number of ideas will have lower utility than those in agriculture. Because skills are sector-specific and need to be acquired when young, these individuals will not move into farming.

higher rents, i.e. a higher value of τ, result in a lower share of agricultural employment for any given price, since the former increases the manufacturing wage and the latter reduces the agricultural wage.[11]

Goods market equilibrium

To obtain the goods market equilibrium, we need to consider the demands of workers and landlords. Those of workers are given by equations (2) above. There are εN landlords, each of whom gets rents equal to $\tau Y_{at} / \varepsilon N$. Since they have the same utility function as workers their demands are also given by (2).[12] Equating the supply and the demand for agricultural goods we have

$$NA_a n_{at}^{\gamma} = N\left(\underline{c}(1+\varepsilon) + \alpha(\overline{w} - \underline{c}) + \alpha(\tau A_a n_{at}^{\gamma} - \varepsilon \underline{c})\right) \tag{8}$$

where $\overline{w}$ is the average wage. The first term in brackets is the minimum food requirement that the population consumes, the second is the additional demand from workers, while the third is the additional demand from landlords. Similarly, equilibrium in the manufacturing good sector is given by

$$p_t B_t (1 - n_{at}) N = (1-\alpha) N \left(\overline{w} + \tau A_a n_{at}^{\gamma} - \underline{c}(1+\varepsilon)\right) \tag{9}$$

These two equations imply

$$(1-\alpha) A_a n_{at}^{\gamma} = (1-\alpha)(1+\varepsilon)\underline{c} + \alpha p_t B_t (1 - n_{at}) \tag{10}$$

which gives the goods market equilibrium relationship between agricultural employment and p_t. The higher employment in agriculture is, the higher the price of manufactures.

The equilibrium allocation of labour

Equations (7) and (10) jointly determine the price and agricultural employment. Since equation (7) implies a negative relation and (10) a positive one, there will be a unique pair of equilibrium price and employment for each set of parameter values. Using equation (7) to substitute for the price, we have the equilibrium share of agricultural employment,

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[11] Other analyses of occupational decisions during the Industrial Revolution have been proposed, such as that of Doepke and Zilibotti (2008) who focus on the appearance of middle-class values. We view their approach as focusing on social developments that took place during the Second industrial Revolution.

[12] We could allow landlords to demand imported 'luxury goods' as well as agricultural goods and manufactures, so that a fraction of output is not spent domestically. This would change slightly the expression for the relative price but would have no qualitative impact.

$$(1-\alpha)A_a n_{at}^{\gamma} = (1-\alpha)(1+\varepsilon)\underline{c} + \alpha A_a \frac{1-\tau}{1-d/B_t}\frac{1-n_{at}}{n_{at}^{1-\gamma}} \tag{11}$$

We can now define the functions

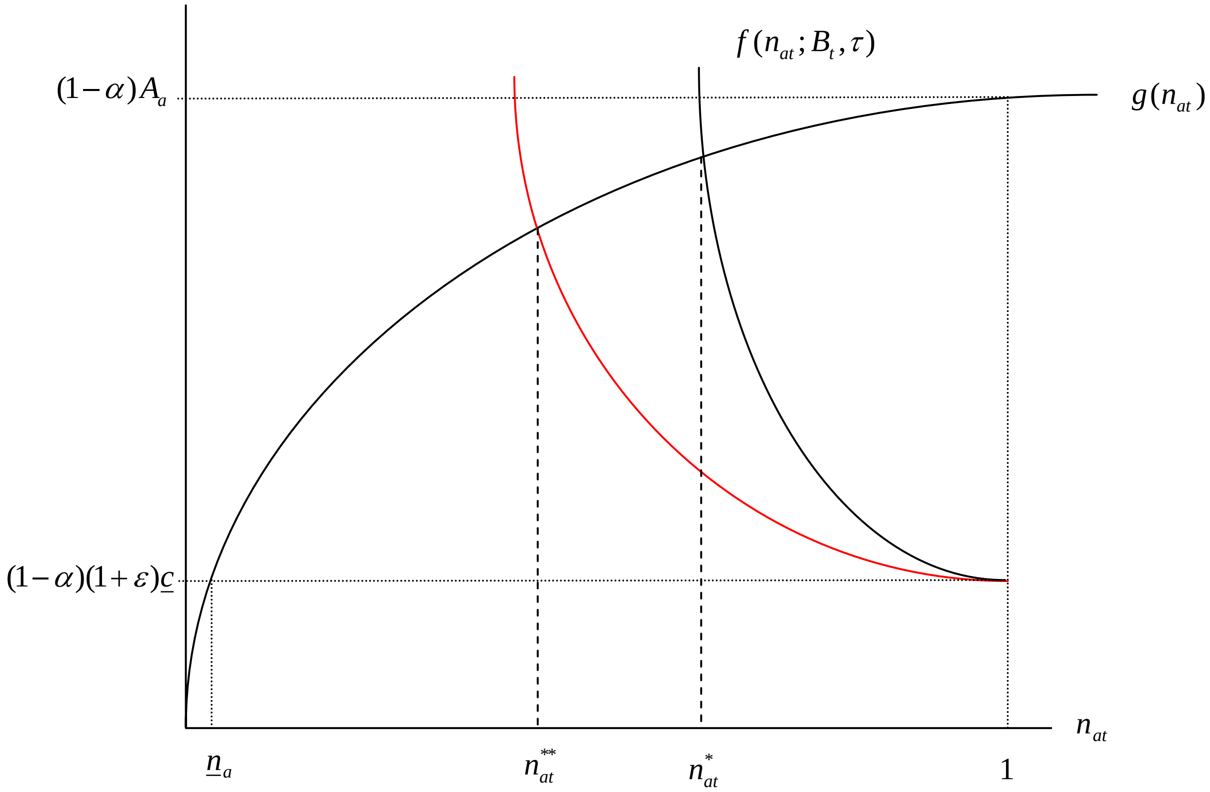
$$g(n_{at}) \equiv (1-\alpha)A_a n_{at}^{\gamma} \tag{12a}$$

$$f(n_{at};\tau,B_t) \equiv (1-\alpha)(1+\varepsilon)\underline{c} + \alpha A_a \frac{1-\tau}{1-d/B_t}\frac{1-n_{at}}{n_{at}^{1-\gamma}} \tag{12b}$$

It is possible to show that $g(n_{at})$ is increasing and concave and $g(0)=0$, while $f(n_{at})$ is decreasing and convex. As long as $A_a > (1+\varepsilon)\underline{c}$ and $\tau < \bar{\tau}$, the two functions intersect once and there is a unique equilibrium level of agricultural employment n_{at}^{*}. Note that these conditions capture the Malthusian trap, since $A_a > (1+\varepsilon)\underline{c}$ is the requirement that when the entire workforce is employed in agriculture they produce enough to satisfy the minimum food requirement for the entire population and $\tau < \bar{\tau}$ that farmers can consume at least $\underline{c}$.[13] Figure 3 represents graphically the equilibrium by plotting the functions $g(n_{at})$ and $f(n_{at})$.

[13] If $A_a < (1+\varepsilon)\underline{c}$, even with the entire population working in farming there would not be enough food to satisfy the minimum consumption requirement, resulting in a reduction in the population as in the UGT. We abstract from these considerations, and simply assume that A_a is sufficiently high.

Figure 4: The static allocation of labour



Under the assumption that $A_a > (1+\varepsilon)\underline{c}$ and $\tau < \bar{\tau}$, there will always be a fraction of workers employed in manufacturing and living in cities. From equation (11) we can see that there are two key variables that affect the share of agricultural employment: τ and B_t. Higher values of these tilt downwards the $f(n_{at})$ function and result in a lower value of n_{at}, as depicted in figure 3 by the red schedule. The intuition is simple. A higher rent reduces the wage in farming, while a higher productivity in manufacturing increases the wage in cities, and both induce a shift of labour away from agriculture.

The other variable of interest is agricultural productivity, *A*, which affects the static equilibrium through A_a. Higher agricultural TPF increases the marginal product of labour in farming but reduces the price of agricultural goods, so that marginal value product of labour may be higher or lower than before the TFP increase. Differentiating (11) we can see that, as long as $\underline{c}$ is strictly positive, prices will fall sufficiently for higher TFP to result in a reduction in agricultural employment.

4. Cities and the transmission of ideas

4.1 The creation and transmission of ideas

We consider now the evolution of ideas. We suppose that at each period in time at most one idea can be invented according to a process defined below. Ideas are ordered from i=1, 2, …t according to the period in which they were invented. An individual may hold all or only a fraction of these ideas, but always in a sequential order. Hence if two individuals hold, respectively, j and and j+1 ideas, the second will hold all the ideas that the former holds and one additional one. We denote by $P(i,t)$ the probability that an individual has at least i ideas at time t, and by $p(i,t)$ the probability that an individual has exactly i ideas at t. Since there are a large number of individuals they are, respectively, the fraction of the urban population that holds at least i ideas and that which holds i ideas. The sequentiality of ideas also implies that $p(i,t) = P(i-1,t) - P(i,t)$. As we will see, at any point in time t there are at most t ideas available in the economy.

There are two ways in which a young individual may increase his productivity (become skilled). First, those in cities may acquire ideas by meeting someone with ideas. We suppose that an agent will imitate the agent with most ideas that he meets. Second, young agents at the frontier of knowledge may also innovate and acquire *one* new idea during the period. We follow Glaeser (1999) and suppose that the number of meetings, D_t, is an increasing function of urban density. In particular we suppose that the number of meetings is an increasing and convex function of the number of old individuals in the city, and for analytical tractability assume that it takes the form $D(n_{mt}) = \rho n_{mt}^2$. As in Glaeser, a young agent who meets someone with at least i ideas, acquires these ideas with probability z. This means that in each meeting the probability of acquiring at least i ideas is $zP(i,t)$, the probability of imitating times the probability that the individual of the previous generation that has been met has at least those skills. A young person will not imitate if he fails to learn in every meeting. The total probability of not acquiring at least i ideas is therefore $(1-zP(i,t))^{D_t}$, and the probability of acquiring at least i ideas is one minus this amount. That is, the fraction of the population that has imitated at least i ideas is given by

$$M(i,t+1) = 1 - (1 - zP(i,t))^{\rho n_{mt}^2}, \qquad (13)$$

An individual may also come up with *one* new idea, i.e. may innovate. This may happen if he meets a sufficiently large number of people. To capture this idea, we suppose that only a fraction of the meetings that take place can potentially give rise to an innovation and assume that only $\sqrt{D_t}$ of meetings provide interactions that may result in innovation. The different effect of density on innovation and imitation captures the idea that the former requires more interactions, and hence much greater density, than the latter. For those meetings were potentially useful information is transmitted, we suppose that the probability that the individual innovates after the meeting is δ. Hence, an individual innovates with probability $q_{t+1} = 1-(1-\delta)^{\bar{\rho}n_{mt}}$, where $\bar{\rho} \equiv \sqrt{\rho}$.

There are two crucial differences between innovation and imitation. First, the amount of imitation depends on how many were skilled in the previous generation, while innovation is independent of this. Second, imitation increases rapidly with the number of meetings, since all meetings can result in a transmission of information. In contrast, innovation requires a 'sufficiently large' number of meetings because the thought process of the individual that leads to innovation is the result of the complementarity between the experiences of two individuals, and only a fraction of meetings can yield it. Note also that the assumption that agents can at most have one new idea during their youth implies that, at any point in time *t*, there is an upper bound to the number of ideas held by an agent, namely *t*. This assumption is not needed for our results but yields a tractable analytical expression for the number of ideas and its distribution at any point in time.

In this context there are two ways in which average productivity will grow: individuals copy the ideas of others that they meet –the diffusion of knowledge- and individuals observe the experiences of others in order to create new knowledge. The importance of these two aspects for the growth process is examined by Jovanovic and Rob (1989). In their setup, agents possess ideas of different 'quality'. When two agents meet, there is both imitation by the less informed agent and invention of new knowledge by both agents, and the amount of imitation and innovation depends on the *distance* between the two. We simplify their setup by separating the two processes.

Let us now consider the distribution of the number of ideas. The average number of ideas is simply $I_t = 1\cdot p(1,t) + 2\cdot p(2,t) + ... + (t-1)\cdot p(t-1,t) + t\cdot p(t,t)$. Expressing the number of individuals with *i* ideas as $p(i,t) = P(i,t) - P(i+1,t)$ and since $p(t,t) = P(t,t)$, we can write

$$I_t = P(1,t) + P(2,t) + ... + P(t-1,t) + P(t,t) = \sum_{i=1}^{t} P(i,t) \tag{14}$$

and it follows that $I_{t+1} = \sum_{i=1}^{t+1} P(i,t+1)$.

Who may have a certain number of ideas? The fraction of individuals that have at least *i* ideas is given by

$$P(i,t+1) = M(i,t+1) + m(i-1,t+1)\left(1-(1-\delta)^{\bar{\rho}n_{mt}}\right) \tag{15}$$

where $m(i-1,t+1) = M(i-1,t+1) - M(i,t+1)$ is the fraction of the population that has imitated exactly *i*-1 ideas at t+1, and

$$m(i-1,t+1) = M(i-1,t+1) - M(i,t+1) \tag{16}$$

Note also that $P(1,t+1) = M(1,t+1)(1-q_{t+1}) + q_{t+1}$ and $P(t+1,t+1) = M(t,t+1)q_{t+1}$.

Using (15), the dynamic equation for the average number of ideas in the population is then $I_{t+1} = \sum_{i=1}^{t} M(i,t+1) + \left(1-(1-\delta)^{\bar{\rho}n_{mt}}\right)\sum_{i=1}^{t+1} m(i-1,t+1)$, which rearranging and using (16) can be rewritten as

$$I_{t+1} = (t+1) - (1-\delta)^{\bar{\rho}n_{mt}} - \sum_{i=1}^{t}\left(1-zP(i,t)\right)^{\rho n_{mt}^2} \tag{17}$$

The first term captures the fact that a new idea is invented each period. This aspect, the “creation of new ideas” is crucial, as it will be what drives long-run growth. The second term captures the extent to which innovation is extended in the population and depends on urbanization. The last term captures the extent of imitation, and again depends on n_{mt}. We can see from equation (17) that the current average number of ideas is increasing in the number of ideas that there were last period and in the number of individuals that were living in cities.

4.2 The dynamics of urbanization

Equations (11) and (17) together with the labour market clearing condition, $n_{mt} = 1 - n_{at}$, and the expression for average manufacturing productivity, $B_t = 1 + hI_t$, determine the dynamics of skills and urbanization. We can express these as the pair of equations

$$\frac{1-n_{mt}}{n_{mt}}\left(1-\left(\frac{1-\bar{n}_m}{1-n_{mt}}\right)^{\gamma}\right) = \frac{\alpha}{1-\alpha}(1-\tau)\frac{1+hI_t}{1+hI_t - d} \tag{18a}$$

$$I_{t+1} = \left(1-(1-\delta)^{\bar{\rho} n_{mt}}\right) + \sum_{i=1}^{t}\left(1-\left(1-zP(i,t)\right)^{\rho n_{mt}^2}\right), \tag{18b}$$

where $\bar{n}_m \equiv (1-\underline{n}_a)$ is the highest possible share of manufacturing employment. Equation (18a) implicitly defines manufacturing employment as a function of the average number of ideas I_t, that is $n_{mt} = F(I_t;\tau)$. Then, we have that the dynamics of the model are given by

$$I_{t+1} = \left(1-(1-\delta)^{\bar{\rho} F(I_t)}\right) + \sum_{i=1}^{t}\left(1-\left(1-P(i,t)\right)^{\rho F(I_t)^2}\right). \tag{19}$$

This equation describes the dynamics of the number of ideas in the economy, from which we obtain the dynamics of urbanization. Since $F'(I_t;\tau) > 0$, then $dI_{t+1}/dI_t > 0$ implying that ideas grow over time, and, by equation (18a), so does urbanization.

4.3 The dynamic behaviour of the economy

The dynamics of the economy are given by

$$\frac{1-n_{mt}}{n_{mt}}\left(1-\left(\frac{\underline{n}_a}{1-n_{mt}}\right)^{\gamma}\right) = \frac{\alpha}{1-\alpha}(1-\tau)\frac{1+hI_t}{1+hI_t - d} \tag{E.1}$$

$$I_t = \sum_{i=1}^{t} P(i,t) \tag{E.2}$$

$$P(i,t+1) = 1-\left(1-zP(i,t)\right)^{\rho n_{mt}^2} + \left(1-(1-\delta)^{\bar{\rho} n_{mt}}\right)\left(\left(1-zP(i,t)\right)^{\rho n_{mt}^2} - \left(1-zP(i-1,t)\right)^{\rho n_{mt}^2}\right) \tag{E.3}$$

The first equation yields urbanization, n_{mt}, given average knowledge, which by (E.2) is determined by the distribution of ideas at *t*, i.e. $P(i,t)$. Then the initial distribution of ideas and urbanization determine, by equation (E.3), next period's average ideas and their distribution. This will in turn determine next period's average productivity and the level of urbanization, n_{mt+1}.

Knowledge, defined as the number of ideas available in the economy will grow without bound, inducing a flow workers into the city until the lower bound of agricultural employment, $\underline{n}_a$, is reached. At this point migration will stop. Note that even if migration stops, both knowledge and productivity will keep growing. Knowledge grows because, as long as $n_{mt} > 0$, each period a new idea will be invented with positive probability. Since productivity in manufacturing is $B_t = 1 + hI_t$, we can see from equation (18b) that it grows due to both the diffusion of existing knowledge and the creation of new ideas. In general, the rate of growth of productivity will be lower than the rate of growth of knowledge because not all workers will acquire the latest idea. In the early stages of development, when urbanization is low, imitation will be moderate and the gap between knowledge and productivity will be large. As urbanization increases, the gap between the two will narrow due to a greater diffusion of knowledge.

Per capita real output in the economy is given by

$$\frac{Y_t}{(1+\varepsilon)N} \equiv \frac{A_a n_{at}^{\gamma} + p_t B_t n_{mt}}{(1+\varepsilon)\,p_t^{1-\alpha}}. \tag{20}$$

In the short-run, there are four effects of increased productivity on output. First, the allocation of labour across sectors has an impact on output, as the reduction in agricultural employment raises output per worker in his sector. Second, output per worker in manufacturing grows due to the increase in average productivity, B_t. Lastly, the price of manufactures, and hence the price index, $p_t^{1-\alpha}$, falls as productivity in industry increases, having a further effect on real output growth. Using equations (7) and (18a), real per capita output can be expressed as

$$\frac{Y_t}{(1+\varepsilon)N} \equiv \left(\frac{B_t - d}{1-\tau}\right)^{1-\alpha} \frac{A_a{}^{\alpha} n_a{}^{1-\alpha(1-\gamma)}}{\alpha(1+\varepsilon)} \left(1-(1-\alpha)\left(\frac{\underline{n}_a}{n_a}\right)^{\gamma}\right) \tag{21}$$

In the long-run, the allocation of labour will be constrained by the number of farmers needed to produce the food requirement, yielding the following expression for per capita output:

$$\frac{Y_t}{(1+\varepsilon)N} \equiv \left(\frac{B_t - d}{1-\tau}\right)^{1-\alpha} \frac{A_a{}^{\alpha} \underline{n}_a{}^{1-\alpha(1-\gamma)}}{(1+\varepsilon)} \tag{22}$$

which grows with the level of productivity.

5. Numerical examples

In order to illustrate our arguments, we provide a numerical example of the dynamics of the model. The parameter values we use are given in table 7. Each period is assumed to last 20 years. We suppose that the long-run share of agricultural goods in expenditure is 0.5, while one per cent of the population are supposed to be landlords. The productivity of labour in agriculture is $\gamma = 0.6$ and the land/labour ratio is assumed to stay constant at 20 acres per capita. Agricultural TFP is set at $A = 0.136$ in the first period and grows to reach $A = 0.210$ at the end, implying TFP growth of 55%

over the period 1540 to 1800, consistent with the figures reported by Clark (2002). The minimum food requirement is set at $\underline{c} = 0.1345$, while *d* takes the value 0.9, both value chosen for the model to match the initial urbanization rate. These figures imply that initially the share of the population needed to produce the minimum food requirement is 45 per cent, and this falls to 60 per cent as agricultural TFP increases. It is difficult to find evidence to pin down the parameters of the imitation and innovation functions. We set *h*=1 and $\rho = 2$. The probability of imitating in a particular meeting is 25 per cent while the probability of innovating at a particular meeting is 70 per cent. The initial value of the tax rate is 0.07 per cent, which yields a rate of urbanization of 3.8, the one observed in the data for the mid 1500s.

Table 7: Parameter values

Parameters	$\alpha = 0.5$, $d = 0.9$, $\underline{c} = 0.1345$, $\varepsilon = 0.01$, T/N=20, $\gamma = 0.6$, $A = 0.136$ to 0.210 ($A_a = 1$ to 1.3), $\overline{n}_m = 0.55$ to 0.60, h=1, z=0.25, $\rho = 2$, $\delta = 0.7$, $I_0 = 0$						
Tax rates	*1540*	*1580*	*1600*	*1620*	*1640*	*1660*	*1680*
	0.07	0.09	0.19	0.19	0.175	0.175	0.18
	1700	*1720*	*1740*	*1760*	*1780*	*1800*	
	0.185	0.205	0.217	0.217	0.23	0.25	

We examine the effect of various shocks, and all figures present the evolution of urbanization in the model as well as in the data. The urbanization data is from De Vries (1984), and is the fraction of the population living in cities of at least 10 000 people. The data are available every 50 years, starting in 1550 when the rate of urbanization was 3.8%. Urbanization then increases steadily, reaching 9.5% in 1650, 14% in 1700 and 22% by 1800.

Figure 5: Urbanization – no shock and agricultural TFP growth

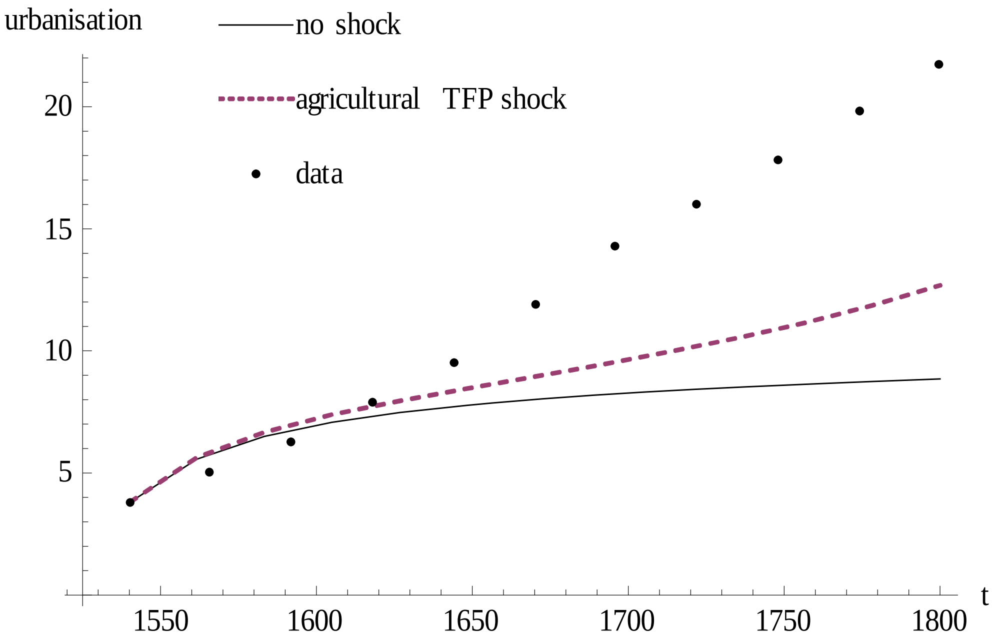


Figure 5 reports the evolution of urbanisation in the model in the absence of any shock, as well as that caused by agricultural TFP growth. In the absence of shocks, innovation and learning cause some increase in urbanization but this is moderate and urbanization converges to a value of around 9%. Low agricultural output implies high prices for food and thus a low return to manufacturing, resulting in low urbanization. Note that agricultural employment is well above the fraction of the population needed to produce the minimum food requirement, a result due to high food prices. The shock to agricultural TFP induces an increase in urbanization due to lower relative prices of food. Although rising urbanization is sustained during the period, the level is well below that observed in the data.

Figure 6: Urbanization – Tax changes vs agricultural TFP changes

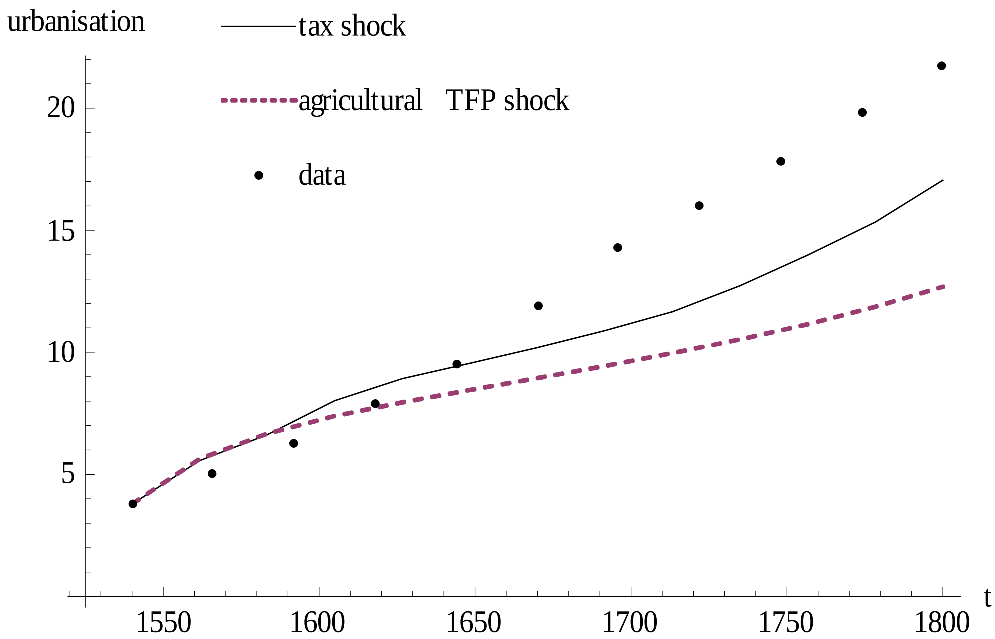
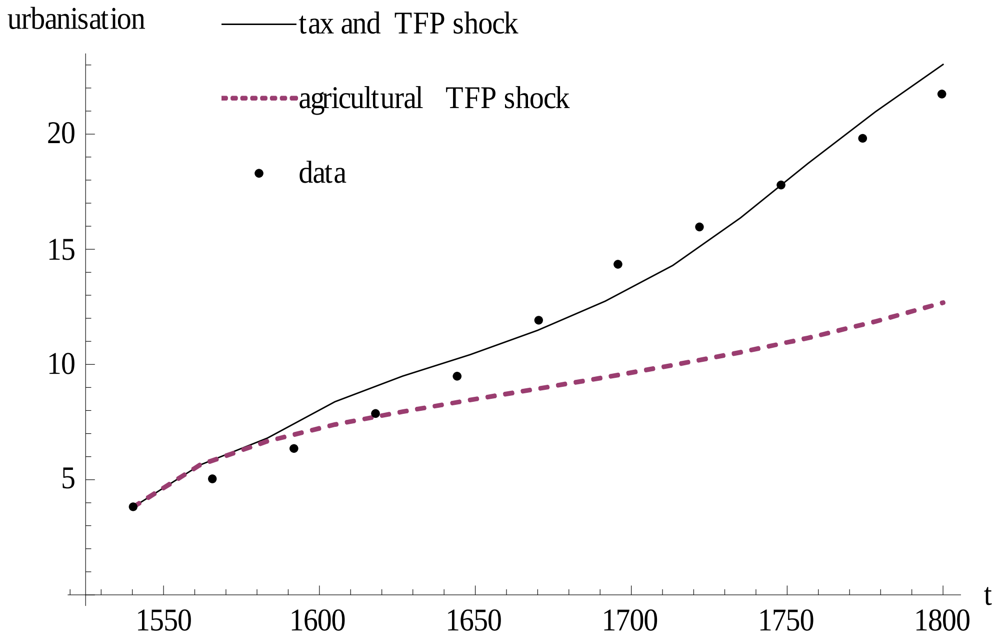


Figure 6 compares the effect of agricultural TFP growth with that of tax changes. We shock the economy by increasing the tax rate in line with the data, using the figures reported in table 7. There was a small increase (from 0.07 to 0.09 per cent) early in the period and then the extraction rate rose sharply around 1600, reaching 0.19 per cent. It fluctuated around 20 per cent during the 17th century and rose again in the 18th century, reaching 0.25 per cent by 1800. The model is successful at reproducing the early acceleration in urbanization that we observe, although from 1650 onwards the increase in urbanization is below the data. Nevertheless, tax changes generate substantially faster urbanization than agricultural TFP changes. Figure 7 combines the two shocks, and the simulated figures fit the data closely. The improvement when compared with the results obtained by having only the agricultural shock is substantial. Moreover, note that although the bulk of the tax increase occurs around 1600, urbanization keeps rising even though tax rates change little after that period. The reason for this is that the high *level* of taxation implies that moderate changes in agricultural TFP or in manufacturing productivity induce substantial flows of labour from rural to urban areas.

Figure 7: Urbanization – Simultaneous tax and agricultural TFP changes



In order to understand what drives the behaviour of urbanization, figure 8 presents our core simulation, with changes in both taxes and agricultural TFP, for an economy with imitation (depicted by the continuous line) and one in which imitation is not possible (that is, z=0, dashed line). We can see that the increase in taxation that took place between the 1550s and 1600 resulted in a moderate increase in urbanization, but the subsequent behaviour of taxes is incapable of reproducing the sharp increase in the urban population that followed, indicating that although higher taxes could have been the trigger of increased urbanization, the creation and diffusion of ideas played a crucial role in the further increases in the urban population. The reason for this is that although the number of available ideas increases at the same rate in both cases, average productivity in manufacturing is not growing fast enough to create a sufficiently large flow of labour from agriculture into industry. As a result, by the end of the 18th century the model without imitation predicts an urbanization rate of 9.33 percent, rather than the 22.5 percent obtained in the benchmark case (the actual urbanization rate was 21.7).

Figure 8: Urbanization – Simultaneous tax and agricultural TFP changes with and without imitation

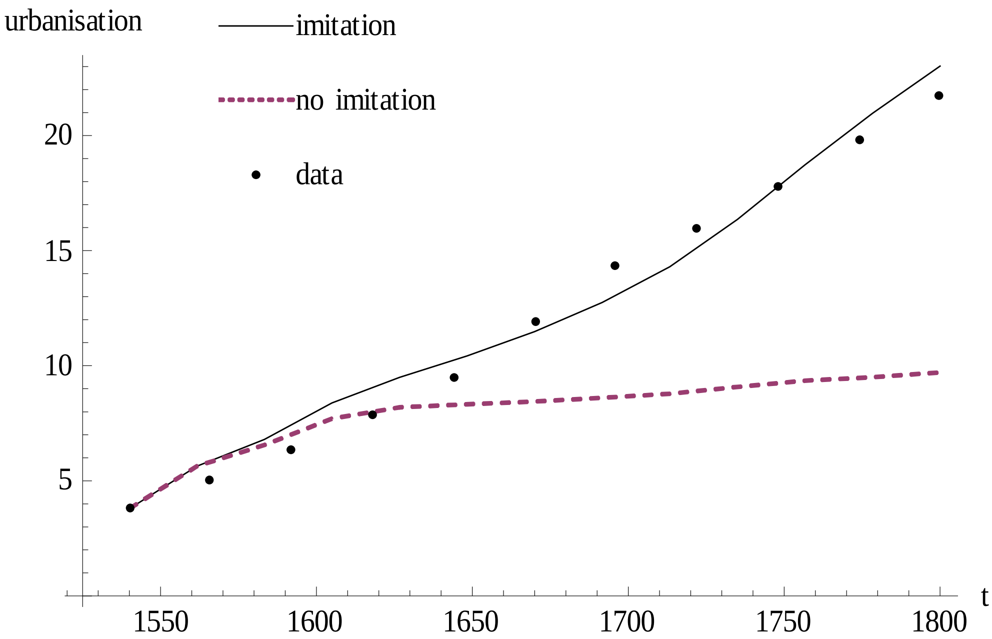


Figure 9 presents the simulated time series for real per capita output, as well as data on British per capita output from Broadberry et al. (2009, tables 19 and 22). It is interesting to see that although urbanization starts increasing rapidly in the 17th century, output growth during that period is slow and starts to accelerate from 1700 onwards. To understand this effect Figure 10 presents the corresponding time series for the number of available ideas or knowledge (dotted line), the average number of ideas in the urban population (dashed line), which is equivalent to average productivity in manufacturing, and per capita output (continuous line). The first thing to note is the gap between knowledge and productivity, capturing the fact that available knowledge and the diffusion of innovations do not move together. Second, although the growth rate of knowledge is constant (one idea per period) the model delivers an acceleration of productivity. The reason for this is that, initially, low urban density implies a slow diffusion of innovations amongst city-dwellers. As urbanization increases, the rate of diffusion or knowledge rises resulting in an acceleration of productivity growth from 1750 onwards. Output growth follows this pattern too. Lastly, output growth remains moderate despite the fact that available knowledge in increasing fast, thus making a fast pace of innovation compatible with moderate per capita output and productivity growth.

Figure 9: Output – data and simulation results

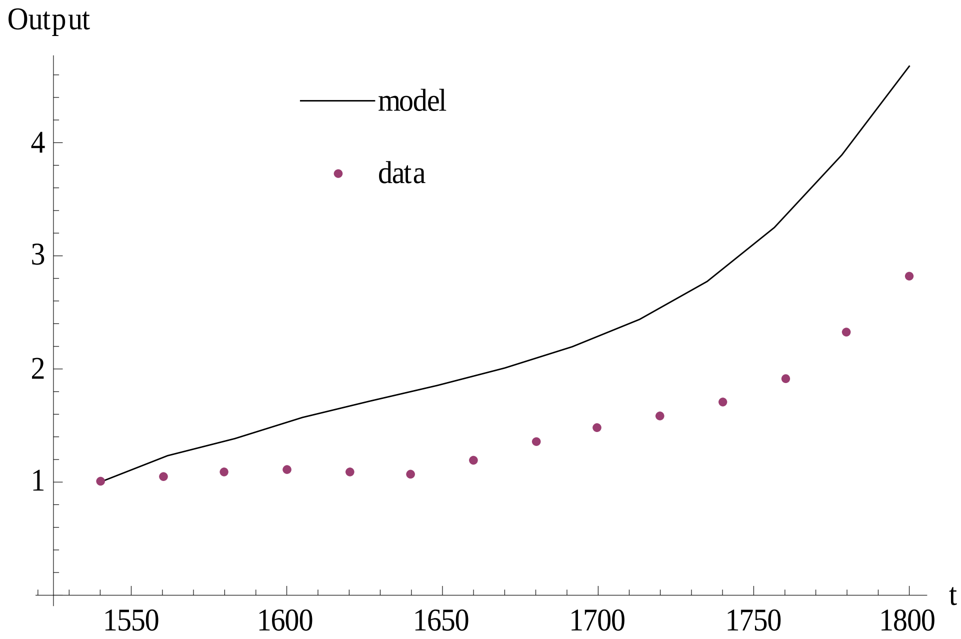
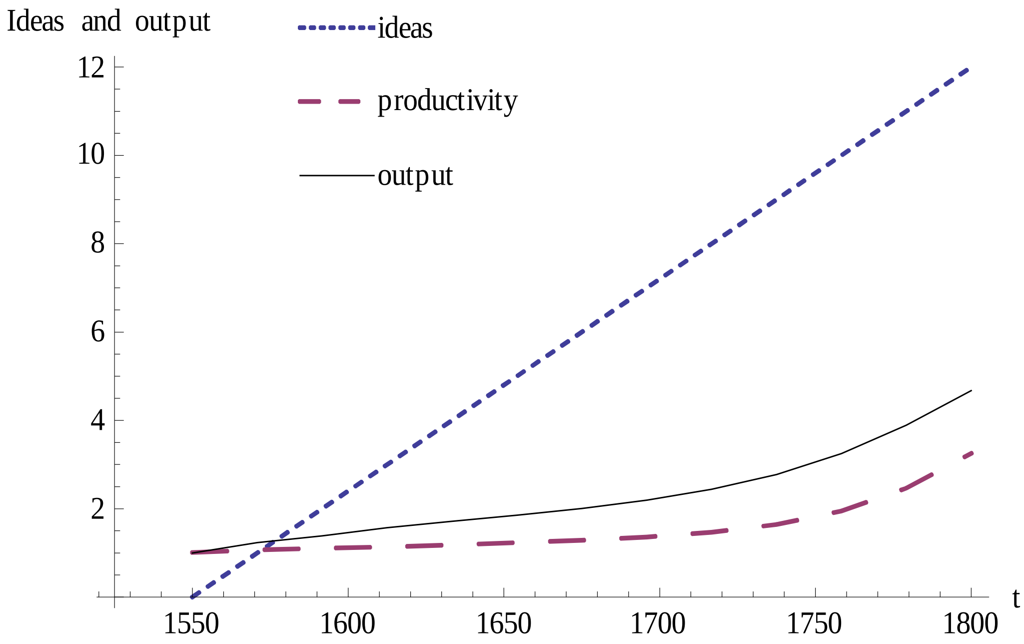


Figure 10: Simulated output, productivity and knowledge



It is important to comment at this point on our choice of model. The key idea in our analysis is that cities are special because they allow for interactions amongst individuals which in turn permit the diffusion and creation of knowledge. We could have model this effect simply by assuming that productivity in manufacturing is an increasing function of the rate of urbanization. Note, however, that unless we had made strong assumptions about the functional form of this knowledge-generating function, it is unlikely that we would have obtained an acceleration of productivity growth. In contrast, our micro-founded model of interactions between agents, based on the idea that urbanization determines the number of encounter and that the probability of imitation or innovation in each of this is constant, has the implication that there is such an acceleration. The intuition is simple. For a given number of encounters, the probability of imitating i ideas in a particular encounter is $zP(i,t)$; if the fraction of individuals with i ideas at t is larger, this will increase the fraction that has i ideas at t+1, making the probability of imitation next period higher. This mechanism creates an acceleration of the transmission of knowledge that results in slow initial growth that increases over time.

6. Conclusions

In this paper we have examined a potential explanation of why the First industrial Revolution took place in England in the mid-18th century. We maintain that urbanization was the cause, and not the consequence, of the unprecedented spur of innovations that started then and there. Cities are *special* in that they generate frequent encounters amongst individuals, resulting in an exchange of knowledge that leads to both imitation and innovation. At the beginning of the 18th century England had reached urbanization rates never before witnessed, which created a degree of exchange of knowledge and experiences that in turn led to the major innovations observed that century.

A key aspect of our analysis is that we see innovation as the result not of market activities but of social interactions. Social interactions are in fact often called 'non-market interactions' to emphasize the fact that they are not determined by the price mechanism.[14] In our model growth is endogenous but, in contrast with much of the recent literature, we suppose that innovation is not motivated by a profit motive but rather occurs as an externality resulting from high urbanization.

Our hypothesis raises the question of why the English population was so concentrated in cities. Although there were certainly several causes, we maintain that a key element was the sharp

[14] See, for example, Scheinkman (2008) and Cabrales and Zenou (2010).

increase in the extraction rate out of agriculture that took place during the 17^{th} century. Rents and taxes paid by farmers rose sharply during that century, leading to a flow of labour out of agriculture that resulted in both the observed high levels of output per worker in agriculture and high urbanization. The evidence we discuss, although limited, lends support to this hypothesis, and our numerical examples show that the model generates dynamics that are consistent with the data.

References

Bairoch, Paul, Batou, Jean, and Pierre Chèvre, (1988). *The population of European cities from 800 to 1850*, Geneva: Droz.

Broadberry, Stephen, Bruce Campbell, Alexander Klein, Mark Overton, and Bart van Leeuwen, (2009). "British economic growth, 1300-1850: some preliminary estimates", mimeo.

Brunt, Liam and Antonio Fidalgo, (2008). "Agricultural land and labour productivity around the world, 1700 to 1870: evidence from a new data set," mimeo., NHH-Bergen.

Brunt, Liam and Antonio Fidalgo, (2009). "Why Europe and not Asia? Agricultural productivity and industrial revolution around the world before 1870," mimeo., NHH-Bergen.

Brunt, Liam and Antonio Fidalgo, (2010). "Death and taxes: the drivers of economic growth," mimeo., NHH-Bergen.

Brunt, Liam and Jan Erik Meidell, (2010). "Occupational structure in England and Wales before and after industrialization: evidence from trade directories," mimeo., NHH-Bergen.

Brunt, Liam, (2000). *Agricultural productivity in England and France, 1700 to 1850*, unpub. Ph.D. thesis, University of Oxford.

Brunt, Liam, (2004). 'Nature or nurture? Explaining English wheat yields in the agricultural revolution.' *Journal of Economic History*, 64: 193-225.

Cabrales, A. and Y. Zenou, (2010). "Social interactions and spillovers," CEPR discussion paper no. 8127.

Clark, G., (2002). "Land Rental Values and the Agrarian Economy: England and Wales, 1500-1912," *European Review of Economic History* 6, 281-308.

Clark, Gregory, (2002). "The Agricultural Revolution and the Industrial Revolution: England, 1500-1912," mimeo., University of California, Davis.

Combes, Pierre-Philippe, Thierry Mayer and Jean-François Thisse, (2008). *Economic Geography*, Princeton University Press.

Crafts, Nicholas F. R., (2004). "Productivity growth in the Industrial Revolution: a new growth accounting perspective," *Journal of Economic History* 64, 521-35.

Crafts, Nicholas F. R., and Knick C. Harley, (1992), "Output growth and the British Industrial Revolution: a restatement of the Crafts-Harley view," *Economic History Review* 45, 703-30.

De Vries, Jan, (1984). *European urbanization : 1500-1800*. Harvard University Press.

Doepke, M. and F. Zilibotti, (2008). "Occupational Choice and the Spirit of Capitalism," *Quarterly Journal of Economics*, vol. 123(2), pages 747-793.

Galor, Oded and David N. Weil, (2000). "Population, technology and growth: from Malthusian stagnation to the demographic transition and beyond," *American Economic Review*, 90: 806-828.

Galor, Oded and Omer Moav, (2002). "Natural selection and the origin of economic growth," *Quarterly Journal of Economics*, 117*:* 1133-1192.

Galor, Oded and Omer Moav, (2004). "From physical to human capital: inequality in the process of development," *Review of Economic Studies* 71, 1001-1026.

Galor, Oded and Omer Moav, (2006). "Das Human-Kapital: a theory of the demise of the class structure," *Review of Economic Studies* 73, 85-117.

Galor, Oded, (2005). "From stagnation to growth: Unified Growth Theory," in Philippe Aghion and Stephen Durlauf (eds.) *Handbook of economic growth*, chapter 4. Elsevier.

Galor, Oded, Omer Moav and Dietrich Vollrath, (2009). "Inequality in land ownership, the emergence of human capital promoting institutions and the Great Divergence", *Review of Economic Studies*, 76(1), 143-179.

Glaeser, Edward L. and D.C. Maré, (2001). "Cities and skills", *Journal of Labor Economics*, Vol. 19, No. 2, pp. 316-342.

Glaeser, Edward L., (1999). "Learning in cities", *Journal of Urban Economics*, 46:254-277.

Gould, Eric D., (2007). “Cities, workers and wages: a structural analysis of the urban wage premium”, *Review of Economic Studies*, 74, 477-506.
Hansen, Gary D. and Edward C. Prescott, (2002). “Malthus to Solow,” *American Economic Review*, 92: 1205-1217.
Jones, Charles I., (2001). “Was an Industrial Revolution inevitable? Economic growth over the very long run,” *Advances in Macroeconomics*, 1(2), article 1.
Jovanovic, Boyan and Rafael Rob, (1989). “The growth and diffusion of knowledge”, *Review of Economic Studies*, 56, 569-582.
Krugman, Paul, (1998). “Supply, demand and English food”, http://web.mit.edu/krugman/www/mushy.html
Lucas, Robert E. Jr., (2009). “Ideas and growth**,”** *Economica*, 76(301), 1-19.
Maddison, Angus, (2000). *The world economy: a millenial perspective*. OECD: Paris.
Marshall, Alfred, (1920). *Principles of economics* (8th edition, London)
Mokyr, J. (2008). “The Institutional Origins of the Industrial Revolution” in Elhanan Helpman, ed., *Institutions and Economic Performance*. Harvard University Press, 2008, pp. 64-119.
Mokyr, J. (2009). “Intellectual Property Rights, the Industrial Revolution and the Beginnings of Modern Economic Growth,” *American Economic Review: Papers and Proceedings*, 99:2, 349-355.
Murphy, Kevin M., Andrei Shleifer and Robert Vishny, (1989). “Industrialization and the Big Push,” *Journal of Political Economy,* 97, 1003-26.
Scheinkman, J.A., (2008). “Social interactions,” in S. Durlauf and L. Blume (eds.) *The New Palgrave Dictionary of Economics*, 2nd ediction, Palgrave, Macmillan.
Voigtläder, Nikolas and Hans-Joachim Voth, (2006). “Why England? Demographic factors, structural change and physical capital accumulation during the Industrial Revolution”, *Journal of Economic Growth*, 11, 319-361.
Voigtländer, Nikolas and Hans-Joachim Voth, (2008). “The three horsemen of growth: plague, war and urbanization in early modern Europe,” mimeo.