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Large-scale mortality shocks and the Great Irish Famine 1845–1852

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ABSTRACT

This paper considers the consequences of a large scale mortality shock arising from a famine or epidemic for long run economic and demographic development. The Great Irish Famine of 1845–1852 is taken as a case-study and is incorporated as an exogenous mortality shock into the type of long-run unified growth theory pioneered by Galor and Weil (1999, 2000), and modelled by Lagerlöf (2003a,b) among others. Through calibration, the impact of such a mortality shock occurring on the cusp of a country's transition from a Malthusian to a Modern Growth regime is then depicted.

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1. Introduction

Despite the phenomenal scientific and technological advances witnessed in all spheres of human endeavour over the last two centuries, the spectre of large scale epidemics and famines continues to loom ominously over many nations even today. And while famine in Ethiopia and Somalia in the 1980s and 1990s as well as the havoc currently wreaked in sub-Saharan Africa by HIV/AIDS may suggest that the threat of such large scale humanitarian crises is largely confined to under-developed third world regions, the outbreaks in Europe and Asia of severe acute respiratory syndrome (SARS) in 2003, Avian Bird Flu strain H5N1 in 2006, and the 2009 H1N1 Swine Flu pandemic caution against such complacency. These outbreaks also warn against consigning to the past the lessons of a whole range of other episodes in modern European history, from the Spanish Influenza pandemic of 1918/19 which claimed the lives of between 50 and 100 million people worldwide, to the more localized Great Irish Famine of 1845–1852 which led to the death of approximately 1 million Irish people from famine related diseases and the exodus of a further 1 million inhabitants, making it one of the most lethal famines in modern history in terms of excess mortality and population loss.¹ With this in

mind, we set about analysing the consequences of a large scale mortality shock arising from a famine or epidemic for long run economic growth. To facilitate this, we take the fore-mentioned Great Irish Famine of 1845–1852 as a case-study and utilize a recently developed school of long-run economic-demographic growth models encompassing the work of Galor and Weil (1999, 2000) and Lagerlöf (2003a,b, 2006) to simulate and analyse the impact of such a mortality shock on a country's subsequent economic development.

In recent years the mechanisms through which epidemics affect long term growth have been considered from an endogenous growth theory perspective. Barro and Sala i Martin (1995, pp. 171–198) and Azomahou et al. (2006), in particular, provide useful summaries of attempts to capture the effects of a Spanish Flu-like epidemic (one which has massive immediate effects) in both a one-sector framework and the two-sector framework of Lucas (1988). Both approaches, however, suffer from a number of shortcomings. As Azomahou et al. (2006) note, the one-sector framework where physical and human capital are substitutes seems to be less suited to this purpose as it essentially reduces the epidemic to an “initial condition shock” whereby the economy returns to its steady state equilibrium after the mortality shock and one merely ends up studying the transitional dynamics. Furthermore, the role of demography in such a model plays only a minor role and does not impact the return to human capital in the short or long run. It does allow for a marked growth episode in the aftermath of the epidemic but only by virtue of the fact that the epidemic's depletion of human capital makes human capital accumulation more desirable in the post-epidemic period. The two-sector model, as per Lucas (1988), allows for a more nuanced story as it differentiates between the production of physical and capital goods

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¹ While the potato blight which triggered the Great Famine struck in 1845, 1846, and 1848, we adopt the convention of Kinealy (2006), among others, of dating the period of the famine as 1845–1852. According to Ó Gráda in “The Great Famine and Today's Famines” (p. 250), proportionally fewer people have died in modern famines than during the Great Irish Famine.

and assumes that there is an education sector that is more human capital intensive than the final good sector. This set-up allows population growth to impact on human capital production through the allocation of effort devoted to the production of human capital. An external effect of human capital can also be built into this set-up. However, [Azomahou et al. \(2006\)](#) point out that in the post-epidemic period the economy must allocate its scarce human capital between the education and final good sectors and might find it optimal to assign more human capital to the sector less intensive in human capital – the final good sector. This is in contrast to the catching-up mechanism of the one-sector model and leads to a post-epidemic period of slow growth and high wages (due to the increased return to human capital).

It is in the context of these somewhat ambiguous theoretical predictions that we turn to the unified growth theory advanced by [Galor and Weil \(2000\)](#) in search of further insights. The [Galor and Weil \(2000\)](#) modelling framework captures, in a single process, Western European economic development from the period of Malthusian stagnation through to the contemporary era of modern growth, generating: (i) the oscillations in population and output per capita observed during the Malthusian period, (ii) an endogenous take-off from Malthusian stagnation to a Post-Malthusian stage that is associated with an acceleration in technological progress and is accompanied initially by a rapid increase in population growth, and (iii) a rise in the demand for human capital, followed by a demographic transition and sustained economic growth.² A key concept for the purposes of this paper is that of *industrialisation*. In unified growth models industrialisation is captured through this process of technological progress, accompanied by population growth and human capital accumulation. In empirical studies, of course, industrialisation is observed through the changing industrial structure of the economy and its transition from an agrarian economy to one where manufacturing plays a dominant role. We argue that these two approaches are compatible in that they represent two different ways of representing the same stages of the development process.

This unified growth framework is particularly suited to modelling the Great Irish Famine by virtue of the time period in which the famine occurred: the period 1845–1852 is one where Ireland could be considered to have been on the cusp of industrialisation, as indicated by its changing industry structure. [Geary \(1998\)](#) finds that the structure of Irish pre-famine employment was consistent with Ireland's position on the path of development as exhibited either by an average for continental Europe or Britain at a similar level of income. [Almquist \(1979\)](#) considers Irish pre-famine development in terms of “proto-industrialisation” theory, which proposes that a major expansion of rural industry, primarily in textiles (domestic spinning and weaving), formed a phase precursory to industrialisation in many European regions.³ Given that Ireland could be seen as being on the cusp of industrialisation prior to the famine, the choice of a unified growth model seems appropriate since in this type of model the process of industrialisation itself is hypothesized to be greatly influenced by the impact of epidemics and large scale mortality shocks.

While numerous studies, such as those by [Fernandez-Villaverde \(2001\)](#), [Jones \(2001\)](#), [Kögel and Prskawetz \(2001\)](#), [Hansen and Prescott \(2002\)](#), [Tamura \(2002\)](#) have sought to further develop this unified growth framework, it is the work of [Lagerlöf \(2003a,b\)](#) that is of particular interest for our purposes. [Lagerlöf \(2003a,b\)](#) models the transition from the Malthusian, through the Post-Malthusian, and on to the Modern Growth stage endogenously, using the stochastic occurrence of a series of unusually soft epidemic shocks as the

mechanism through which this transition is brought about. This model serves as a useful analytical tool in our case, since mortality shocks can be expected to exert a large influence on the subsequent economic development. The set-up offers us the opportunity to consider the impact of an exogenous mortality shock of unusually large magnitude, such as the Irish Famine, in the context of a country's entire economic and demographic development process. In this way, the [Lagerlöf \(2003a,b\)](#) approach helps us to disentangle the demographic and economic effects of epidemics and famines, place such effects in the multiple equilibrium setting of industrialisation brought about by human capital accumulation, and characterize epidemics and famines as having long run impacts through emigration and demographic channels rather than being short, sharp shocks.

The remainder of the paper is organised as follows: [Section 2](#) provides a brief overview of the factors contributing to the occurrence of Great Irish Famine 1845–1852, as well as discussing in more detail pre- and post-famine demographic and economic trends. [Section 3](#) sets out a framework for embroidering emigration into the single economy model of long run economic development of [Lagerlöf \(2003a,b\)](#) in order to utilize such a model in the context of a large scale mortality shock. [Section 4](#) presents the results of our calibration exercise, and assesses the model's ability to capture the observed demographic and economic post-famine recovery. Conclusions and avenues for future research are set out in [Section 5](#).

2. Irish economic climate before and after the Great Famine

The purpose of this paper is to calibrate and analyse the economic development of nations in the aftermath of large scale mortality shocks, using the Great Irish Famine of 1845–1852 as a case study. While it is not our intention to undertake a comprehensive treatment of the complex political and social issues contributing to this tragic episode, a brief overview of the economic and political issues pertaining to the Great Irish Famine is provided.⁴ A more detailed presentation of various Irish economic and demographic trends over the course of the nineteenth and twentieth century is also provided, as it is these trends that will serve as the yardstick from which to gauge the success or failure of our long run economic growth simulations in [Section 4](#).

2.1. The Great Irish Famine

The blight that decimated the Irish potato crop for three harvests over the period 1845–1848 was the catalyst for the last major famine to be seen in the western world. Despite being unsuited to storage or transportation, the potato's high nutritional content, relatively dependable yield even in poor soil during the pre-famine years, and its flexibility as a food for both man and livestock led to an over-dependence on the crop, particularly among the poorer layers of Irish society. By 1845, according to [Ó Gráda \(1993\)](#), the potato's share in tilled acreage was little short of one-third and about three million people were largely dependent on it for food. As [Kinealy \(2006, p. xvi\)](#) notes, “the Great Irish Famine remains unsurpassed, in relative terms, in terms of demographic decline with the Irish population falling by approximately 25% in just six years, due to a combination of excess mortality and emigration”. While the diseased potato crop may have triggered the Great Famine, it was a complex web of economic, political, and social issues that exacerbated the situation and ultimately contributed to the shocking level of distress witnessed during the famine years.

Despite the fact that the 1800 Act of Union officially merged Ireland and Great Britain into one United Kingdom, Ireland was very much regarded as a separate entity by the Westminster government. This fact, as well as Ireland's quasi-colonial *de facto* political status

² For a more detailed treatment of unified growth theory see [Galor \(2005\)](#).

³ That said, a number of economic historians have asserted that Ireland experienced a certain amount of de-industrialisation in the first half of the nineteenth century prior to the famine due to a decline in importance of manufacturing; see for example [Mokyr \(1985a,b\)](#). However, [Geary \(1998\)](#) casts doubts on the occurrence of Irish de-industrialisation prior to 1841 by pointing out that in previous literature the Irish industry structure may have been unwisely compared with Britain of 1841 structure, rather than with Britain at a lower level of income.

⁴ For a detailed treatment of the Great Irish Famine see [Kinealy \(2002, 2006\)](#), [Ó Gráda \(1993\)](#), [Mokyr \(1985a,b\)](#), among others.

Fig. 1. Irish population trends in '000 s, 1700–2004. Sources: the Irish data comes from a variety of different sources: 1712–1791 O Connell estimates and Irish Census data 182–1841 reproduced in Mokyr and Ó Gráda (1984); 1838–1900 data available from ESRC quantitative database. Irish population data is also available in Vaughan and Fitzpatrick (1978). Irish population data for 1900–2003 available from <http://www.ggd.net/maddison/> (Angus Maddison homepage). Pre-1838 data points joined using a median spline.

impeded integration with Britain.⁵ That said, Ireland enjoyed an important trading relationship with Britain, exporting enough corn to feed two million people on the eve of the famine. If over-dependence on one crop, as well as the Irish practice of subdivision of land were instrumental in creating the conditions in which the famine, once ignited, could rampage, attitudes towards Ireland emanating from British political circles also played a part. Kinealy (2002) notes that official reports into the condition of Ireland confirmed that the Westminster government was anxious to modernize Ireland in order to end Irish dependency on British resources. In light of this, the Great Famine presented the Westminster government with the social dislocation necessary to replace both poor tenants and impoverished landlords with a new class of commercial farmers, with a crucial element of this approach being the minimal intervention by the Westminster government despite the extent of the famine afflicting Ireland. Consequently, what relief was provided was nowhere near sufficient to cope with the sheer scale of the famine over the 1845–1848 period.⁶

While the specific weight of each causal factor is still open to debate, the consequences of the famine for Irish society are in no doubt: approximately 1 million people famine related deaths, the exodus of a further 1 million, a continued population decline long after the famine due to emigration, delayed marriages, and lower fertility.⁷

⁵ By 1841, Ireland accounted for almost one third of the United Kingdom population: England and Wales 15,929,000; Scotland 2,622,000; and Ireland 8,200,200. Despite this, Ireland was under-represented in Westminster and retained an Irish Administration in Dublin reminiscent of colonial status. See Kinealy (2002, pp. 18–19).

⁶ A national system of poor relief was only established in Ireland in 1838 by the Irish Poor Law establishing a system of 130 administrative unions, each to have a workhouse where the destitute could work for their keep. Rather than alleviating poverty, this regime seemed to aim at abolishing poverty through harsh regimes and a heavy financial burden on rate payers. During the famine this regime was supplemented by a more generous public works system and the distribution of Indian Corn by the Dublin administration. Soup kitchens were also set up by the British government in 1847. Temporary fever acts were also introduced in 1845 and 1847. While these measures were enough to prevent excess mortality in 1845 and early 1846, they were found to be completely inadequate for the levels of distress that followed from 1846 to 1848. See Clarkson (1989, pp.228–29) and Ó Gráda (1993, pp. 99–111).

⁷ While emigration plays a central role in our modelling set-up, delayed marriages and lower fertility are not explicitly modeled in our approach. This modeling choice finds some support from Guinnane (1994) who indicates that the Irish post-famine birth rate was unremarkable by European standards, though it was the product of an unusual combination of large families and low marriage rates.

2.2. A closer look at pre-and post-famine economic and demographic trends

As Mokyr and Ó Gráda (1984) point out, all Irish population figures over the period 1700–1845 are rather speculative. Nevertheless they all point to Ireland's position at the top of the population growth table over this period – driven in part by reduction in costs of family formation brought about by the diffusion of the potato crop. However, a clear deceleration in Irish population growth did occur prior to 1845 due in large part, it is thought, to emigration.⁸

Estimates of deaths due to the Famine over the 1845–1852 period range from 800,000 to 1,500,000, according to Mokyr (1980). After 1845 the lasting impact of the famine on Irish population trends is evident in Fig. 1, with a clear negative trajectory over the 1852–1900 post-famine period. The longevity of the Great Famine's impact on Irish demographic trends has also been well documented.⁹ The Irish population continued its decline after 1890, falling a further 5% between 1891 and 1926 – the first year in which a census was held for the newly independent 26 county state which would become the Republic of Ireland – and remained relatively stable until the 1960s.¹⁰ Only from the mid 1960s on has this negative trend been reversed, due to a combination of falling emigration (culminating in net inward migration in the 1990s), strong natural population growth, and the economic success experienced in recent years.

Irish emigration flows in the pre-famine period, illustrated in Fig. 2, were substantial but pale in comparison to the exodus triggered by the distress endured over the 1845–1852 period. Mokyr (1985a,b), p.35) calculates that Irish emigration was on average 7 per 1,000 between 1815 and the famine and that the corresponding figures for the 1850s and 1880s were in the region of 19 per 1000 and 16 per 1000, respectively. Hatton and Williamson (1993) identify similar post-famine emigration trends and note that in the years immediately preceding the First World War emigration had returned to its pre-famine level of about 8 per 1000. Ó Gráda (1994) notes that in the period between the famine and the First World War, Irish living standards improved steadily and this may have contributed to the return of emigration flows to pre-famine levels. America and Britain

⁸ Boyle and Ó Gráda (1986) and O'Rourke (1995) both provide a comprehensive treatment of the role of emigration in Irish post-famine demographic and economic trends.

⁹ See, for example, CSO (2004) and Kennedy and Clarkson (1993).

¹⁰ The Irish Free State was the name given to the 26 of Ireland's 32 counties that were separated from the United Kingdom of Great Britain and Ireland under the Anglo-Irish Treaty of December 6, 1921. It was not until 1949 that the transition to a Republic was officially completed with the passing of the Republic of Ireland Act.

Fig. 2. Total Irish emigration, 1821–1900. Sources: Boyle and Ó Gráda (1986) calculations of Irish emigration to North America and Britain (1821–1850); Vaughan and Fitzpatrick (1978) total Irish emigration 1851–1900.

were the main destinations for Irish emigrants, receiving approximately 72% and 20%, respectively, of all Irish emigrants over the 1876–1913 period.¹¹ The age profile of these emigrants is also interesting: over the 1861–1911 period between 60–70% of the emigrants were under the age of 24.¹² Factors driving these Irish emigration trends are considered in more detail in Section 3.

The shortage of both pre- and post-famine Irish economic data has made it difficult to accurately depict the economic growth of 19th century Ireland and, as a result, there is no clear consensus on the Irish economic performance in this period.¹³ A rough impression of the Irish pre-famine economic climate can be gleaned from the following: Mokyr's national income estimate for Ireland in the early 1840s puts Irish income per capita at around 40% of contemporary British levels, or the same as Zaire or Uganda in 1970 (Mokyr 1985a,b, pp10–11; Ó Gráda 1994, pp.96–97), while O'Rourke (1995) surmises that unskilled wages were stagnant, if not falling, in pre-famine Ireland.¹⁴ That said, pre-famine Ireland has been labelled “the bread-basket of Britain”, as it enjoyed an important trading relationship with Britain in agricultural products — something which would subsequently become a contentious issue, as Ireland was exporting enough corn to feed two million people on the eve of the famine; Kinealy (2002). Turning to post-famine estimates, Geary and Stark (2002), using sectoral wage and labour force data to construct estimates of Irish and British GDP for the period 1861 to 1911, estimate that Ireland's GDP per capita growth clocked in at an average of 0.9% per annum over the period 1871–1911, with GDP per worker averaging at 1.1% over the same period. The corresponding figures for Great Britain are 0.8%, both in per capita and per worker terms. These positive developments are supported by Ó Gráda (1994, p242) who notes that Irish national income per capita almost trebled between 1845 and 1914; and rose from 40% to 57% of the British level between 1845 and World War 1. The Irish post-famine performance has even been hailed by O'Rourke (1995) as the “Irish Miracle” and points to increased post-famine emigration as being crucial in facilitating this economic revival.

From Fig. 3, the increase in GDP per capita in the late 1800s and early 1900s is clear to see. It is also apparent that it is not until the 1960s that Irish GDP really achieves a definitive take off, culminating

in the phenomenal Irish economic performance of the last two decades.

Having outlined the salient characteristics of Irish demographic and economic development over the last three hundred years, we now describe in more detail the model with which we hope to simulate the impact of the Irish famine of 1845–1852.

3. The basic model

This model is based on that of Lagerlöf (2003a,b), but in this case emigration and time-varying labour productivity are explicitly included. As per Lagerlöf (2003a,b), we start by considering a single economy, but we modify the set-up so that the inhabitants can leave, i.e. emigrate, for good without returning or having any further interaction with the economy. The significance of this explicit modelling of emigration is that it recognises the crucial role that emigration plays in shaping both demographic and economic trends long after the occurrence of a mortality shock which is not global in scale. The inhabitants', or agents', lives have two stages: childhood and adulthood. In our version of the model, however, surviving children either become adults in their single economy or they emigrate. In this way the emigration decision in this model is made once, before adulthood, and emigration is similar to a leakage from the single economy.¹⁵ The emigrants do not return to their home country (a reasonable assumption for Irish–US emigration in the 1800s and well into the 1900s, but perhaps less so for Irish–British emigration) and we do not consider remittances from the host country as we assume such remittances would be too small and sporadic to influence the GDP of the source country. We do address the issue of previous waves of emigrants enticing new emigrants to join them in the host country (the “friends and relatives effect”) by positing that the emigration decision is influenced by the stock of emigrants from previous years.¹⁶ This very simple portrayal of emigration may seem unrealistic at first, but less so if one believes that people emigrate at a young age and, more crucially, that these young emigrants do not remain in Ireland long enough to have children.

¹¹ Hatton and Williamson (1993), p.577, Table 1.

¹² Mokyr (1985a,b), p.234, table 8.1.

¹³ See Geary and Stark (2002, pp.1–3) for an overview of the conflicting estimates of Irish economic growth and convergence trends with Great Britain in the 19th century.

¹⁴ Irish real wage data available from Bowley (1899) and reproduced in Williamson (1992). For a discussion of the pitfalls of relying on this Real wage data see Ó Gráda (1993, p.16).

¹⁵ Hatton (2001) notes that more than three quarters of the immigrants entering the United States between 1868 and 1910 were aged between 16 and 40. Furthermore, he notes that in the Irish demography of this time the 15–34 year old cohort were only 35% of the total population but over 80% of Irish emigrant bound for the US came from this age group.

¹⁶ In order to make this “friends and relatives effect” compatible with a single economy model one could think of it in terms of potential emigrants being influenced in some way by previous emigration flows.

Fig. 3. Irish GDP per capita 1700–2004. Source: GDP per capita data for 1700–2004 (in 1990 international Geary-Khamis dollars) available from <http://www.ggdc.net/maddison/> (Angus Maddison homepage). Pre-1921 data points joined using a median spline.

Agents live in childhood and as adults but, to simplify the model, children do not consume, so period- t output per person (Y_t) equals adult per capita consumption (C_t)¹⁷:

$$Y_t = [1 - (v + h_t)B_t] D_t (L + H_t) = C_t, \quad (1)$$

where, as per Lagerlöf (2003a,b), $L + H_t$ denotes total human capital per person. L is the part of human capital which nature equips every agent with and H_t is the part of human capital which is inherited from the parents. The variable D represents labour productivity per person, in that it captures developments in per capita labour productivity which are not related to the level of human capital per person.

The modelling strategy of Lagerlöf (2003a,b) characterises D , labour productivity per person, as a constant. However, an assumption of constant labour productivity is at odds with what has been empirically observed in post-famine Ireland: for example, Geary and Stark (2002) estimate that between 1861 and 1911 Irish labour productivity grew at 0.9% per year and that between 17% and 28% of Irish labour productivity gains were due to labour force declines arising from emigration, with the combined effects of capital accumulation and total factor productivity (TFP) accounting for the rest. The results of Geary and Stark (2002) are derived assuming a neoclassical economy with constant returns to scale Cobb–Douglas production. In the neoclassical framework, a fall in the labour force with a constant capital stock leads to an increase in GDP per capita. This phenomenon has also been observed in the aftermath of the Black Death, where a population decline that exceeded the fall in output led to an increase in output per capita; Pamuk (2007). In light of this, it is desirable that our modelling set-up allows labour productivity to vary over time.¹⁸ This inclusion of a time-varying labour productivity term enables us to incorporate into our set-up a post-famine economic recovery brought about by labour force outflows or efficiency gains. We set up a simple dynamic function, Eq. (2) below, where labour productivity per person increases linearly over time and is non-decreasing. We allow labour productivity per person, D_t , to be time-varying by linking it to emigration. The emigration flow in each period, E_t , is then presented in Eq. (7) below. This simplified approach is

intended to operationalize our time-varying labour productivity term, rather than fully characterizing the process through which the labour productivity is generated.

In every period, D_{t+1} is given by

$$D_{t+1} = D_t + \xi E_t, \quad (2)$$

where E_t is the amount of emigrants in period t and ξ is a constant. Parameter values for this equation are presented in Section 4. One criticism of the specification in Eq. (2) is that, while emigration is posited to affect labour productivity positively, the negative impact of “brain drain” due to the emigration of skilled workers is overlooked. While we would advocate the inclusion of a term capturing “brain drain”, in the Irish post-Famine case the influence this phenomenon is far from clear. Ó Gráda (1994) notes that is reasonable to assume that, though most of those who emigrated after the Famine were described as “labourers” or “servants” in both emigration returns and passenger lists, there was probably some selection bias towards the most talented. However, Ó Gráda (1994) also points out that skilled workers were relatively well paid in Ireland in nineteenth century Ireland. A wage survey conducted by the Fiscal Inquiry Committee in 1923 indicated that by 1914 skilled workers in Ireland were paid almost as much as their British peers.¹⁹ As our specification (2) represents a first pass at embedding dynamic labour productivity and emigration into the Lagerlöf (2003a,b) setting, we opt for a simple, yet reasonable, specification and leave refinements to future research.

Each parent has a time endowment of one unit, so time input in the consumption goods sector is $1 - (v + h_t)B_t$. B_t denotes the number of children of that agent, and $v + h_t$ is the time spent on each child, where v is a fixed time cost and h_t denotes education time. For the purposes of the adult's consumption function it is irrelevant whether or not the child will emigrate in the future; each adult will still invest the same amount of time and effort in their child. Out of the B_t children born, a fraction T_t will survive to be adults in our single economy, and of this surviving group, E_t individuals will emigrate. As is the convention, we let P_t denote the adult population size in period t , which in the Lagerlöf (2003a,b) set-up also measures population density since land size is fixed. The survival rate is an increasing function of the ratio of inherited per capita human capital to adult population (H_t/P_t) and in keeping

¹⁷ In keeping with the notation of Lagerlöf (2003a,b), capital letters Y_t and C_t denote per capita terms (as distinct from total output and total consumption).

¹⁸ In Lagerlöf (2003a,b) labour productivity, D , is represented by a constant which is normalised to unity.

¹⁹ See Ó Gráda (1994, p.238, Table 10.2).

with the Lagerlöf (2003a,b) framework is given the following parametric form:

$$T_t = T(H_t / P_t, \omega_{Rt}, \omega_{Ft}) = \frac{H_t / P_t}{\omega_{Rt} + \omega_{Ft} + H_t / P_t}, \quad (3)$$

with ω_{Rt} denoting the period- t random mortality shock as per Lagerlöf (2003a,b). This shock is log normally distributed, and thus always positive:

$$\ln(\omega_{Rt}) \sim N(\mu, \sigma^2). \quad (4)$$

The exogenous mortality shock, which in our set-up represents the Irish Famine, is given by the following expression

$$\omega_{Ft} = \begin{cases} \omega_F, & t = t_F \\ 0, & t \neq t_F, \end{cases} \quad (5)$$

where ω_F is a constant which denotes the size of the famine and t_F is the time period in which the famine occurs.

It follows that P_{t+1} , the adult population size in the period $t+1$, can be represented very simply as:

$$P_{t+1} = P_t T_t B_t - E_t. \quad (6)$$

One must now consider the factors that determine the number of emigrants, E_t , leaving our economy in time period t . Hatton (2001) and Hatton and Williamson (2002) provide comprehensive studies of the factors influencing the emigration decision. Based on the contributions of Sjaastad (1962) and Borjas (1987), among others, Hatton and Williamson (2002) observe that emigration from Europe in the late 19th century was driven by a number of key factors: the purchase power parity adjusted real wage of the source country relative to the destination; demographic forces reflecting the deteriorating employment conditions in the source country; a “friends and relative effect” attracting migrants to the destination; and, to a lesser extent, the differential mobility between urban and rural populations in the source country.

In the Irish context, the role played by post-famine emigration in inducing persistent depopulation cannot be overstated. According to Watkins and Menken (1985) the resumption of “normal” patterns of Irish population growth in the aftermath of the Famine would have implied that by 1900 the famine’s effects would barely have been noticeable. However, as Whelan (1999) notes, Ireland’s post famine demographic experience was not normal: the persistent decline in Irish post-famine population occurred despite the Irish post-famine birth rate being unremarkable by European standards, albeit due to an unusual combination of large families and low marriage rates (Guinnane, 1997). It was continued emigration flows rather than low birth rate growth that principally caused this persistent depopulation.

A number of factors have been advanced as possible drivers of Irish post-Famine emigration such as (i) the decline in rural population and decimation of agricultural small-holdings [Ó Gráda (1989), O’Rourke (1991)] and (ii) the decrease in agricultural labour demand as the potato blight permanently reduced Irish potato yields, O’Rourke (1991). However, these “push factor” explanations may only capture one side of story, as post-Famine Ireland did not experience decline in living standards (outlined in Section 2.1 above). It may have been the case that “pull factors” of growing demand for labour in USA and Britain. Ó Gráda (1994) suggests that during the famine emigrants were not concerned about the trends in living standards abroad, but were motivated by the “push factor” of domestic levels of distress. The forced nature of famine era migration is evident from Ó Gráda and O’Rourke (1997): “the emigrants of this year are not like the former ones; they are now actually running away from fever, disease and

hunger, with money scarcely sufficient to pay passage for and find food for the voyage”. Forced migration such as that witnessed in the famine era has been a prominent feature in development studies, where it emerges as a result of environmental, economic or demographic crises [(de Haan (1999), Ahmed (2009)]. After the famine, “pull factors” must have dominated, since emigration persisted despite slowly improving conditions at home. Ó Gráda (1994) points out that that between the mid-1850s and 1910 the American real wage rose by two-thirds or more, while the emigration rate from Ireland fell from about 12 to 6 per thousand.

The incorporation of emigration and its determinants into our modelling set-up is limited by data availability for pre- and post-famine Ireland. Mokyr and Ó Gráda (1988) pp. 210–211 note that no reliable real wage series exists for this period. They also note that, “the Irish labour force in 1845 still consisted largely of self-employed workers in agriculture and rural industry, or workers who were paid for their labour services in allotments of small plots”, and that, apart from the urban and wealthy, “most of the Irish grew their own food, provided their own fuel, and were close to self sufficiency in clothing and housing”. Two of the other drivers of migration, however, are easier to embed into our model: the “friends and relatives effect” of those who emigrated in previous years is represented by lagged emigration data, while we use the exogenous mortality shock to capture the demographic forces unleashed by the level of distress experienced in pre- and post-famine Ireland.²⁰ This series of exogenous random mortality shocks, presented in Eqs. (4) and (5) above, is constructed as per Lagerlöf (2003a,b), who calibrates the series to fit mortality data for France, Sweden, and the UK for the period 1749–1839.²¹ While this characterisation of emigration is rather simplistic, we feel that it represents a useful first pass at incorporating emigration into unified growth models such as that of Lagerlöf (2003a,b).

Emigration flow in period t is modelled as:

$$E_t = \kappa[\omega_{Rt} + \omega_{Ft}] + \gamma[E_{t-2} + E_{t-1}], \quad (7)$$

where $\omega_{Rt} + \omega_{Ft}$ is the total exogenous mortality shock capturing the impact of the level of distress on the emigration level, $E_{t-2} + E_{t-1}$ represents the “friends and relatives effect”, and κ and γ are constants.²² The exogenous mortality shock here reflect the forced nature of emigration in response to a large scale epidemic, as discussed above. We do not allow for inward migration or return of migrants to their home country. This implies that E_t could be zero but not negative.

Next we specify, again as per Lagerlöf (2003a,b), the production of inherited per capita human capital and the utility function for each adult agent. Importantly for our purposes, the choice to emigrate plays no direct role in either of these: the adult agent has already decided against emigrating; the adult agent’s provision of parental nursing and childhood education to his/her child are not influenced by the likelihood of that child deciding ultimately to emigrate; and it is also assumed that the utility of each adult is not reduced by the emigration of his or her child, nor does the parent regard nursing or education of this child as a loss or a wasted investment.²³

²⁰ Carrington et al. (1996) note that the newly created Irish communities overseas continued to pull new migrants well after the time when Irish wages and income had surpassed their pre-famine relative levels.

²¹ Famine and subsistence crises were a regular occurrence in pre-famine Ireland, though not on the scale of the Great Famine of 1845–1852. Wilde (1856) estimates that there were 56 subsistence crises and 29 famines in Ireland over the period 1290–1900. See Crawford (1989), p.225, Table 1).

²² The impact of the friends and relatives emigrating in previous years on the current emigration rate here is limited to those emigrating up to two periods (50 years) before the actual period.

²³ One could complicate the adult agent’s utility function in a number of ways, such as by assuming his utility falls in the aftermath of a child’s emigration as he now has one able-bodied family member less available to him to produce output (or work agricultural land) or by assuming his utility increase as income per capita increases due to the fall in population brought about by sustained emigration, but in order to keep the model simple we do not pursue these considerations here.

Inherited human capital per person is produced using

$$H_{t+1} = A(P_t)F(C_{t-1})[L + H_t](\rho v + h_t), \quad (8)$$

where $\rho < 1$ in order to ensure that in the building of human capital education time is more productive than “nursing time”. Lagerlöf (2003a,b) also includes a scale effect in human capital production which captures the effectiveness with which one generation passes on human capital to the next and is represented by $A'(P_t) > 0$. $A(P_t)$ is specified as:

$$A(P_t) = A^* - \tilde{A} + \tilde{A} \left(\frac{P_t}{\eta + P_t} \right) = A^* - \tilde{A} \left(\frac{\eta}{\eta + P_t} \right), \quad (9)$$

where $A^* > \tilde{A}$ and $\eta > 0$. Lagerlöf (2003a,b) opts for this functional form to ensure that increasing population density does not raise human capital productivity indefinitely, but only up to the level A^* . With this specification zero population implies positive human capital productivity.

In our modelling set-up we also include a further scale effect in inherited human capital production. This scale effect is designed to capture the impact of per capita income on human capital production. The underlying intuition is that a period with high per capita income leads to greater investment in education infrastructure during the whole lifetime of an adult agent. The resulting stock of education infrastructure is inherited by the next generation of adults and used in the education of their children. Therefore, the level of per capita income affects (inherited) human capital transfer in the next period. For simplicity, we let this scale effect take the same functional form as the scale effect in Eq. (9). The scale effect is denoted $F(C_{t-1})$, and is given by

$$F(C_{t-1}) = F^* - \tilde{F} + \tilde{F} \left(\frac{C_{t-1}}{\psi + C_{t-1}} \right) = F^* - \tilde{F} \left(\frac{\psi}{\psi + C_{t-1}} \right), \quad (10)$$

where $F^* > \tilde{F}$ and $\psi > 0$.

Each adult agent maximizes his utility in period t as follows:

$$U_t = \ln(C_t) + \alpha \ln(B_t T_t) + \alpha \delta \ln(L + H_{t+1}), \quad (11)$$

subject to Eqs. (1) and (8). It is assumed that $\delta \in (\rho, 1)$ (see below), and that $\alpha > 0$. Again, emigration does not affect the adult agent's utility function: he/she has already decided against emigrating and does not regard the potential emigration of his/her child as rendering redundant the human capital invested in that child.

Substituting Eq. (8) into Eq. (11) yields

$$U_t = \ln(C_t) + \alpha \ln(B_t T_t) + \alpha \delta \ln(L + A(P_t)F(C_{t-1})[L + H_t](\rho v + h_t)). \quad (12)$$

The maximization problem now consists of maximizing Eq. (12) subject to Eq. (1).²⁴ Solving the maximization problem finally yields

$$B_t = \left(\frac{\alpha}{1 + \alpha} \right) \frac{1}{v + h_t}, \quad (13)$$

$$C_t = [1 - (v + h_t)B_t]D_t(L + H_t), \quad (14)$$

and

$$h_t = \frac{1}{1 - \delta} \left[v(\delta - \rho) - \frac{L}{A(P_t)F(C_{t-1})(L + H_t)} \right]. \quad (15)$$

²⁴ As the utility function is logarithmic, T_t can be regarded as merely an additive constant in Eq. (12). Further details regarding all calculations are available on request from the authors.

Due to the non-negativity constraint on h_t , h_t is given by Eq. (15) only when the right hand side of this equation is greater than zero. Otherwise h_t is equal to zero. In his depiction of the transition from a Malthusian steady state to a state of sustained economic growth, Eq. (15) provides Lagerlöf (2003a,b) with a “quantity–quality” switch in which h_t can be constrained to zero and birth rates are high. In this Malthusian setting, parents invest little in their children, human capital is low and mortality high – a situation which keeps the population level stationary but highly volatile as the low human capital stock makes the economy vulnerable to mortality shocks. On the other hand, h_t can become operative (non-zero) and human capital and population both enjoy sustained growth. $\delta \in (\rho, 1)$ ensures that h_t converges to something positive as H_t goes to infinity. It is via the scale effect on human capital production that a series of mild mortality shocks can raise human capital productivity and induce the quality–quantity shift (adult agents decide to have less children, but invest more in the human capital of these children) of h_t becoming operative.²⁵ As we are interested in modelling an exogenous mortality shock which occurs at the cusp of that nation's industrialisation we retain this “quantity–quality switch” in our set-up.

4. Results of the modelling exercise

As the unwieldy algebraic expressions in Eqs. (13)–(15) render further analytical analysis impractical, we adopt numerical simulations in order to investigate how well our model performs in simulating the situation of an economy on the cusp of industrialisation subjected to a large mortality shock and ensuing unprecedented emigration flows.

In the Lagerlöf (2003a,b) model, the timing of industrialisation is an outcome of the stochastic set of exogenous mortality shocks. In order to perform our modelling exercise, we make the model deterministic through simulating the model with one set of mortality shocks ω_{Rt} . In this way, the time scale can be set so that the baseline economy industrialises in a given time period, as in Lagerlöf (2003b), where a similar technique is used to extract the difference in timing of the industrial revolution between England, France and Sweden. As discussed in Section 2, we characterise Ireland as being on the cusp of industrialisation prior to the famine. Thus set the baseline economy to industrialise within the period 1825–1850.²⁶

4.1. Choice of parameter values

Given that our model originates from the Lagerlöf (2003a,b) framework, we adopt many of the parameter values directly from the latter paper. Lagerlöf's (2003b) depiction of the industrialisation of Sweden, England and France is of particular relevance here as the parameters used for these countries represent those pertaining to what are now developed North European countries – countries which did not suffer the mortality shock afflicted on Ireland in 1845–1852. In order to simulate the counterfactual case of an Ireland, which did not

²⁵ The role of population density in the Malthusian epoch is discussed in Galor (2005 p.9) where he notes that variations in population density across countries during the Malthusian epoch reflected primarily cross country differences in technologies and land productivity. Due to the positive adjustment of population to an increase in income per capita, differences in technologies or in land productivity across countries resulted in variations in population density rather than in the standard of living. By way of example, Galor (2005) notes that China's technological advancement in the period 1500–1820 permitted its share of world population to increase from 23.5% to 36.6%, while its income per capita in the beginning and the end of this time interval remained constant at roughly \$600 per year. The model posits that this pattern of increased population density persists until the demographic transition, namely, as long as the positive relationship between income per capita and population growth is maintained. It should be noted, however, the model utilised in this paper does not explicitly incorporate policy decisions, which may have played an influential role in Chinese demographic trends over time.

²⁶ In keeping with Lagerlöf (2003b), the parameter values in our model are derived using a period length corresponding to 25 years.

experience the impact of such a mortality shock, we assume that Irish economic and demographic development would have followed a similar path towards industrialisation as did England, France and Sweden. In this way we calibrate the model to represent a case where initially no famine occurs using the parameter values of Lagerlöf (2003b). This initial case is then used as a benchmark against which the impact of the famine on Irish development can be compared.

The parameters of the Lagerlöf (2003b) model are calibrated in order to give rise to the multiplicity of equilibria that the model is constructed to yield. Since we retain the model's "quality-quantity switch" whereby industrialisation (brought about by a series of sufficiently mild mortality shocks) sees adults choose to have less children but invest more in the education of these children, a scenario with multiple equilibria – one Malthusian steady state and one phase of sustained growth in GDP per capita and population – is embedded in our model. In Lagerlöf (2003b), the model is calibrated with endogenous growth rates suited to the Malthusian equilibrium as well as to the Modern growth regime.

Values for the birth rate in the Malthusian regime, the gross growth rate of population in the Modern growth regime, as well as the gross growth rate of GDP per capita in the Modern growth regime are taken to fit Swedish data. It is these parameter values that are used to fit the development paths of England, France and Sweden and that we utilize for our depiction of an Ireland developing in a similar fashion to its Northern European neighbours until it is stricken with a sudden mortality shock in the 1845–1852 period. The values of the parameters originating directly from Lagerlöf (2003b) are reported in Table 1. The parameters ξ , κ , γ , ω_F , ψ , $\bar{F}$ and F^* are introduced in the course of our modelling set-up. A brief outline of these new parameter values is now provided.

As the Lagerlöf (2003a,b) model does not aim to replicate observed population levels, we rescale the levels of population and emigration with a scaling factor, denoted ζ . In this way, our simulations better reflect our Irish case-study. In order to assign a suitable value to ζ , we revert to the original Lagerlöf (2003a,b) model, where $F(C_{t-1}) = F = 1$, $D_t = D = 1$ and emigration is excluded. We then set ζ such that the level of population in the initial year of the simulation (1700) is correctly represented by the model simulations. The resulting value of this parameter is reported in Table 1. Next, we turn to the calibration of the parameters of the emigration function (7). Given the value of ζ , observations on the level of emigration and a chosen set of shocks ω_{Rt} a value of κ can be estimated during a period within the Malthusian era.²⁷ The value of κ derived from this calibration is presented in Table 1. With respect to the weight assigned to previous emigration, γ , we set the parameter such that we obtain a reasonable match between the observed and simulated levels of post-famine emigration (using the year 1875). The value $\gamma = 0.05$ gives reasonable results. In order to calibrate the remaining parameters, we first must choose a value for the exogenous mortality shock, ω_F , such that the observed Irish population decline (illustrated in Section 2) between years 1850 and 1875 is well captured by the model. A suitable approximation for this demographic decline is achieved by ensuring that the 1875 population level is about 70 % of the 1850 level – a requirement that fits neatly with the 25 year time steps of the model. This parameter value is also provided in Table 1.

Turning to the dynamic equation for labour productivity, Eq. (2), we first set the initial value of D_t , i.e. D_0 , such that the model predicts the correct value of the level of GDP per capita in year 1700.²⁸ It then remains to calibrate ξ , the parameter which allows labour productivity

Table 1

Baseline parameter values and initial values.

Parameters	Values
ρ	0.0046
δ	0.4615
α	0.067
V	0.03
L	500
η	12
μ	−3.9
$\tilde{A}$	52.9
A^*	74.2
σ^2	0.1
H_0	10
P_0	10
Y_{-1}	723
ξ	0.02
D_0	1.512
κ	168
γ	0.05
ψ	1.6
$\bar{F}$	1.002997
F^*	1.003
ω_F	0.021
ζ	9684

Note: The first 10 parameter values in Table 1 are as per Lagerlöf (2003a,b). The remaining parameter values are those of the authors.

to vary over time with changes in the emigration level. As discussed in Section 3, we base our calibration of ξ on the findings of Geary and Stark (2002), who provide some very compelling empirical evidence relating to Irish post famine growth. With regard to the phenomenon of Irish post famine convergence in output per capita with Great Britain prior to World War 1, they use 1861 and 1911 data to disaggregate the observed Irish labour productivity gains of this period and identify the contribution of labour force changes and Total Factor Productivity (TFP). Their results indicate both labour market outflows and productivity gains were the drivers of the Irish post-famine performance, with traditional explanations based on capital accumulation and TFP growth explain the bulk of the Irish performance. Their estimates indicate that between 1861 and 1911 labour productivity grew at 0.9% per year, and that between 17% and 28% of Irish labour productivity gains were due to labour force declines arising from emigration. We then take 23% (the middle value of this range) of the growth of labour productivity during this time period as being due to emigration, which suggests that labour productivity growth due to emigration flows was $0.23 \times 0.9 \approx 0.21\%$ per year. As our simplified labour productivity specification just uses emigration flows in order to endogenize labour productivity trends, we calibrate ξ such that it yields an annual average growth in labour productivity of 0.21% over the 25 year time step 1850 to 1875.

Finally, we calibrate the parameters of Eq. (10), our scale effect linking per capita income and human capital such that (i) in the scenario where the economy does not experience a famine shock, it industrialises in 1825 (i.e. h_t becomes non-zero), and (ii) in the scenario where the economy is hit by an Irish-like famine shock, the economy does eventually industrialise, and that the difference in timing of the take-off in GDP per capita between our baseline "no famine" case and our Irish-like case is reasonable, given the developments observed in Irish economic history over the past 150 years. The parameter values which yield results that fulfil these conditions are given in Table 1.²⁹

In Section 4.2, we simulate the model with the parameter values as in Table 1 and analyse to what extent the impact of our exogenous shock ω_F impact the timing of the take-off in industrialisation, when the level of GDP per capita is considered to be the major variable of interest when measuring this take-off.

²⁷ The parameter κ is estimated from observations corresponding to years 1800 and 1825, using non-linear least squares. In this calibration we set $\gamma = 0$. Further details regarding all calibrations are available from the authors on request.

²⁸ By choosing this parameter value, we can scale the level of GDP per capita to observable levels. It should be noted that the original Lagerlöf (2003a,b) model is not calibrated to replicate the actual levels of the variables that are involved.

²⁹ For simplicity, we set $Y_{-1} = Y_0$. This value can be derived from equations (13)–(15) and by noting that $h_t = 0$ initially.

Fig. 4. Population levels (left) and levels of GDP per capita (right), 1700–2300. Notes: the solid line corresponds to the benchmark case, the dashed line corresponds to the “famine scenario”, and the crossed line corresponds to the “severe famine”. The vertical axis of the GDP per capita graph is given in 1990 US\$, as per Lagerlöf (2003b).

4.2. Simulation results

Having chosen the parameters as outlined above, we now consider the extent to which an exogenous mortality shock occurring at a point where a country is on the cusp of industrialisation impacts upon this process of industrialisation. To facilitate this, we begin by simulating our benchmark model which represents Irish long run economic and demographic growth, where we assume that Irish economic and demographic development would have followed a similar path towards industrialisation as did England, France and Sweden, and identify the point at which industrialisation is triggered by the modelling set-up (i.e. $h_t > 0$). We deem this switch to industrialisation to represent the period just prior to 1850—that is, we define the date of industrialisation as the first period when $h_t > 0$. In the period starting in year 1850, we apply the exogenous mortality shock to our benchmark model, i.e. $t_F = 1850$. This shock represents the occurrence of the 1845–1852 famine. This initial case is then used as a benchmark against which the impact of the famine on Irish development can be compared. We also consider the hypothetical situation for a more severe mortality shock than that experienced in Ireland over the 1845–1852 period. This allows us to hypothesise about the impact of a more severe mortality shock on the Irish industrialisation process, when that shock occurs on the cusp of Irish industrialisation. For this case, we choose $\omega_F = 0.041$, which means that in this harsher famine case only 50% of the Irish pre-famine population level remains after the famine.³⁰

In all, we simulate three distinct cases: (i) our benchmark model, which represents the Irish development path towards industrialisation in the absence of the famine mortality shock, (ii) a “famine scenario”, where a mortality shock proportionate to that actually experienced in Ireland over the 1845–1852 period is modelled, and (iii) a “severe famine scenario”, where we hypothesise a mortality shock far more severe than that actually experienced in Ireland. Figs. 4 and 5 present the results for the important variables of our model (population, GDP per capita, emigration, and education time) over the 1700–2300 period, with each graph presenting the three simulated scenarios together for ease of comparison.

In order to provide a meaningful interpretation of the simulations presented in Figs. 4 and 5, we must be clear on what these simulations can and cannot explain. The insights that can be gleaned from these simulations concern (i) the occurrence or otherwise of industrialisation,

in terms of a take-off in population and GDP per capita, due to a sufficiently mild set of mortality shocks, (ii) the occurrence or otherwise of such an industrialisation when the country under consideration (Ireland, in this case) is stricken with a significant exogenous mortality shock (such as that arising from the Irish famine) above and beyond the mild “run-of-the-mill” mortality shocks when that country is on the cusp of its industrialisation process, (iii) if industrialisation does occur in the aftermath of this exogenous mortality shock, to what extent is this economic and demographic take-off delayed, and (iv) if, in the Irish case, the exogenous mortality shock arising from the famine of 1845–1852 had been significantly larger than that actually experienced, would the outcome in terms of the occurrence and timing of industrialisation have been significantly altered? Among the issues not addressed by our simulations are the following: exact measurement of population, emigration or GDP per capita in levels — we use initial values and scaling factors that ensure that the variables are within a reasonable order of magnitude to depict the long run development of the Irish economy; forecasting of future levels of Irish population or GDP per capita; and the synergies and interactions that may occur once GDP per capita taken off, arising from factors such as international trade, foreign direct investment, structural change and so on.³¹ In short, the focus of our simulations based on a simple, stylised model is the *occurrence* and *timing* of industrialisation.

Regarding the occurrence of Irish industrialisation, over time our benchmark model does industrialise (as illustrated by the take-off in population and GDP per capita in Fig. 4) as a sufficiently mild set of mortality shocks leads to lower mortality and rising population growth which through the scale effect on human capital production raises human capital productivity and brings about a quality-quantity switch at the point in time where education time (that adults dedicate to their children) becomes operative (i.e. $h_t > 0$). This, of course, is exactly what the Lagerlöf (2003a,b) is designed to achieve. As outlined above, the period in which our benchmark model industrialises is then set to 1825 i.e. $h_t > 0$. What is of particular interest to us, of course, is what happens to industrialisation, and the population and GDP per capita take-off, when an exogenous mortality shock such as that which struck Ireland in 1845–1852 occurs on the cusp of the industrialisation process. As

³⁰ Note that we set $D_t = D = 1$ and $F(C_{t-1}) = F = 1$ in the calibration of ω_F .

³¹ It should be noted that this model represents one means of explaining industrialisation and long-run growth. As such, it yields insights into simplified feedback effects between a set of key variables.

Fig. 5. Levels of emigration (left) and education time, ht , (right), 1700–2300. Notes: the solid line corresponds to the benchmark case, the dashed line corresponds to the “famine scenario”, and the crossed line corresponds to the “severe famine”. The variable h_t is scaled up by 100.

illustrated by our “famine scenario” in Figs. 4 and 5, industrialisation in terms of h_t is preserved during the famine period – that is, $h_t > 0$ in 1825 and the famine shock is not severe enough to cause the Irish economy to de-industrialize in terms of this variable – and a definitive take-off does still occur but is delayed by about 75 years. The post famine population level appears to revert back to its Malthusian level within 50 years, but a definitive take-off does not occur until about 1950. One can compare these results to what has been observed in the Irish demographic trends discussed in Section 2: after the initial mortality shock the Irish population continued its decline well after 1890, falling a further 5% between 1891 and 1926 and then remaining relatively stable until the 1960s, when it eventually began to pick up. Our model results predict a relatively swift recovery to the average Malthusian level of population. Since our model only takes into account the direct effects that the famine had on demographics, through mortality and emigration, and not the impact of the famine on fertility and nutrition, the simulated population level may be somewhat overestimated. That said, our simulation results are broadly in line with those demographic trends observed in Ireland: a substantial fall in the level of population after the famine, a recovery to the average pre-famine level and then a definitive take-off in the mid-twentieth century. Our “famine scenario” GDP per capita also broadly resembles the empirics of Section 2 in that a clear take-off in Irish GDP per capita occurs post 1960. This suggests that the impact of the famine delays the GDP take-off associated with industrialisation by approximately 75 years. This “famine scenario” simulation also captures the strong post-famine economic performance experienced by Ireland over the 1860–1913 period, as discussed in Section 2.

But what facilitates the recovery and subsequent demographic and economic take-off, and what determines how quickly or slowly this process occurs? We have augmented the original Lagerlöf (2003a,b) to allow two channels through which the post-famine economy can recover: (i) labour productivity and (ii) human capital accumulation. In our modelling set-up, we aim to incorporate empirically observed labour productivity trends and this is achieved in our simplified labour productivity specification by using emigration flows in order to endogenize labour productivity trends. This allows us to capture in our simulations the findings of Geary and Stark (2002), whose results indicate that the strong Irish post-famine economic performance partly was driven by labour productivity growth, arising from labour market outflows and TFP growth. While labour productivity may have contributed significantly to the post-famine economic performance, our modelling set-up also affords human capital accumulation a prominent role. In the Lagerlöf

(2003a,b) model, industrialisation is measured by the variable h_t , which is the time that parents spend educating their children. In our model, we augment this in Eq. (10) by assuming that GDP per capita in the previous period facilitates the transfer of education infrastructure into the next period which is inherited by the next generation of adults and used in the education of their children. Through this mechanism we assume that this period's GDP per capita contributes to the accumulation of next period's human capital. If a large mortality shock was to occur in the original Lagerlöf (2003a,b) model, the resulting impact on human capital would be entirely negative: due to the fall in population density associated with large scale mortality, knowledge transfer is hampered (through Eq. (9) above) and human capital production, H in Eq. (8), declines. Our set-up, however, mitigates this fall in human capital production: due to the gain in GDP per capita brought about by rising labour productivity, post-famine human capital accumulation gets a “push” which prevents the famine mortality shock from causing de-industrialisation (i.e. h_t becoming non-operative). In this way, as the post-famine economy experiences a sudden increase in GDP per capita – be it from efficiency gains from increased emigration or through TFP gains, this raises the standards of living and helps to rebuild the level of human capital in the aftermath of the famine. This human capital recovering process turns out to have a decisive impact on the process of industrialisation, in that the economy remains industrialised (in terms of h_t) in the aftermath of the famine mortality shock. This retention of the ability to produce human capital may provide an explanation as to why the recovery appears to occur relatively swiftly: the economy remains in an industrialised state despite the onslaught of the famine mortality shock and once the level of population returns back to the Malthusian state, h_t can continue to drive the demographic and economic take-off which had been delayed by the famine.³² This characterization of human capital is in line with the findings of Crayen and Baten (2009), who report a small deterioration in Irish numeracy (a proxy for human capital) directly after the famine, with convergence back to pre-famine levels occurring around 1870. After 1870 a take-off in

³² Simulation analysis of the interaction between factors in the model that may be responsible for the transition to the Modern growth regime has also been undertaken. These factors are (i) a series of soft mortality shocks, (ii) the dynamic labour productivity specification captured through the variable D_t and (iii) the scale-effect that allows GDP per capita to increase human capital production, $F(C_{t-1})$. Our results show that the increase in labour productivity that occurred after the famine, in conjunction with the resulting increase in GDP per capita and its impact on human capital transfer, played a determining role in post-famine industrialisation (in terms of h_t) and thereby speeded up the post-famine recovery. Results are available from the authors on request.

Irish numeracy is observed and convergence to numeracy levels of other developed North European countries is reached in the 1920s.

Fig. A1 and 2 in the [Appendix](#) provide a comparison of the timing of the industrialisation “take-off” for observed Irish population and GDP per capita data and our “famine scenario” simulations. It should be emphasised that Fig. A1 and 2 do not attempt to predict the observed series in levels: the data used to calibrate the model (British population data points and parameters taken from [Lagerlöf \(2003a, b\)](#)) creates gaps between the actual and simulated series. The comparison of this take-off timing illustrates the usefulness of this class of unified growth model for the modelling of large scale mortality shocks, as well as displaying features that could be further refined in future research. Indicative of the usefulness of the model is the fact that the timing of the take-off of actual and simulated GDP per capita coincides almost exactly circa 1950. The population graph (A2) identifies a number of shortcomings of the model: (i) the size of the famine shock may be impaired due to the initial population data points used to calibrate the model (ii) the simulated population series rebounds relatively quickly after the famine shock. This reflects the fact that the number of channels through which the aftermath of the famine shock can impact population is limited in our simplistic model. A host of demographic factors, for example post-famine health, nutrition or the age and gender of emigrants, are not explicitly included in the model but may have long-run consequences for post-famine population growth. Simulated population take-off occurs circa 1925, while actual population take-off was delayed until 1960.

Lastly, we consider the hypothetical case where the exogenous mortality shock arising from the Irish famine of 1845–1852 is significantly larger than that actually experienced. Would the outcome in terms of the occurrence and timing of industrialisation have been significantly altered? As is clear from “severe famine” scenarios of [Figs. 4 and 5](#), industrialisation does occur in this more severe case and population and GDP per capita do still take off.³³ However, in our simulations this industrialisation (i.e. h_t becoming operative) is now delayed by 250 years compared to the benchmark “no famine” scenario, and when compared to the case in which the famine did occur, this “severe famine” scenario yields a delay of a similar length of time in the eventual take-off of GDP per capita and population levels.³⁴ What can one conclude from this “severe famine” case? It seems that a harsher famine at the cusp of industrialisation does indeed act as a larger deterrent to industrialisation in terms of demographic and economic growth. Perhaps the most important insight to be gleaned from this “severe famine” scenario in [Figs. 4 and 5](#), however, is that the impact of this harsher famine could be so significant that it serves to completely de-industrialise the economy, in terms of the education time variable h_t . The post-famine economy would then recover to its Malthusian level but remain stuck at this level for a protracted period of time until demographic and economic take-off eventually occurs (through the human capital accumulation mechanism of the model). Clearly, one could envisage that if, on the cusp of industrialisation, Ireland had been struck by a more prolonged famine than that caused the potato blight of which ruined the harvest of 1845, 1846, and 1848 or by a famine more deadly in terms of mortality and displacement, Ireland may not have been in a position to initiate its successful industrialisation in the 1960s.

5. Conclusion

This paper aims to shed further light on consequences of a large scale mortality shock arising from a famine or epidemic for long run economic

and demographic development. To facilitate this, we take the fore-mentioned Great Irish Famine of 1845–1852 as a case-study and utilize a recently developed school of long-run growth models epitomised by [Lagerlöf \(2003a,b\)](#). Such models are capable of endogenously generating multiple equilibria: one Malthusian growth path of stagnation in population level and living standards and one industrialised path of sustained growth in population and income per capita. The transition between these equilibria is brought about by a series of random mortality shocks. When a sequence of such shocks is sufficiently small, the survival rate of children rises, and the population level rises beyond a threshold after which a “quantity-quality shift” in children is generated and human capital is growing away from population.

We extend the [Lagerlöf \(2003a,b\)](#) model in order to allow for a large exogenous, mortality shock representing a large-scale famine. The timing of the shock is such that it is applied in the period right after the “quality-quantity shift” in children is due to take place. This ensures that the set-up is applicable to an economy that is on the cusp of industrialisation. We augment the [Lagerlöf \(2003a,b\)](#) model in a number of ways to make it more realistic in the face of a large scale mortality shock, such as a famine. Firstly, we introduce emigration into the model and characterise it as being influenced by the level of distress endured and by the previous levels of emigration outflows. Secondly, we incorporate a labour productivity specification that is allowed to vary over time, and, finally, a scale effect which allows GDP per capita increases in one period to contribute to human capital production in the next period. We then simulate three distinct cases: (i) a benchmark model, which represents the Irish development path towards industrialisation in the absence of the famine mortality shock, (ii) a “famine scenario”, where a mortality shock proportionate to that actually experienced in Ireland over the 1845–1852 period is modelled, and (iii) a “severe famine scenario”, where we hypothesise a mortality shock far more severe than that actually experienced in Ireland.

In a nutshell, our simulations capture the following attributes of Irish post-famine economic and demographic development: our “famine scenario” population trends are broadly in line with those of observed in Irish demographic data: we see a substantial fall in the level of population after the famine, a recovery to the average pre-famine level and then a definitive take-off in the mid-twentieth century; our “famine scenario” GDP per capita also broadly resembles the empirics of Irish post-famine economic development in that a strong post-famine economic performance is apparent over the 1860–1913 period, while the definitive take-off in Irish GDP per capita occurs post 1960. In all, our simulations suggest that the impact of a mortality shock similar in magnitude to the Irish famine delays the GDP take-off associated with industrialisation by up to 100 years. What is more, we see that this Irish famine-sized mortality shock does not cause the Irish economy to de-industrialize – its nascent industrialisation appears to stall and the eventual economic and demographic take-off is delayed for a period of about 75 years, but the industrialisation process is not derailed entirely.

This result finds some support in [Crayen and Baten \(2009\)](#), who note a small decrease in Irish human capital after the famine, followed by a swift reversion to prefamine levels and an eventual take-off.

This post-famine recovery is facilitated in our simulations through two channels: (i) labour market productivity gains in the aftermath of the famine, which have been found to stem from both efficiency gains from increased labour market outflows and increased total factor productivity, and (ii) human capital production, which we characterise as increasing in tandem with GDP per capita increases. In this way, the post-famine economy retains its ability to increase its labour productivity and human capital levels, despite the massive impact of the famine mortality shock. We also simulate the hypothetical case of the Irish economy being struck by a more severe famine shock in the 1845–1852 period, than that actually experienced. What emerges is the finding that a harsher famine shock could have been so severe as to completely de-industrialise the economy. The post-famine economy would then

³³ The economy industrialises in terms of h_t in year 1825, as set by calibration. However, in our severe famine scenario the famine mortality shock causes de-industrialisation and the variable, h_t , becomes zero in year 1875. What we refer to by industrialisation in this case is the economy experiencing a second industrialisation and never reverting back to the non-industrialised state.

³⁴ The exact point of industrialisation in this “severe famine” scenario is influenced by the component of the mortality shock, ω_{Rt} , which originates from the [Lagerlöf \(2003a,b\)](#) framework.

recover to its Malthusian level but remain stuck at this level for a protracted period of time until demographic and economic take-off eventually occurs.

In all, our modelling approach and simulations offer a number of insights relating to both post-famine Irish economic development and the broader discussion of long run economic growth in the face of large scale mortality shocks. With regard to Irish economic development, it seems that if Ireland had been struck by a harsher famine than that endured over the 1845–1852 period, the country may have de-industrialised and remained stuck in a Malthusian state for a much longer time period than actually has been the case. It is difficult to speculate on exact timing of industrialisation in this case, since if industrialisation was severely delayed it is likely that other factors outside the scope of our model would have come into play. Of broader application, and perhaps relevant to the economic and demographic travails of developing nations in modern times, is the following feature of our simulations: it appears that should a country on the cusp of industrialisation be stricken with a large scale mortality shock, its ability to recover from such misfortune and the speed of such a recovery may greatly depend on the extent to which that country's human capital stock, and human capital production capabilities, are damaged and whether or not the labour productivity of the remaining population is capable of being enhanced in the aftermath of such a mortality shock.

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Appendix A

Fig. A1. Observed GDP per Capita 1750–2004 (left scale, solid line) and simulated GDP per Capita (right scale, dashed line) in 1990 Geary Khamis international dollars.

References

- Almqvist, E., 1979. Pre-famine Ireland and the theory of European proto-industrialization: evidence from the 1841 census. *Journal of Economic History* 39 (3), 699–718.
- Ahmed, I., 2009. Environmental Refugees and Environmental Distress Migration as a Security Challenge for India and Bangladesh, Facing Global Environmental Change. Springer Verlag, Berlin-Heidelberg.
- Azomahou, T., Boucekkine, R., and B. Diene (2006), The Growth Economics of Epidemics, Discussion Paper, Department of Economics, Université Catholique de Louvain.
- Borjas, G.J., 1987. Self-selection and the earnings of immigrants, *American Economic Review*. *American Economic Association* 77 (4), 531–553.
- Bowley, A.L., 1899. Statistics of wages in the United Kingdom during the last hundred years. (Part IV.) Agricultural wages—concluded. Earnings and general averages. *Journal of the Royal Statistical Society* vol. LXII.

Fig. A2. Irish Population 1750–2004 (solid line) and simulated Population Series (dashed line). Note: Irish population and GDP per capita data sources as per Figs. 1–3. Shaded area indicates the famine era (1845–1852); dashed vertical line indicates observed take-off of actual data. Both simulated population series are included Fig. A2 for comparison purposes.

- Boyle, P.P., Gráda, C.Ó., 1986. Fertility trends, excess mortality, and the Great Irish Famine. *Demography* 23, 543–562.
- Carrington, J.C., Detragiache, E., Vishwanath, T., 1996. Migration with endogenous moving costs. *American Economic Review* 86 (4), 909–930.
- Crayen, D. and Baten, J. (2009) Global trends in numeracy 1820–1949 and its implications for long-term growth, *Explorations in Economic History*, (forthcoming).
- Clarkson, L.A., 1989. Conclusion: famine and Irish history. In: Margaret Crawford, E. (Ed.), *Famine: the Irish experience 900–1900*. John Donald Publishers Ltd, Edinburgh, pp. 220–236.
- Crawford, E.M. (Ed.), 1989. *Famine: the Irish Experience 900–1900*. John Donald Publishers, Ltd, Edinburgh.
- de Haan, A., 1999. Livelihoods and poverty: the role of migration — a critical review of the migration literature. *Journal of Development Studies* 36 (2), 1–47.
- Fernandez-Villaverde, J., 2001. Was Malthus Right? Economic Growth and Population Dynamics. University of Pennsylvania, Mimeo.
- Galor, O., 2005. From stagnation to growth: unified growth theory. *Handbook of Economic Growth* 171–293.
- Galor, O., Weil, D.N., 1999. From Malthusian stagnation to modern growth. *American Economic Review* 89, 150–154.
- Galor, O., Weil, D.N., 2000. Population, technology and growth: from the Malthusian regime to the demographic transition and beyond. *American Economic Review* 110, 806–828.
- Geary, F., 1998. De-industrialization in Ireland to 1851: some evidence from the census. *Economic History Review* vol. LI, 512–541 August.
- Geary, F., Stark, T., 2002. Examining Ireland's post-famine economic growth performance. *The Economic Journal* 112, 919–935 October.
- Guinnane, T., 1994. The Great Irish Famine and population: the long view. *American Economic Review* Vol. 84 (No. 2), 303–308.
- Guinnane, T., 1997. *The Vanishing Irish*. Princeton Univ. Press, Princeton.
- Hansen, G.D., Prescott, E.C., 2002. Malthus to Solow. *American Economic Review* 92, 1205–1217.
- Hatton, T.J., Williamson, J.G., 1993. After the famine: emigration from Ireland, 1850–1913. *Journal of Economic History* 53, 575–600.
- Hatton, T.J. and J.G. Williamson (2002) What Fundamentals Drive World Migration?, CEPR Discussion Papers 3559, C.E.P.R. Discussion Papers
- Hatton, T.J., 2001. The age of mass migration: what we can and can't explain published. In: Ghatak, A.S., Showstack-Sassoon, A. (Eds.), *Migration and Mobility*. Macmillan, London.
- Jones, C., 2001. Was an industrial revolution inevitable? Economic growth over the very long run. *Advances in Macroeconomics* 1 (2), 1–43.
- Kennedy, L., Clarkson, L.A., 1993. Birth, Death and Exile: Irish Population History, 1700–1921. In: Graham, B.J., Proudfoot, L.J. (Eds.), (1993) *An Historical Geography Of Ireland*. Harcourt Publishers Ltd.
- Kinealy, C., 2002. *The Great Famine in Ireland: Impact*. Palgrave Press, Ideology and Rebellion.
- Kinealy, C., 2006. *This Great Calamity: The Irish Famine 1845–52*, 2nd Edition. Gill and Macmillan.
- Kögel, T., Prskawetz, A., 2001. Agricultural productivity growth and escape from the Malthusian trap. *Journal of Economic Growth* 6, 337–357.
- Lagerlöf, N., 2003a. From Malthus to modern growth: can epidemics explain the three regimes? *International Economic Review* 44, 755–777.
- Lagerlöf, N., 2003b. Mortality and early Growth in England, Sweden, and France Scandinavian. *Journal of Economics* 105, 419–439.
- Lagerlöf, N., 2006. The Galor–Weil model revisited: a quantitative exercise. *Review of Economic Dynamics* 9, 116–142.

- Lucas, R.E., 1988. On the Mechanics of Economic Development. *Journal of Monetary Economics* 22, 3–42.
- Mokyr, J., 1980. The deadly fungus: an econometric examination of the short term demographic impact of the Irish famine. *Research in Population Economics* 2, 237–277.
- Mokyr, J., 1985a. *Why Ireland Starved: a Quantitative and Analytical History of the Irish Economy, 1800–1850*, 2nd ed. George Allen and Unwin, London.
- Mokyr, J., 1985b. *Why Ireland Starved: A Quantitative and Analytical History of the Irish Economy, 1800–1850*. George Allen & Unwin, London.
- Mokyr, J., Gráda, C.Ó., 1984. New developments in Irish population history, 1700–1850. *Economic History Review*.
- Mokyr, J., Gráda, C.Ó., 1988. Poor and getting poorer?, living standards in Ireland before the famine. *Economic History Review* 41, 209–235.
- Ó Gráda, C., 1989. *The Great Irish Famine*. Macmillan, London.
- Ó Gráda, C., 1993. *Ireland Before and After the Famine: Explorations in Economic History, 1800–1915*. Manchester University Press, Manchester.
- Ó Gráda, C., 1994. *Ireland: A New Economic History, 1780–1939*. Oxford University Press, Oxford.
- Ó Gráda, C., O'Rourke, K., 1997. Migration as a disaster relief: lessons from the Great Irish Famine. *European Review of Economic History* 1, 3–25.
- O'Rourke, K., 1991. Rural depopulation in a small open economy: Ireland 1856–76. *Explorations in Economic History* 28, 409–432.
- O'Rourke, K., 1995. Emigration and living standards in Ireland since the famine. *Journal of Population Economics*, Springer 8 (4), 407–421.
- Pamuk, Ş., 2007. The Black Death and the origins of the 'Great Divergence' across Europe, 1300–1600. *European Review of Economic History* 11, 289–317.
- Sjaastad, L.A., 1962. The costs and returns of human migration. *The Journal of Political Economy* 70 (5), 80–93.
- Tamura, R., 2002. Human capital and the switch from agriculture to industry. *Journal of Economic Dynamics and Control* 27, 207–242.
- Vaughan, W.E., Fitzpatrick, A.J. (Eds.), 1978. *Irish Historical Statistics: Population 1821–1971*. Royal Irish Academy, Dublin.
- Watkins, S., Menken, J., 1985. Families in historical perspective. *Population and Development Review* 11, 647–675.
- Whelan, K., 1999. Economic geography and the long-run effects of the Great Irish Famine. *The Economic and Social Review* 1–20.
- Wilde, W.R., 1856. *The Census of Ireland, 1851, Part V, Table of Deaths, Vol. I*, British Parliamentary Papers 1856 [2087-I] XXIX, p. 249.