University of Sussex
Business, Management & Economics

Economics Department Working Paper Series

No. 48-2012

The declines in infant mortality and fertility: Evidence from British cities in demographic transition

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Abstract: At the beginning of the twentieth century Britain was roughly halfway through a 60-year demographic transition with declining infant mortality and birth rates. Cities exhibited great and strongly correlated diversity in these rates. We demonstrate cross–section correlations with, for instance, women's employment, population density, literacy and improved water supply and sanitation, that have been linked to the transition. When we analyse data from the late 1850s and the early 1900s, the changes in the two rates are not correlated across cities, but we find a robust and large impact from sanitation improvement to long-period infant mortality reduction. We also find the extension of basic literacy is related to increases in female labour market participation, which is in turn related to fertility reduction. Lastly we find that more rapid urban growth accelerates fertility decline, but, in late 19th century Britain it slowed the reduction of infant mortality.

JEL Classification: N33, J13, I15.

Key Words: Fertility, infant mortality, education and sanitary reform, 19th century and early 20th century Britain.

1. Introduction

The relationships between demographic transition and economic growth continue to be studied intensely studied. For example, a recent landmark in this area is Galor's *Unified Growth Theory* (2011), the title of which reflects a long-standing concern to bring together the theory of demographic transition and economic theory. One challenge within this programme of work is to understand the causes of the fall in fertility and family size in the transition. These falls is that they have often been accompanied by similarly timed falls in infant mortality and this has prompted some, see below, to suggest linkages. In this paper we study data from period in British history when these transitions were taking place. We report findings with respect to the relationships between infant mortality rates and crude birth rates using data from a group of about seventy towns and cities in England and Wales in the first few years of the twentieth century.

At that time Britain was roughly halfway through its demographic transition. Between the 1870s and the 1930s, Britain's crude birth rate dropped from around 3.5 per cent to around 1.5 per cent (Mitchell and Deane, 1962). Woods, Watterson and Woodward (1988) show that the infant mortality rate in England and Wales fell from about 15 per cent in the 1870s to about 7 per cent by the 1930s.[i] WHO data indicate that these rates for the 1870s would be amongst the highest in the world today. The birth rate decline had the larger effect upon total fertility which declined so that household dependency ratios also fell. This process played a large part in the improvement of household living standards. Gazeley and Newell (2011) calculate that reduced family size accounts for about one-half of the doubling of real household per capita income 1904-1937, the other part accounted for by real wage growth.

Our main data source is a Board of Trade report of an investigation into living standards in British towns and cities (Cd. 3864, 1908). The research for the report took place between 1905 and 1907, and collected data for the period 1901-06. The report gives crude birth rates 1902-06, that vary on average between 42.7 per thousand for Castleford and 19.4 for Bedford. Infant mortality rates, similarly averaged (deaths among children aged less one year) vary between 202 per thousand in Burnley and 102 per thousand in Swindon and Taunton. Thus some of the towns and cities of England and Wales could be said to have been fifty years ahead of others in terms of the demographic transition. It is this diversity that we exploit in our empirical work.

One purpose of the study is to shed some British historical light upon the debate among economists between those who see infant mortality reduction as an important driver of fertility decline and those who are sceptical of such a link. The former group include Conley, McCord and Sachs (2007) and Eastwood and Lipton (2011), while Doepke (2005) and Galor (2011, 2012) are representative of those who are doubtful. If there was a reliable, exploitable linkage, demonstrated over time and space, then a range of policy options would have very useful spill-overs from fertility reduction to increased infant survival and vice-versa, so the importance of the issue is considerable. This is the issue that we seek empirical evidence on. Did, for instance, the introduction of a water and sanitation improvement programme impact upon decisions about family size as well as upon infant mortality? Or, conversely, did improvements in women's education, family planning or in women's employment prospects impact upon infant mortality as well as family size?

A by-product of this work is to add British evidence to the literature that studies the importance of public interventions on their primary targets during the demographic transition. In particular we can attempt to measure the impact of water and sanitation improvement upon infant mortality. For Britain, Szreter's work on the health and mortality impact of municipal interventions in has been very influential, see Szreter (1988) for instance. A number of studies for other countries have provided empirical evidence. For the US in the later 19th and 20th centuries there is Cain and Rotela (2001), Condran and Crimmins-Gardner (1978) and Cutler and Miller (2005). For France there is Preston and van der Walle (1978). As Cutler and Miller (2005, p2) point out that the empirical work of most of the earlier studies '… shares common problems: it is difficult to rule out the influence of confounding factors, and the interventions themselves are often difficult to pinpoint (municipal water and sewer projects often spanned many decades, for example).' Our approach is to use reports on the state of, for instance, sanitation improvements, to obtain comparable measures at the city level.

We find significant cross-section correlations, between fertility and infant mortality, measure of illiteracy, the extent of women's labour market participation, population density and the degree of sanitation improvement. However, when we supplement these early 1900s data with data from the late 1850s and the 1860s, so that we can study what caused the differences across cities in *changes* in infant mortality and fertility between those periods, we do not find any significant correlation between changes in infant mortality and changes in crude birth rates. The experience of cities in late 19th century Britain therefore offers no direct support for a causal link in either direction between infant mortality reduction and fertility reduction. However, we find other strong and robust links: between sanitation improvement and infant mortality decline; between declining illiteracy and rising labour market participation for women; and between rising participation and fertility decline. Lastly we find the more rapid urbanisation accelerated the fertility decline, but slowed the infant mortality decline.

2. The links between infant mortality and fertility decline

(a) Theory

The theory linking child mortality and fertility has been reviewed many times, see, for instance, Angeles (2010, pp 4-5, and references therein). Briefly, demographers focus upon three linkages: the physiological effect, the replacement effect and the hoarding effect. The first two of these gives reasons for an increased likelihood of pregnancy following the death of a child. The hoarding effect comes about if the chances of infant mortality cause parents to produce more children than desired to pre-empt future losses. Only this hoarding, or precautionary, effect could produce a causal relationship between child mortality and ultimate family size, but the scale of the reduction in family size seems much greater than warranted by the likely impact, via that mechanism, of falling child mortality. Doepke (2005) shows the hoarding effect only produces a positive link from infant mortality to net fertility under fairly extreme assumptions with respect to risk aversion.

Economic theories of fertility generally follow the pioneering work of Becker (1960). A characteristic of these models is that they treat infant mortality as an exogenous factor that influences the cost, by requiring more pregnancies, of achieving a family of a given size. In this case, if utility depends positively on the number of surviving children, then a reduction in the chances a child might die may, by lowering costs, *increase* a family's optimal number of children. Doepke (2005) shows this result survives in a number of different theoretical settings, including one that incorporates Becker's (see for instance Becker and Lewis, 1973) quantity-quality trade-off by allowing educational investments to be made endogenously. Thus there does not appear to be a standard theoretical model consistent with a causal interpretation of a positive mortality-net fertility correlation.

The reason for this result lies in the treatment of the probability of child mortality as an exogenous environmental factor impacting only on the cost of attaining the desired number of children, and not being related to factors that affect the well-being of surviving children. Even if we leave aside this likely quality-quantity trade-off, treating the mortality probability as exogenous to household time allocation seems inappropriate in the light of the evidence, summarised in detail in the next section, on how the reduction in mortality was achieved in Britain a century ago. All these phenomena that are likely to have lowered infant mortality required changes in the care regimes of parents and guardians. Most of these changes would have directly entailed more work for the parents. Examples included: improvements in household hygiene, post-natal care and food preparation and storage. Public health interventions such as municipal water and sanitation improvements would also have required work by parents for them to improve the survival probability of children. In the simple illustrative model of Galor (2012, pp5-6), in which a choice is made between the level of consumption and family size, the optimal number of surviving children depends inversely upon the proportion of the time budget spent on childcare per child, and not directly upon the survival probability, see Galor's equation (6), op. cit, page 6. In this model, the reforms of the late 19th and early 20th centuries which are generally accepted to have reduced infant and child mortality would have acted to raise the time spent on child care and thus lower the optimal number of surviving children, irrespective of any quality-quantity trade-off, that would only reinforce the effect.

In a more general theoretical setting, and in Becker's language, it is possible that these reforms and changes, by providing the means and knowledge to protect a child's health, may also have lowered the shadow price of child quality as well as that of child quantity. These hygienic practices that reduced the risk of potentially fatal diarrhoea epidemics, may have caused a partially off-setting rise in the shadow price of child quantity by raising the amount of work required to keep a young child healthy. In addition, the net effect of the reforms might have been to lower the shadow price of child quality relative to that of child quantity sufficiently to move households towards higher quality and lower quantity.[ii] Note this version of the quality-quantity switch, in which infant mortality and total fertility fall, does not require the educational capital channel.

(b) Empirical evidence

Recent empirical evidence suggests that child mortality Granger-causes fertility, at least for the post-1950 period. Angeles (2010), using an international panel of quinquennial data, 1955-2005, for over one hundred countries, finds that lagged child mortality rates have large and well-determined positive effects on total and net fertility rates. This is suggestive of causation. The European fertility decline of the late 19th and early 20th centuries did not follow this pattern.

Van de Valle 1986, pp 228-233) discusses in detail how the history of European regions is not consistent with Angeles' (*op. cit.*) findings on Granger-causality for post 1950s international data. In the late nineteenth and early twentieth centuries, falls in infant mortality rates were in advance of falls in fertility in Swedish and Dutch data, but the timing was the other way around for Belgium and England. Germany is roughly equally split into administrative areas in which infant mortality decline either lead or lagged fertility decline. [iii]

Van De Valle (*op. cit*. page 221) finds the correlations between birth rates and infant mortality rates emerge over time with many more positive and significant correlations at or close to 1900 than for the years around 1870 and these positive correlations mostly become stronger again by the 1930s. Thus these correlations emerge through the later part of the nineteenth century. In the cities of England and Wales that we study in this paper, the correlation between infant mortality and our measure of fertility also emerges over time, being absent in 1850s data and quite distinctly present in data for the early years of the 20th century.

These two stylised facts set the European context of our study: a similar timing in falls in infant mortality rates and fertility rates, but no clear temporal sequence; and a slowly emerging positive regional correlation between the two.

Two papers by Woods, Watterson and Woodward (1988, 1989, hereafter WWW), analyse of the decline in infant mortality in England and Wales from the mid-Victorian period to the early part of the twentieth century. They first document the decline in infant mortality, noted above, and show (1988, Table 2, p253) that the main decline was in the mortality of post-neonatal infants (those aged between 1 month and 1 year) rather than the new-born (neo-natal). This decline was particularly pronounced in urban areas, where infant mortality had been especially high. The most likely cause of high urban mortality was the interaction between seasonal climate variations, in particular hot summers, with poor sanitary conditions 'which resulted in high levels of diarrhoea and dysentery among infants' (1988, p360). As discussed below, in the early 1900s municipalities throughout urban England and Wales were engaged in programmes of cleaning up sanitary conditions, as well as engaging in educative propaganda campaigns aimed at parents of young children.

Secondly, WWW demonstrate the clear negative correlation between 'social class' and infant mortality (1988, Table 5, p364), and, in their second paper, their empirical study of district-level data shows that women's education, rather than household income, is a reliable and strongly negative predictor of infant mortality (1989, p127). Thirdly, WWW record that contemporary experts were aware of the association between the hygienic quality of milk and other food supplies and infant mortality (1989, p120). Fourthly, WWW acknowledge that improvements in health care, for example the extensions of post-natal health visitors and midwives, may have made differences (1989, p120). WWW conclude that the secular decline in infant mortality was most likely to have been due to: declining fertility; women's education; improved sanitation, especially in cities; more hygienic milk and food; better diets and, perhaps, less poverty.

To summarise this section: the economic theory of fertility can be made consistent with a positive link between infant mortality and net fertility if we take a step back from Becker's formulation and consider the likely impact on fertility choice of the social and scientific changes that reduced infant mortality. There is econometric evidence that for the post-1950s period, infant mortality decline tends to lead fertility decline. The evidence for the 1870-1930 period in Europe is much less clear-cut on temporal causality, and for Britain the regional evidence is that fertility decline leads infant mortality decline. Several variables have been suggested as possible causes and many include fertility decline as a cause of infant mortality decline, and vice versa. Next we turn to describing the data we bring to bear on the issues.

3. The data set

In 1908 the Labour Department of the Board of Trade published the report, Cd. 3864, of their enquiry into wages, prices, rents and housing in over ninety cities in Britain and Ireland. The study was a follow up to their earlier attempts to collect household-level data on working class living standard, reported in Cd. 1761 (1903) and Cd. 2337 (1904). The new enquiry was aimed at collecting data and first-hand observations at the level of the conurbation, and in particular to obtain better information on rents and fuller coverage of the country. From October 1905 to late in 1907, fourteen officers of the Department were employed collecting information and every town was visited at least once. The officers were assisted by local government and tax officials, medical officers and sanitary inspectors, among others. From this source, we take data on: weekly wages by skill in the building trade, a cost-of-living index, rents for properties of different sizes, main industry of the city, infant mortality rate, crude birth rates and crude death rates. In addition, within the text of the report for each town, we are given: the size of the population, an estimate of population density, the participation rate of women who work and the proportion of the population working as domestic servants, all from the 1901 census. We supplement these data on the literacy, age at marriage and religion of brides, taken from the last time these data were reported at town/city level, from the Annual Report of the Registrar-General on Births, Marriages and Deaths, C.4722 (1886). We also collect birth rates, brides literacy rates and infant mortality rates for the mid 19th century from earlier Annual Reports (1857 Session 2 [2260] and 1860 [2712]). Lastly we collected the participation rate of women from The Census of England and Wales for 1871. This is the nearest year to the late 1850s/early 1860s that is available.

One final set of variables are inferred from the text in Cd, 3864. The Board of Trade's town reports describe aspects of the built environment, in particular the general condition of sanitation and the extent of older dwellings arranged in courts, yards or alleys or as back-to-back houses. Poor sanitation and older housing were being eradicated by municipalities across England and Wales at the time of the enquiry. There was great diversity in the extent of this work. Towns such as Barrow, Crewe or Swindon, which had grown from tiny villages is relatively recent times, tended to have better than average sanitation and fewer of the older styles of dwelling houses by the time of the survey in 1905-7. Many older centres of population inherited stocks of 'court' and 'back-to-back' dwellings that combined very poor accommodation in cramped conditions with very poor ventilation and sanitation. The adverse health consequences of these slum areas had become better understood by the authorities over the previous fifty years (Szreter, 1997). There are many references in Cd. 3864 to cases where a city corporation had been encouraged into action on housing and sanitation by the reports of Medical Officers. Here is an example, from the discussion of Manchester:

> The Corporation of Manchester has made an attempt to alleviate the twin evils of overcrowding and insanitary housing conditions. The question was first pressed seriously upon the attention of the City Council some twenty years ago when the Medical Officer reported upon the high mortality which existed in those portions of the borough-notably in Ancoats-in which narrow courts and dilapidated dwellings were most numerous. (Cd 3864, page 300)

In Manchester, as everywhere on which the Report makes comment, slum clearance was the business of local authorities, who introduced legislation to set hygiene standards for the building trades, but mostly intervened directly, demolishing or refurbishing areas of poor housing and building better quality housing for those displaced from slums. In the case of Birmingham, for instance:

> …the municipal authorities of Birmingham are fully conscious of the gravity of the question…. For some years past individual houses of insanitary character have been repaired and rendered dry and clean…Since

> 1901, when the Housing Committee was appointed, the activity in this connection has been very great. Houses have been rendered habitable to the number of 1,132, while over 500 have been demolished and 824 have been ordered to be closed. (Cd. 3864,)

In order to create a numerical index of the degree of reform, we classified each town as one of 'good', 'moderate' or' bad' in terms of sanitation. The list of cities and their classifications are given in the data appendix, but the great majority of towns and cities classified as having relatively good sanitation in 1908 were from the more southerly parts of England and Wales, though there are exceptions. [iv]

We classified each town or city as having a high proportion, a moderate proportion, or few courts and back-to-back dwellings. The exercise resulted in us classifying eight cities has having a high proportion of courts: Bradford, Birmingham, Castleford, Hull, Merthyr Tydfil, Middlesbrough, Norwich and Stockport[v].

Table 1 gives descriptive statistics for some of these variables across at most 72 industrial towns and cities in England and Wales.[vi] As mentioned in the introduction, the crude birth rate ranges from just under 2% to just over 4%. The infant mortality rate varies between just over 10% and just over 20%. Both rates were significantly higher in average in the late 1850s. Population density varies widely. Some of the larger northern cities had population densities in excess of 40 people per acre or 10,000 per square kilometre, which would put them among the most densely populated cities in the world today[vii]. The proportion of adult women in paid employment also varies widely, from single-figure percentages in some of the ship-building towns, such and Barrow and the North-Eastern towns to well over 50 percent in some of the Lancashire cotton towns and in the millinery town of Luton. We estimate that sanitation is improved to a good standard as judged by Board of Trade investigators in sixteen of these towns and cities. We also estimate that courts and back-to-back housing is non-existent in twenty-eight of these towns and cities.

The proportion of brides who sign with a mark is our measure of literacy. The average rate of mark-signing in 1858 and 1860 was 44.3%, with a range from 16.5 % in Reading to over 78% in Merthyr Tyfil. The last Registrar-General's report that lists this variable by town was for 1884. From then on, only county-level data is recorded.

In order to estimate a 1905 town-level value, we took 1884 town and county level data and calculated the proportion gap between the town and the county. Then we apply those ratios to the 1905 county-level data. Our average rate for 1905 is 16.7%, so the practice of mark-signed had more than halved over the period. Similarly the practice of marriage for the very young was gradually declining. We collected data on the proportion of brides who were minors, adjusting to calculate 1905 values as for the mark-signing rate. According to Cd. 3279 (1905, p xi) the prevalence of marriages involving minors had been decreasing over this period, having risen steeply from at least the 1840s to the 1860s-70s.

4. Analysis.

In Table 2 we investigate the correlations between our set of variables. Note firstly that in the early 1900s, the crude birth rate is correlated with the infant mortality rate. See also Figure 1. Figure 1, though suggestive of a relationship, also issues us with a warning. In order to generate such a distribution with a clear positive scatter plot and a strongly significant correlation coefficient, we only need to assume that both rates are in decline, but that the timing of decline is different across cities. With these assumptions alone, which require no relationship, causal or otherwise, such a correlation would emerge.

Both the infant mortality and the crude birth rates are correlated with their levels fifty years previously. However, fifty years earlier, there was little cross-section correlation between infant mortality and birth rates. We have already noted this *emergence* of the infant mortality-birth rate correlation was found across European regions by Van der Valle (*op. cit.*), as was the strong persistence of both rates. In other words, both phenomena were slow to evolve, but as both began to fall, sets of more advanced and less advanced towns emerged. There is also a lack of correlation between longer-term changes in infant mortality and birth rates that we present in Table 4 and discuss below. We find a cross-city correlation coefficient of -0.05 between the two changes and Figure 2 illustrates this.

Returning to Table 2 and the town characteristics of the early 1900s we find population density is positively correlated with both infant mortality and the birth rate. This is consistent with the contemporary observation that infant mortality was particularly high in densely-populated urban areas, see Dyhouse (1979, p251). The share of women in paid employment is also correlated with both infant mortality and with the birth rate. But here the signs of the correlations are opposite. High proportions of working women working are statistically associated with high infant mortality, a phenomenon noted by contemporary observers. Dyhouse (1979, p252) explains that one of the main reasons that some commentators objected to mothers working was that work made mothers less available for breast-feeding and forced reliance on other, much less healthy, forms of milk to feed infants. On the other hand, the birth rate is negatively correlated across towns with women working, as Crafts (1989) noted. There are strong regional patterns here. For example, in Blackburn, a cotton goods-producing town, with plenty of work available to women and almost 38% of married women working in 1901, the average birth rate was 2.5%, while in Jarrow, a shipbuilding town with little work for women, only 5.7% of married women worked and the birthrate was about one-third higher, at 3.4%.

Our measure of sanitation is negatively correlated with both the birth rate and the infant mortality rate in the early 1900s. Our measure of the elimination of court and back-to-back housing is also negatively correlated with infant mortality. Both of our illiteracy mark-signing variables are strongly correlated with infant mortality rates in the early 1900s and also in the late 1850s, see Figures 3 and 4. Both measures are also strongly associated with the crude birth rate for the early 1900s. That tells us there were long-persistent differences, between, for instance, industrial cities like Manchester with high levels of signing with a mark, infant mortality and birth rates and prosperous semi-suburban towns like Croydon where all those phenomena were at much lower levels. As with our sanitation measures, the extent to which *changes* in signing with a mark are associated with changes in mortality or fertility has yet to be established. The preponderance of juvenile brides is correlated of the crude birth rate, both in the early 1900s and the late 1850s. This would be easy to understand if, as is usually the case, earlier marriage is associated with larger families.

The variables presented in Tables 1 and 2 are a subset of the variables that we amassed from Cd. 3864 and elsewhere. These are the variables with strong partial correlations with either the infant mortality rate or the crude birth rate, or both. Other variables that we collected, but which were not strong correlated with our principal variables of interest were: measures of real wages, the proportions of schoolchildren who were staying on a school, either boys or girls; the proportion of domestic servants in the population, the share of Catholics (measured by the percentage of catholic services at weddings) and overcrowding (calculated as the share of people living at or more than 2 people per room).

Table 3 gives cross-section regression results for our chosen variables. We interpret the estimated coefficients as reflecting partial correlations, or conditional associations, rather than the impact of these variables on the dependent variables. In the first and third columns, where we exclude controls for late 1850s birth and infant mortality rates, we find coefficients that mostly follow the correlations of Table 2. Again we see the negative association between women working and the birth rate contrasting with the positive association between the rates of women working and infant mortality. The sanitation and housing improvement variables are also associated with different signs: with positive links between improved environments and birth rates, and negative links with infant mortality. The two variables derived from marriage records, signing by mark and juvenile brides and also population density are all consistently positively associated with the rate of infant mortality and the crude birth rate.

These cross-section associations suggest causal relationships and are useful in their own right, but if we want to understand why these cities came to be so different in terms of fertility and infant mortality, we need to study longer-term changes directly. To do that, we turn to a difference in differences methodology, comparing the late 1850s/early 1860s and the first decade of the 20th century[viii]. The late 1850s/early 1860s make a good comparison period for the early 1900s for several important reasons. Firstly the reductions in infant and fertility are generally judged to have begun a started a decade later on, in the 1870s at the earliest. Secondly, though the science of water-borne disease was becoming better understood, local authorities, as Szreter notes (1997, pp707-11), lacked the powers to act in the public interest until at least decade later. Also, public intervention in housing improvement and in slum clearance had barely started in the 1850s. Roberts (1855) illustrates this, in his description of the pilot projects undertaken by some charitable societies to provide more healthy lodgings for workers in some major English cities.

Almost all of the variables available for the early 1900s are available for the earlier period. We have already introduced our data on infant mortality and crude birth rates for the late 1850s. We can supplement that with data from the Registrar of Births, Marriages and Deaths, on the proportion of brides who sign with a mark, and on juvenile brides. We lack data on population density, but have 1861 census populations, so replace density with log population size, given the positive correlation between the two measures. The closest date from which women's participation rates are available is 1871, taken from the census of that year.

Simple difference in differences models, the purpose of which is to eliminate confounding variables that do not change over time, may not be quite appropriate in this context. Over a period of almost fifty years, any confounding variables are likely to have evolved, so simple differencing will not eliminate them. Our alternative models of the change in infant mortality and the crude birth rate take the following form. Let, for instance, infant mortality in city *i* at time *t* is given by:

$$IM_{it} = \alpha S_{it} + \lambda X_{it} + f_{it} + u_{it} \quad (1).$$

Here *IM* is the infant mortality rate, *S* is an indicator for fully improved sanitary conditions, *X* stands for other included and observed forcing variables, *f* is an unobserved city effect and *u* is an error term. Now assume that *n* years earlier, before the introduction of sanitation improvements, infant mortality is given by:

$$IM_{i,t-n} = \lambda X_{i,t-n} + f_{i,t-n} + u_{i,t-n} \quad (2).$$

Finally allow the unobserved city effects to evolve according to the following scheme

$$f_{it} = \beta f_{i,t-n} + z_{it} \quad (3).$$

Here z is a city-specific shock. Combining (1), (2) and (3), we can derive the following quasi-difference-in-differences formulation:

$$\Delta_n IM_{it} = \alpha S_{it} + \lambda\left(X_{it} - \beta X_{i,t-n}\right) + (\beta - 1) IM_{i,t-n} + \left[u_{it} + z_{it} - \beta u_{i,t-n}\right] \quad (4).$$

The interpretation of equation is as follows. The change in infant mortality over the *n* years depends positively upon *S* and the quasi-differenced change in *X*. If $0 < \beta < 1$, it also depends negatively on the initial level of infant mortality, but this dependency is lower the greater is the persistence, β, of the unobserved city effects, and finally there is a composite error that is correlated in principle with the lagged dependent variable.

Table 4 presents correlations between long-period changes. Correlations that are significant at the 5% level are written in bold. There are only four. Changes in the birth rate are positively correlated with changes in the extent of signing by mark. Changes in infant mortality and positively associated with city population growth rate, and negatively associated with improved sanitation. Lastly changes in women's participation are very strongly and negatively associated with the rate of signing by mark. Clearly changes in women's participation rates are potentially endogenous with respect to fertility. In Table 5 we estimate quasi-difference in differences models for infant mortality, the crude birth rate and women's participation.

The econometric results in Table 5 are presented with insignificant variables omitted. This is purely to simplify presentation; none of the results are qualitatively changed. Estimation is by instrumental variables. Some of the omitted variables are as follows. First, interaction terms, which would have been interesting, proved unfruitful. Second, the change in the rate of juvenile marriage was tested and never found to be significant in any of the models. The key results are in line with the correlations of Table 4. Firstly, a more rapid population growth rate, reflecting rapid urbanisation, is associated with declining birth rates and increasing infant mortality. This latter finding is consistent with the view of Millward and Bell (2001), that rapid urbanisation, uncompensated for by sanitation improvement, slowed and in some places reversed the fall of infant mortality for a period in the latter part of the 19th

century. Secondly, more rapid growth women's participation is associated with declining birth rates. Thirdly, a more rapid reduction in illiteracy is associated with a more rapid increase in women's participation. Lastly, there is evidence of strong persistence in the unobserved components of all three dependent variables.

5. Conclusions

Infant mortality rates and crude birth rates are correlated across the industrial towns and cities of England and Wales in the early 1900s and they also correlated with many of the variables that have been suggested as determinants. We discuss how a positive association is not unlikely from a theoretical perspective if the theory more accurately reflected the processes underlying the infant mortality reduction. However, between 1850s-60s and the early 1900s, long period changes in these two rates are not correlated across Britain's cities, which means we find no support for the idea that infant mortality decline, at the city level at least, was a cause of the fertility decline in England and Wales. Our approach has been to look for changes that impact upon either infant mortality or fertility and then search for any interconnectedness. We find some common influences and on the two phenomena and an interesting and straightforward picture emerges.

As contemporary observers noted, there was long term persistence in the patterns across Britain of the rate of infant mortality, the birth rate, and women's labour market participation. On women's participation, our results reflect the fact that the growth of women's participation was a lot faster in places where more women were working initially, which might be via a demonstration effect in the transition to higher levels of women's participation. On other important results, rising participation of women in paid work is associated with a more rapid decline in illiteracy among women. Also, the birth rate decline is associated with more rapid urbanisation, and via increased women's participation, with the fall in illiteracy.   For infant mortality changes, we find offsetting effects, negative from water and sanitation reform and positive from more rapid urbanisation.

To emphasise magnitudes, recall first that our sanitation variable simply indicates where sanitation is deemed to be good by 1905-7. The average city fall in the infant mortality rate was 2.6 percentage points. We estimate that in the cities with good sanitation, infant mortality fell by 3 percentage points compared to 1.2 percentage points for the others and recalling that the other cities were a mix of those with different degrees of incompleteness in sanitation improvement, it is little wonder the effectiveness of these programmes was widely accepted. Lastly, with respect to the original empirical question of the paper, we conclude the British historical experience does not support the idea that the factors that reduced infant mortality also reduced the crude birth rate.

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Table 1: Descriptive statistics for key variables

Variable	*Obs*	*Mean*	*s.d.*
Crude birth rate, average 1902-6	70	0.029	0.004
Infant mortality rate average 1902-6	71	0.145	0.021
Crude birth rate, average 1855-60	60	0.039	0.006
Infant mortality rate, average 1855-60	60	0.167	0.024
Population density, 1901 (hundreds per acre)	68	0.208	0.116
Share of adult women working, 1901	72	0.504	0.251
Share of adult women working, 1871	61	0.371	0.127
Sanitation fully improved by early 1900s	72	0.222	0.464
No courts or back-to-backs, early 1900s	72	0.389	0.491
Share of brides who sign with a mark, 1858-60	60	0.443	0.160
Share of brides who sign with a mark, 1905	72	0.167	0.075
Share of juvenile brides 1858-60	60	0.213	0.052
Share of juvenile brides 1905	72	0.164	0.027

Notes and sources: All rate and share variables are written as simple decimals, rather than percents or per thousand. The methods of estimation for the sanitation and housing variables are discussed in the text. Taken from Cd. 3864 (1908), except for the bridal signature variables. The 1855, 1858 and 1860 variables are from several of the Reports of the Registrar-General, see 1857 Session 2[2260], 1860 [2712] and 1862[2977]. The 1905 bride signature variable is derived from the Registrar-General's report for 1884, C.4722 (1886), which was the last year that the numbers of brides who sign with a mark, and from the report for 1905, Cd. 3279 (1906). We take town and county level data for 1884, and calculate, for each town, the proportional deviation from the county average. We then apply those deviations to the county data of 1905 to come to an estimated town rate for 1905.

Table 2: Correlation coefficients

	A	*B*	*C*	*D*
A: Crude birth rate, average 1902-6	1			
B: Infant mortality rate average 1902-6	**0.46**	1		
C: Crude birth rate, average 1855-60	**0.61**	**0.35**	1	
D: Infant mortality rate, average 1855-60	0.17	**0.64**	0.12	1
Population density, 1901	**0.35**	**0.28**	0.13	**0.29**
Share of all women working, 1901	**-0.44**	**0.28**	-0.18	**0.34**
Share of all women working, 1871	**-0.50**	0.11	**-0.31**	**0.30**
Sanitation fully improved by early 1900s	**-0.26**	**-0.54**	-0.18	**-0.30**
No courts or back-to-backs, early 1900s	-0.09	**-0.39**	-0.14	**-0.37**
Share of brides who sign with a mark, 1858-60	**0.22**	**0.56**	**0.36**	**0.40**
Share of brides who sign with a mark, 1905	**0.58**	**0.62**	**0.45**	**0.49**
Share of juvenile brides 1858-60	**0.32**	0.17	**0.40**	0.17
Share of juvenile brides 1905	**0.38**	0.20	**0.51**	0.09

For notes and sources, see Table 1. Numbers in bold are significant at the 5% level on a one-tailed test.

Table 3: Cross-section regressions of the 1902-1906 infant mortality and birth rates

Dependent variable:	*Crude birth rate*	*Crude birth rate*	*Infant mortality rate*	*Infant mortality rate*
Crude birth rate, average 1855-60		0.119**		
Infant mortality rate, average 1855-60				0.171*
Population density, 1901	0.010***	0.008***	0.040***	0.021
Share of women working, 1901	-0.007***	-0.077***	0.024***	0.021*
Sanitation fully improved by early 1900s	0.002**	0.001	-0.012**	-0.014***
No courts or back-to-backs	0.001**	0.001**	-0.004	-0.003
Share of brides who sign with a mark, 1905	0.229***	0.210***	0.640***	0.531***
Share of juvenile brides	0.044***	0.021*	0.119**	0.103**
N	67	59	68	59
R-sqd	0.69	0.71	0.58	0.66
RMSE	0.0024	0.0022	0.013	0.012

Notes: Method of estimation, weighted least squares, weighted by the square root of 1901 population. *, **, and *** denote significant at the 10%, 5% and 1% levels respectively. Estimated with robust standard errors.

Table 4: Correlations in long-period differences

	Δ Crude birth rate	*Δ Infant mortality rate*	*Δ Women's participation rate*
Δ Crude birth rate	1		
Δ Infant mortality rate	-0.05	1	
Δ Women's participation	-0.18	0.01	1
Δ Log population	-0.16	**0.30**	-0.05
Δ Share of brides who sign by mark	**0.27**	-0.16	**-0.40**
Sanitation fully improved by 1905	0.01	**-0.22**	-0.07

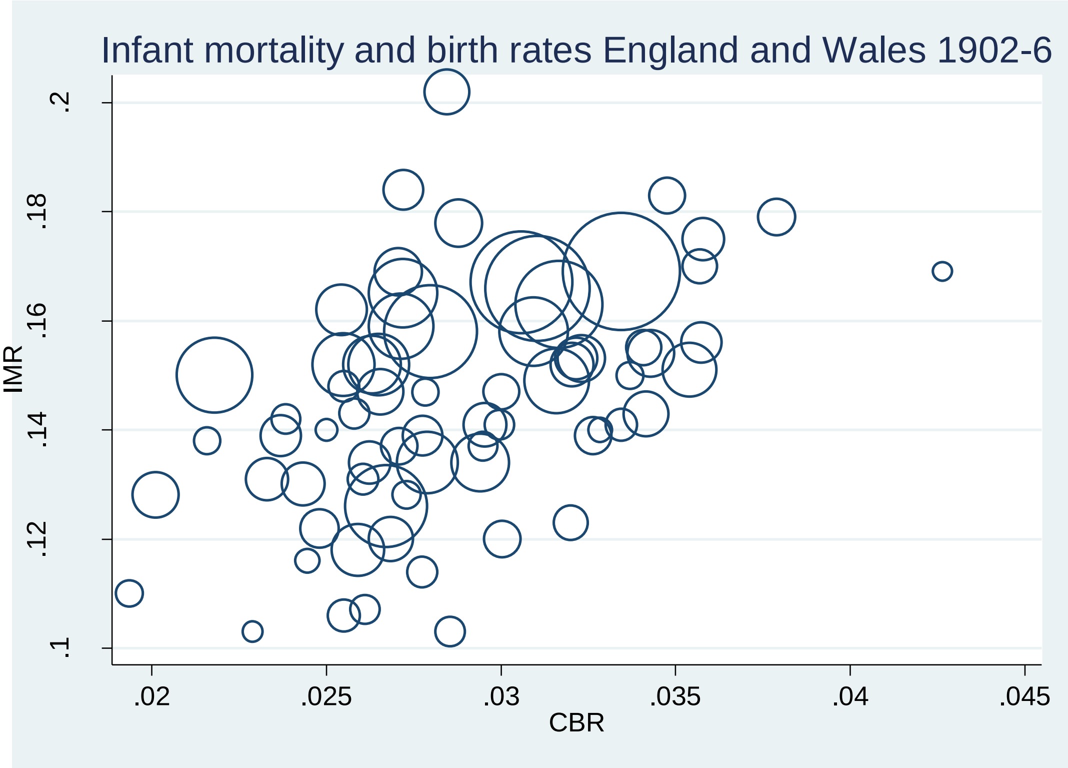
For notes and sources, see Table 1 and text. For the crude birth rate and the infant mortality rate, changes are measured 1855/8 to 1903/6. Women's participation rate change is 1871-1901. Log population change is 1861-1901. The change in the share of brides who sign with a mark is measured 1855/8-1905. Numbers in bold are significant at the 5% level on a one-tailed test.

Table 5: Quasi-difference in differences longer-period regressions

Dependent variables: Change from late 1850s to early 1900s:	*Δ Crude birth rate*	*Δ Infant mortality rate*	*Δ Adult women's participation rate*
Explanatory variables			
	(1))	(2)	(3)
Crude birth rate 1855-8	-0.68***		
Infant mortality rate, 1855-8		-0.397***	
Adult women's participation, 1871			0.73***
Sanitation fully improved by early 1900s		-0.018***	
Change in log population 1861-1901	-0.002***	0.010**	
Change in the share of brides who sign with a mark 1858-1905			-0.301**
Change in the participation rate of women 1871-1905	-.008***		
R-sqd	0.69	0.54	0.65
N	60	60	60
Root MSE	0.003	0.014	0.012

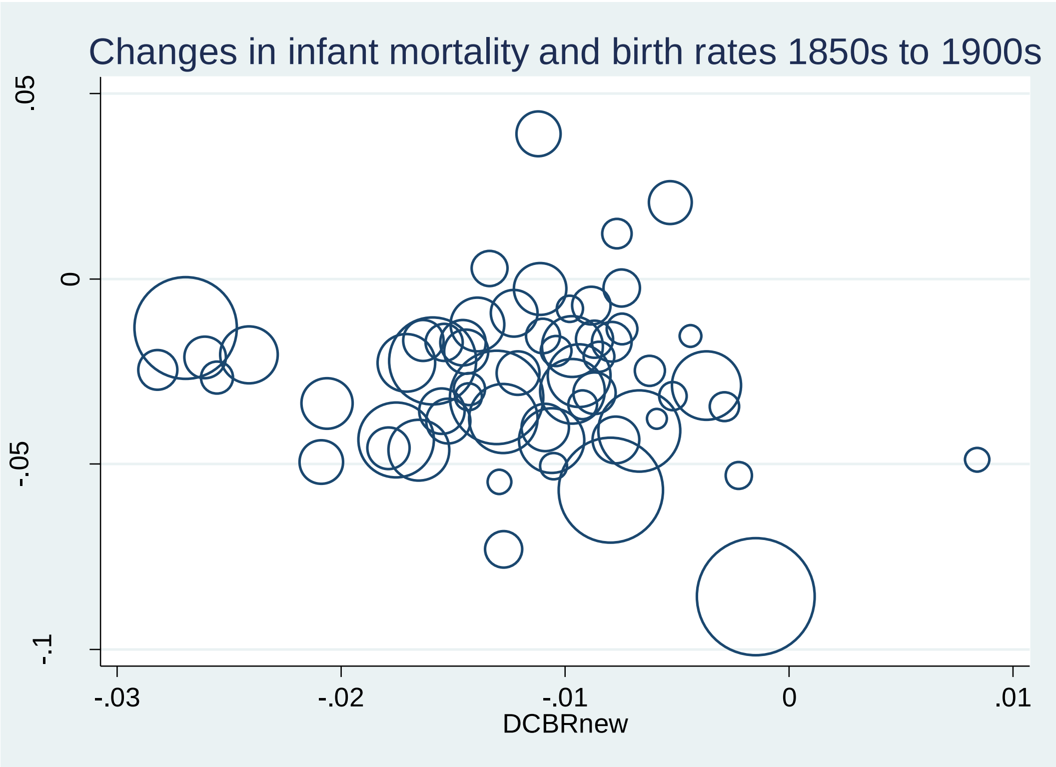
Notes: method of estimation: weighted instrumental variables. Lagged dependent variables are instrumented by log population 1861, dummies for shipbuilding, mining and cotton towns and the share of brides who sign with a mark in 1858-60. *, **, and *** denote significant at the 10%, 5% and 1% levels respectively. Estimated with robust standard errors.

Figure 1



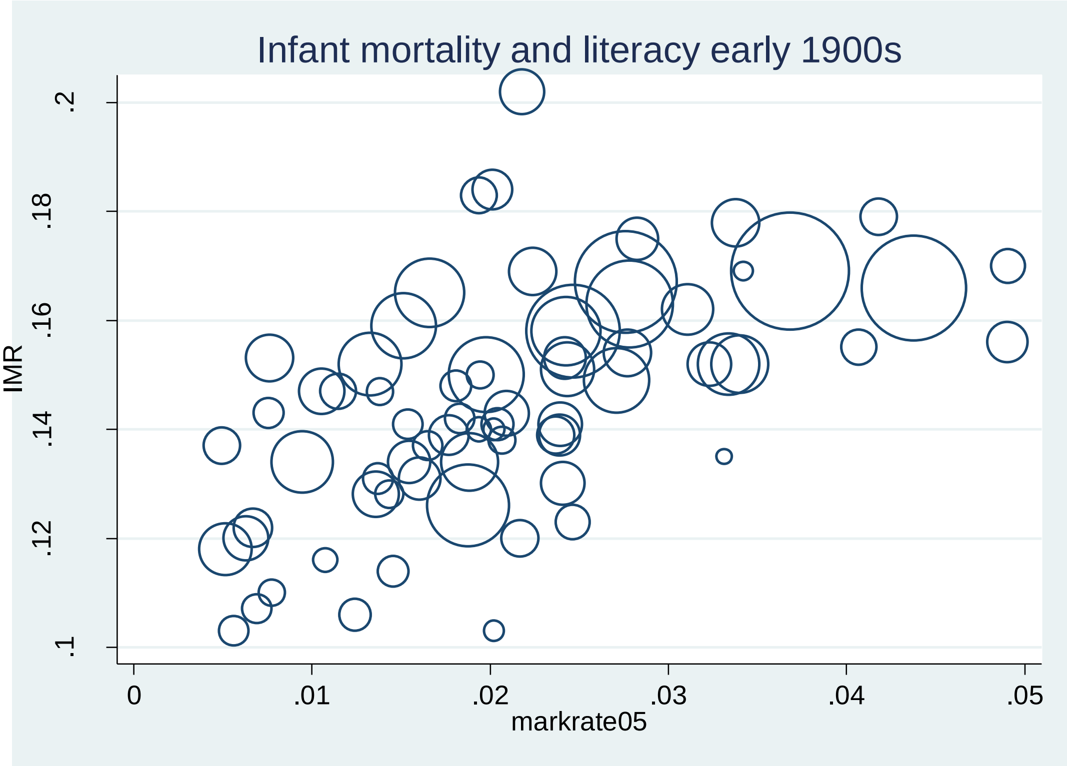
Note: Each circle represents a city and is proportional in size to 1901 population.

Figure 2



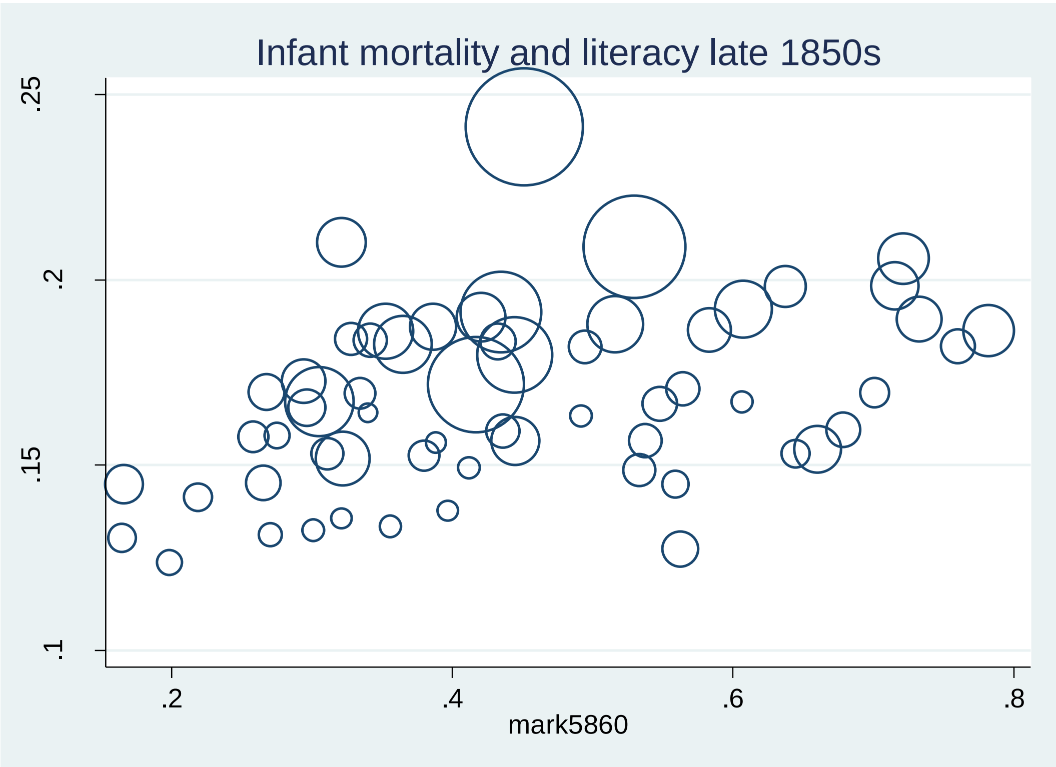
Note: Each circle represents a city and is proportional in size to 1901 population.

Figure 3



Note: Each circle represents a city and is proportional in size to 1901 population.

Figure 4



Note: Each circle represents a city and is proportional in size to 1861 population.

Endnotes

[i] By the early 1900s, the birth rate decline was well under way, whereas the infant mortality decline accelerated a little later.

[ii] This requires the substitution effect of raising the relative shadow price of quantity to offset any real income effect of the falls in shadow prices.

[iii] The Princeton study has been criticised by Brown and Guinnane (2007), but this finding is not subject to those reservations.

[iv] In order that the assessment of the text was reasonably free of investigator bias we employed two researchers, who had no knowledge of our research objections, to perform the classifications.

[v] For Bradford ' …although the present building byelaws prohibit the erection of 'back-to-back' houses, the prohibition has been in force for six years only and practically all the existing workmen's houses are of the 'back-to-back' type.' (Cd 3864, page 107).

For Birmingham 'The exact number of houses of the back-to-back type in the city is not known, but is usually stated a between 30,000 and 40,000.' (Cd. 3864, page 84)

For Castleford ' In the central part of the town houses are packed closely, often in narrow streets and courts…Water closets and infrequent.. Privies and ash pits, placed in yards and shared by several households, are the rule' (Cd. 3864, page 145)

For Hull, where housing was said to be built mainly on a 'terrace system' '…The word terrace is used elsewhere to describe simply a long unbroken row of houses, while in Hull it denotes a short blind side street usually 18 to 20 feet in width, running out from the main street…usually has six to ten houses facing one another.' (Cd. 3864, page 231)

For Merthyr Tydfil '…the old parts of the town…abound in courts and alleys containing houses without any respect for order or plan, and in some cases without ventilation' (Cd. 3864, page 307)

For Middlesbrough, in the Marsh District '…most of the houses of two and three rooms are to be found, many in courts or 'yards'…'. (Cd. 3864, page 314)

For Norwich, 'In the central area the houses are situated, for the most part, in the courts, alleys and yards forming part of the old city'. (Cd. 3864, p344)

For Stockport: 'Stockport presents a feature common with many old towns in the unsatisfactory housing conditions which prevail in certain parts of the central nucleus of the borough…more than 300 courts exist, most of these being of a very unhygienic character.' (Cd. 3864, page 430).

[vi] The 1905 survey included towns and cities in Scotland and Ireland, but these reports do not consistently include discussions of sanitation. As Gazeley, Newell and Scott (2010) discuss, housing conditions were very different in Scotland from England and Wales. For these reasons we omit the Scottish and Irish cities from our data set. We also omit London, since the boroughs of London are highly diverse, and it is inappropriate either to include London as a single observation or to treat the London boroughs as separate towns.

[vii] According to Citymayors.com the 19th most densely populated city in the world is Bangalore with a density estimated at 10,1000 people per km^2, or just under 41 people per acre.

[viii] Bertrand *et. al.* (2004) note several advantages of taking a before-after long-period difference in differences approach.