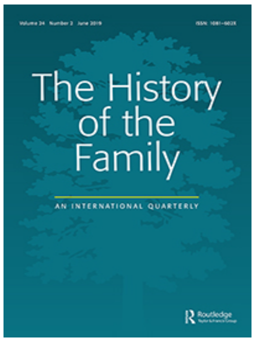

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Later, smaller, better? Water infrastructure and infant mortality in Finnish cities and towns, 1870–1938

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ABSTRACT
We analyse the role of modern water infrastructure in reducing infant mortality in Finnish cities and towns in the late nineteenth and early twentieth centuries. Estimates from US data suggest that urban water infrastructures greatly affected the health transition in Western countries, implying policy lessons for developing countries. Finland is a relevant case due to the early onset of mortality decline in a predominantly agrarian context in a country with a low GDP. Our sources enable analysis across population centres of varying size as well as over different phases of development. We construct panel data on infant mortality and the initiation of three major water interventions – piped water, sewers and chlorination – in 37 Finnish cities and towns from approximately 1870 to 1938. We show that in line with previous literature, the interventions had a significant effect on infant mortality, jointly accounting for roughly 40% of the average decrease in different cities. However, most of the measurable effect was driven by small- and medium-sized cities adopting more advanced technology in the twentieth century rather than by pioneering larger cities in the nineteenth century. Weighting by population size rather than using average effects reduces the estimate to about 32%. Due to low levels of urbanisation, the measurable impact on national mortality decline was only about 4–5 % over the entire period, but roughly twice as high in the twentieth century, when both urbanisation and a decline in urban infant mortality rates gathered pace. Following development economics, our findings emphasise the importance of distinguishing the effects of sanitation by period and developmental context rather than compressing them into a single estimate.

KEYWORDS
Urban sanitation; infant mortality; mortality decline; Finland

1. Introduction

This article analyses the impact of urban sanitation on infant mortality in Finland, historically a predominantly rural ‘developing country’ in Europe. Innovations and technology related to clean water in cities have long been seen as crucial for the health transition of Western countries during the ‘Second Industrial Revolution’ of the late nineteenth and early twentieth centuries (e.g. Easterlin, 1998, pp. 69–82; Fogel, 2004, pp. 37–39; Riley, 2001, pp. 64–67; Szreter, 1988). The interventions studied in the existing

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literature include the provision of piped water, chlorination, improvements in filtration techniques and the introduction of sewerage.

After revising their original estimates, Cutler and Miller (2015) argued that filtration and chlorination accounted for 41% of overall mortality decline and a staggering 59% of infant mortality decline in 13 major US cities between 1900 and 1936 (cf. Cutler & Miller, 2005, pp, 1, 13–14). While Cutler and Miller's estimates have again been significantly degraded as the result of a recent replication effort (Anderson, Charles, & Rees, 2018), Alsan and Goldin (2015, p. 3) estimate that approximately 44% of the dramatic overall fall in the infant mortality rate (IMR) in the greater Boston metropolitan area cities and towns between 1880 and 1915 can be attributed to the impact of providing clean water and constructing a sewerage system.[1] The high figures coming from relatively industrialised and developed contexts have emphasised the importance of an adequate water infrastructure in historical health transitions.

From the outset, the idea of Western historical developments in water infrastructure providing lessons for contemporary developing countries has been cited as a motivation for the research efforts. Both differences and similarities between the historical West and contemporary global South have been highlighted, showing the complexities of extrapolating from Western experience. A recent paper on Mexico, for instance, deals with the problems caused by badly maintained pipelines by controlling for the age of the network, finding statistically significant effects (Bhalotra, Diaz-Cayeros, Miller, Miranda, & Venkataramani, 2017). On the other hand, Kremer and Zwane (2007) have emphasised the proven effectiveness of classic, large-scale sanitation infrastructure as opposed to the more inexpensive communal schemes favoured in recent development policy.

Some of the arguments in development economics are in turn relevant to historical research. In the early stages of economic and social development, studies have highlighted the necessity of complementary inputs. When habitats are crowded and unsanitary, poverty rates high and levels of human capital very low, the mere provision of piped water may not have a significant impact (for an example from India, see Jalan & Ravallion, 2003). In a 'threshold-saturation model' outlined by Shuval, Tilden, Perry, and Grosse (1981), the authors hypothesize that returns are low at the lowest levels of development, increase at moderate levels of development and level off again at high levels of development, where other technology, knowledge and general conditions have already brought mortality down. This model has been fruitfully applied by Gamper-Rabindran, Khan, and Timmins (2010) in an empirical study on piped water provision and IMR in Brazil for the years 1970–2000 using quantile regressions.

In historical analysis with a deeper time dimension, the operation of the model can be based on time-dependent, initially quite severe constraints caused by the levels of available knowledge and technology. For instance, when a basic awareness of germ theory and its implications was still rare, piped water might not have been used to its full potential. The design of the urban environment or housing might have been more detrimental to health than in later periods, making sanitary life virtually impossible. In cities in the late nineteenth and early twentieth centuries, the influx of migrants, growing population densities and increased crowding created new, multidimensional problems that policy makers had to combat with new technology and infrastructure. The largest cities, where the problems were most severe, were often the first to develop better sanitation, but they were still constrained by the magnitude of the challenges (Oris & Fariñas, 2016, p. 6; Cain & Hong, 2009). The early schemes for providing piped water also occasionally suffered from quality issues, making them ineffective or potentially even harmful (Evans, 1990 pp. 144–161, 190–191; Snow, 1855).

The contributions of this article are threefold. First, we add a case from the European periphery to the pool of historical estimates on the magnitude of the effect of urban water interventions on mortality. This makes it possible to compare and analyse the impact of introducing the same technology in smaller towns, in a less industrialised society and with lower incomes and human capital than usual. Second, we make comparisons across periods and city sizes in order to apply the 'threshold-saturation' perspective discussed in development economics to the historical data and produce results supporting a more nuanced approach to the estimation of the impact of sanitation on mortality. Finally, we contribute to a reassessment of a previous narrative on Finland's early health transition and its drivers.

2. Cities and towns, sanitation and mortality in Finland

In the 1870s, the Grand Duchy of Finland, an autonomous part of the Russian Empire, had an estimated per capita GDP equal to roughly half the Western European average (the Maddison project, http://www.ggdc.net/maddison/maddison-project/home.htm). The country was agrarian, with less than 10% of a population of approximately 1.8 million residing in cities and towns and approximately 80% supporting themselves in the primary sector (Pitkänen, 2007, Table 1; Vattula, 1983, Table 1.11). Against this backdrop, the beginning of the health transition was quite early. Following the Great Famine of 1867–1868 – the last major subsistence crisis in Europe not caused by war or deliberate policy – a permanent decline in mortality set in. A decline in fertility ensued beginning around 1910, closing a period of rapid population growth. Immediately after the crisis, improved nutrition, supported by an increased supply of cheap grain from Russia transported via a newly built railway, may have played a role (Turpeinen, 1986). However, in the final decades of the nineteenth century, mortality already appeared to be falling faster in cities and towns. This has typically been attributed to urban sanitary reforms in the previous literature, giving them a key role in the entire transition (Pitkänen, 2007; see also, e.g. Nygård, 2004; Lento, 1956; Waris, 1934).

After the famine, migration to cities and towns started to pick up, even if the population shares and absolute numbers remained modest Table 1 and Figure 1. The 10% urbanization mark was passed around 1890, and around half a million people resided in cities and towns by the year 1920. Following independence and civil war in 1917–1918, internal migration accelerated markedly in the 1920s and 1930s. Rural fertility rates remained high, and the relative share of the population of cities and towns grew via internal migration. On the eve

Table 1. Indicators of city and town size in Finland, 1870–1940.

	All				Helsinki	Others		
Year	Obs.	Mean pop. (sd)	Min.	Max.	Pop.	Mean pop. (sd)	Min.	Max.
1870	33	4307 (6021)	258	28519	28519	3551 (4234)	258	19617
1880	35	4813 (8096)	342	43334	43334	3680 (4610)	342	2701
1890	36	6296 (11310)	526	61583	61583	4717 (6261)	526	28946
1900	37	9176 (17172)	907	93576	93576	6832 (9702)	907	38235
1910	38	12023 (25159)	910	147218	147218	8369 (11363)	910	49691
1920	38	14291 (33028)	825	197848	197848	9330 (12647)	825	58367
1930	38	17680 (40761)	726	243560	243560	11575 (15874)	726	66654
1940	38	23191 (53189)	1058	319939	319939	15171 (19886)	1058	80955

Source: SVT VI Väestötilastoa.

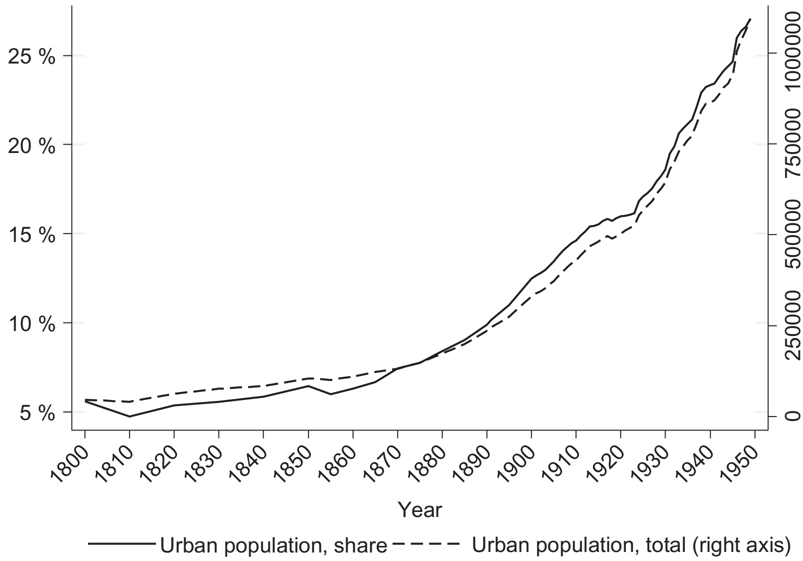

Figure 1. Urbanisation in Finland, 1800–1950.

Notes: Parish of Tornionjokilaakso annexed to Grand Duchy in 1809 (population 11 800). Province of Viipuri annexed to Grand Duchy in 1811 (population 185 000). Orthodox Christian population included since 1830 (population 25 200). Territorial losses with complete evacuation and resettlement in 1940 and 1944 (population affected 430 000). Source: (Suomen Tilastollinen Vuosikirja, 1950, p. 6), Table 7.

of WWII, the population statistically classified as urban was just above 20% out of a total population of approximately 3.7 million.

In the case of Finland, the concept of 'city' merits qualification. Partly due to the predominantly agrarian economy, partly due to Nordic institutional history, many of the administrative-statistical units included in this category were small and essentially non-urban compared to the industrial cores of the Western world. Like in Sweden, of which Finland was a part until 1809, being denoted a city was based on rights granted by the Crown, which introduced a degree of historical arbitrariness into the process (see Enflo, Henning, & Nousiainen, 2016, pp. 14–15). Many small towns on the western coast of Finland had been granted this status to legalise trade by sea before the nineteenth century. Having experienced reversals of fortune and a loss of significance, these towns would by the twentieth century at times consist of fewer than a thousand inhabitants. During the years 1905–1938, after the promotion of Lahti to the status of a city, the number of legally denoted cities remained stable at 38. Their average population was only about 13,000 in 1910, with Helsinki having 147,000 inhabitants, Turku 49,000 and Tampere 45,000; but 29 cities had populations of less than 7,000 (Table 1). As Figure 2 demonstrates, Helsinki was in a league of its own and continued to grow much faster than any other city throughout the period.

The smaller towns were characterised by wooden construction, unpaved streets and water infrastructure based of wells and ditches. The few cities of more considerable size and industry, such as Helsinki, Turku and Tampere, were for the most part similar aside from a small but growing core of buildings and homes made of brick or stone and grid plans for the central streets. Yet, most of these places adopted innovations from the Second Industrial Revolution to deal with sanitation during the period under study.

The Finnish localities studied here cannot be compared with contemporary metropoles in the USA or the UK, and the term 'cities and towns' is applied throughout the article with

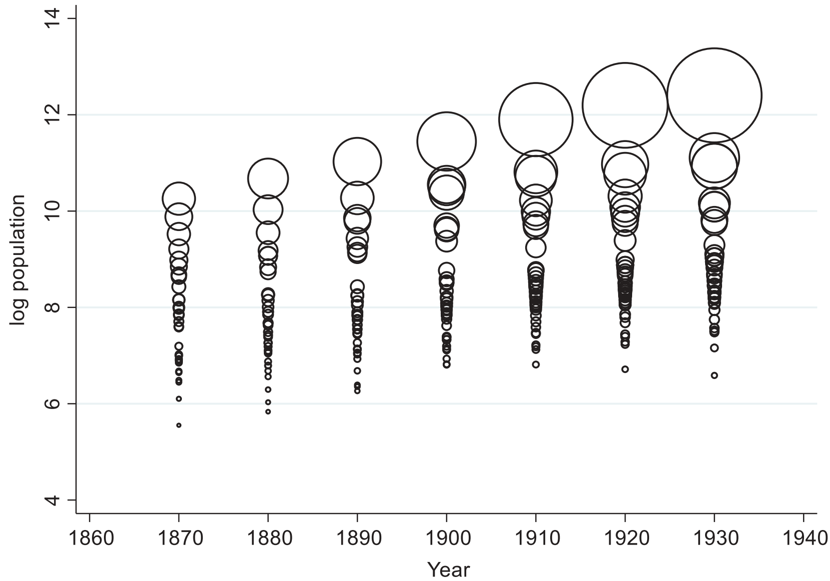

Figure 2. The distribution of city sizes in Finland, 1870–1930. Circles weighted by absolute population, y axis in logs. Source: SVT VI Väestötilastoa.

this caveat in mind. This is not entirely unusual. While large and growing cities in industrial countries have been the typical context for discussing sanitary interventions, water infrastructure investment has also been analysed in outlying regions and small towns both in developing countries and in the peripheries of wealthier countries (Gamper-Rabindran et al., 2010; Watson, 2006). Some of the work on major early industrial countries has at times actually been based on data from smaller localities (Alsan & Goldin, 2015; Gallardo Albarrán, 2018). Furthermore, literature on infant and child mortality in the Nordic countries has suggested that certain phenomena usually associated with larger cities, such as the urban penalty, might also have applied to small, non-industrial communities with a high population density or to rapidly industrialising rural localities (Edvinsson, Garðarsdóttir, & Thorvaldsen, 2008, p. 459; Lazuka, Quaranta, & Bengtsson, 2016, pp. 1, 41).

2.1. Urban IMR and mortality trends

A number of historical and contemporary papers have analysed the impact of sanitation specifically on IMR (Alsan & Goldin, 2015; Gamper-Rabindran et al., 2010; Watson, 2006). While child mortality (1–5 years) is usually seen as a better indicator of environmental conditions due to a lack of distortion by birth defects and variations in breastfeeding (e.g. Oris, Derosas, & Breschi, 2009, p. 367), infant mortality has its merits as an outcome variable of sanitary investment. Infant mortality tends to form a high share of total mortality in 'pre-transition' populations. It is highly likely that the first ingestion of water used for food preparation and drinking as well as washing occurs during the first year of life, as strictly exclusive breastfeeding for 12 months tends to be rare in most past and present populations.[2] A lack of water for hygiene increases early risk of infection (Gamper-Rabindran et al., 2010).[3] Data on IMR is also readily available due to its early establishment as a public health indicator, first pioneered in mid-eighteenth-century Sweden (Laurent, 2017, pp. 44–47). In a long time series, all-cause IMR does not suffer from historical inaccuracies in establishing causes of death (Koskinen & Martelin, 2007, pp. 180–181). For these reasons, infant mortality has often turned out to be the dependent variable of choice in sanitation studies. In the case of Finland, the IMR is available for the entire relevant period and produces consistent estimates.[4] As a conservative first pass, we therefore focus on the measurable effect of sanitation on infant mortality.

Over the period, both urban and rural mortality measured by the crude death rate (CDR) fell considerably. In terms of CDR, the urban penalty disappeared around the 1890s. For infant mortality, this took until the 1920s. Nascent urbanisation created new health problems in the largest cities. Still, both rural and urban IMR fell steadily together, resulting in a remarkably stable urban penalty until a step-like drop in the 1920s, when cities and towns finally took the lead in the decline (Figure 3).[5]

How large a share of the overall mortality decline has urban IMR represented in the case of Finland? Population statistics make it possible to decompose the changes in the CDR into urban and rural by period, and to further extract the share of urban IMR. The findings are predictable (Table 2). Over the period from 1870–75 to 1930–35, overall CDR

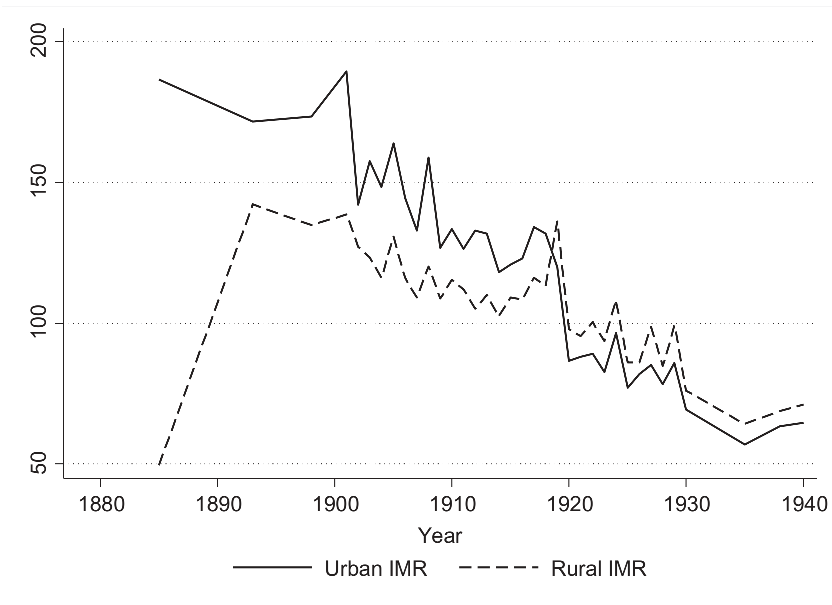

Figure 3. Urban and rural infant mortality rates in Finland, 1880–1940. Source: SVT VI Väestötilastoa, Väestönmuutokset.

Table 2. Reductions in urban and rural mortality and contributions of urban and rural mortality decline to overall mortality decline over 30-year periods, from 1870–75 to 1930–35.

	Urban (CDR 1900–1905 = 23.8)		Rural (CDR 1900–1905 = 21.5)		Total (CDR 1900–1905 = 21.7)		Contribution to total CDR change, %	
	ΔCDR	%	ΔCDR	%	ΔCDR	%	Urban	Rural
1870–75-1900–05	−6.3	−26.6	−2.1	−10.0	−2.6	−11.8	10.0	90.0
1900–05-1930–35	−6.1	−35.0	−5.6	−28.7	−5.8	−30.4	46.4	53.6

Source: Computations from data based on Suomen Tilastollinen Vuosikirja, 1950 (1951), pp. 44–45.

fell from approximately 24.3 to 15.9 per 1000. In cities and towns, the drop was from a much higher 30.1 all the way down to 17.7 per 1000. However, urbanisation was still quite modest in the nineteenth century, and the effect of a decline in mortality in cities and towns on overall mortality remained small. Over time, cities and towns gradually started to grow faster and simultaneously took the lead in the health transition. Their contribution to the total fall in mortality grew markedly as a consequence, accounting for about half of the total decline between 1900–1905 and 1930–1935, despite the fact that urbanisation still barely reached 20%.

In the early 1870s, the deaths of infants still constituted roughly 25% of the national CDR. With respect to the total fall in urban CDR, the falling IMR accounted for approximately 43% in the period from 1870–1875 to 1930–1935. The contribution increased markedly in the twentieth century, when the urban IMR fell quickly and the urban IMR penalty vanished (Table 3 and Figure 4). Estimating how much of the decline in urban IMR can be attributed to water interventions will make it possible to experimentally estimate the contribution of this particular, measurable part of the impact of urban sanitation on general mortality trends.

Table 3. The contribution of infant mortality to the crude death rate and its decline over 30-year periods in Finnish cities and towns, 1870–75 to 1930–35.

Period	Total CDR	Infant CDR*	Infant share, %	Total CDR change	Infant CDR* change	Infant share of change, %
1870–75	23.1	5.9	25			
1900–05	17.1	4.3	25	−6.0	−1.6	26.3
1930–35	11.1	0.8	7	−5.9	−3.5	58.6

Source: Computations from SVT VI Väestötilastoa: SVT VI, Väestönmuutokset 1865–1940; SVT VI 29:1–3, Väestön tila, 1750–1890; Suomen Tilastollinen Vuosikirja, 1879–1940. *Refers to deaths of infants per 1000 people.

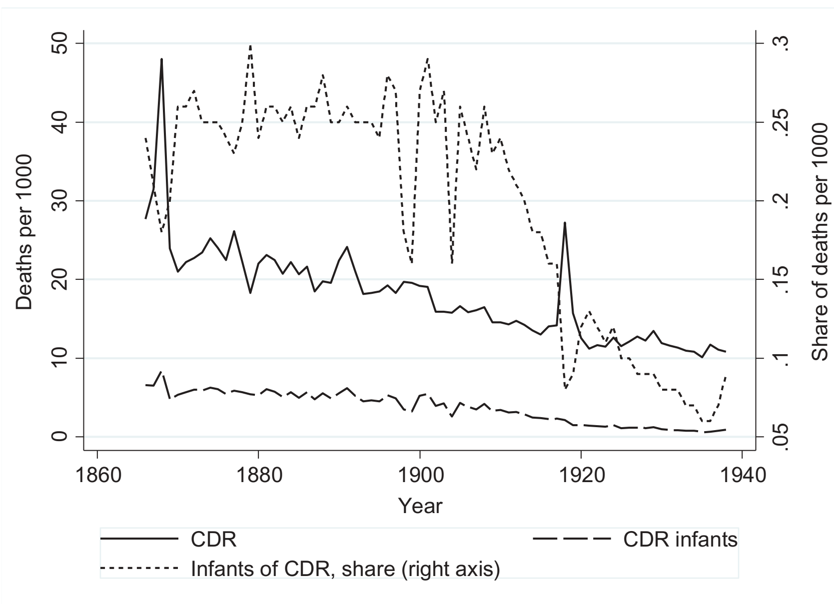

Figure 4. The share of infants in the crude death rate, 1865–1938 (sources: SVT VI Väestötilastoa: SVT VI, Väestönmuutokset, 1865–1940; SVT VI 29:1–3, Väestön tila, 1750–1890; Suomen Tilastollinen Vuosikirja, 1879–1940). "CDR infants" refers to deaths of infants per 1000 people.

2.2. The spread of sanitation

As this section shows in detail, the introduction of a modern water infrastructure in Finland occurred in two distinct phases, with different characteristics. In the nineteenth century, piped water was initiated in some of the largest, growing cities. Since the technology was novel, there were more quality issues, sometimes including confirmed or suspected outbreaks of disease spread through the supply system itself (see Evans, 1990, pp. 144–161, 190–191 for a similar experience from Hamburg, Germany; Snow, 1855 is a classic on London). Dissemination and take-up were gradual. Sewers were introduced in eight Finnish cities and towns before 1900, but importantly they often *preceded* piped water. The aim was to contain local waste water issues, and the concept and technology differed from what came afterwards. The pioneering largest cities were also dealing with a host of problems related to early urbanisation, which applied negative pressures at the same time that overall mortality rates were improving. In the twentieth century, sanitation spread to smaller cities and towns, and it was introduced as a modern 'package' with simultaneous water and sewer service (see Table A1) and the application of chlorination also started. This later phase, particularly from the 1920s onwards, was underpinned by quickly declining mortality rates, growing incomes and generally improving social capability (on this concept, see Abramovitz, 1986).

Despite the general poverty of most in the country, the technical elite of Finland was informed and cosmopolitan. Developments in more advanced European countries were keenly followed and local conditions carefully studied with modern techniques (e.g. Hietala, 1987, 1992; Laakkonen, 2001; Niemi, 2007).[6] Waterworks providing piped water were first introduced by Helsinki (1876), Tampere (1882) and Viipuri (1892), with three more cities and towns (Oulu, Turku and Hanko) following suit in the 1900s. The initiation of such waterworks clustered around the years 1909–1917, when 11 new cities and towns began piping water. Figure 5 plots the establishment of new facilities and the

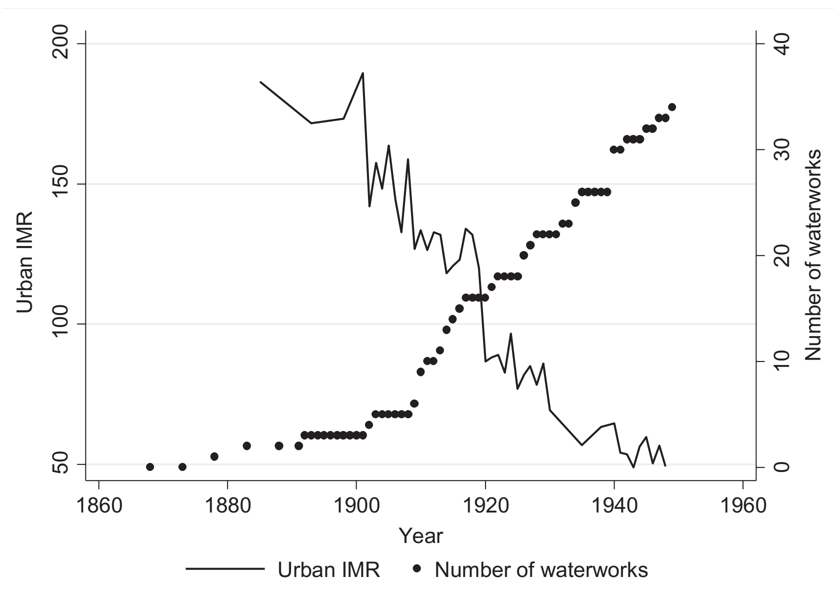

Figure 5. Urban infant mortality and the number of Finnish cities with waterworks, 1870s–1950s.

simultaneous decline of urban IMR. Out of the 38 official cities and towns, 27 had introduced piped water by 1938 (Table A1). In the early cases, the needs of the fire brigade were discussed in tandem with health and hygiene. In Helsinki, the Imperial Senate of the Grand Duchy wanted to improve the fire safety of its own castle. In Tampere, a series of fires in the city and its factories had given urgency to the issue. Unsanitary conditions and fever epidemics were also cited, however, and the supply of cleaner water was a simultaneous goal. As cities and towns grew more densely populated, the contamination of wells by human waste became an increasingly pressing issue (Juuti, 2001; Juuti & Katko, 2005; Kallenautio, 1983; Turpeinen, 1995; Waris, 1934).

Moving in phases and acceleration of development are perceivable also in water improvement through filtration. Surface water was commonly used in Finnish cities and towns due to its easy availability, leading to filtration needs (Linnavuori, 1946, pp. 440–441). In Helsinki, piped water was initially unfiltered and drawn from a river north of the city. Sand filtration was started in August 1878. More modern filters were installed in 1909–1910. In Tampere, water was sourced from a lake in 1882, with filtration modernised in 1898. In contrast, the smaller towns initiating waterworks in the twentieth century adopted modern filtration systems at the outset (Herranen, 2001; Turpeinen, 1995).

Intra-city dissemination of services and related inequalities have been the subject of a number of important studies (e.g. Kesztenbaum & Rosenthal, 2017; Troesken, 2002). Drawing on decennial urban censuses, Table 4 shows the dissemination of piped water within cities and towns with available data. What these figures suggest is that progress was steady, but growth slowed down close to the saturation point, as the constant expansion of cities and towns and the annexation of new territories made universal coverage unattainable. In some large cities, small private schemes catering to the elite had been launched in advance of actual waterworks. Occasionally, their waste would complicate things for the rest of the population.[7]

Chlorination, an effective chemical purification method responsible for the eradication of typhoid fever in many contexts (e.g. Ferrie & Troesken, 2008, pp. 2–3), was introduced in Helsinki in 1915, in Tampere following a typhoid epidemic originating from tap water in 1916 and in four smaller cities and towns throughout the 1920s and 1930s. Chlorination could be expected to cause a uniform and rapid improvement in water quality wherever implemented.

As for sewers, the early separation from piped water in principle could have reduced their effectiveness, as it meant that water closets spread more slowly. Initially, untreated sewage was also deposited in nearby bodies of water, causing further problems. Helsinki started treating

Table 4. Percentage of housing connected to piped water in some cities, 1870–1930.

	Helsinki	Tampere	Turku	Viipuri	Kotka	Vaasa	Oulu	Pori	Lahti	Kuopio
1870	0.5	2.0								
1880	8.0	2.0								
1890	25.6	14.0								
1900	43.2	29.0		27.2						
1910	60.8	42.7	20.3	59.0		4.5	5.4	1.3	4.4	
1920	82.4	62.3	46.0	80.5	7.6	24.2	31.9	2.9	48.1	26.5
1930	84.7	74.3	74.2		42.3	58.2	58.7			43.2

Notes: Percentages preceding initiation in Helsinki and Tampere are estimates of coverage of private systems catering to wealthy households.

Sources: SVT VI Väestötilastoa, Asuntolasku Suomen kaupungeissa, 1910, niteet 50:1–50:8; SVT VI Väestötilastoa, Kiinteistö- ja asuntolaskenta Suomen kaupungeissa, 1920, niteet 54:1–54:11; SVT VI Väestötilastoa, Rakennus- ja asuntolaskenta Suomen kaupungeissa, 1930, niteet 72:1–72:13.

Table 5. Percentage of housing with sewers and WC in some cities, 1910–1930.

	Helsinki	Tampere	Turku	Viipuri	Vaasa	Oulu	Pori	Kuopio
				Sewers				
1910	58.6	41.7	21.1	54.4	16.3	12.5	4.7	
1920	75.4	55.8	44.0	73.3	40.9	29.9	4.9	24.8
1930								
				WC				
	Helsinki	Tampere	Turku	Viipuri	Vaasa	Oulu	Pori	Kuopio
1910	31.6	9.5	3.0	28.4	1.3	1.8	1.0	
1920	50.6	19.8	9.8	50.6	14.3	10.1	1.8	8.4
1930	68.0	38.9	25.9	10.9	34.0	15.6		22.4

Sources: SVT VI Väestötilastoa, Asuntolasku Suomen kaupungeissa, 1910, niteet 50:1–50:8; SVT VI Väestötilastoa, Kiinteistö- ja asuntolaskenta Suomen kaupungeissa, 1920, niteet 54:1–54:11; SVT VI Väestötilastoa, Rakennus- ja asuntolaskenta Suomen kaupungeissa, 1930, niteet 72:1–72:13.

sewage in 1913 (Laakkonen, 2001). A study from 1923 maps the development of sewer networks up to that year in all 27 cities and towns with new urban sanitation systems (Backman, 1923). The manuscript lists 10 places, including major cities like Tampere but mostly consisting of mid-sized population centres, as having provided sewers to at least 75% of the city at that time.[8] A further 13 cities and towns were cited as having covered the zoned urban area fully, but having left out peripheral working-class suburbs or been otherwise less comprehensively serviced.[9] Four cities and towns had made only very limited progress (Backman, 1923, pp. 96–103). All in all, the initiation of urban sanitation did not mean an overnight regime change, and the modern technologies only gradually pushed out and replaced wells and outhouses (Table 5).

Apart from the crucial measure of chlorination, we are not able to directly measure other degrees of quality improvement or intra-city advances in dissemination in our analysis due to a lack of reliable and homogenous indicators. This is an important limitation, but by no means unusual (see section 3). However, indirect methods, like event study analysis, are applied for gauging delayed effects. On the other hand, the fact that we are able to present quantitative estimates on the impact of the initiation of sanitation systems across cities will help us, for instance, assess whether previous descriptive analyses arguing for the decisive importance of filtration in specific cities are plausible.[10]

3. Data and methods

The analysis is based on city- and town-level panel data on infant mortality, water interventions and control variables for 37 of the officially designated cities in Finland.[11] The population statistics were based on record keeping and reporting by parish clergy. Infant mortality by city is reported in *Suomen Virallinen Tilasto* VI (SVT, Official Statistics of Finland) for most of the period.[12] A gap between 1884 and 1905 has been complemented with handwritten parish-level sources.[13]

The main independent variables are dummies for the initiation of one of the three most important and relatively clearly defined interventions, piped water, sewers and chlorination, gleaned from local histories and contemporary reports (Backman, 1923; Juuti, 2001; Linnavuori, 1946; Turpeinen, 1995). What is captured is only the starting year. However, this is a standard problem (see, e.g. Alsan & Goldin, 2015; Cutler & Miller, 2005; Gallardo Albarrán, 2018), and as with other countries specifications based on the starting year turn out to be a reasonably effective tool. Models with leads, lags and interactions as well as event study analysis are applied to seek traces of pre-trends, private head starts, anticipatory behavioural changes or delays in dissemination, even in the absence of direct measurements.

We first estimate the effects of sanitary interventions on log IMR using a standard panel regression with time and city fixed effects:

$$Y_{it} = \propto City_i + \beta Intervention_{it} + \delta Yeardum_t + \gamma(Controls)_{it} + \mu_{it} \quad (1)$$

We run the model separately for each of the three interventions as well as jointly for all three, finally including an interaction term for piped water and sewers. In the absence of sewers, improved water quality alone might be less effective, as the disposal of dirty water would remain deficient. Alsan and Goldin (2015) found that the interaction is particularly significant, while our data produces less clear-cut findings. Joint significance for all three interventions is then estimated via a linear combination. The coefficients β on log IMR can be converted back to the implied percentage change due to sanitary investment by calculating $(e^{\beta} - 1)$.[14] Since the total percentage change for a given period of time is known, the ratio of the implied percentage change resulting from interventions to the total percentage change can be used to arrive at an estimation of the share of decline in urban IMR attributable to water interventions, as has been done in similar studies since that of Cutler and Miller (2005). This makes it possible to gauge the share of urban sanitation in the overall IMR decline, and further, to experimentally compute what this would have meant in terms of the contribution to total mortality decline.

To scrutinise causality more closely and explore the possibility of leads and lags in effects, event study graphs are explored. The specification applied is of the form:

$$Y_{it} = \propto City_i + \sum_{k=-10}^{10} \beta Intervention_{ik} + \delta Yeardum_t + \gamma(Controls)_{it} + \mu_{it} \quad (2)$$

This is similar to Equation (1), but the subscript κ indicates leads and lags for 10 years preceding and following the impact of the intervention. Observing the behaviour of the coefficients should make visible a trend shift in mortality, if any. It can also shed light on the dynamics of the response. In the case of lags, the distribution of the effect over time could be related to slow dissemination. If sanitary investment was preceded by a heightened discussion or awareness of related health issues, this could affect behaviour and show up in mortality as a decline ahead of initiation, with the sanitary intervention only representing the culmination of a broader process. The visibility of the investment itself could also possibly raise awareness already during construction phase.[15]

The varying size of the cities and towns constitutes a potential problem. With small populations, IMR would naturally be volatile and the administrative capacity of the clergy could vary, which can be reflected in, for instance, the number of missing observations. Attempts to trim the dataset by omitting smaller cities or by removing extremes in the distribution of variations only degrade the estimates, however, suggesting that small towns are not a source of measurement error but rather part of the phenomenon. The full set of cities and towns for which statistics are reported has thus been kept in the data.

A common methodological problem is the question of exogeneity. If local conditions, such as the IMR itself, determine the adoption of sanitation, then the estimates will be contaminated by endogeneity. A number of studies have argued that although conditions may create a demand for sanitation, administrative delay and stochastic processes at the

Table 6. Urban mean IMRs at the beginning and end of the period and the years preceding the interventions, 1870–1938.

Period	Mean IMR	Mean IMR, other cities	Difference
1870–75	176	-	
Pre-piping, t-1 to t-6	122	113	+8.0%
Pre-sewers, t-1 to t-6	125	117	+6.8%
Pre-chlorine, t-1 to t-6	106	92	+15.0%
1935–38	62	-	

level of local and national politics add a sufficient random component to the timing of the actual implementation to generate plausible exogeneity (Cutler & Miller, 2005; Watson, 2006; see also Helgertz & Önnerfors in this issue). While this seems like a daring argument to make, the changing, two-phased logic of the interventions in Finland over the period could at least engender different types of endogeneity.

Helgertz and Önnerfors (in this issue) cite a lack of relationship between the initial IMR and decision to provide sanitation in Swedish cities as support for exogeneity. In Finnish cities and towns throughout the period under study, the picture is slightly different. We compare the mean IMR for a period of five years preceding an intervention $(t_{-1} - t_{-6})$.[16] in a city that adopted an intervention with other cities and towns in the same period. Table 6 suggests that the IMR was above average on the eve of initiating sanitary measures. This might imply that such investments were responses to a perceived problem, although policy makers might in fact have been more responsive to public concerns brought by absolute mortality peaks than statistical indicators.[17] However, Figure 6 suggests this relationship was changing over time. A higher than average IMR might suggest that a new sanitation policy was a response to acute problems in large cities, but such a response was more typical of the nineteenth century. In the twentieth century, this was less frequently the case. This would be more compatible with forward-looking initiatives adopted under stable conditions in the latter period. The twentieth-century intervention of chlorination appeared to be somewhat more consistently related to an above average IMR.

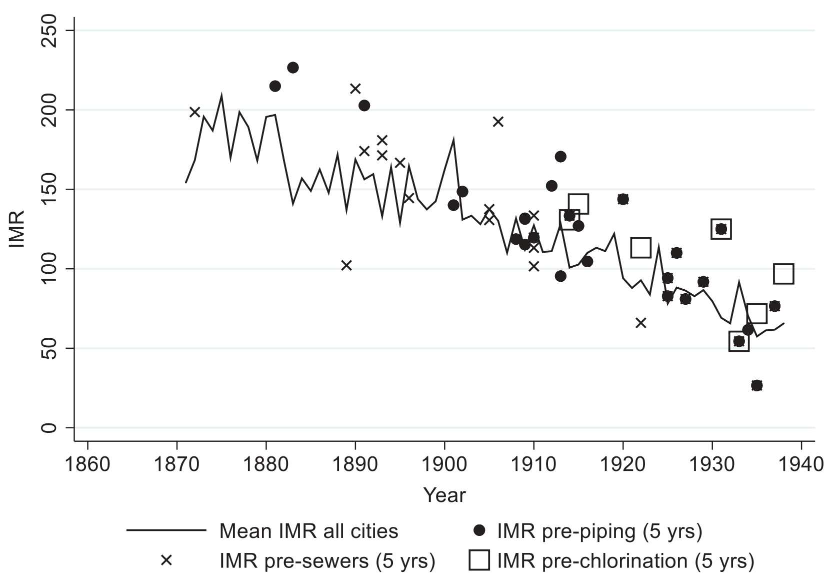

Figure 6. Infant mortality rates in cities prior to sanitary interventions (mean, t-1 – t-6).

Table 7. Sanitary interventions and infant mortality in Finnish cities, 1870–1938 (fixed effects estimates).

lnIMR	I	II	III	IV	V
Piped water	−0.104			−0.060	−0.134
	(0.054)*			(0.044)	(0.093)
Sewers		−0.111		−0.058	−0.079
		(0.048)**		(0.036)	(.036)**
Chlorination			−0.197	−0.183	−0.191
			(0.074)**	(.082)**	(.081)**
PipedXSewers					0.096
					(0.086)
lnPopdens	−0.030	−0.025	−.034	−.025	−.025
	(0.041)	(.041)	(.039)	(.039)	(.040)
Popgrowth	0.001	0.001	0.001	0.001	0.001
(t/t-5 yrs)	(0.000)**	(.000)**	(.000)**	(.000)**	(.000)**
R^2	0.38	0.39	0.38	0.39	0.39
Sanitation joint effect				−.300	−.308
				(.092)***	(.092)***

Notes: Dependent variable: *ln* IMR. All models include year and city fixed effects. Number of observations = 2424; number of groups = 37. Standard errors clustered by city in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

4. Estimation results

4.1. Fixed effects: impact over time and space

Table 7 presents the results from time and entity fixed effects regressions on the impact of the three major sanitary interventions, piped water, sewers and chlorination, on (log) IMR in Finnish cities and towns from 1870 to 1938. Models I–III include only one intervention at a time as dummy variables given a value of 1 from initiation onwards. Model IV includes all three interventions simultaneously. Model V further includes an interaction term for piped water and sewers to test for any indications of complementarity. All of the models include controls for (log of) population density (population/square kilometre), population growth over the five previous years (percentage change) as well as city and year effects. Standard errors are clustered by city. For the last two models, the joint significance of all sanitary interventions is computed via linear combination. The regressions are unweighted by population, and therefore present the average effect across cities (see Alsan & Goldin, 2015, pp. 12–13).

At the outset, the estimates suggest that taken separately, each of the three interventions had a significant effect on IMR, at minimum at a 10% confidence level. The coefficient for chlorination is clearly higher than the largely identical ones for piped water and sewers, retaining its significance across each of the models. The separate estimates on piped water and sewers would imply an average percentage change of approximately 10% in IMR. This would mean that approximately 15% of the average unweighted decline in IMR in the cities and towns included in the data would have been due to these interventions. As for chlorination, the estimates imply, on average, a 17% change, which would mean that approximately 26% of the average decline in IMR across cities would have been due to this factor alone.

The joint effect of sanitation was high and significant in the last two models, implying an approximately 26% change in IMR. This would have equalled a contribution of approximately 40% to the average decline in urban infant mortality from the years 1870–75 to 1935–38. The estimate is high and comparable with findings by Alsan and

Goldin (2015) on non-metropolitan greater Boston and Cutler and Miller (2005, 2015) on major US cities in the early twentieth century.[18]

When taking into account the interactions between piped water and sewers, the results differ from previous literature showing complementarity (Alsan & Goldin, 2015; see also Helgertz & Önnerfors in this issue). While the term itself is not significant, it strengthens the separate effect of the sewers dummy. It is not clear whether there is a meaningful way to interpret this. Altogether, nine cities and towns initiated some type of sewer service ahead of introducing piped water, with a mean delay of 15 years, which can be considered a long time in this context. These nine cities and towns included smaller as well as larger localities. Most initiated sewer service in the nineteenth century, but some did so only in the beginning of the twentieth century. Assuming these interventions were direct responses to perceived problems and had less risk of causing damage through contamination than early piped water systems, perhaps they tended to work well enough to have an identifiable effect, and adding piped water brought no further statistically discernible change. On the other hand, five cities in the data began offering water service on average 5.5 years ahead of sewer service. It is possible this could have either improved the situation or been ineffective due to a lack of waste water management. It might even have caused further problems due to the dumping of waste water on the rest of the community. Because of the often counterintuitive behaviour of the interaction term, limited weight is given to estimates obtained with this model, however. The joint effect, free from collinearity issues, remains stable.

When compressed into regressions covering the whole period, the findings would therefore suggest that the Finnish experience was not that different from those of more advanced industrial countries. Knowledge of the different phases and methods regarding sanitary investment in the late nineteenth and early twentieth centuries as well as the variation in population size and physical characteristics between cities and towns warrants further exploration. Were these results driven by the largest, 'real' cities, as pioneers in introducing the new technology at the turn of the century? Or were the early movers possibly handicapped by a lack of complementary inputs, as the discussions in development economics would suggest, giving an edge to the small- and medium-sized latecomers from the 1910s onwards?

It is not possible to break down the introduction of modern sanitation systems by time frame and city size, as these spread from larger cities to smaller towns and no control group of non-treated large cities exists for the nineteenth century. However, running the regression entirely *without* the four biggest cities – Helsinki, Tampere, Turku and Viipuri – in fact yields estimates that are significant and somewhat higher for piped water and sewers, while the effect of chlorination disappears entirely. In the joint models, the effect of piped water is more significant than that of chlorination, while the joint effects are volatile (Table 8).

If, on the other hand, the regression estimates are weighted by population in each cell, the covariation from the largest cities should dominate. When doing so, the findings are reversed: no significant estimates are generated for piped water or sewers at all, but the impact of chlorination is substantively unchanged from the initial model. Further removing the larger cities from the weighted regressions leads again to an elimination of the effect of chlorination. The coefficients for piped water and sewers have a sign and magnitude similar to the unweighted estimates, but no statistical significance.

The larger cities pioneered piped water and sewers from the 1870s to the early 1900s, yet it would seem that statistically these systems – especially piped water – had a

Table 8. Sanitary interventions and infant mortality in Finnish cities, 1870–1938 (comparison of fixed effects estimates across data and specification variants).

Variant	No large cities			Population weighted			Population weighted, no large cities			20th-century interaction terms		
Models	I–III (Separate)	IV (Multiple)	V (Interact)	I–III (Separate)	IV (Multiple)	V (Interact)	I–III (Separate)	IV (Multiple)	V (Interact)	I–III (Separate)	IV (Multiple)	V (Interact)
Water	−0.143	−0.113	−0.450	0.065	0.052	0.036	−0.077	−0.029	−0.436	−0.238	−0.136	−0.471
	(0.064)**	(0.064)*	(0.171)**	(0.073)	(0.045)	(0.062)	(0.066)	(0.058)	(0.126)***	(0.064)***	(0.059)**	(0.166)***
Sewers	−0.122	−0.042	−0.083	−0.033	−0.079	−0.086	−0.090	−0.072	−0.099	−0.144	−0.054	−0.087
	(0.057)**	(0.048)	(0.044)*	(0.057)	(0.048)	(0.053)	(0.063)	(0.059)	(0.061)	(0.065)**	(0.063)	(0.053)
Chlorine	0.018	0.092	0.094	−0.226	−0.217	−0.218	0.028	0.056	0.061			
	(0.079)	(0.081)	(0.081)	(0.075)***	(0.069)***	(0.068)***	(0.084)	(0.095)	(0.095)			
Joint effect		−0.062	−0.438		−0.244	−0.268		−0.046	−0.474			
		(.086)	(0.185)**		(0.070)***	(0.089)***		(0.107)	(0.188)***			

Notes: Dependent variable: *ln* IMR. All models include year and city fixed effects. Coefficients extracted from models I–V, as in Table 7. Separate: coefficients extracted from separate regressions for each intervention; multiple: coefficients extracted from multiple regression: interact: coefficients extracted from specifications with the PipedXSewers interaction. Standard errors clustered by city in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

greater impact in small- and medium-sized localities. Did the effect of introducing piped water and sewers also appear to change over time? Table 8 presents estimates for an interaction term with a dummy for the twentieth century for these two interventions. The estimates are negative and significant, whereas the (unreported) constituent effects are not.[19] In this specification, piped water and sewers were significantly more clearly related to reductions in IMR in the period after 1900.

The findings would seem to point to the same direction. The early phase, when the very first piped water systems were launched in the largest cities, did not seem to affect IMR as much at the city population level. Only later, when small- and medium-sized towns followed suit using tried and improved technology and coordinated roll-outs among populations of manageable size, did the effects become statistically visible.

There are plausible explanations for these results. The early introduction of sanitation took place in challenging circumstances. Piped water often had quality issues before filtration developed; in Tampere, it actually caused a typhoid epidemic in 1916, and in Helsinki there were suspicions of the same in the 1890s (Herranen, 2001, p. 61). Dissemination and take-up were slow, and sometimes inhabitants persistently preferred the old unsanitary wells to new water outlets if the latter involved payments or were inconveniently located (Herranen, 2001, p. 62; Pietikäinen, 2018, pp. 27–30). In larger cities with more inequality between residential areas, access to piped water spread more slowly. Factors like the growth of slums might have pulled mortality rates up at the same time that better sanitation was pulling them down, creating local confounders. In the twentieth century, the newly treated populations were smaller and more homogenous. Modern filtration was the norm, and sewers were immediately linked to water provision.

Even if sanitation was bound to improve conditions in the larger cities compared to a counterfactual completely without interventions, at the level of the entire population this was not necessarily measurable in the short run. Within cities, a more fine-grained analysis could yield more positive results (*cf.* Kesztenbaum & Rosenthal, 2017; Troesken, 2004). Between cities, the latecomers were the ones registering clearer successes. The strong effect of chlorination, which results in a one-off treatment of a population dependent on a pre-existing water system and largely eliminates quality issues, is the only separate estimate remaining significant in the population-weighted regressions. In Finnish cities, this was a twentieth-century technology.

4.2. Robustness checks and event study analysis

The sensitivity of the results is tested with added controls and event study analysis. Log population, which was left out of the main specification due to concerns about the mechanical correlation between population and a dependent variable measuring mortality, has been reinserted. We also control for a variable measuring the share of industrial workers out of the total city population. Similar controls are typically applied based on changing health risks due to industrialisation. The measure could only be constructed from 1886 onwards, however, leading to a loss of 16 years' worth of data, including several early interventions; it also presented some issues regarding smoothness.[20]

All the results discussed above are fully robust to the inclusion of these two variables, and the estimates are not reported separately. Furthermore, city-specific trend variables have been added (Tables 9 and 10). These variables control for potential factors affecting

Table 9. Sanitary interventions and infant mortality in Finnish cities, 1870–1938 (fixed effects estimates with additional controls and city and town specific trends).

lnIMR	I	II	III	IV	V
Piped water	−0.094			−0.082	−0.372
	(0.047)*			(0.057)	(0.094)***
Sewers		−0.065		−0.014	−0.102
		(0.046)		(0.056)	(0.052)*
Chlorination			−0.091	−0.081	−0.038
			(0.084)	(0.086)	(0.086)
PipedXSewers					0.358
					(0.091)***
lnPopdens	−0.075	−0.079	−0.088	−0.078	−0.091
	(0.054)	(0.054)	(0.054)	(0.053)	(0.051)*
Popgrowth	0.000	0.000	0.000	0.000	0.000
(t/t-5 yrs)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
lnPopulation	0.192	0.219	0.214	0.189	0.182
	(0.107)*	(0.109)*	(0.106)*	(0.111)*	(0.111)
Share ind workers	0.340	0.324	0.324	0.333	0.279
	(0.617)	(0.617)	(0.632)	(0.620)	(0.623)
City trends	Yes	Yes	Yes	Yes	Yes
R^2	0.42	0.42	0.42	0.42	0.42
Sanitation joint effect				−0.176	−0.511
				(0.113)	(0.143)***

Notes: Dependent variable: *ln* IMR. All models include year and city fixed effects and city- and town-specific trends. Number of observations = 2424; number of groups = 37. Standard errors clustered by city in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

mortality linearly over time in city-specific ways, but they also further saturate the model. In the main set of regressions, piped water still retains its significance, while models II–IV now lack significant estimates, notably even for chlorination. In model V, the sewer variable again becomes borderline significant, but the behaviour of the piped water estimate and the interaction term defies meaningful interpretation. Joint effects are unstable. Turning to Table 10, with the four largest cities removed the findings are partly robust to the inclusion of city trends, with a significant estimate on piped water but the p-value for sewers dropping to .12 in the separate regressions (models I-III). In the case of weighted regressions, chlorination also loses all significance. Instead, the coefficients for piped water become significant. With the largest cities removed, the coefficients are substantively similar to those in Table 8, but they now show significant estimates for piped water and sewers separately. The interaction term for the twentieth century does not yield any results.

In sum, it would seem that the findings on differences between cities of different sizes and periods are sensitive to assuming local trends. However, the assumption of linear trends in mortality over the entire research period at the city level can be considered strong. Losing some results due to unit trends is not unusual, and it is not necessarily enough to reject the findings (*cf.* Beach, Ferrie, Saavedra, & Troesken, 2016, pp. 49–50; Kesztenbaum & Rosenthal, 2017, p. 181). In particular, the disappearance of any effect from chlorination in the specifications suggests treating the findings with caution. They do provide occasional support for a stronger impact in the late adoption of sanitary interventions by small- and medium-sized cities and towns through slightly higher coefficients without the large cities in the weighted regressions.

Event study graphs derived from Equation (2) have also been drawn to complement the regressions. Ideally, these graphs should indicate a discontinuity at the point of impact and afterwards; they can also capture pre- and post-trends. The graphs in Figures 6–8 present

Table 10. Sanitary interventions and infant mortality in Finnish cities, 1870–1938 (comparison of fixed effects estimates across data and specification variants with additional controls and city- and town-specific trends).

Variant	No large cities			Population weighted			Population weighted, no large cities			20th-century interaction terms		
Models	I–III (Separate)	IV (Multiple)	V (Interact)	I–III (Separate)	IV (Multiple)	V (Interact)	I–III (Separate)	IV (Multiple)	V (Interact)	I–III (Separate)	IV (Multiple)	V (Interact)
Water	−0.109	−0.095	−0.485	−0.084	−0.075	−0.273	−0.093	−0.046	−0.449	0.026	0.019	−0.208
	(0.055)*	(0.072)	(0.153)***	(0.037)**	(0.042)*	(0.057)***	(0.050)*	(0.064)	(0.117)***	(0.083)	(0.084)	(0.156)
Sewers	−0.082	−0.018	−0.087	−0.058	−0.026	−0.113	−0.103	−0.073	−0.111	−0.029	−0.003	−0.001
	(0.051)	(0.067)	(0.058)	(0.042)	(0.045)	(0.049)**	(0.051)*	(0.066)	(0.067)	(0.048)	(0.060)	(0.050)
Chlorine	−0.089	−0.012	−0.008	−0.016	−0.028	−0.015	−0.061	−0.012	−0.006			
	(0.196)	(0.196)	(0.197)	(0.027)	(0.028)	(0.031)	(0.142)	(0.165)	(0.166)			
Joint effect		−0.125	−0.580		−0.125	−0.580		−0.132	−0.565			
		(0.201)	(0.255)**		(0.202)	(0.255)**		(0.182)	(0.229)**			

Notes: Dependent variable: *ln* IMR. All models include year and city fixed effects and city- and town-specific trends. Coefficients extracted from models I–V, as in Table 7, with additional controls for the share of industrial workers and log total population. Separate: coefficients extracted from separate regressions for each intervention; multiple: coefficients extracted from multiple regression: interact: coefficients extracted from specifications with the PipedXSewers interaction. Standard errors clustered by city in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

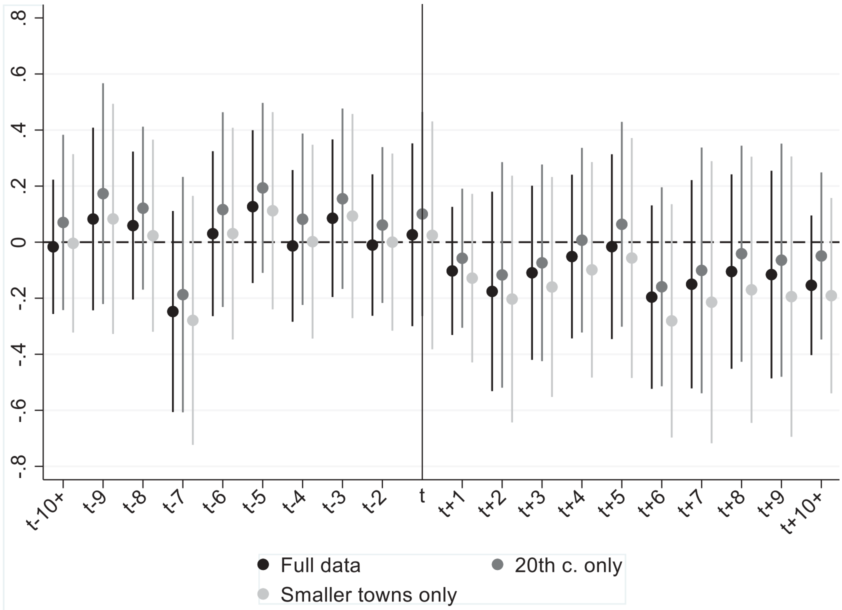

Figure 7. Event study: piped water and infant mortality. Coefficients extracted from regressions, as in Equation (2), with the ends of the event window binned and year t-1 used as a reference; 95% confidence intervals based on standard errors clustered by city; controls are those shown in Table 7.

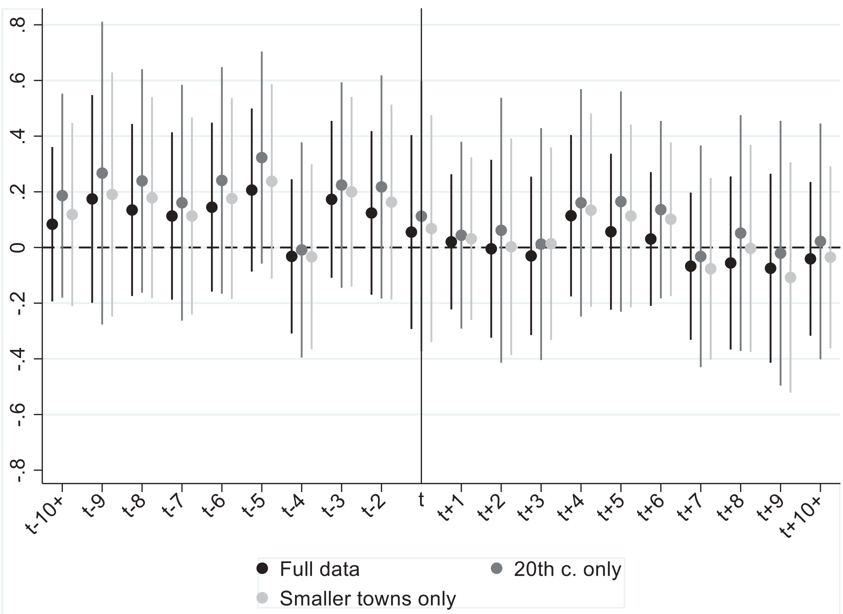

Figure 8. Event study: sewers and infant mortality. Coefficients extracted from regressions, as in Equation (2), with the ends of the event window binned and year t-1 used as a reference; 95% confidence intervals based on standard errors clustered by city; controls are those shown in Table 7.

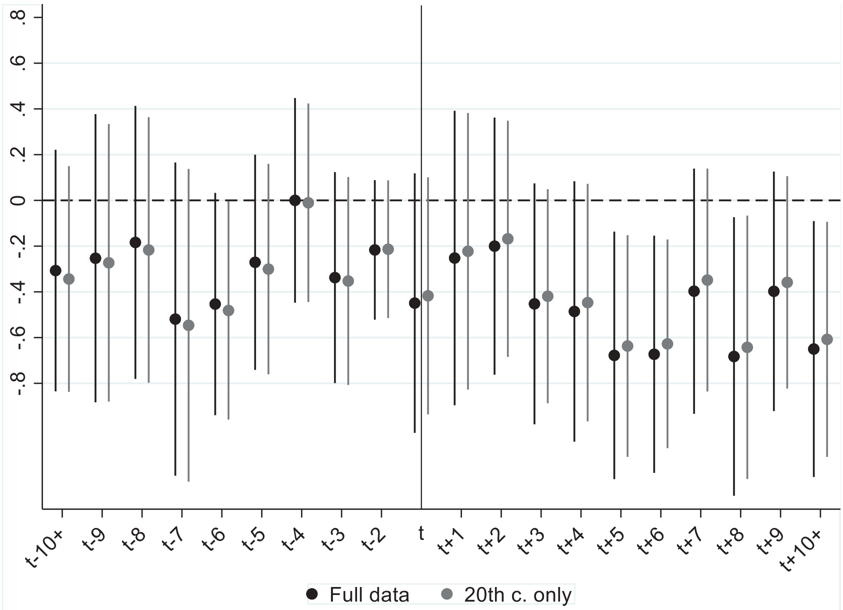

Figure 9. Event study: chlorination and infant mortality. Coefficients extracted from regressions, as in Equation (2), with the ends of the event window binned and year t-1 used as a reference; 95% confidence intervals based on standard errors clustered by city; the controls are those shown in Table 7.

estimates with a 10-year event window in each direction around the point at which each intervention was initiated, modelled separately (models I-III). All of the models include year and fixed effects and controls, as in Table 7, and they cluster standard errors at the city level. The ends of the event windows have been binned into categories of '10 years or more'. The year before initiation (t-1) is the reference category. This is a common approach, although conventions on the size of the window, binning and combining years currently vary in the literature (*cf.* Alsan & Goldin, 2015, p. 40; Hjørt, Sölvsten, & Wüst, 2017, pp. 92–94; Helgertz & Önnerfors in this issue for variants). The figures superimpose coefficients and confidence intervals from three regressions each: one on the full data, one on twentieth-century observations only and one with the four largest cities left out.[21]

While the resulting graphs are not ideal in terms of clarity or consistency, significant parts do support a treatment effect.[22] The pattern is clearest for piped water. There is no visible trend preceding the intervention, after which the coefficients drop to an asymptotically lower level below zero. The pattern is slightly stronger with the data excluding the large cities, in line with previous findings. The graph for sewers also has a pattern, although this time with signs of a pre- and post-trend of about three years around the time of initiation. This could be connected to anticipation, awareness and gradual dissemination in the context of early cases of 'reactive' sewer construction, where there was no close association with piped water. Of the three estimations on sewers, the one done on the full data including the nineteenth century would in this analysis actually seem marginally more suggestive than the others. This would conform to the hypothesis regarding the effectiveness of some of the early, stand-alone sewer schemes. For chlorination, the dispersion of the estimates is higher, and all are on the low side.

All in all, one key result remains robust: piped water had a clear effect on IMR, and this appeared stronger in smaller cities and towns.

4.3. Contribution to total mortality decline

Previous Finnish literature has suggested a key role for urban sanitation in initiating the overall national mortality decline since the 1870s (e.g. Pitkänen, 2007). However, no attempts at measurement have been made thus far. It is therefore of interest to conduct an experiment with the figures at hand. What could these estimates of the effect of sanitation have meant for total mortality decline?

As mentioned, only all-cause IMR provided clear and consistent estimates in our data; nothing comparable could be found using CDR or the available truncated data on cause-specific mortality (see endnote 4). Until the 1920s, urban IMR based on total aggregate births and deaths in Finnish cities and towns was above the unweighted mean in the cities and towns discussed so far (Appendix Figure A1), evidently due to the influence of the largest cities. It declined from 205 to 62 during the period from 1870–75 to 1935–38, or by approximately 70%, as opposed to a decline in the unweighted average of approximately 65% (from 176 to 62). If applying the coefficient of joint significance from the unweighted regressions, approximately 37% of this decline could be attributed to sanitation over the whole period. However, this coefficient estimates the unweighted average effect across cities and towns, and can be considered an overestimation for our purposes. Disregarding population size inflates the larger effect found in smaller cities and towns. In principle, population-weighted regressions should be more appropriate. If we would take the coefficient of joint significance from these regressions (Table 8), the implied percentage change over the whole period would be approximately −22.6%.[23] This would yield a contribution by sanitary interventions of approximately 32.4% rather than 40% to the overall decline in infant mortality in cities and towns from 1870–75 to 1935–38.

In terms of the contribution to total national mortality decline, the low levels of urbanisation for most of the period automatically lead to very low estimates. In the period from 1870–75 to 1930–35, the contribution of the decline in urban infant deaths to total CDR decline could be estimated to have been only about 12% on the basis of the figures presented in section 2.1. If 32–40% of this decline were due to sanitation, this would have implied a measurable contribution of only about 4–5% to the overall mortality decline throughout the period. While the finding is in many ways obvious, it is relevant for assessing the previous Finnish literature, which emphasizes the role of urban sanitation already in the nineteenth century.

In the early twentieth century, the contribution grew due to both growing urbanisation and the rapid decline in urban mortality, which was largely driven by a decline in urban IMR at that time. The decline in urban infant deaths accounted for approximately 27% of the total national decline in CDR from 1900–05 to 1930–35. When applying the above estimates of the effect over the whole period, approximately 9–11% of the decline in CDR could at this point be attributed to improved sanitation. It is also possible to estimate coefficients separately for the twentieth-century observations in the data.[24] In this case, unweighted regressions like those in

Table 7 would yield an estimate of roughly *one half* of the decline in urban IMR in the 1900s being attributable to sanitation. As much as about 14% of the total decline in CDR would thus have stemmed from this source. The joint significance for the tenuous population weighted regressions would actually be lower with truncated data. The coefficient would imply merely a 17.5% change due to sanitation, yielding approximately an 8% change in total CDR.

All in all, the figures would suggest a sizable and growing impact on infant mortality *within* the cities and towns, possibly reaching as much as one half in the twentieth century. Due to modest urbanisation, the effect on the overall decline in mortality throughout the country would have remained small. In the twentieth century, however, it can be estimated to have been roughly double the average throughout the whole period. This growth in importance was not simply a mechanical outcome of growing urbanisation, but a confluence of several factors: the rapid decline in urban IMR, its growing share of the overall decline in national mortality and the greater effectiveness of the sanitary interventions themselves.

5. Conclusions

In this article, we have provided quantitative estimates of the impact of the introduction of major sanitary reforms – piped water, sewers and chlorination – on infant mortality in the cities and towns of Finland in the years 1870–1938. We discovered significant and sizable effects resulting from the three key sanitary interventions, which is comparable with findings in previous literature on e.g. the United States. On average, chlorination in particular seemed to be associated with steep declines in IMR.

When breaking this down by city size and period, however, variations emerge. At the level of city and town populations, it is difficult to discern the effects of sanitation for the larger pioneer cities of the nineteenth century. On the other hand, the effects in smaller cities and towns that followed appear more robust, and in particular piped water seems to have had a greater impact when introduced in such contexts in the twentieth century. Our findings suggest that while sanitation became a crucial technology in lowering urban mortality, its impact appears different when analysed according to variations in surrounding conditions, time and space. Observations in development economics regarding the importance of complementary inputs, such as basic disease avoidance skills and quality of living environment, seem relevant for historical analysis as well. More manageable and more developed, early twentieth century small towns were more responsive to the more mature water technology installed than their troubled nineteenth century counterparts.

Combining national mortality statistics with our estimations enables an experimental accounting of the strictly measurable part of the contribution of the urban sanitary interventions to overall mortality trends. In the twentieth century, this measurable contribution reached 8–14%. In this period, the weight of urban IMR decline in total CDR decline was augmented over and above the growth in urbanisation by an acceleration in the decline itself. Our results suggest that urban sanitation did have a significant role in this acceleration.

However, in the case of Finland, it seems placing much emphasis on the role of urban sanitary investment in the initial nineteenth-century onset of mortality decline, as has been done in some previous literature, is not well founded. The large and expanding cities that first started to develop water infrastructure in the nineteenth century were challenging environments compared to the small- and medium-sized towns that followed suit in the increasingly prosperous twentieth century. The early technology was less functional and more risky. Focusing on average estimates over the long run without accounting for such variations would preclude the observation that populations with the most acute problems seemed to gain less from sanitary interventions than those already better off when such efforts first began. Investments were more effective and their measurable returns higher in the later period, when necessary complementary aspects of development had already improved over those prevailing in the nineteenth century Grand Duchy.

Notes

1. The 37% effect in log points reported by Alsan and Goldin (2015, p. 18) has been converted to percentage change for comparability using figures from (Alsan & Goldin, 2015, p. 3) and footnote 9. See Cutler and Miller (2015) for technical discussion. The original publication by Cutler and Miller in 2005 presented an estimate of a 74% share of the decline in infant mortality attributable to sanitation (p. 13). Alsan and Goldin pointed out in 2015 that their way of interpreting regression coefficients on log IMR directly as percentage change was not appropriate for large, discrete changes, and that the transformation (e^{β}-1) should have been applied (p. 1, fn 3). This led Cutler and Miller to revise their estimate to 59% in an erratum (2015). Most recently, Anderson et al. (2018) have acquired the original data and code from Cutler and Miller, and seem to be suggesting that after correcting a large number of errors in e.g. timing of interventions and data transcription, the appropriate unweighted estimate could in fact be closer to 2% (although joint effects or their standard errors are not directly reported by the authors). With the population weighted specification preferred by Anderson et al., this could potentially go up to 8% assuming the joint effect is statistically significant (Our computations from Anderson et al., 2018, Table 15, columns 5 and 6,; Cutler & Miller, 2005, p. 13, Table 5).
2. See section 2.3 on historical Finland; on Sweden, see Bengtsson, 2009, p. 150, fn 16; Oris et al., 2009, p. 36, fn 17; for current global estimates indicating rates well below 100% for exclusivity during the first six months, see the WHO database at http://apps.who.int/gho/data/node.main.52?lang=en . Even partial breast-feeding could still have provided additional protection against infections also in the case of exposure.
3. While Davenport, Satchell & Shaw-Taylor (in this issue) argue against a link between water quality and the IMR in mid-nineteenth-century England, the contextual nature of the possible protective factors they identify, such as using boiled water or food handling practices, and the number of significant estimates of IMR across many other cases, suggest this connection is still widely plausible. Channels are explicitly discussed in Alsan & Goldin, 2015, p. 14, for instance.
4. While some direct association of sanitation with the crude death rate (CDR) is detectable in the nineteenth century, it is not sufficient enough to build on. Cause-specific mortality data are only available at the city level from 1896 onwards; the truncation is unhelpful for the task of evaluating the role of urban sanitation in the mortality decline starting from the 1870s.
5. Kari Pitkänen has observed that this was mainly due to high mortality among infants born out of wedlock, whereas for children born to married couples the penalty ended already in the years 1916–20 (Pitkänen, 1983).
6. Archival sources document detailed technical discussion of and reporting on planning and the preparations for introducing piped water in Helsinki and Tampere in reports to

municipal authorities, including comparisons of filtration methods, chlorination and the health hazards of lead pipes. (Kansalliskirjasto, Pienpainatekokoelma 1 B, Kunnallishallinto, Teknilliset laitokset, 1810–1944.)

7. In Tampere, wastewater from such a scheme was dumped into the Tammerkoski river, a potential source of water for other residents. Tampereen kaupungin terveydenhoitolautakunnan kertomukset, 1883–1904, Tampereen kaupungin arkisto.
8. It is not immediately clear from the manuscript what the metrics were for shares of cities covered by sewers. The source was a query sent to municipalities Backman, 1923, p. 97.
9. In some cases, the description is not clear and the author had still provided the highest score on the index that he applied to eight of the cases, even when the lack of service for suburbs was specifically mentioned.
10. The previous analysis is not always unequivocally convincing in light of closer scrutiny of the statistics. In Helsinki, Turpeinen (1995) attributes the fall in overall mortality in the early twentieth century to improved filtration from 1909–1910 onwards. However, there was a marked collapse in the number deaths from waterborne disease, particularly enteritis, already in 1902. The closure of certain unsanitary wells in working-class quarters was a likely culprit (Waris, 1934).
11. The city of Lahti, which was granted city rights only in 1905, was dropped from the regressions due to a lack of figures for constructing a population density variable.
12. Fifty observations are missing, while the panel regressions were run with approximately 2500 observations for the entire period.
13. Parish-level tables for population changes, National Archives. We collected the data from microfilms in a mirror archive at Statistics Finland.
14. See Alsan & Goldin, 2015, footnote 3, and Cutler & Miller's 2015 *erratum*.
15. Credit for these important points belongs to Jonas Helgertz and Andrew Hinde (conference discussions).
16. Thanks to Susan Hautaniemi Leonard for bringing this up.
17. However, on the ultimate size of effect in Cutler and Miller's work, see Anderson et al., 2018. The separate estimate for tap water is also close to that of Ogasawara and Matshushita, 2018, p. 206 for Japanese cities the years 1922–1940, although the period, measurements and specifications differ. Ogasawara and Matsushita estimated approximately 13.5% of the decline in IMR could be attributed to an increase in tap water consumption. While the specifications again differ significantly, Helgertz and Önnerfors also present separate estimates of the effect of water and / or sewage on IMR in this issue, with the effect being at approximately 6% in their basic model for Swedish cities adopting such systems in the years 1875–1930, and with consistently higher estimates for waterborne disease mortality. The experiments on the truncated Finnish data available on waterborne disease mortality have yielded no significant results.
18. In fact, piped water has a significant coefficient with the wrong (positive) sign.
19. The series available in SVT (Official Statistics of Finland) includes craft workers until 1908, after which only industrial workers are included. The series was constructed by applying the yearly percentage changes in the early data to a backwards-extrapolated industrial workers' share.
20. With the exception of chlorination, which has collinearity issues in the last specification.
21. The lack of statistical significance for individual coefficients is standard in the literature.
22. The mean of joint effects coefficients for models IV and V for the population weighted regressions.
23. Unreported, available on demand.

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Appendix

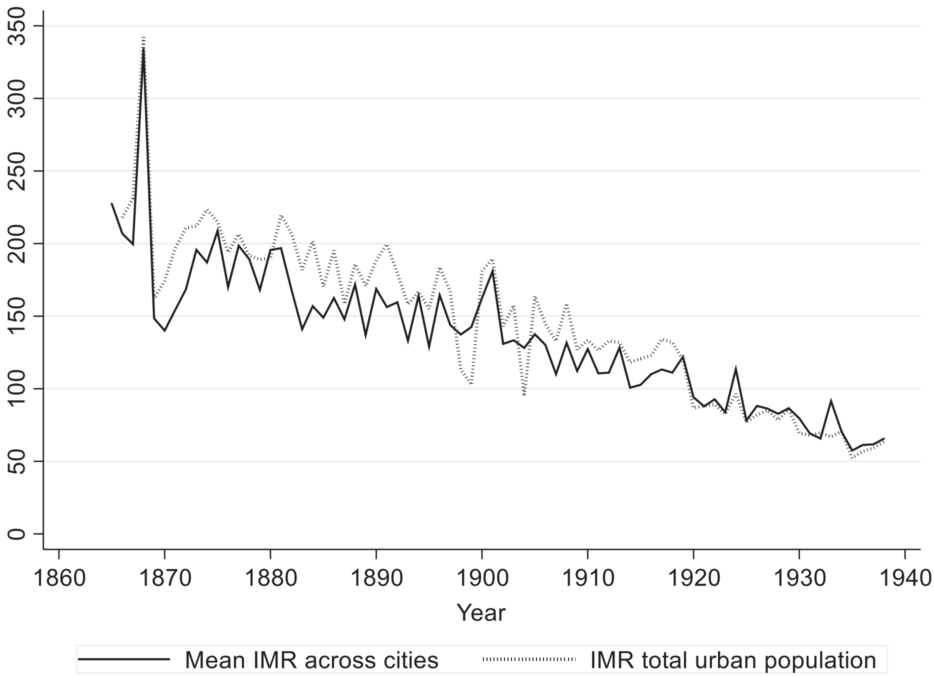

Figure A1. Comparison of mean IMR across cities and total IMR for the urban population, 1870–1938 (sources: Sanitation database; SVT VI Väestötilastoa).

Table A1. The initiation of piped water and sewer systems in Finnish cities, 1876–1969 (population in 1910 in brackets).

	Waterworks	Sewers		Waterworks	Sewers
Capital			Towns with sanitation after 1920–1934		
Helsinki (147 218)	1876	1880	Kajaani (2850)	1921	1921
Major cities			Tornio (1716)	1926	1926
Tampere (45 442)	1882/1898	1894	Lappeenranta (3000)	1926	1926
Viipuri (27 508)	1892	1873	Joensuu (4789)	1927	1927
Turku (49 691)	1903	1896	Pietarsaari (6511)	1928	1928
Medium-sized towns with sanitation before 1917			Tammisaari (3124)	1930	1930
Oulu (19 802)	1902/1927	1897	Iisalmi (2515)	1932	1932
Lahti (5081)	1910	1910	Rauma (5888)	1934	1934
Kuopio (15 845)	1914	1906	Hamina (3348)	1936	1936
Vaasa (21 819)	1915	1915	Loviisa (3740)	1938	1938
Kotka (10 313)	1916	1890	Käkisalmi (1977)	After 1938	After 1938
Pori (16 921)	1935	1894	Savonlinna	1940	1940
Small towns with sanitation before 1917			Kemi (2209)	1940	1940
Hanko (6401)	1909	1906	Naantali (910)	After 1940	After 1940
Hämeenlinna (6376)	1910	1911	Maarianhamina (1368)	1949	1949
Jyväskylä (3619)	1910	1911	Raahe (3863)	1951	
Mikkeli (4611)	1911	1911	Heinola (1755)	1951	
Porvoo (5466)	1913	1894	Uusikaupunki (4497)	1953	1953
Sortavala (3085)	1914	1907	Kristiina (3202)	1962	
Kokkola (3714)	1917	1923	Kaskinen (1243)	1963	
			Uusikaarlebyy (1317)	1969	

Sources: Backman, 1923; Linnavuori, 1946; Turpeinen, 1995; Juuti, 2001.