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A bitter epidemic: The impact of the 1918 influenza on sugar production in Java

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ABSTRACT

Research about the economic consequences of past epidemics has mostly focused on the experience of industrialized countries, thus providing little knowledge about the effects of health shocks on developing economies. We fill this gap by studying the impact of the 1918 influenza in Java, with a new dataset on aggregate food production and district-level figures on (i) sugar production, the major export commodity and the predominant source of labour demand; (ii) agricultural and plantation wages, and (iii) annual crude death rates. The mortality impact of the influenza on Java was high, as crude mortality rates doubled in 1918 relative to the preceding years, but its economic impact was mixed. Aggregate food production did not decline, but sugar output did fall in 1919. Indeed, our regional panel data analysis does not establish a direct relationship between regional epidemic mortality variation and sugar output decline. Instead, we hypothesize that economic activity was rediverted towards food production in order to avoid famine that could have resulted from the combined effects of disrupted shipping at the end of the First World War, climatic conditions and the public health crisis. This is supported by both qualitative observations and quantitative evidence suggesting that those regions that were highly suitable for rice production saw a larger reduction in sugar production, and that in regions that had more flexibility in land tenure arrangements experienced substantially greater reductions in sugar output.

1. Introduction

The COVID-19 pandemic has dramatically impacted citizens across the world. The hazardous symptoms of this disease, its rapid spread and the overburdening of health care facilities have resulted in high mortality in a number of countries regardless of their income level (Roser et al., 2020). The disruptive effects of this health crisis have deeply affected the normal functioning of economies. Countries in Europe and North America have experienced sharp declines in employment, spending and total income (Chetty et al., 2020; Conte et al., 2020); and lower-income countries are suffering similar or worse challenges (World Bank, 2020).

Some of the current economic and health challenges have clear parallels with history, since past pandemics also altered fundamentally the normal functioning of society. For instance, the Black Death killed between one third and half of the European population, and is thought to have raised wages and led to rising urbanization and development (Postan, 1966; Voigtländer and Voth, 2013).[1] This event also led to substantial declines in wealth and income inequality, although subsequent plague epidemics, especially those of the 17th century, seemed to have had different effects (Alfani, 2021; Alfani and Murphy, 2017). A more recent and highly-disruptive epidemic took place at the beginning of the 20th century: the 1918 influenza pandemic. This deadly disease is estimated to have taken the lives of about 50 million people worldwide, mostly young adults, during the period 1918–1920 (Johnson and Mueller, 2002, p. 114), and have caused major economic short- and long-term disruptions after the end of the First World War (e.g. Almond, 2006; Barro et al., 2020; Basco et al., 2021; Beach et al., 2020, 2018; Correia et al., 2020). The predominant focus of this literature on the experience of Western countries has left unexplored the economic consequences of past pandemics on developing countries.[2] This is problematic because

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[1] Recent real wage estimates downscale the 'Golden Age of Labor' following the Black Death (Humphries and Weisdorf, 2019).
[2] Some exceptions are Noy et al. (2020) and Fenske et al. (2020).

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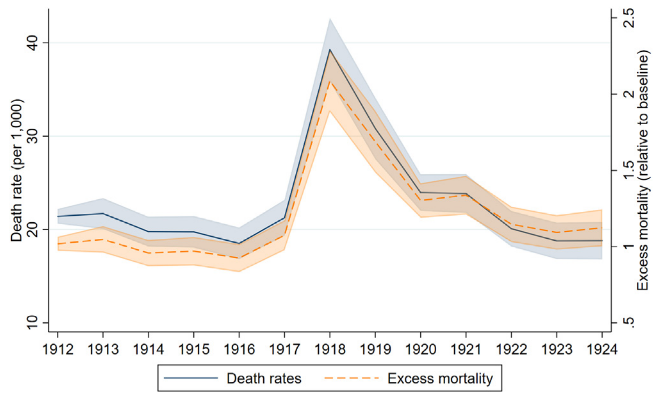

Fig. 1. Death rates and excess mortality, 1912-1924.
Note: mortality sources are MBGD (1925). The left vertical axis shows average death rates (per 1,000) and the right vertical axis presents excess mortality calculated by comparing observed death rates in a given year relative to a baseline level. This baseline was estimated for each regency by regressing mortality before 1918 on regency-specific linear time trends. Point estimates and 90-percent confidence intervals (vertical bars) were obtained by regressing death rates and excess death rates on a set of year- and regency-fixed effects, clustering standard errors by regency.

the economic impact of health crises depends on a complex set of factors influencing disease diffusion, public health response and market disruptions that vary substantially across different contexts.

We fill this gap by studying the impact of the 1918 influenza in Java, a relatively densely populated island in the early twentieth century that was controlled by the Dutch. Its economic activity was largely dominated by agricultural production (rice, sugar, coffee and rubber) and most of the population had comparatively low average incomes (de Zwart, 2021). The case of Indonesia is particularly interesting because national accounts estimations suggest that material living standards did not fall during the influenza during the period 1918–1920 (van der Eng, 2010; Fig. 1 below), despite the large mortality rates caused by the epidemic (Chandra, 2013; Johnson and Mueller, 2002). How can we reconcile these two developments? We hypothesize that in low-income agricultural societies, such as colonial Indonesia, resources are shifted from non-essential economic activities to essential food production during large mortality crises. To test this, we have developed a new dataset about Java with aggregate information on aggregate food production and regional regency-level figures on (i) sugar production, the major export commodity and the predominant source of labour demand; (ii) agricultural and plantation wages, and (iii) annual crude death rates. Furthermore, we consulted newspapers and detailed colonial reports to understand the reaction of regional and national colonial administrators to the arrival of influenza in Java.

Our analysis of the impact of the 1918 influenza in Java provides three main contributions to the literature. First, we go beyond national aggregates (e.g. Barro et al., 2020) and study the experience of a number of *regencies* (districts) to better understand how an epidemic interacts with local social, geographic and economic factors. Our historical setting is particularly interesting because of its institutional embedding as a Dutch colony, thus showing the response of colonial authorities to a major health shock. Furthermore, it shows the effects of the epidemic on a primary commodity export economy, rather than the more industrialized economies that have more often featured in the literature (e.g. Almond, 2006; Correia et al., 2020).

Second, in the same spirit as Rosenberg (1992, p. 110), we use the experience of Java with the 1918 influenza as a way to unveil the deeper economic and institutional characteristics of the Javanese society that otherwise remain hard to explore. We not only provide a quantification of the economic impact of this major mortality crisis, but also study decisions by producers and the colonial administration as well as the functioning of labour and production markets, with detailed factory-level sugar production and regency-specific wage data. A further added value of our production dataset is that we cover a large number of years before and after 1918. This allows us to examine the economic and demographic dynamics after the epidemic, while carefully controlling for pre-1918 trends.[3]

Third, we contribute to Indonesian economic history with the first study to investigate the economic impact of the influenza on the main export sector of the country. We complement long-run economic history analyses of Indonesia (e.g. Booth, 1998; van der Eng, 2010; van Zanden and Marks, 2012), by focussing on the impact of one particular shock on short-term economic development. The Java sugar industry employed about 1 million people and was therefore by far the largest employer on the island (Koningsbergen, 1948, p. 388); in the 1920s 10 percent of the total adult male and 3.6 percent of the adult female population worked in this industry (Bosma and Curry-Machado, 2012, p. 253). The value of sugar exports was good for between 40 and 70 percent of total exports in the 1920s (Koningsbergen, 1948, p. 290). By the early 20th century, Java was also the most important supplier of sugar on Asian markets (Bosma, 2013, p. 172).

Our analysis proceeds in two steps. First, we analyse the mortality impact of influenza in 1918 across Java for disaggregated administrative units. We observe that mortality varied remarkably across the island, since some regencies experienced a 200-percent increase in crude death rates relative to 1917, while other regions witnessed a 20-percent rise. When we put together the epidemic experience of all regencies, we find that mortality rates stayed above pre-epidemic levels between 1918 and 1921.

In the second step of our analysis, we show that food crop cultivation does not decline during the epidemic, following the same trend as gross domestic product (GDP) per capita. However, the same is not true for sugar production that experiences a sizeable fall. Between 1918 and 1921, output in this industry declined between 10 and 25 percent relative to 1917. The decline in per-hectare output spanned the same period and it reached about 12–15 percent. Using panel data, we establish that the fall was *not correlated* with the incidence of the influenza epidemic, consistent with our hypothesis that labour was redistributed from sugar to food crop cultivation.

Several pieces of evidence further support this idea. First, sugar production drops were more acute in regions growing relatively more rice as these crops competed for the same labour. Also, regions with more flexibility to cultivate different crops (as a consequence of the periodical redistribution, or rotation, of lands) experienced up to 15 percent lower output levels than regencies without rotating lands. These analyses are robust to controlling for a host of baseline factors that differed across regencies (including geographic variables), and using various functional forms for the relationship between variables. Second, we tested an alternative hypothesis to explain why high rates of mortality may not lead to large production declines drawing on Lewis' theory of development (Lewis, 1954). In his two-sector model, an unlimited supply of labour would lead to very low marginal productivity of labour. Therefore, a fall in labour supply would not lead to a drop in production due to its low productivity. Our wage analyses do not support this hypothesis as labour markets clearly responded to workers' scarcity. Third, qualitative evidence on production

[3] The importance of this issue has been recently highlighted with the American case (Lilley et al., 2020).

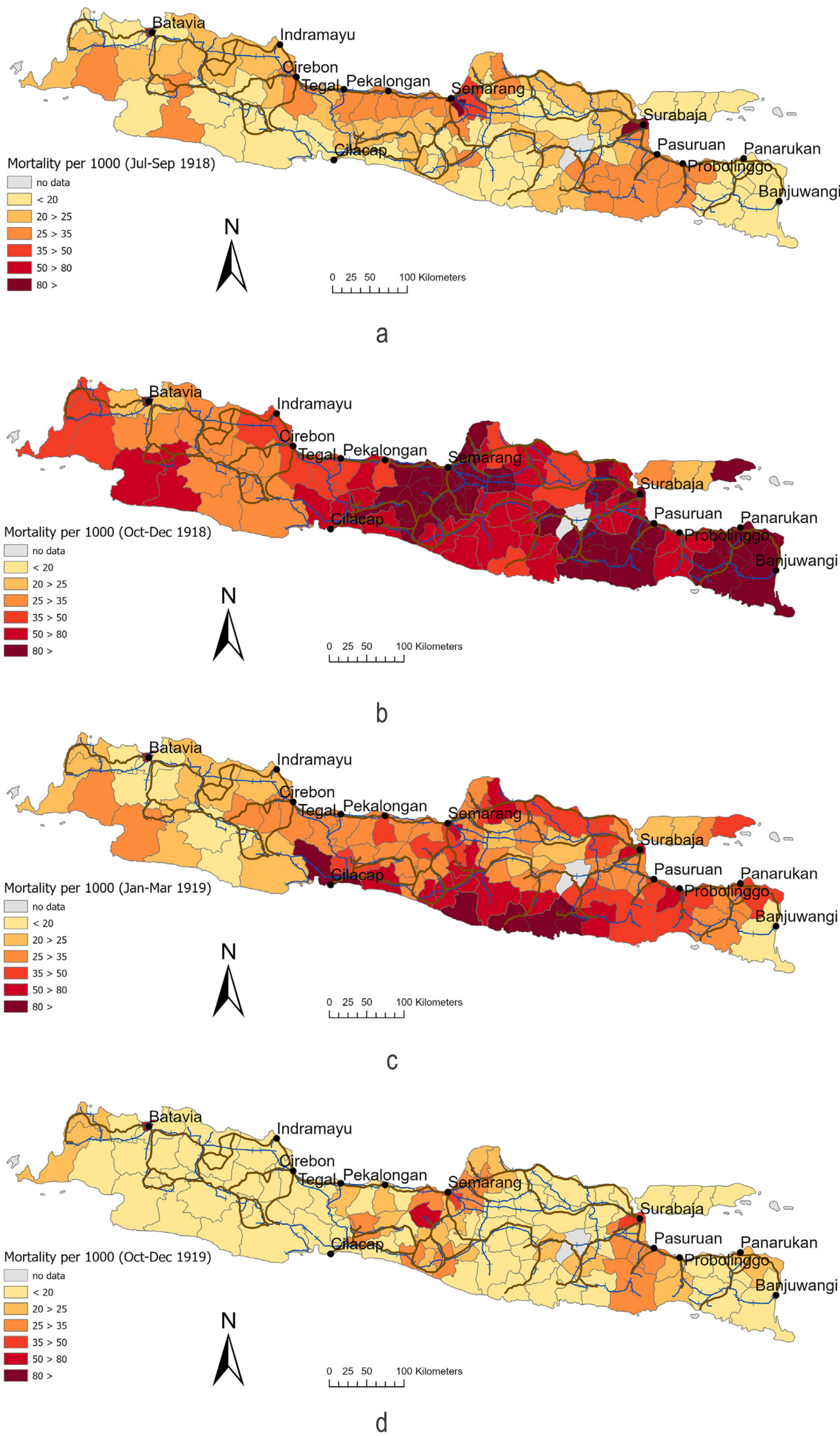

Fig. 2. Mortality per 1,000 people across regencies in Java between July 1918 and December 1919: (a) July-September 1918; (b) October-December 1918; (c) January-March 1919; (d) October-December 1919.
Note: source for mortality is Chandra (2013). Borders depict regencies and dots refer to main harbours. Blue and brown lines refer to railroads and roads, respectively.

decisions shows that in response to an impending food crisis sugar production was put on a lower level and some sugar factories even closed down entirely, to facilitate a shift toward food production.

2. Historical context

The global mortality impact of the 1918 Influenza was enormous. Johnson and Mueller (2002, p. 114) estimate that about 50 million people died from this disease between 1918 and 1920, which represented 2.5–5 percent of the world population. These death rates were far from homogeneous across countries, since some places such as Western Samoa or India suffered a 23-percent and 6-percent death rate, respectively, whereas the Netherlands or France did not reach one percent (Johnson and Mueller, 2002, pp. 112–114). Similarly, within-country variation could be very substantial, as the American experience shows (Murray et al., 2006, pp. 2212–2213). The influenza pandemic of 1918 also had the peculiar characteristic that its fatalities were concentrated among young and healthy people, rather than small children or the elderly that were usually overrepresented in mortality rates. For this reason, its economic impact may have been particularly bad (Johnson and Mueller, 2002).

The mortality impact of this epidemic in the Dutch East Indies was somewhat above that of the global average, although the situation was probably not as bad as in India. A contemporary observed that the severity of influenza in the East Indies was greater than in Europe: comparing Amsterdam with Magelang (Kedu Residency, Central Java) he finds that mortality was 6 times higher in the latter (Van Steenis, 1919, pp. 908–909). According to Brown (1987, p. 235), about 1.5 million people died from influenza in Indonesia. In the last years, there has been some debate about the total size of the mortality impact in the Dutch East Indies. A major upward revision of the total mortality estimate came from Chandra (2013, p. 191) who found that on the island of Java alone (the most populated island of Indonesia) mortality was more likely to be around 4.3 million, suggesting a total death rate of over 10 percent. This figure has been questioned recently, though. On the basis of contemporary newspaper articles, Bosma (2019, pp. 151, 158) finds that it was probably between 5–6 percent of the total Javanese population. Van der Eng (2020) analysed detailed weekly data on total mortality to estimate excess mortality. He finds over 900,000 deaths from influenza across Java, implying a death rate of 2.5 percent as Java's total population was about 37 million at the time.

Our approach is perhaps closer to van der Eng, since we consider the mortality impact of the epidemic by showing all-cause death rates and excess death rates using monthly and annual regional data from official reports of the Civil Medical Service (MBGD, 1925). Across Java, the health shock was very substantial, since the unweighted average death rate, considering 81 regencies, in 1918 was 39 per 1,000 people (MBGD, 1923). This stunning figure represents a 104-percent increase (or a doubling) of mortality in 1918 as compared with the period 1915–1917. Fig. 1 presents the annual evolution of this indicator for the period 1912–1924 across regencies in Java (left vertical axis, solid line). Before 1918, average mortality per 1,000 hovered around 20 without a distinguishable trend. In the year of the influenza epidemic, death rates climbed up to almost 40 and then gradually declined to 31 in 1919, 24 in 1920 and 1921. By 1922, the health shock seems to have waned from Java.

The unusually high death rates during the epidemic years resulted in substantial excess death rates, which we calculated as the ratio between observed death rates and a baseline level (see right vertical axis of Fig. 1). This baseline was obtained by regressing death rates before 1918 on regency-specific time trends, and it can be interpreted as expected mortality in the absence of the influenza epidemic. If the ratio equals one in a given year, it means that average mortality is in line what we would expect, given the evolution of crude death rates between 1912 and 1917. Fig. 1 (dashed orange line) shows that the ratio of excess deaths per 1,000 people in Java is roughly one until 1917, and then it ranges between 1.9 and 2.3 in 1918, and it remains relatively high until 1921. In this paper, we are concerned with the regional spread of the epidemic, rather than its overall mortality impact. Nonetheless, our regency-specific excess mortality figures during the epidemic imply that a total of about one million people died from influenza across Java, or 2.7 percent of the population, during the period 1918–1919.[4] This figure is closer to the estimates of Bosma (2019) and Van der Eng (2020), than those of Chandra (2013), but our numbers may suffer from some underreporting for which we did not correct.

Prior to the epidemic, mortality rates in many regencies across Java were below 20 per 1000, and they were somewhat higher in the densely populated coastal cities of Batavia (47), Semarang (42) and Surabaya (43) as was a common pattern. The arrival of the pandemic to the island did not take place gradually during 1918, as shown by Fig. 2 using data from Chandra (2013) and Fig. A1. In the earlier months of 1918, while the disease already spread across the United States and Europe, Java remained unaffected. Influenza was first reported in the East Indies in the town of Pankattan on the east coast of Sumatra in June, probably imported from Singapore (Brown, 1987, p. 236; Locomotief, 1918: 24-07-1918). Between July and September 1918, the disease first hit the large coastal centres, in particular Semarang (where the death rate had already doubled to 86 per 1000) and Surabaya (with a death rate of 90 per 1000), as we can see in Fig. 2a. From these commercial centres, the epidemic spread across the rest of the island, and, just like in the rest of the world, October to December 1918 represent the height of the mortality crisis. While no regency was spared the epidemic, Central and Eastern Java were more heavily affected than Western Java. In important sugar-producing regencies like Malang, Panarukan and Pasuruan the situation was particularly bad, with crude death rates increasing to 164, 184 and 205 per 1000 respectively (Fig. 2b). According to the Colonial Report of 1919, regions already suffering a chronic malaria outbreak were more heavily hit than others, due to a weakened population (KV, 1919, p. 175). The health crisis continued during the first quarter of 1919, as crude death rates across regencies averaged 40 per 1,000 people. In particular regions in the southern parts of the island, like Cilacap, Wonosari and Pacitan, were suffering high mortality rates in the early months of 1919 (Fig. 2c). But also later in the 1919, the flu was not entirely gone and cases were further reported in August (NDNI, 1919: 22-08-1919).

By the end of 1919, mortality in some regions was returning back to normal, although there were some notable exceptions, such as the regency of Temanggung that exhibited a crude mortality rate of 60 (Fig. 2d). Interestingly, Brown (1987, p. 240) suggests that Europeans living in Indonesia were affected much more than Indonesians. This may, of course, also be the consequence of more complete reporting for those Europeans (at least in part). Furthermore, institutes where large groups of people were brought together confined within spaces, like schools, prisons, and military barracks, were particularly badly hit (Brown, 1987, p. 241; Koloniaal Weekblad, 1919, p. 6; KV, 1919, p. 175).[5]

[4] We arrive at this figure by using regency-specific estimations of excess mortality (i.e. difference between observed and expected crude death rates; see note in Fig. 1) and total population numbers from KV (1918).

[5] It seems that in military barracks morbidity was high, but mortality was not. Brown (1987, p. 241) explains this by the fact that the military had access to better medical aid, food and housing and that soldiers were generally in a better physical condition.

The sudden and disruptive nature of the influenza epidemic, in the words of one contemporary journalist “an enemy with a Prussian lust for annexation” (Koloniaal Weekblad, 1919; 09-01-1919, p. 6), was rapidly felt throughout Java and had important repercussions on social life. Besides, shops, offices were closed and market places remained deserted. The epidemic may also have incited increased crime and violence (Brown, 1987, p. 247). For example, the decline in available men for the night watch led to an increase of theft in Surakarta, while in Madura there were increases in the number of robberies and murders, while in Kudus the epidemic may have played a role in inciting a large-scale anti-Chinese riot in November 1918 (Brown, 1987, p. 247). Local newspapers suggest that as late as March 1919, the epidemic may have affected some to purchase food and that people were dying not directly from the disease, but instead from hunger (Sri Diponegoro 03-03-2019, cited in IPO 11, 1919).[6] Similarly, it was noted that the regions of Wonogiri and Surakarta suffered from a simultaneous lack of food and a spread of influenza causing increased morbidity and mortality (Darmo-Kondo 21-12-1918, cited in IPO 51, 1918; Darmo-Kondo 3-12-1918, cited in IPO 49, 1918).

Contemporary Indonesian doctors lamented the lack of action by the colonial government. Areas affected by the epidemic were not quarantined, since the Civil Medical Service had no real authority to do so. As Brown (1987, p. 252) explains, influenza was not described in the Epidemic Diseases Ordinance of 1911, and therefore it was not possible to limit the movement of people across infected regions. Thus, schools and shops were closed as a result of high morbidity and mortality and probably a widespread fear for contracting the disease, rather than as a consequence of systemic quarantines to reduce the spread of the epidemic. The main action that the colonial government undertook was to hand out food and medicine to those in need (KV, 1919, p. 176; Locomotief, 1918: 04-12-1918). Colonial doctors treated influenza with quinine, aspirin and other drugs, in efforts to reduce symptoms and keep patients’ temperatures down (e.g., KV, 1919, p. 50). Government employees of the Department of the Interior, and the Department of Agriculture, Industries and Commerce tried to avert a potential famine resulting from lack of labourers in the field. For this purpose, workers and fields were redirected towards food production (Brown, 1987, p. 249), as will be discussed in greater detail below.

3. Descriptive analysis of the economic impact of the 1918 influenza epidemic

3.1. Aggregate living standards and food crop cultivation

With high rates of morbidity and mortality, it may be expected that the epidemic impacted negatively the economy. Barro et al. (2020) show for a cross-section of 48 countries that GDP and consumption in the typical country declined by 6 and 8 percent, respectively. In the specific case of Indonesia, however, this does not seem to be the case. If we look at the available figures on the development of GDP in Indonesia for this period from van der Eng (2010), no drop can be discerned. In fact, as shown in Fig. 3, GDP exhibits a slightly increasing trend since 1912, which is not interrupted after 1918.

A more disaggregated measure of economic production, and crucial for living standards, concerns food crop cultivation. Contemporary accounts make clear that scarcity of food was a growing problem in 1918 and 1919, resulting from a

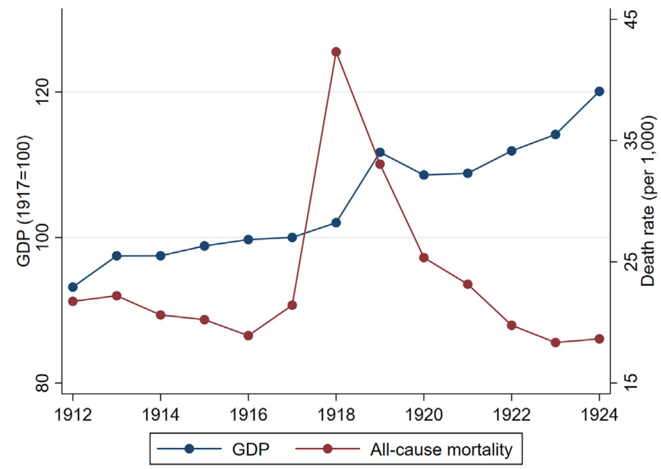

Fig. 3. Mortality and GDP in Indonesia, 1912-1924.
Note: the mortality series is the same as that presented in Fig. 1; the GDP series is taken from van der Eng (2010).

combination of import problems, drought and labour scarcity due to influenza (Archief Suikerindustrie, 1919, pp. 561–564). Drawing on MSK (1924), Fig. 4 presents total annual rice production (Panel A) and the amount of area planted with food crops (Panel B) on a monthly basis between 1916 and 1922. In line with GDP trends before 1919, Panel A shows that food supply in Java in the end did not really decline, as according to Brown (1987, p. 249) “all those not sick dropped all other activities in order to work on the land.” Rice production only declined in 1920 and 1921, but for reasons unrelated to the epidemic. In fact, this was “entirely the result” of extensive harvest failures that were caused by the spread of root rot (*mentek*) and insect infestation (*walangsingit*) (MSK, 1924, pp. 43, 57-58). In 1920 and 1921, over 10 and 16 percent of the total Javanese rice harvest failed respectively (MSK, 1924, p. 39). A more comprehensive indicator of agricultural production for essential consumption is presented in Panel B of Fig. 4: hectares planted with all food crops combined. This evidence shows almost no decline in plantings in November 1918, and a substantial increase until February 1919, and another peak was reached in February 1920. In fact, peak cultivation was 15 and 19 percentage points higher relative to 1917 in 1919 and 1920, respectively. Clearly efforts to maintain food production during the epidemic were largely successful as overall volumes of rice produced were about 10 million *picul* (1 picul =61.76 kg) higher in 1919 than in 1918 (when it was about 1 million *picul* higher than in 1917).

At the same time, contemporary accounts indicate that at least some sectors and parts of the Javanese economy were severely hit by the crisis. In Surabaya, high mortality caused a shortage of labour and military personnel had to aid with the work in rice fields (Locomotief, 1918: 12-12-1918). Rice and tobacco production declined due to a lack of labourers in Situbondo and Djombang, located in Surabaya residency, and sugar production was reported to have faltered for the same reasons in Sidoardjo (Surabaya residency), Kediri (central Java) and Banyumas (Locomotief, 1918: 19-12-1918). In the latter region of Banyumas, located in the south-central Java near Cilacap, not even a fifth of the labourers in rice had appeared in the fields (Locomotief, 1918: 23-11-1918). In Western Java, while less hard hit by the epidemic, tea production suffered as a result of high death rates among estate workers (Brown, 1987, p. 242). Companies continued operations at very limited capacity (KV, 1919, p. 175). Reports from the sugar industry note that in “many districts stagnation of work is the consequence

[6] IPO was the Inlandsche Pers Overzicht (Indigenous Press Overview), a journal that summarized the most important news from Javanese newspapers.

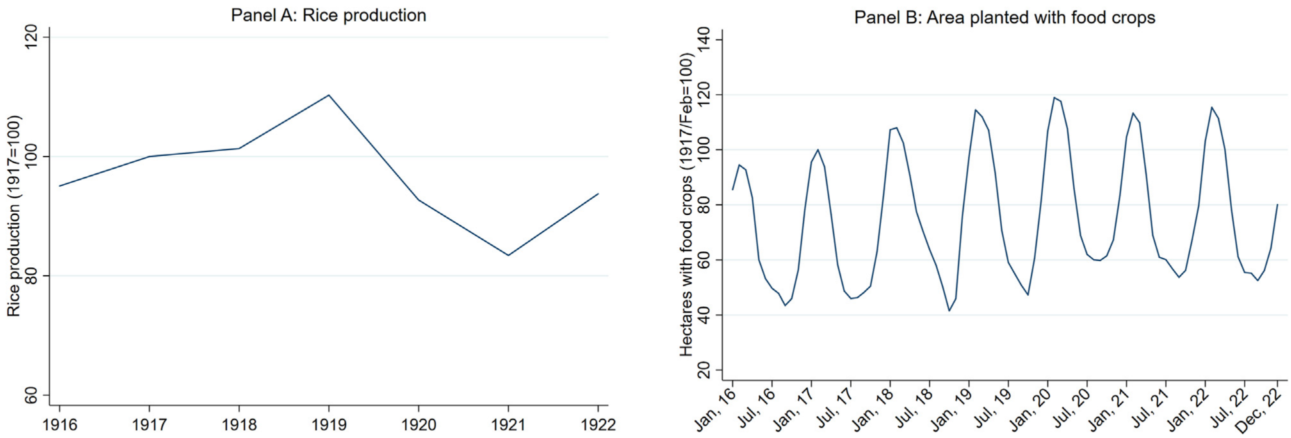

Fig. 4. Rice production and area planted with food crops in Java.
Note: source is MSK (1924).

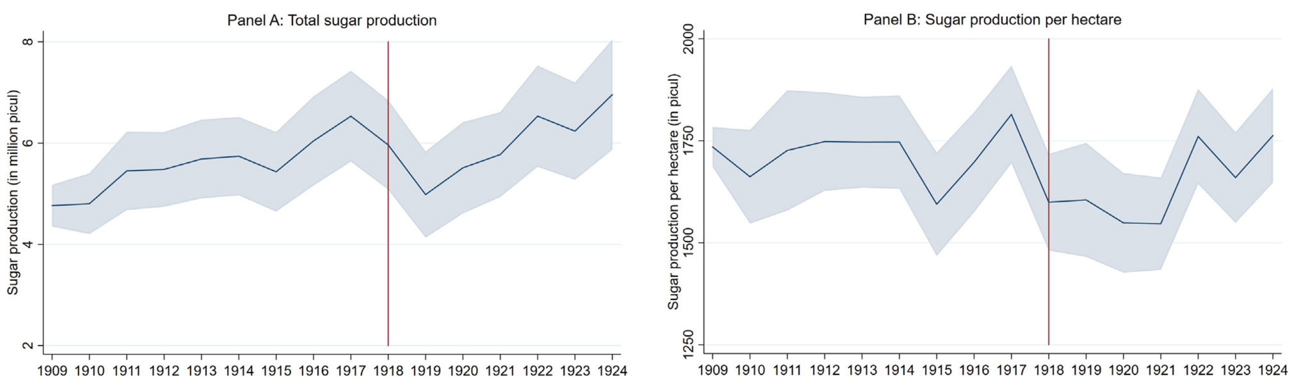

Fig. 5. Average sugar production across regencies in Java, 1909–1924.
Note: the sources for sugar production and sugar-producing hectares are the Colonial Reports (KV, 1907-1925). Panel A presents average sugar production in millions of picul for a sample of 41 regencies. Panel B shows sugar production per hectare. Point estimates and 90-percent confidence intervals (vertical bars) were obtained by regressing sugar production (Panel A) and sugar production per hectare (Panel B) on a set of year- and regency-fixed effects, clustering standard errors by regency. The red vertical line indicates when the epidemic hit Java.

of the high impact of the influenza" (Archief Suikerindustrie, 1919, p. 37).[7]

3.2. Sugar production

The scattered evidence above suggests that it is important to examine the effects of the influenza in a disaggregated fashion across regions and in other sectors than food crop cultivation. For this purpose, we draw on the well-documented sugar industry using information from the Colonial Reports published between 1910 and 1925 (KV, 1907-1925). Each volume contains data on the sugar production and sugar area in use in the previous year, thus covering the time period for which we have mortality data and a few additional years before 1912. The data concerns the returns of 220 separate factories which we aggregated at the regency level to match the mortality data for our subsequent analysis (MBGD, 1925).

The data on sugar area and production were reported by private factories and sent to the government each year. One contemporary source notes that the recording of both the area and volume of production of private estates was very accurate (MCKS, 1926, p. 1).[8] The sources often explicitly state when an estate had not produced any sugar (zero production), or whether the factory had failed to return figures to the government (missing data). In a few cases, we encountered that a particular sugar estate that had been in operation for a number of years suddenly dropped from the source. This could be due to a closing of said business (i.e. zero production) or failure to report production (i.e. missing data). We took a conservative approach and treated these cases as missing production data, although this choice does not affect our results, since they remain unaltered if we assume zero production for these non-reported factories. When aggregating factory-specific data at the regency level, we saw some instances in which data for some of the factories were missing. As done previously, we dealt with this in a conservative fashion. Data for a regency in a given year were set to missing, if information for one or two factories in that regency were missing for only one year or two years. If data were missing for one factory for more than 2 years, and the regency had more

[7] Own translation of "uit vele streken komen berichten van stagnatie van alle werk tengevolge van het hevig epidemisch optreden van der influenza".

[8] The source notes specifically that on page 1: "for estates, it can generally be ascertained with great accuracy what the total area of the planting and the total volume of production is, which is not the case for indigenous production." [own translation].

than two factories in operation, the data for that particular factory were omitted from the dataset, while data for the remaining factories were aggregated to get a regency production figure.

We think our sources are reliable and representative of the economic performance of the sugar industry during the analysed period. First, they have been used in other historical studies of sugar production and productivity in Java (e.g. Knight, 1993). Second, we cross-checked the main trends we obtain with other works from the literature (see next section) that take an aggregated approach (Koningsbergen, 1948; van der Eng, 1993). Third, there were no changes in regency borders during this period which could influence the time-series of sugar and mortality data. Fourth, we cross-checked the spatial distribution of our sugar production figures from the *Koloniaal Verslag* with information on regency-level refined sugar output from the Landbouwatlas (1926) in 1922. These show almost identical spatial patterns with a correlation coefficient of 0.96. Thus, we regard this information as accurate of sugar output and differences across regencies.

What was the impact of the 1918 influenza pandemic on Java's sugar industry? To answer this question, consider the evolution of sugar production during the period 1909–1924 in Fig. 5. We use two measures: total and per planted hectare production (Panel A and B, respectively). The former captures the total or aggregate impact of the pandemic, and the latter focuses on productivity consequences, which may be the result of both decreased labour and capital, such as fertilizer. Considering Panel A, we observe a clear increasing trend in average total sugar production across regencies before 1918 from slightly less than 5 million picul in 1909 to 6.5 million in 1917. Then, production suffered a decline in 1918 and a further fall in 1919 (half a million and one million picul, respectively). This production shock was so significant that its accumulated effect resulted in production figures comparable to those observed 9 years earlier. In 1920 and 1921, the industry recovered slightly but production capacity was still below pre-epidemic levels. Only five years after the outbreak of the influenza epidemic did total production reach the level observed in 1917.

Panel B of Fig. 5 shows the evolution of sugar productivity, as measured with output per planted hectare of sugar, during the period 1909–1924. Contrary to Panel A, we do not find signs of intensive growth until the eve of the epidemic, which suggests that increasing levels of total output were achieved by increasing the amount of cultivated area for sugar crops. In 1915, there was a very significant drop in the series that can be explained by weather conditions in 1914 and 1915. Sources report that first a severe

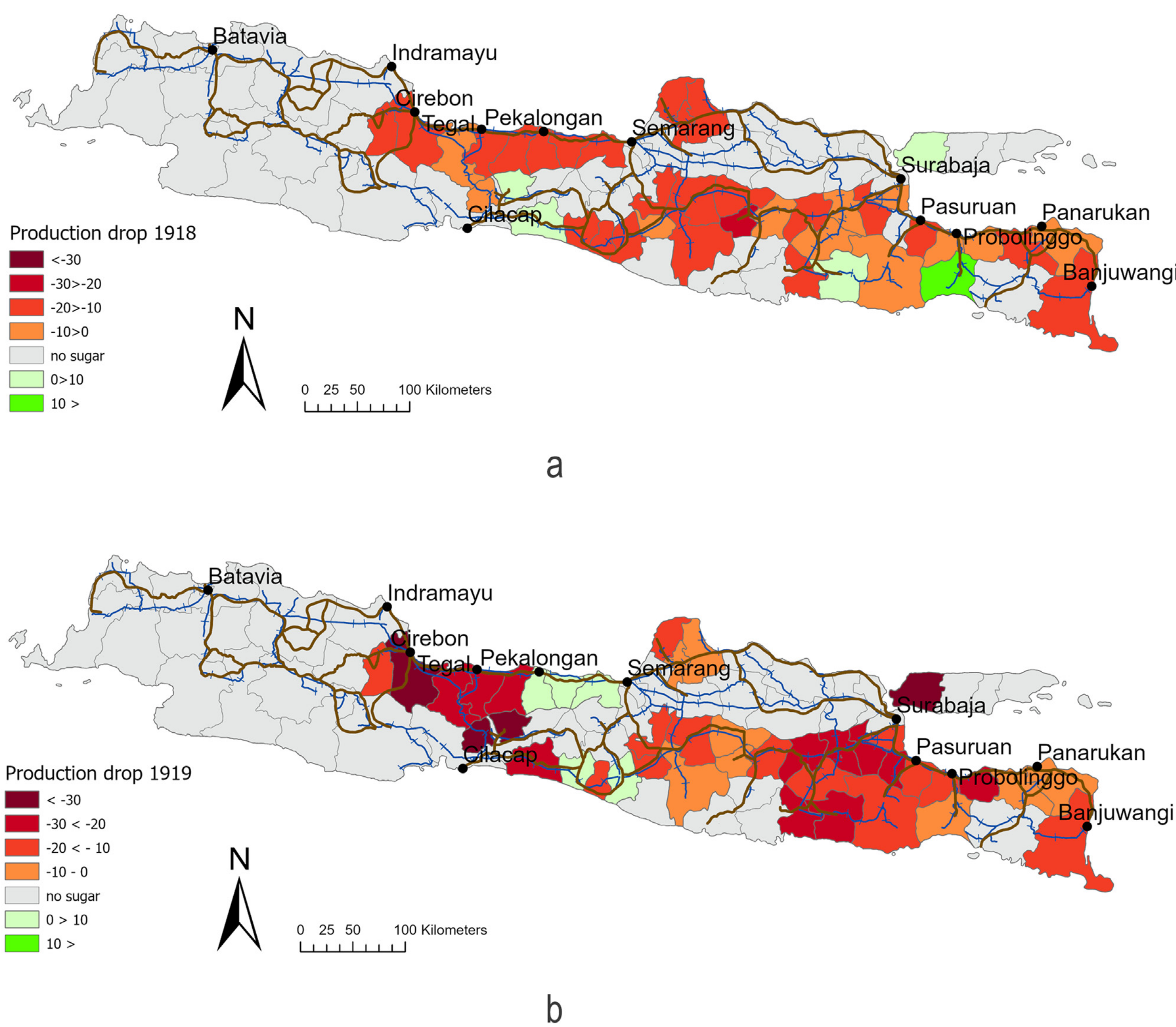

Fig. 6. Sugar production fall in 1918 and 1919: (a) production in 1918 relative to 1917 (percentage difference); (b) production in 1919 relative to 1918 (percentage difference). Note: see Fig. 5 for the sources. See Fig. 2 for further details on the information displayed in the map.

drought in 1914 reduced sugar production and that then high rainfall during transportation of the sugar in 1915 led to severely reduced sugar supplies (KV, 1916, pp. 8, 181). When the health shock starts in 1918, we observe an immediate production fall of about 200 picul per hectare that continues until 1921, without any sign of recovery. Then, output levels rise in 1922 to those observed in 1917 and hover around that level until 1924.

The trends we have discussed are representative of the average experience of sugar producing regions. Fig. A2 (Panel A) shows that the 30-percentage-point production increase between 1909 and 1917 is statistically significant. And the same applies to the production slump after 1918 as well as the slow recovery until 1921. Similarly, Panel B of this figure supports the stagnant pattern of sugar output per hectare until 1917, and the subsequent decrease that lasted until 1921. These trends, and in particular the large production drop in 1919, are consistent with those shown for the whole of Java shown by Koningsbergen (1948, pp. 391-397) and van der Eng (1993, p. 191).

Fig. 6 goes beyond regional averages and presents the spatial distribution of the sugar production shock across regencies in Java. In 1918, a sugar production drop can already be observed in most of the regencies. The drop was limited to about 10 or 20 percent compared with the production figures in 1917 (see Fig. 6a). Sugar was harvested roughly between June and September, before the epidemic really hit the island most significantly in October-December (see Figs. 2 and A1). It was in 1919, however, that sugar production showed a really substantial drop, with a number of regions with production declines of over 30 percent relative to 1917, and most other with declines of between 10 and 30 percent (see Fig. 6b). While annual climatic conditions play an important role in the precise timing of the workload, most planting of sugarcane in Java is generally done between May and August (Levert, 1934, p. 127), but additional planting (*bijplant*) could continue until December. During the months October-December work was done on maintenance and additional planting in the gardens (Levert, 1934, p. 131), while the least amount of work was done in sugar in the months February and March (Levert, 1934, p. 130). Sugar takes about 14 months to mature, so that the sugar planted between April and August 1918 was harvested roughly between June and October 1919. In particular the maintenance work put into the 1919 harvest could have suffered from labour scarcity related to the pandemic. Plotting the decline in sugar production on the map of Java, we do not find a clear spatial pattern of production decline, since both coastal and interior areas were affected, and the output shock was felt from the east to the west of the island.

4. Resource diversion and resilience during the epidemic

4.1. Mortality and sugar production

We have shown in the previous section that the 1918 influenza epidemic did not affect aggregate measures of the economic capacity of Java, such as GDP or the production of rice and food crops in general. However, the same is not true for the sugar industry, which experienced a marked decline during the epidemic years, especially after 1919. How can we reconcile these contrasting developments? We hypothesize that in low-income agricultural societies, such as colonial Indonesia, resources are shifted from non-essential economic activities to essential food production during large mortality crises. We test this in various steps. First, we consider whether the decline of labour supply, as a result of the epidemic, had a direct impact on sugar production after 1918. If labour was redirected from sugar to food crop production, we should not expect a link between mortality and sugar output. We use the following model:

$$\log production_{i,t} = \alpha(mortality_{i,1918} * epidemic_t) + \gamma_i + t_t + \varepsilon_{i,t}, \quad (1)$$

where i and t index regency and year, respectively; *production* is a measure of sugar output; *mortality* is all-cause mortality in 1918; *epidemic* is a dummy variable that turns one in 1918, the first year of the epidemic shock (see Fig. 1); γ_i is a set of regency-fixed effects, and t is a linear time trend. Intuitively, the main coefficient of interest in our model (α) measures whether, after 1917, the level of sugar production in regions with high levels of mortality in 1918 (like Blitar or Malang) differed from those in relatively less affected areas (such as Djombang and Magetan). Given that we estimate Eq. (1) with annual sugar production data for the period 1909–1924, this coefficient would be negative (and statistically significant) if the influenza epidemic had a lasting impact on the sugar industry between 1918 and 1924.

Table 1
The impact of the influenza epidemic on sugar production.

	Dep. Var: log sugar production				Dep. Var: log sugar production per hectare			
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
epidemic	−0.144	−0.389*	−0.241**	−0.472***	−0.076	−0.062	−0.095*	−0.094
	(0.106)	(0.193)	(0.115)	(0.127)	(0.045)	(0.077)	(0.050)	(0.059)
epidemic*mortality(1918)	−0.002				−0.001			
	(0.002)				(0.001)			
epidemic*mortality(1918−1921)		0.005				−0.001		
		(0.006)				(0.002)		
epidemic*ex_mortality(1918)			0.0004				−0.002	
			(0.050)				(0.021)	
epidemic*ex_mortality(1918−1921)				0.138*				−0.003
				(0.074)				(0.032)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	627	627	627	627	622	622	622	622
R2	0.24	0.24	0.23	0.25	0.05	0.05	0.05	0.05

Standard errors in parentheses, *p < 0.10, **p < 0.05, ***p < 0.01.
Note: see Figs. 1 and 5 for the sources on mortality and sugar production, respectively. This table shows the results of estimating Eq. (1) using log-transformed total sugar production (columns I to IV) and log-transformed sugar production per hectare (columns V to VIII), as dependent variables. Each model specification uses a different variable to measure the mortality impact of the epidemic: death rates in 1918 (columns I and V), average death rates between 1918 and 1921 (columns II and VI), excess mortality in 1918 (columns III and VII; see the notes of Fig. 1 for a description of this measure), and average excess mortality between 1918 and 1921 (columns IV and VIII). Standard errors are clustered at the regency level.

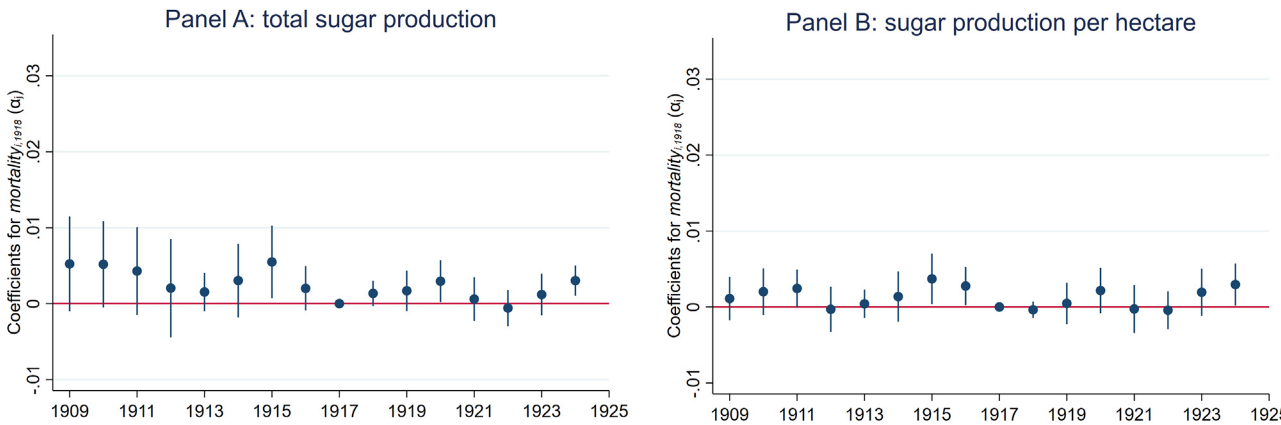

Fig. 7. The impact of the influenza epidemic on sugar production in Java, 1909-1924.
Note: see Fig. 1 and 5 for the sources on sugar production, sugar-producing hectares and mortality. This figure plots the series of coefficients (α_j) after estimating Eq. (2) using log-transformed total and per-hectare sugar production (Panel A and B, respectively). Standard errors are clustered at the regency level.

Our analysis also considers the possibility that the impact of the epidemic varied over time by extending Eq. (1) as follows:

$$\log production_{i,t} = \sum_{j \neq 1917} \alpha_j mortality_{i,1918} 1_{j=t} + \sum_{j \neq 1917} X_i \beta_j 1_{j=t} + \gamma_i + \delta_t + \varepsilon_{i,t} \quad (2)$$

This model allows us to estimate a series of coefficients (α_j) for each year j excluding the benchmark year (1917), to measure the level of sugar production in regions with high levels of mortality due to the epidemic relative to less affected areas during the period 1909–1924. Furthermore, we include a set of year-fixed effects to control more flexibly for time trends common to all regencies, a vector of variables (X) interacted with the year-fixed effects to control for shocks that vary over time and are correlated with baseline differences across regencies. The controls are native population and urbanization shares as measured by the percentage of people living in towns with more than 3000 inhabitants in 1905. We took this information from the Colonial Report of 1907 (KV, 1907, Appendix A). In Table A1 we present the summary statistics of the variables used in our empirical framework.

Our sample refers to a set of 41 sugar-producing regencies in Java and it is thus informative to assess how the mortality experience of this sample relates to that of the whole island. Fig. A3 presents series of mortality and excess mortality (in Panel A and B, respectively) for both our sample (blue solid line) and the whole island, as discussed above. We can see that these are similar, although our sample exhibits slightly higher levels for both indicators. This suggests that the regions we consider were somewhat more affected by the epidemic.[9] Regions producing sugar were generally located in low-lying coastal areas and were generally better connected to world trade, therefore it seems likely that they were indeed more heavily afflicted than other regions. This also matches with the observations of contemporaries that villages near main roads were more affected than those less connected (Van Steenis, 1919, p. 915).

The results of estimating Eq. (1) are presented in Table 1. The first columns (I to IV) use log-transformed total sugar production as dependent variable. Beginning with column I, we see that the coefficient of the interaction between the post-1918 dummy variable (*epidemic*) and mortality rates in 1918 has negative sign. This suggests that regencies largely affected by the epidemic, as measured by death rates in 1918, had lower sugar output levels relative to regions with lower mortality during the period 1918–1924. Although this result is intuitive because it would indicate a supply shock in the sugar industry caused by the epidemic, we cannot claim that this was the case because the coefficient of the interaction is not statistically significant.

One reason why our first model specification fails to find a robust relationship between mortality and sugar production may be that we are not measuring the health impact of the epidemic accurately. For instance, Fig. 1 shows that the mortality shock lasted until 1921, which suggests that a more temporally-comprehensive measure of the epidemic should consider the period 1918–1921. We do this in column II by interacting *epidemic* with mean death rates between 1918 and 1921. The result of this exercise supports our earlier finding, since the coefficient of the interaction is not statistically significant (see column II). In columns III and IV we measure the impact of the epidemic with an indicator of excess mortality. This is very similar to the metric we presented in Panel B of Fig. 1, since we subtract observed death rates in a given year from a baseline mortality level. This baseline represents expected death rates in the absence of the epidemic and it was estimated for each regency by regressing mortality before 1918 on regency-specific linear time trends. As we can see, the main coefficient of interest is not statistically significant in column III, and only marginally significant in column IV. Thus, we can conclude that our mortality measures are not significantly related to varying sugar production across regencies in Java after 1918.

If we turn to our results using log-transformed sugar production per hectare as dependent variable (columns V to VIII), we observe a similar pattern indicating that output levels do not seem to be associated with differences in mortality and excess mortality across regencies. Indeed, the coefficients for the interactions of mortality measures with *epidemic* are statistically insignificant, including the coefficient for average excess mortality that was marginally significant in column IV. All in all, we find no robust evidence that the differential mortality impact of the influenza epidemic influenced total or per-hectare sugar production across regencies.[10]

[9] Formal tests comparing sugar-producing with non-sugar-producing regencies support this claim. We found that the regencies in our sample exhibit higher levels of mortality in 1918 and 1919 (about 6 deaths per 1,000 people); but not in 1917, 1920 and 1921. The same applies if we repeat this exercise with a measure of mortality relative to 1917: sugar-producing regions have a relatively higher mortality ratio in 1918 and 1919; but not in 1920 and 1921.

[10] The results of Table 1 remain the same if we use regency-specific time trends instead of a single time trend to account for time-varying factors or log-transformed variables in the interactions with *epidemic* (see Tables B1 and B2).

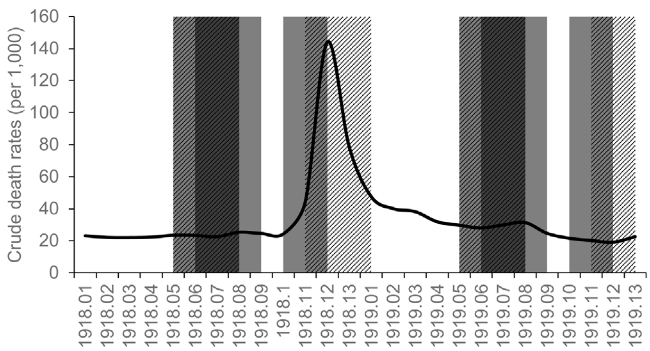

Fig. 8. Mortality and periods of planting and harvesting in sugar and rice in Java, 1918-1919.
Note: see Fig. 1 for the source on mortality. We show periods of labour demand for rice with oblique black lines; for sugar we use grey shadow (dark grey shadow implies both harvesting and planting takes place). The data were reported in 13 four-week periods, rather than months.

The models we have estimated so far do not allow for dynamics over time in the relationship between the health and production shocks. This may be too simplistic since the intensity of these shocks varied over time, as shown in Figs. 1 and 5. To account for this possibility, we estimate Eq. (2) and examine the pattern of year-specific coefficients (α_j) for $mortality_{i,1918}$. These allow us to examine how the relationship between the epidemic shock and sugar production evolved during the period 1909–1924. Fig. 7 shows the results of this exercise by plotting such coefficients. Beginning with total sugar production (Panel A), we find suggestive evidence that regions more affected by the epidemic had higher levels of production before 1917, though only the coefficient for 1915 is statistically significant. This means that there are no discernible pre-epidemic trends in sugar production across regencies differently affected by the influenza-driven mortality shock. After the epidemic hits Java, we find a few positive coefficients, but these are statistically insignificant for the whole post-1918 period, except for 1924. The results are very similar if we consider per-hectare sugar production in Panel B. Most coefficients are positive, but statistically insignificant before 1918, with the exception of 1915, when weather conditions (as discussed above) had a large negative impact on sugar production totals. After the epidemic, none of the coefficients are statistically significant, with the exception of 1924. All in all, our analyses suggest that the large sugar production drop during the period 1918−1921 cannot be explained by the differential impact of the health crisis in the island.[11]

4.2. Resource diversion in Java

What explains the fall in sugar production in Java during the influenza epidemic, if mortality is uncorrelated with output measures in this sector? We argue that labour and land was redirected from non-essential crops to food production during the influenza epidemic. This shift was spurred by a number of partially interrelated developments. At the end of the First World War, markets were disrupted and shipping capacity was limited which meant that more sugar remained stored across Java (KV, 1917, p. xx). Together with the fact that the sugar harvest of 1917 had been exceptionally high (Verslag Suikersyndicaat, 1917–1918, p. 6) this pushed down sugar prices to their lowest levels in years. At the same time, disrupted markets and a drought across Southeast Asia caused a shortage of rice in Java, driving up prices of rice. These price developments implied that when the impact of influenza caused a labour shortage across Java (Bosma, 2019, p. 151), there were incentives to divert labour from sugar to rice.

While climatic conditions influence precise labour demands in both crops and may thus vary slightly from year to year and between the various regencies, the following schedule applies in general. Owners prepare the rice fields and make sure irrigation channels and embankments are in good order before the rainy season begins in November or December. Planting commences with the start of the rainy season, while harvesting begins at the end of the rainy season. The fastest rice varieties will have ripened by April, while the longer-growing, but more nutritious, varieties can be harvested by August. Harvesting is done by large groups of workers, including women (Boomgaard and van Zanden, 1990, p. 17). There is a clear concentration of work at the beginning of the rainy season (November/January) and the beginning of the dry period (May/June). Only limited labour was required in the months preceding November in terms of preparing the fields, and between January and May only some weeding was done in terms of maintenance (Smits, 1929, p. 134). In the case of sugar, planting takes place generally between April and August and harvesting (roughly) between June and October, just over a year later (as also noted above). Some additional work in sugar was done in maintenance and additional planting in October to December (Levert, 1934, pp. 127-131). The least amount of work in sugar is done between January and March and there is a large concentration of work in the period June to August, with work in both planting and harvest. Rice is also harvested during those months so that there are overlapping claims on labour in that period, as there is in the beginning of the rainy season, when rice is planted and maintenance work and *bijplanting* takes place in sugar.

Fig. 8 below plots monthly mortality in Java together with the periods of labour demand for rice (oblique black lines) and sugar (grey shadow, dark grey shadow implies both harvesting and planting takes place). In the months from May to September in 1918, rice was harvested, while sugar was both being planted and harvested. While the influenza did not claim many casualties in this period yet, problems with the import of food and drought are already apparent at that time, so that some shifts towards food production may already have taken place then. Additionally, there are overlapping claims on labour at the beginning of the rainy season in November and December 1918, exactly at the height of the mortality shock. This likely resulted in less labour in sugar planting and maintenance leading to smaller total production for the 1919 harvest, which is what we observed in Figs. 5 and 6.

Besides competing claims on labour, sugar and rice also competed for the same land, as both crops grow best under quite similar geographical and climatic conditions. Both crops benefit from relatively high temperatures, as they are best grown in temperatures between roughly 25 and 30 °C and in comparatively high humidity. They require high annual precipitation, but sugar cultivation benefits from greater constancy in rainfall (Driessen and Konijn, 1992, pp. 16–17). In addition, both crops are best grown in lowland areas (<500 m elevation) that are largely flat (slopes below 15 percent) (Dippel et al., 2020; Driessen and Konijn, 1992, p. 41); they grow in soils with pH values of between 5 and 8; their optimum pH levels are between 6 and 7; and they are moderately sensitive to salinity (Driessen and Konijn, 1992, pp. 16–17). The fact that rice and sugar competed for some of the same land is widely noted in the literature (e.g. Elson, 1994).

The discussion above suggests that our 'resource diversion' hypothesis is plausible, given the overlapping labour and land demands in the sugar and rice sectors. In the following, we provide two additional pieces of evidence indicating that there was a shift

[11] Our findings are robust to using various measures of the mortality impact of the epidemic (see Figs. B1 and B2) and using log-transformed mortality variables (results available upon request).

Table 2
Accounting for the fall in total and per-hectare sugar production, 1918–1921.

	total sugar production	*per-hectare sugar production*
Rotating shares 1917 (base year)	0	0
Rotating shares 1918	−0.0468	−0.0550
	(0.0310)	(0.0340)
Rotating shares 1919	−0.1210**	−0.1624***
	(0.0514)	(0.0575)
Rotating shares 1920	−0.1370***	−0.1690***
	(0.0488)	(0.0560)
Rotating shares 1921	−0.0256	−0.0567
	(0.0443)	(0.0493)
Regency-fixed effects	Yes	Yes
Year-fixed effects	Yes	Yes
Controls	Yes	Yes
Observations	613	608
R2	0.39	0.23

Standard errors in parentheses, *p < 0.10, **p < 0.05, ***p < 0.01.
Note: see Figs. 1 and 5 for the sources on mortality and sugar production, respectively. The control variables are native population and urbanization rates in 1905 (see Table A1 for the sources). Standard errors are clustered at the regency level.

in land and labour devoted to rice at the expense of sugar production.

First, we consider how different regimes of property rights allowed for resource reallocation. There were essentially three different systems of land tenure in operation for *sawah* land in colonial Java: (1) hereditary private property, (2) communal property with fixed shares and (3) communal property with rotating shares. In the first category, land tenure was fixed and lay with individual owners. These owners could rent out their land to the sugar factories. The second category consisted of land that was the communal property of the village (*desa*). Individuals using these lands were not authorized to sell them to others. In these areas, the same individuals worked the same plot each year. Finally, there is the category of land that is communal and where a periodic rotation of shares took place. In this latter system, annual redistribution of plots took place, which, as Elson (1984, pp. 12–13; 40–41) notes, allowed flexibility in local social arrangements. In the Western-most parts and Eastern-most parts of Java, heritable private property was the most common, whereas in Central Java most villages had communal lands (Boomgaard, 1989). Because sugar production exhausts the soil, it has been noted in the literature that sugar factories could benefit from the periodic redistribution of lands as they could influence village heads to hand out the best lands for growing sugar each year to the sugar factory (Breman, 1983, pp. 24–25; van Zanden and Marks, 2012, p. 73). In those areas where sugar plantations were located, the system of periodic redistribution of land continued after the nineteenth century, “or were perhaps even reinforced” (van Zanden and Marks, 2012, p. 88). At the same time, it must be kept in mind that between 1902 and 1925 the share of total land under rotating tenures declined (van der Eng, 1993, p. 133). Nonetheless, we argue that it is likely that in areas with more communal land under rotating shares, land and labour can be more flexibly allocated to sugar or rice production from year to year.

With this idea in mind, we replace *mortality* in Eq. (2) with *rotatingshares*, a dummy variable indicating whether a regency has (at all) rotating land drawing on information about the different types of property rights regimes prevailing in each residency from the Declining Welfare Study (OMW, 1907-1909). Table 2 presents the results of this exercise for total and per-hectare sugar production focusing on the epidemic years, thus we report coefficients for the period 1918−1921 (Fig. A4 plot all coefficients). We find that regencies with rotating shares experienced larger production declines in 1919 and 1920, and the same applies to per-hectare production.[12] In line with our resource-diversion hypothesis, the estimates imply that sugar output was between 0.12 and 0.17 logarithmic points lower than in regencies where the rotating system was present.[13]

Our second piece of evidence indicating resource diversion to food crops during the epidemic relates to contemporary discussions about the difficult situation of food availability in Java. Shortages of food were already noted by officials in the first half year of 1918. These were not caused by the epidemic, but rather by a combination of diminished food imports (good for 10 % of total consumption on Java) and drought. As noted above, a shift towards food production was actively pursued by the government. In 1918, conditions were so dire that the colonial government considered a mandatory reduction of the total area under sugar cultivation by 25 percent and it had already published a draft of this ordinance (Archief Suikerindustrie, 1918, p. 2296). The law was supported by Javanese leaders of the *Sarekat Islam* (the main Indonesian political organization in the early 20th century), but it met with fierce opposition from the vested sugar interests and was eventually retracted. Nonetheless, the long discussion about the measure had led some estates to voluntarily decrease the land under sugar cultivation and some even closed down entirely for 1919 (Archief Suikerindustrie, 1918, pp. 1153, 2300; Indische Mercuur, 1918, nos. 32, 42, 43, 44 and 45).[14] In addition, to spur food production the central government decided to guaranty minimum prices for the main food crops in November 1918 (Archief Suikerindustrie, 1919, p. 572). Indigenous tobacco planters were encouraged to shift to food production. Local officials, the colonial planters ‘syndicate’, as well as the department of forestry were all requested to expand the planting of food crops as much as possible (Locomotief, 1918: 02-12-1918). District banks were encouraged to provide additional advances for the cultivation of food crops (Archief Suikerindustrie, 1919, p. 572). In November 1918 the government prohibited the

[12] Our findings are robust to including variables measuring geographic characteristics at regency-level to control for baseline differences in geographic and spatial factors, such as elevation above sea level, average distance from a road, average distance from a railway line and soil suitability to grow sugar.

[13] We also found that some of the coefficients for *rotating shares* are negative, but statistically-insignificant, before 1917 (see Fig. A4). Although we do not focus on this period, they may indicate early evidence of resource-diversion following the climatic shocks discussed above.

[14] These decisions were also influenced by the low sugar prices in 1918 (Koloniale Studiën, 1918, pp. 564-565).

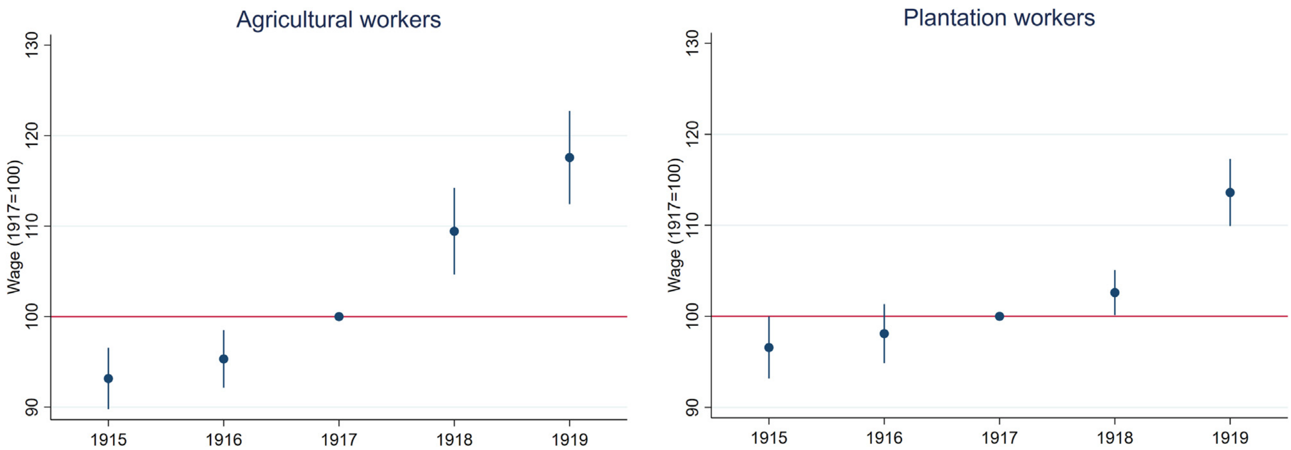

Fig. 9. Average wages across regencies for non-plantation and plantation workers in Java, 1915–1919 (1917 = 100).
Source: KV, 1920. Note: The cross-regency averages were obtained by regressing wages on a set of year-fixed effects.

practice of 'braakhuur' (Staatsblad, 1918, no. 791), in which sugar plantations rented fallow land in order to start preparing the sugar fields earlier in the year (before work in rice fields drove up wages) that resulted in less available land for rice cultivation. Only in June 1919, a general decree followed that obligated peasants and planters to plant suitable unused lands with food crops (Staatsblad, 1919, no. 287).

We find quantitative evidence supporting these developments. In Table A2, we report the results of a model akin to the one used in Table 2, but using sawah land per person as the main independent variable.[15] The intuition behind this exercise is that the presence of greater amount of rice fields in a regency and their demand for local laborers may have put a large deal of pressure on the sugar industry. We measure this with the amount of sawah land per capita across regencies in 1920 from Landbouwatlas (1926).[16] In line with our hypothesis, we find that regencies with more hectares of sawah experienced larger total sugar production declines between 1918 and 1920 (Table A2). This fits with the idea that in these regencies more land could be used for rice cultivation.

4.3. Wages and migration

We turn now to an alternative hypothesis to explain why the epidemic did not have an impact on GDP and food crop production drawing on Lewis' two-sector model. This posits that a surplus of labour in agriculture leads to low workers' productivity levels due to diminishing marginal returns. Consequently, there are a large number of laborers that are not really contributing to overall production. If this was the case in Java, this would explain why aggregate production did not fall even though labor supply decreased due to the epidemic. This hypothesis was also mentioned by Brown (1987, p. 249), although he lamented that this 'proposition is very difficult to verify [. . .]'. We have made an effort to fill this knowledge gap by gathering two series of agricultural nominal wages at the regency level for the period 1915–1919: non-plantation wages and plantation wages for 87 regencies in Java. We took this information from the Colonial Report of 1920, which gives a detailed overview of wages paid in different sectors of the economy (KV, 1920, Appendix GG).

According to the low-productivity hypothesis, we should expect no increases in agricultural wages during the epidemic years, if workers' marginal productivity was close to zero. Fig. 9 does not support this proposition, since non-plantation wages of agricultural workers (coolies) did increase noticeably in 1918 and 1919 by almost 10 and 20 percentage points, respectively, relative to 1917. If we turn to plantation wages, that refer to a large extent to workers in sugar, the largest sector of the plantation economy, we do not see a significant increase in workers' remuneration in plantations in 1918, but only in the subsequent year. This lines up well with the evidence of Fig. 5 showing that sugar production mostly declined in 1919, and not in 1918. In sum, these wage trends do not conform with the low-productivity hypothesis, since labor markets clearly responded to the labor shortage caused by the epidemic.

Another reason why our analyses may not show a significant relationship between mortality and sugar concerns migration. If workers were highly mobile between regencies then the mortality shock in the worst affected areas could be mitigated from workers from less affected regions. Indeed, a proportion of the necessary labour could also be recruited from outside of the immediate vicinity of the estates (Knight, 1994, p. 68). Mostly this would still be within the same regency and residency (and are thus accounted for by our regency-fixed effects),[17] but there are also examples of workers coming from further away. For instance, some plantations in the eastern parts of the island, such as Pasuruan and Besuki, relied on seasonal migrants from Madura (Bosma, 2013, p. 187). Cross-border seasonal migrants were also observed between Pekalongan and Cirebon, and between Kediri, Semarang and Rembang (Levert, 1934, p. 125). Unfortunately, we cannot assess the extent of these worker flows accurately before the influenza epidemic, since comprehensive and systematic data are not available then. However, we found information from the Census of 1930 (EZ, 1933-1934) on the total number of immigrants per regency, i.e. number of people enumerated in a regency that were born in a different regency and residency. Certainly, we cannot be

[15] Also, we add rotating shares as a control variable.
[16] Although this variable is measured after the epidemic, allocated land to rice was mostly a decision determined by constant (or slow-varying) geographic and climate factors. Indeed, data from MSK (1924, p. 5) at the *residency* level shows the amount of *sawah* in 1916 and 1922 was very similar (correlation coefficient between those years is 0.97), which indicates that the spatial distribution of *sawah* land did not change significantly after 1918.

[17] Using residency-fixed effects does not alter our results (results available upon request).

entirely confident that these data also show seasonal migration accurately, and it seems that sugar harvesting, in particular, was done by seasonal migrants. But assuming that broad migration patterns did not change substantially in the decade following the epidemic, we can use these data to test whether our results are robust to controlling for migration. More specifically, we repeat the analyses in Fig. 7 for both total and per hectare sugar production, but controlling for differences in migration rates across regencies. As the results show in Fig. A5, this variable does not alter our finding that varying levels of mortality during the influenza epidemic do not explain the fall in sugar production.[18]

Our results are in line with the observation that although migration between regencies was taking place, the majority of sugar workers were still recruited locally (Levert, 1934, p. 118) and that even on plantations characterized by a large proportion of migrant workers, such as Kalimati factory in Batang regency, two thirds of the estate area was worked by local workers (Knight, 1994, p. 68). Nonetheless, more detailed research into regional labour migration in these years, based on archival research in, for example Eastern Java, may lead to more detailed numbers that would allow to assess the role of seasonal migrants in the decline of sugar output and the shift from sugar to food production more accurately.

5. Conclusions

We have examined the spread of the influenza across Java and its effects on the economy. For this purpose, we have developed a new dataset about Java with aggregate information on aggregate food production and regional regency-level figures on (i) sugar production, the major export commodity and the predominant source of labour demand; (ii) agricultural and plantation wages, and (iii) annual crude death rates.

We show that the shock to mortality, especially in the months October to December 1918, but continuing in the first months of 1919, was high across Java and in Eastern Java in particular.

While the mortality shock caused temporary labour shortages and disrupted production processes across various sectors of the agricultural economy, as our qualitative sources indicate, we find no direct relationship between the extent of the mortality shock at the regency level and local output declines in the sugar industry. Instead, our findings show that sugar production falls took place in both regencies suffering from an important mortality crisis and regions that were less affected. This finding is robust to using various indicators to measure the regency-specific impact of the epidemic, controlling for confounding factors and using different functional forms.

We hypothesize that the lack of a systematic relationship between mortality and sugar production was due to resource diversion, as labour and land was redirected from non-essential crops to food production during the epidemic. The year 1918 was not only characterized by the influenza pandemic, but it also marked the end of the First World War, which had interrupted global markets. Furthermore, a severe drought influenced agricultural production across Southeast Asia and caused problems for both food imports from Thailand and the rice harvest in the Dutch East Indies itself, giving rise to an impending food crisis. At the same time, the combination of disrupted shipping and a record sugar harvest in 1917 meant large amounts of sugar remained stocked in Java, which pushed down sugar prices across 1918. As result of these factors, economic activity was rediverted towards food production in order to avoid famine. We find three supporting pieces of evidence to this idea. First, regions producing relatively more rice experienced a larger sugar production drop. As rice production was prioritized over sugar, labour input was reallocated between crops when local markets faced labour scarcity as a result of the epidemic. Second, our results show that regions with more flexibility to cultivate different crops experienced up to 17 percent lower output levels than regencies without rotating lands. Rotating land tenures were more flexible in shifting land use from sugar to rice during the epidemic years. Third, we found qualitative evidence on the shift from cash to food crop production in colonial newspapers and reports.

No data on food production at the regency level is available for these years, which could have shed further light on our resource diversion hypothesis. Furthermore, we lack detailed regional information on other inputs that may have influenced the sugar harvest. Disrupted international markets could also have impacted the availability of fertilizer, for instance, the effects of which could have differed regionally. These caveats notwithstanding, we suggest that this paper has shown the complex effects of the influenza pandemic in an agricultural colonial economy, and discussed how these interacted with wider contextual conditions in terms of climate and global markets.

Author statement

We state that we have no conflicts of interests.

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Appendix A.

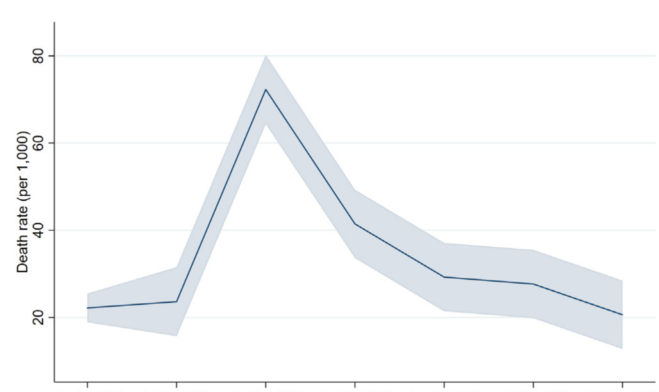

Fig. A1. Mortality in Javanese sugar-producing regions between 1918 and 1919. Note: see Fig. 1 for the sources. The mortality series refers to the whole of Java. Point estimates and 90-percent confidence intervals (vertical bars) were obtained by regressing death rates per 1,000 on a set of year-fixed effects.

[18] An additional test supports this result, in which we excluded the regencies that had high migration rates by combining information from the 1930 Census with qualitative observations from the literature (Bosma, 2013; Knight, 1994; Levert, 1934). These regencies are: Banyuwangi, Lumajang, Malang, Blitar, Kediri and Surabaya. Results are available upon request.

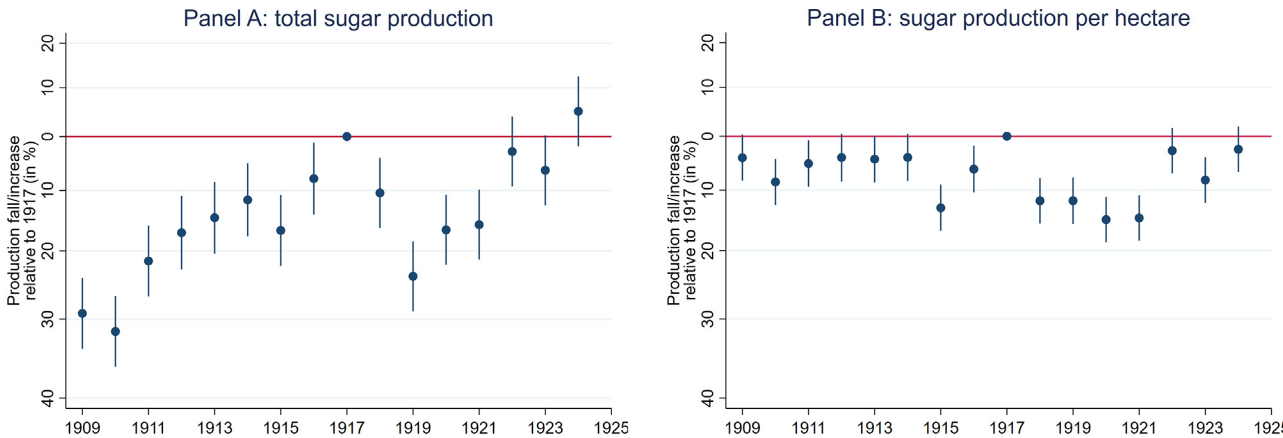

Fig. A2. Sugar production in Java, 1909–1924.
Note: see Fig. 5 for the sources. Panel A shows the coefficients of year-fixed effects (base year is 1917) from a regression where the dependent variable is total (log) sugar production and the independent variables are a set of regency- and year-fixed effects. Panel B presents the same, but using sugar production per hectare as dependent variable.

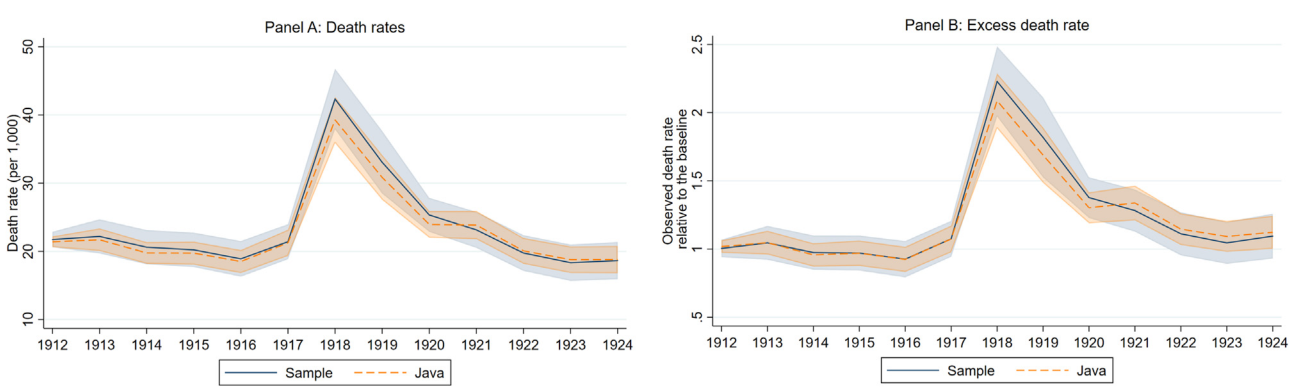

Fig. A3. Mortality and excess death rates, 1909–1924.
Note: see Fig. 1 for the sources and the procedure used to calculate excess death rates in Panel B. The 'Java' series is taken from Fig. 1.

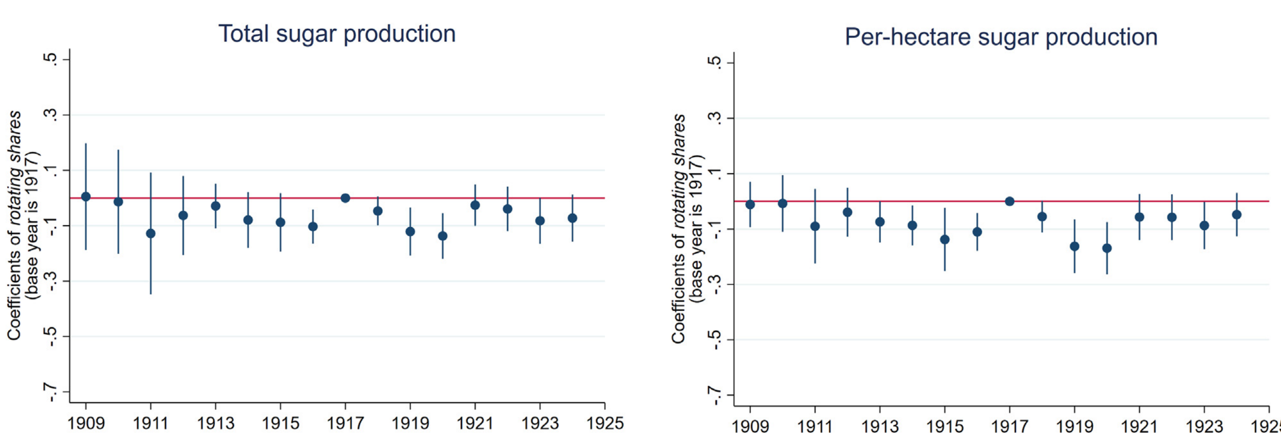

Fig. A4. Accounting for the fall in total and per-hectare sugar production, 1909-1924.
Note: see Fig. 5 for the sources on sugar production, and Table A1 for the remaining variables including the control measures mentioned in Table 2. This figure plots the series of coefficients (α_j) of *rotating shares* after estimating Eq. (2) using log-transformed total and per-hectare sugar production (standard errors are clustered at the regency level).

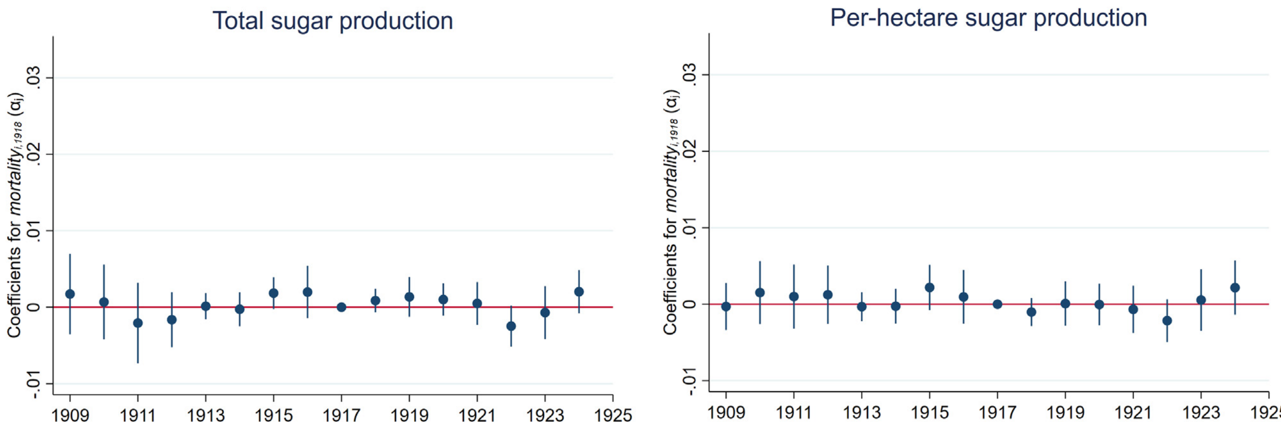

Fig. A5. The impact of the influenza epidemic on sugar production in Java, 1909–1924 (robustness test: controlling for migration).
Note: this figure repeats the analyses performed in Fig. 7, but controlling for regency-level migration rates. The source for migration is EZ (1936).

Table A1
Summary statistics.

	Observations	mean	st. dev.	min.	max.
Total sugar production (thousand picul.)	627	5,757.000	5,100.567	431.538	26,271.300
Per-hectare sugar production (picul per hectare)	622	1,683.289	259.076	759.750	2,861.394
Mortality in 1918 (per 1,000 people)	41	42.317	13.064	25.000	89.000
Native population in 1905 (in thousands)	41	361.699	153.587	135.450	808.990
Urbanization in 1905 (in percentages)	41	5.400	4.700	0	27.000
Medical personnel in 1919 (per 1,000 people)	41	0.011	0.004	0.003	0.022
Sawah area in 1920 (hectares per capita)	41	0.084	0.024	0.049	0.144
Rotating shares areas in 1903	41	0.463	0.505	0	1

Note: see Fig. 1 and 5 for the sources of mortality and sugar production, respectively. The source for native population and urbanization is KV (1907, Appendix A); for medical personnel is X BGD (1920); for sawah area (Landbouwatlas, 1926); and for rotating shares is OMW (1907-1909).

Table A2
Accounting for the fall in total and per-hectare sugar production, 1918–1921.

	total sugar production	*per-hectare sugar production*
Sawah land p.c. 1917 (base year)	0	0
Sawah land p.c. 1918	−1.5741***	−0.8450
	(0.5308)	(0.7527)
Sawah land p.c. 1919	−2.0431*	−2.0536
	(1.1106)	(1.3866)
Sawah land p.c. 1920	−1.1982	−1.1461
	(0.9743)	(0.9937)
Sawah land p.c. 1921	0.0283	0.2543
	(0.8800)	(1.0330)
Regency-fixed effects	Yes	Yes
Year-fixed effects	Yes	Yes
Controls	Yes	Yes
Observations	613	608
R2	0.41	0.28

Standard errors in parentheses, *p < 0.10, **p < 0.05, ***p < 0.01.
Note: see Figs. 1 and 5 for the sources on mortality and sugar production, respectively. The control variables are native population, urbanization rates in 1905 and rotating shares (see Table A1 for the sources). Standard errors are clustered at the regency level.

Appendix B. Robustness tests

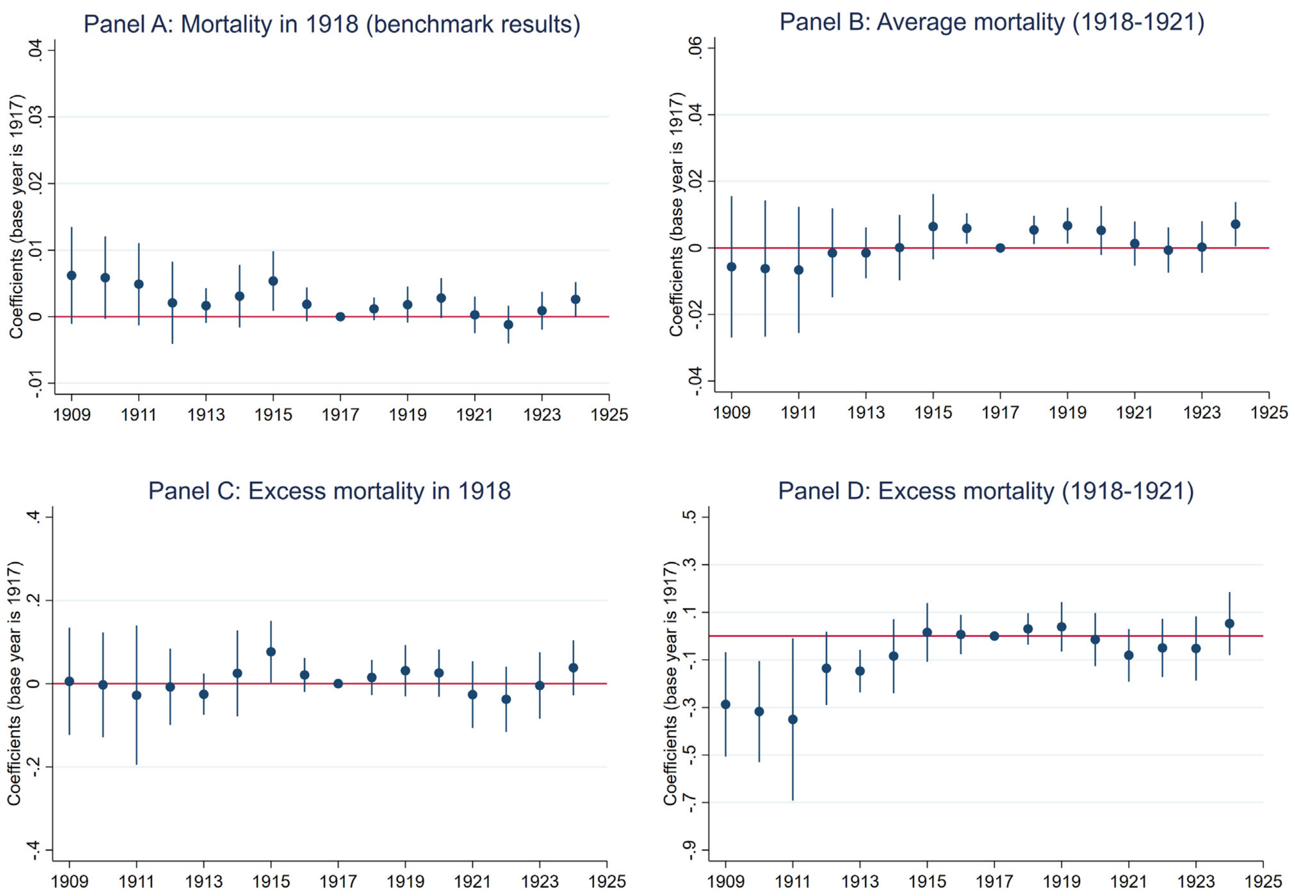

Fig. B1. The impact of the influenza epidemic on total sugar production in Java, 1909–1924 (robustness test: using different mortality measures).
Note: see Fig. 7 for information on the sources and estimation procedure. See Table 1 for a description of the various mortality variables.

Table B1
The impact of the influenza epidemic on sugar production (robustness test: using regency-specific time trends).

	Dep. Var: log sugar production				Dep. Var: log sugar production per hectare			
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
epidemic	−0.313	−0.103	−0.184***	−0.150***	0.180	−0.016	−0.046	−0.080*
	(0.250)	(0.366)	(0.048)	(0.042)	(0.189)	(0.268)	(0.043)	(0.042)
epidemic*mortality(1918)	0.019				−0.076			
	(0.068)				(0.051)			
epidemic*mortality(1918−1921)		−0.041				−0.024		
		(0.108)				(0.079)		
epidemic*ex_mortality(1918)			−0.078				−0.071	
			(0.065)				(0.051)	
epidemic*ex_mortality(1918−1921)				−0.189**				−0.040
				(0.078)				(0.075)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regency-specific time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	627	627	627	627	622	622	622	622
R2	0.59	0.59	0.59	0.59	0.147	0.15	0.15	0.15

Standard errors in parentheses, *p < 0.10, **p < 0.05, ***p < 0.01.
Note: see Table 1. The only difference between the model specifications reported in this and Table 1 is that time dynamics are measured using regency-specific linear trends.

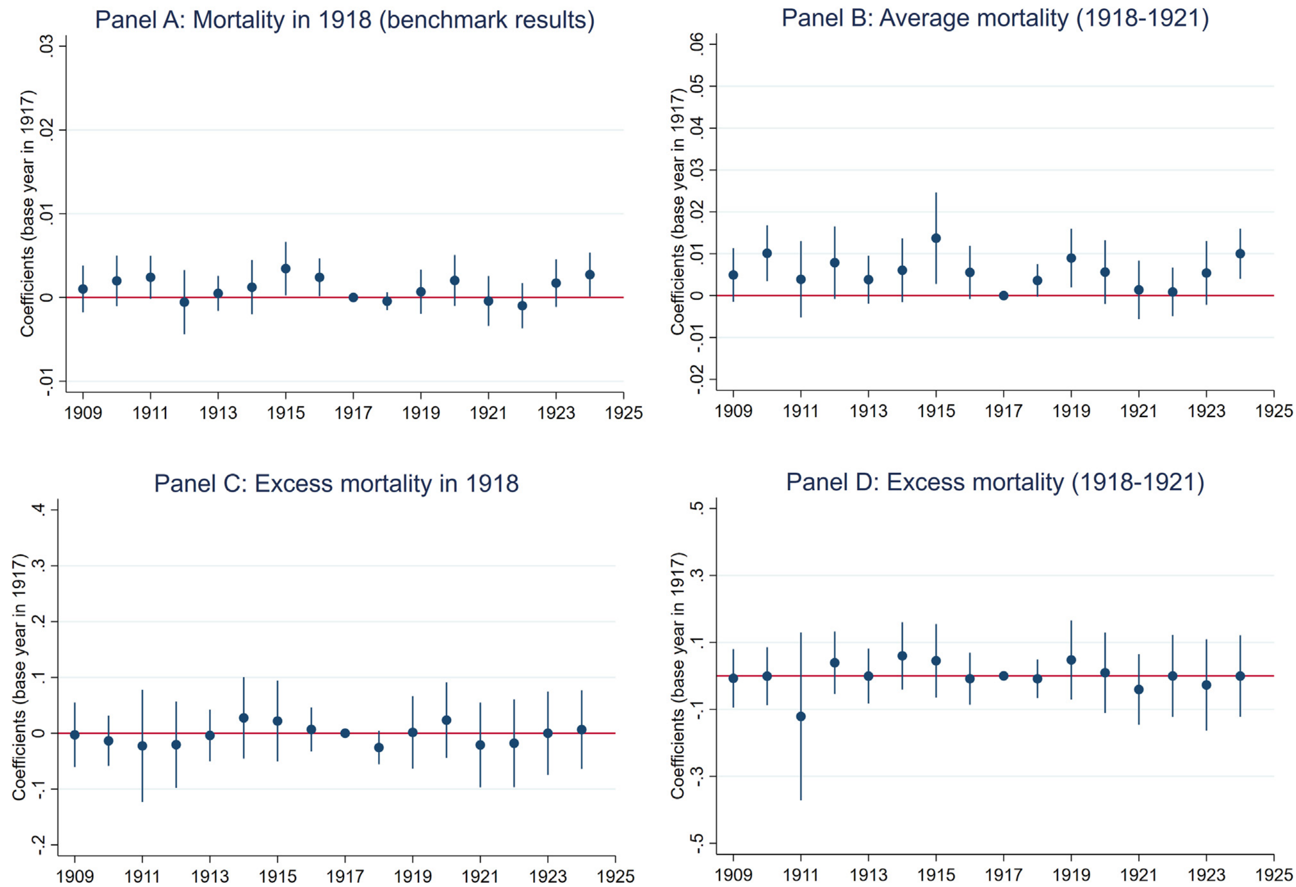

Fig. B2. The impact of the influenza epidemic on per-hectare sugar production in Java, 1909-1924 (robustness test: using different mortality measures). Note: see Fig. 7 for information on the sources and estimation procedure. See Table 1 for a description of the various mortality variables.

Table B2
The impact of the influenza epidemic on sugar production (robustness test: using log-transformed mortality variables).

	Dep. Var: log sugar production				Dep. Var: log sugar production per hectare			
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
epidemic	0.239	−0.735	−0.226**	−0.349***	0.052	0.056	−0.081*	−0.093**
	(0.481)	(0.691)	(0.095)	(0.073)	(0.186)	(0.275)	(0.041)	(0.035)
epidemic*l_mortality(1918)	−0.130				−0.041			
	(0.130)				(0.050)			
epidemic*l_mortality(1918−1921)		0.145				−0.045		
		(0.203)				(0.081)		
epidemic*l_ex_mortality(1918)			−0.019				−0.025	
			(0.120)				(0.047)	
epidemic*l_ex_mortality(1918−1921)				0.220				−0.013
				(0.138)				(0.058)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	627	627	627	627	622	622	622	622
R2	0.24	0.23	0.23	0.25	0.05	0.05	0.05	0.05

Standard errors in parentheses, *p < 0.10, **p < 0.05, ***p < 0.01.
Note: see Table 1. The only difference between the model specifications reported in this and Table 1 is that the mortality variables are log-transformed.

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