Housing Markets in a Pandemic: Evidence from Historical Outbreaks

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Abstract

How do housing markets respond to the outbreak of a major pandemic? This paper answers this question by analyzing unique transaction and mortality data around historical outbreaks of the plague in Amsterdam and cholera in Paris. We document that these outbreaks had a significant impact on house prices, but a smaller impact on rent prices. We find particularly large reductions in house prices during the first six months of an epidemic, as well as in heavily-affected areas. However, these price shocks were only transitory, and both cities quickly reverted to their initial price paths. Our findings suggest that urban housing markets are very resilient to major shocks originating from epidemics, even if they result in the death of a substantial part of the population.

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The recent outbreak of COVID-19 has brought the globalized world to a standstill, costing the lives of thousands of people and keeping millions in 'lockdown' in their homes. Although the full economic consequences of the outbreak are still to unfold, its short-term impact has undoubtedly been significant. One of the many economic sectors that could be affected by this epidemic is the housing market. On the one hand, pandemics can result in a direct decline in housing demand due to excess mortality and economic hardship. On the other hand, the uncertainty brought by the epidemic might refrain households and investors from buying and selling property.

It is challenging to assess the impact of such an epidemic on the housing market. While epidemics typically arrive suddenly and are therefore unrelated to the state of the economy, they are also infrequent, such that data availability is limited. Experts have argued that the current pandemic is the worst since the Spanish Flu, which happened over a century ago (Ferguson et al., 2020). Because major epidemics affect the lives of nearly everyone, it also is difficult to separate causal effects from underlying time trends using a single epidemic.

In this paper, we exploit historical outbreaks of cholera in Paris and the plague in Amsterdam to study the impact of major epidemics on housing markets. First, each of these outbreaks resulted both in high mortality and in enormous distortions in the economy. In Amsterdam, some plague epidemics killed over 10% of the total population, and the cholera outbreaks in Paris killed about 2% of the population. Second, for both Paris and Amsterdam, unique micro-level data survived in the archives, allowing us to track both the evolution in mortality and the developments in the housing market around epidemics.

Our contribution is straightforward. First, we measure the impact of epidemics on aggregate house prices and rental prices over time. We find that epidemics result in significant declines in house prices and smaller responses in rent prices. House prices fall by about 5% per year until one year after the end of the epidemic, while we find declines of about 2% per year for rent prices. Second, we exploit transaction-level data for Amsterdam to study the immediate response of house prices to the outbreak of an epidemic. Controlling for annual price trends, we find that properties transacted within six months after the outbreak of an epidemic realize about 13% lower prices. Third, we study whether heavily affected neighborhoods experience worse price declines than other neighborhoods, using cholera outbreaks in 1832 and 1849 in Paris. We find that a doubling of cholera mortality reduces neighborhood-level house price growth following the epidemic by about 10%, but that this decline reverses quickly. In line with our aggregate findings, the impacts on rent prices are much smaller.

Our findings are consistent with asset pricing models where housing is priced by discounting future expected rents with the safe rate and a risk premium that is governed by the level of risk aversion. Rents are set by the supply and demand for urban housing space, while house prices also incorporate the demand for capital and risk.[1] We deem a standard asset pricing model for housing appropriate because buy-to-let investors owned most properties in both cities.[2]

We hypothesize that the outbreak of deadly epidemics causes enormous economic uncertainty for exposed individuals and that this results in increased risk aversion and, correspondingly, significantly reduces property prices. Existing literature has shown that exposure to major natural disasters (Cameron and Shah, 2015; Goetzmann et al., 2016) or violence (Callen et al., 2014) can result in increased risk aversion or pessimism, and epidemics might have similar consequences. Although we cannot go back in the minds of 17th- and 19th-century property investors to determine what exactly causes shifts in risk aversion, existing literature suggests several channels.

First, changes in wealth or expected income triggered by epidemics could increase risk aversion, such as in the canonical model of Campbell and Cochrane (1999). The prospect of uncertainty in future income can generate similar increases in risk aversion (e.g. Guiso and Paiella, 2008). Second, theoretical and empirical work shows that when risks are salient, and when events trigger negative emotions, risk aversion can temporarily increase

[1] Contrary to modern rental markets, there was limited government interference in the pricing of rental housing before 1900.

[2] In Amsterdam, about 85% of housing units were buy-to-let (Korevaar, 2020). In Paris, this number was above 82% (Kesztenbaum and Rosenthal, 2017). For Paris, the evidence also suggests that home-owners typically did not live in or near the buildings they rented out.

significantly (e.g. Loewenstein, 2000; Bordalo et al., 2012; Cohn et al., 2015; Guiso et al., 2018), and affect risk perception (Slovic et al., 2007). Historical descriptions confirm the picture that the epidemics we study often went hand-in-hand with fear and significant uncertainty. Additionally, the loss of tenants and rental income due to epidemics might make the risks of housing investments more salient to investors, even if the actual losses were small and temporary. This channel could also potentially explain why house prices decline more in profoundly affected areas, even if landlords lived elsewhere.

Despite the sizeable short term declines in property prices, we also find that house price growth quickly returned to normal, and that rent prices did not respond strongly to outbreaks in general. We argue this results from the fact that population losses due to epidemics were quickly compensated by increasing migration, despite both cities being relatively more affected by these pandemics than the general population. As a result, the demand for housing consumption was not strongly affected by the epidemics. Most stunningly, Amsterdam experienced its 'Golden Age' during the century when plagues regularly wiped out a big part of its population.

This finding links to an extensive literature on the impact of large urban shocks on subsequent urban development. Various papers have documented that cities tend to be very resilient to large urban shocks and that their effects tend to be transitory, in line with our findings. The most prominent examples study warfare and urban bombing (Davis and Weinstein, 2002; Brakman et al., 2004; Miguel and Roland, 2011; Sanso-Navarro et al., 2015). A closer comparison might be the work of Hornbeck and Keniston (2017) on the Great Boston Fire in 1872. They find that the Fire had positive consequences on the growth of the city, because they allowed for significant reconstruction, increasing the quality of the housing stock and significantly increasing land values. In a similar spirit, the outbreak of cholera in Paris paved the way for significant urban redevelopment, as the outbreak made citizens realize that the clogged and dense streets of Paris were catalysts of epidemic disasters.

Finally, our paper closely links to two papers that directly study the impact of epidemics on property markets. Ambrus et al. (2020) exploit the Broad Street cholera outbreak in London in 1854 to study its long-term consequences on rental prices and urban poverty. The highly local nature of the outbreak provides for precise identification, and they show the epidemic persistently lowered rental prices in the areas affected by the outbreak. Wong (2008) studies the impact of the 2003 SARS outbreak in Hong Kong on local house prices. She finds that the outbreak caused a small decline in property prices of about 1.5%.

Our study differs from these papers in three essential ways. First, we study epidemics that had wide-ranging consequences for the entire urban economy and housing market. They affected the entire population rather than a single neighborhood (Ambrus et al., 2020), and beyond their more substantial death toll, these epidemics likely distorted the economy more significantly than the SARS epidemic in Hong Kong (Wong, 2008). This difference in epidemic intensity could explain why we find much more significant effects on prices than in Wong (2008). Second, rather than confining ourselves to a single episode, we study multiple epidemics both in the cross-section and over time. Finally, we study changes in both rental prices and house prices. Rent prices primarily reflect the local demand for housing, whereas investment demand also influences house prices.

Relative to Ambrus et al. (2020), we do not find that cholera outbreaks led to persistent declines in relative property values. In 1854 London, the cholera outbreak was confined to a single neighborhood, and it did not result in large changes in infrastructure or housing construction. As a result, the negative impact of the cholera income shock persisted over time. In Paris, the outbreak affected the entire city, and similar to Hornbeck and Keniston (2017), it triggered significant changes in the future structure of the city and improvements of its neighborhoods. Because these renovations improved local amenities, they likely went hand in hand with increased property prices. These findings highlight the importance of policy responses to major urban shocks: the cholera epidemic in Paris was a catalyst for urban redevelopment. In contrast, the London epidemic did not do so and created a pocket of poverty in the affected neighborhood.

We proceed with this paper as follows. Section 1 introduces the data sources. In Section 2, we present a descriptive overview of the outbreaks of plague in Amsterdam and cholera in Paris. Section 3 presents our empirical strategy and the results of these analyses. We end the paper with a conclusion.

1 Data

To estimate changes in house values and volume, we gather data on sale and rent prices from administrative records. For Amsterdam, we use mandatory registrations of property purchases that were made by the local government, and stored in the Amsterdam city archives.[3] This data provides information on 158,757 house transactions between the late 16th century and 1811, with data or prices missing for most years in the 16th and early 17th century. These records include the street of each property, its transaction price, a brief description of the property, and the names of the buyer(s) and the seller(s). The data cover both foreclosure sales and regular sales. For our analysis, we use the repeat-sales pairs identified in Korevaar (2020). For rents, we use the existing index of Eichholtz et al. (2019).

For Paris, we use data from the sommier foncier. This government register served to check the veracity of property tax and estate tax payments and contains information on the universe of sale prices in Paris between 1809–1943, as well as data on the rent prices of these properties. Rent prices were either obtained from new rental contracts (1809–1859) or from the total rent, which was determined each time an individual inherited property. In total, we draw on a sample of 78,785 rent or sales prices, covering 17,300 properties. For details on sampling and data, we refer to Eichholtz et al. (2020). During the main epidemic, we estimate that our sample covers about 27% of the total number of transactions in Paris.

To obtain mortality data in Amsterdam, we use burial registers from parishes and cemeteries, available from the Amsterdam city archives.[4] The first of these registers date back to the 1550s. Because parish registers are missing in some periods, we construct relative estimates of mortality. We compute these by dividing per parish or cemetery in

[3] "Transportakten." https://archief.amsterdam/uitleg/indexen/33-kwijtscheldingen-voor-1811.
[4] "Indexen", https://archief.amsterdam/indexen/persons.

each month and year the number of deaths relative to the preceding and following five years. To aggregate data into a single statistic, we take the average of all parishes and cemeteries, weighted by the number of deaths in each parish or cemetery. To convert these into approximate death rates, we use mortality rates reported in Van Leeuwen and Oeppen (1993) for the late 17th century, which we extrapolate using our relative mortality measure.

Data on plague outbreaks in the Dutch Republic in this period come from the seminal work by Noordegraaf and Valk (1996). They list each year for which historical sources mention plague outbreaks in Amsterdam, but they do not provide information on the severity and the exact timing of the outbreaks. In our analysis, we consider two measures. At the annual level, we define an entire year to be plague year if annual excess mortality is higher than 25% and Noordegraaf and Valk mention a plague year. To be more precise about the start of plague outbreaks, we construct a monthly measure. We define the start of a plague epidemic if, for the first time, excess mortality in a given month exceeds 100%, and Noordegraaf and Valk mention a plague outbreak in the same year. We count epidemics that last for more than a year only in the month of the first outbreak.

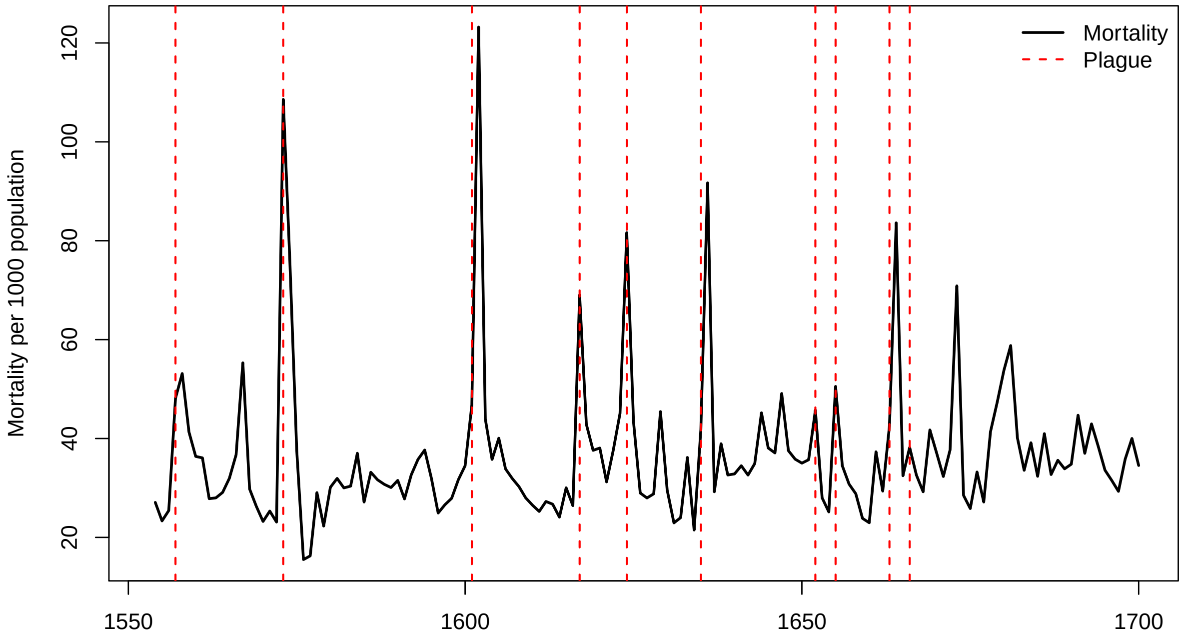
For Paris, we take data on neighborhood-level mortality of the 1832 and 1849 epidemic from the official government reports of the epidemic Administration Générale de l'Assistance Publique (1850); De Châteauneuf (1834). We digitize this data and match it to the addresses of the properties in the sommier foncier. To adjust for streets that changed names over time, we verify our estimates with the street atlas of Lazare (1844).

2 Historical background

2.1 Plague in Amsterdam

In the 16th and 17th centuries, outbreaks of plague frequently ravaged Amsterdam. Figure 1 plots the estimated evolution of annual mortality in Amsterdam between 1554 and 1700. Nearly all major spikes in annual mortality coincide with the eight different periods we identified as major plague epidemics.[5] Major plague epidemics were deadly: the largest epidemics wiped out over 10% of the total population. Potentially, this number is even higher due to the under-registration of deaths during the most severe outbreaks (Noordegraaf and Valk, 1996). The three main other mortality spikes coincide with famine (1566, Kuttner et al., 1949), major war and potential other epidemics (1673, Brouwer, 2014) and outbreaks of malaria and other infectious diseases (1679–1680, Curtis, 2016). After a final minor outbreak in 1666, plague epidemics did not return to Amsterdam.

Figure 1: Mortality per 1000 inhabitants



Notes: These figures plot the estimated total mortality per 1000 inhabitants in Amsterdam. The dashed line represents the starting year of an identified plague epidemic.

Plague epidemics were not specific to Amsterdam, and often ravaged other parts of the Dutch Republic and Europe at about the same time (Alfani, 2013). Although it is hard to compare mortality estimates over time and across space, it seems that the plague affected Amsterdam more heavily than other places in the Dutch Republic. Relative to the figures reported for a more extensive set of localities in the Dutch Republic (Curtis, 2016), we find higher relative mortality in Amsterdam.

Within Amsterdam, it is not entirely clear whether the plague affected some groups more than others. On the one hand, many contemporaries and historical writers note

[5]Epidemics started in 1557, 1573, 1601, 1617, 1624, 1635, 1652, 1655, 1663, and 1666.

that the plague was a universal killer, both in terms of age and social status. On the other hand, it seems likely that the plague spread more quickly in poor neighborhoods because the urban poor lived closely-packed together (Noordegraaf and Valk, 1996). However, we lack detailed statistics to back up these claims, and the historical evidence for other countries is divided as well (Alfani and Murphy, 2017).

It is undoubtedly clear though that the plague resulted in widespread death and despair, and also affected the economy. Noordegraaf and Valk (1996) cite dozens such examples, and we will name a few here. For example, the Amsterdam plague law of 1558 prohibited people from visiting markets, inns, and churches during epidemics, as well as any other place where many people gathered. In some cases, the government even announced movement restrictions around outbreaks. After the 1617 epidemic, owners of inns complained that they lost most of their income because travelers avoided the city due to the epidemic. In the 1635 epidemic, Amsterdam merchants halted all orders from the textile industry in Leiden because they were afraid of the spread of the plague. In Hoorn, a town nearby Amsterdam, a chronicler wrote in 1656 that "all businesses and artisans have shut down by now, and people have not much else to do than to help the sick." The plague impacted the housing market as well, both due to mortality and because many individuals fled Amsterdam during outbreaks. In historical work on the Amsterdam rental market, Lesger (1986) already suggested that rental prices declined during plague outbreaks.

On the other hand, the frequent plague outbreaks do not seem to have prevented Amsterdam's growth over the longer term. Between the late 16th century and the late 1660s, the period of the most severe epidemics, Amsterdam rose to prominence and established itself as the merchant capital of the world. Its population rose from about 30,000 in the 1580s to over 200,000 in the 1660s, and in their landmark work on the Dutch economy, De Vries and Van der Woude (1997) classified this period as the "first round of modern economic growth." So while plague outbreaks ravaged the city over the shorter-term, migration towards Amsterdam stayed very high, resulting in significant population growth over time (Nusteling, 1985).

2.2 Cholera in Paris

Cholera arrived in Paris for the first time in March 1832, when the first cases were reported and transmitted to the Hotel-Dieu, Paris's main hospital. Although cholera had broken out already in other parts of the world, the outbreak came unexpectedly. As late as 1831, the famous French doctor Baron de Larrey (1831) wrote that "the topographic situation of France is so advantageous, that there is little reason to worry about the introduction of cholera-morbus in this country." However, within a month of the outbreak in March, the 'cholera-morbus' killed over 11,500 people in the city. The total death count of the epidemic amounted to more than 18,500 people or about 2.5% of the total population. It took until March 1849 for the second epidemic to arrive. Although the outbreak spread less quickly than the initial epidemic in 1832, by the end of the epidemic in September 1849, over 15,000 people had died, 1.5% of the total population.

The epidemics happened in what were already turbulent times. Both epidemics followed relatively quickly after the revolutions of February 1848 and July 1830, which overturned the government. Among the most vivid descriptions of the 1832 epidemic is that of German writer Heinrich Heine.[6] On the one hand, he describes the epidemic left the city in a quiet state of despair. On the other hand, with the revolution in recent memory, stories went around quickly that the government had poisoned wells, fueling a rebellion in 1832 prominently described in Victor Hugo's Les Miserables. However, in the same book Hugo also writes that cholera "had been chilling all minds for the last three months and had cast over (the revolutionaries) agitation an indescribable and gloomy pacification".

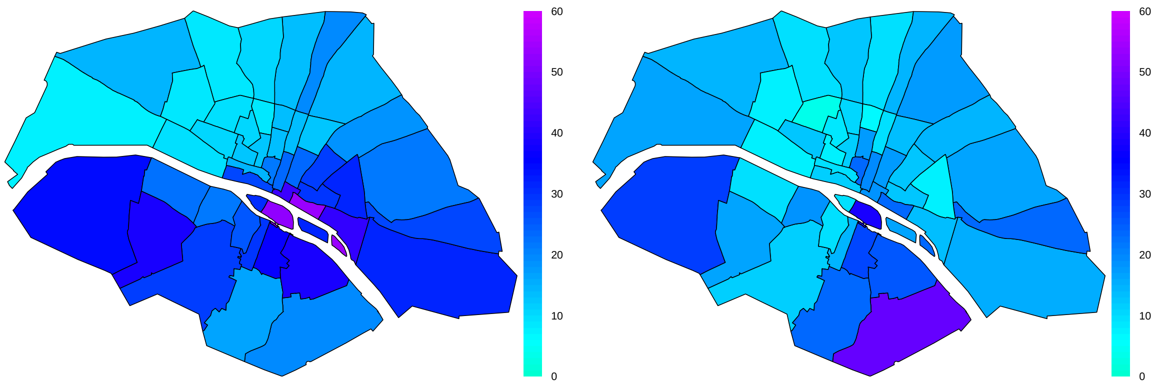
Beyond the revolutionary spirit of the French, the spatial distribution of cholera mortality likely also contributed to these tensions. Building on the figures reported in the official government reports about the epidemics, Administration Générale de l'Assistance Publique (1850) and De Châteauneuf (1834), Figure 2 reports the mortality per neighborhood in Paris during both epidemics.

Although cholera affected people of all ages and classes, the first outbreak of cholera,

[6]"Französische Zustände, Artikel VI", April 1832: http://www.heinrich-heine-denkmal.de/heine-texte/fr-zst06.shtml.

visible in Panel 2a, primarily affected the most central areas of the city around the Hotel de Ville, where more than 5% of the total population died. In these areas, the working class lived in a maze of narrow streets and over-populated, unhealthy homes (Le Mée, 1998). Even in better neighborhoods, the most impoverished alleys and streets were most affected.

Figure 2: Cholera Mortality per 1000 inhabitants.



(a) Paris, 1832 (b) Paris, 1849

Notes: These figures plot the cholera mortality per 1000 inhabitants in Paris. In both epidemics, in each neighbourhood 1 to 6 percent of population died. Boundaries are based on Vasserot quartiers. The correlation in neighbourhood mortality between epidemics is 0.5.

The government recognized that there existed a close link between poor and dense neighborhoods and cholera mortality, although, unaware of the exact cause of cholera, they primarily believed such poor neighborhoods favored the development of miasmas (De Châteauneuf, 1834). Nevertheless, when Count de Rambuteau came to power in Paris in 1833, he proclaimed that his mission was to provide "air, water and shadow" to all citizens in Paris, and started clearing unhealthy housing in the worst-affected central areas of the city, as well as introducing public urinals to improve sanitation. This was highly needed: despite the epidemics, population and population density kept growing. Between 1831 and 1836, the Paris population grew by 14%, and except for a brief spell around the 1849 epidemic and the 1848 Revolution, Paris's population grew the entire 19th century.

The epidemic in 1849 confirmed the validity of Rambuteau's approach: mortality levels were still much higher in the working-class areas in the cities on the left bank but had gone down in the historical city center (Panel 2b, where much of the slum housing had been cleared (Le Mée, 1998). This confirmation paved the way for massive renovations: the Hausmann renovations that took place in the late 1850s and 1860s destroyed a large part of the unhealthy medieval Paris and gave Paris the image it still has today.

3 Analysis

3.1 Epidemics and Aggregate Price Changes

To provide a starting point for our principal analysis, we describe how rent and house price growth evolved around the epidemics that we study, combining data from existing house and rent price indices for Paris and Amsterdam.[7] They are based on the same repeat-sales methodology that we use later in our analysis. The rent price indices cover 12 epidemics lasting together 17 years, and the house price indices cover eight epidemics lasting together ten years. The house price indices cover a smaller period because insufficient data is available to estimate an index before 1620.

We plot theses indices in Figure 3, together with dashed vertical lines representing the starting dates of epidemics. In most cases, epidemics coincided with falling house prices, but this pattern seems less consistent for rent prices.

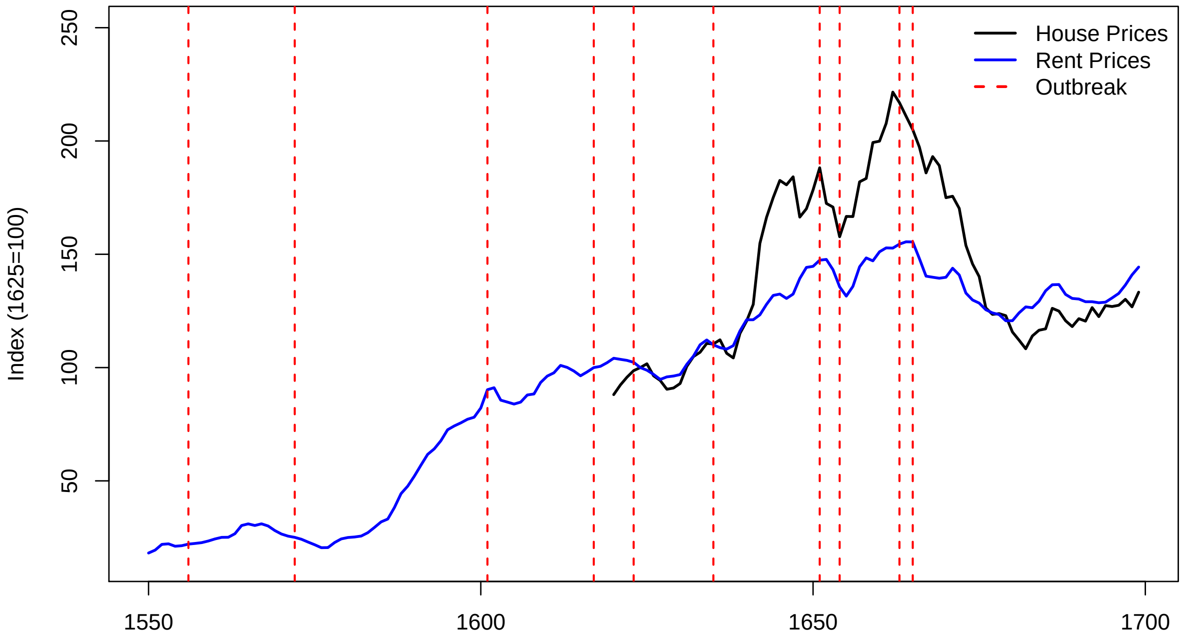
To investigate more formally whether outbreaks caused property or rent price to decline, we estimate the following regression separately for rents and house prices:

$$\mu_{j,t} - \mu_{j,t-1} = \alpha_j + Epidemic_{j,t} + Epidemic_{j,t-1} + x'_{j,t}\beta + \varepsilon_{j,t}, \tag{1}$$

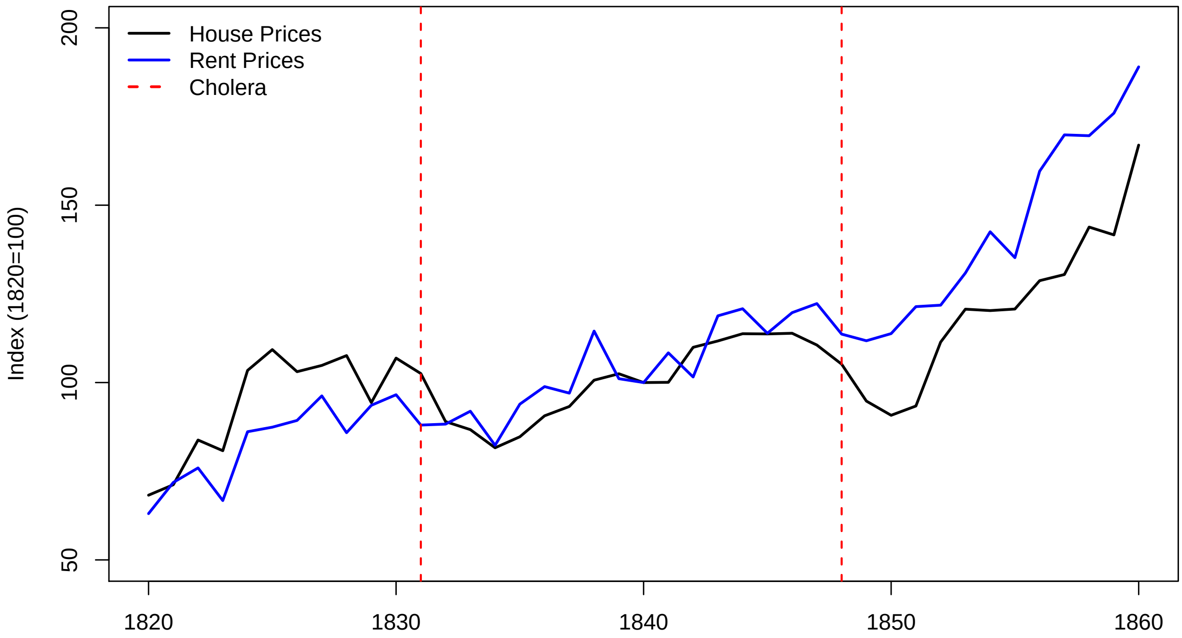
where $\mu_{j,t}$ denotes the log rent or house price index in city j at time t. $Epidemic_{j,t}$ is a dummy variable that takes the value of 1 if in a particular year there is a severe epidemic of cholera or plague. $Epidemic_{j,t-1}$ is a dummy variable that takes the value of one in the year immediately following the final year of an epidemic. α_j is a city fixed effect and $x_{j,t}$ a vector of control variables. As controls, we will use changes in consumer prices, wages

[7] These are from Eichholtz et al. (2019) for Amsterdam and Paris housing rents and for house prices from (Eichholtz et al., 2020, Paris) and (Francke and Korevaar, 2019, Amsterdam).

Figure 3: Housing Prices and Rents around Epidemics.



(a) Amsterdam



(b) Paris

Notes: These figures plot the evolution of house pries and rents in both Paris and Amsterdam, in the time periods surrounding the epidemics. The dashed line reflects the level of house prices or rents just prior to the outbreak. In all but one case, house prices decline following an epidemic. For rent prices, the pattern is less pronounced.

and interest rates.[8] We will also consider a model where we control for rent price growth

[8]Data on controls come from Eichholtz et al. (2020) and Francke and Korevaar (2019).

in the three years around an epidemic, to detect potentially unobserved time trends. For each city, we only include data between 10 years before the first epidemic (if available), and 10 years after the final epidemic. Figure 1 reports the outcome of these regressions.

Table 1: House Prices and Rents in Epidemics.

	Dependent variable:					
	Δp_t	Δr_t	Δp_t	Δr_t	Δp_t	Δr_t
Epidemic_{t+3}					-0.029	0.008
					(0.033)	(0.010)
Epidemic_{t+2}					0.029	-0.00000
					(0.025)	(0.012)
Epidemic_{t+1}					-0.008	-0.006
					(0.022)	(0.016)
Epidemic_{t}	-0.055^{**}	-0.029^{***}	-0.061^{*}	-0.018^{*}	-0.064^{*}	-0.023^{**}
	(0.027)	(0.008)	(0.034)	(0.011)	(0.034)	(0.011)
Epidemic_{t-1}	-0.041^{***}	-0.024^{*}	-0.056^{***}	-0.022^{**}	-0.061^{***}	-0.025^{**}
	(0.012)	(0.012)	(0.016)	(0.010)	(0.016)	(0.011)
Epidemic_{t-2}					-0.038	-0.031
					(0.031)	(0.024)
Epidemic_{t-3}					0.023	-0.007
					(0.028)	(0.022)
Controls	No	No	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Observations	104	174	104	128	104	128
R^2	0.063	0.022	0.167	0.084	0.218	0.098
Adjusted R^2	0.044	0.011	0.116	0.038	0.124	0.013
Residual Std. Error	0.067	0.065	0.065	0.066	0.064	0.067
F Statistic	3.381	1.924	3.245	1.842	2.330	1.149
Note:				*p<0.1; **p<0.05; ***p<0.01		

For house prices, we document a reduction in house prices of about 5.5% per year during an epidemic (Column 1). After an epidemic, prices fall by another 4.1%. For rental prices, the effects are substantially smaller, with rent prices falling by 2.9% during an epidemic and another 2.4% when an epidemic ends (Column 2). These effects are robust to the inclusion of control variables. We also do not find any significant deviations in house or rent price growth from their average level before an outbreak. This is in line with our assumption that outbreaks were exogenous to the state of the housing market.

Our results indicate that the epidemics we study typically did not coincide with major housing market disasters, despite killing several percents of the total population. While prices were falling during epidemics, these price falls were rather short-lived: house price growth quickly returned to its historical average. The historical evolution of Amsterdam and Paris confirms their resilience to these major epidemic disasters. In the decades around the epidemics, annualized population growth rates were in both cities in the range of 1.5 to 2.5 percent per year. Citizens that died were quickly replaced by new migrants, limiting reductions in housing demand. As a result, real house prices and rents grew in the decades around the epidemic by almost one percent per year—significantly above their historical average.

So our first conclusion from this aggregate analysis is that epidemics lower prices, but that price growth quickly returns to its long-term trend. In both Paris and Amsterdam, the epidemics did not cause a fundamental break to the positive population growth trajectories of these cities, and the corresponding growing demand for housing.

There are limitations to this analysis. First, because the indices are in some years based on a small number of observations, measurement error could be affecting the significance and magnitude of our results. A related limitation is that other economic trends around epidemics explaining part of the effect since the number of epidemics is still small in absolute terms.

We deal with these issues in two ways. First, we exploit differences in the exact timing of the arrival of the plague in Amsterdam. Relative to Paris, our data for Amsterdam contains more epidemics and more transactions around these epidemics. Controlling for all annual time trends, we aim to identify whether the arrival of plague results in significant price distortion in the first six months following the start of the outbreak. Thus, our identifying assumption is that the outbreak of a major plague epidemic dominated all other underlying trends happening *within a year*. This assumption seems consistent with the anecdotal historical evidence that we have.

For Paris, we exploit cross-sectional differences in the severity of the cholera outbreak to study whether more- or less-affected neighborhoods experienced different trajectories in rental and housing prices directly after the outbreak. While aggregate economic changes such as the 1830 and 1848 revolutions might have affected the entire city, it seems less plausible that they still caused different effects on property prices or rents in neighborhoods more or less affected by cholera.

3.2 Short-Term Price Responses in Amsterdam

To estimate the short-term impact of the plague on house prices we estimate a modified version of the repeat sales model (Bailey et al., 1963). The repeat sales model is given by

$$\ln P_{i,t} - \ln P_{i,s} = \begin{pmatrix} 0 \cdots 0 & f_{i,s} & 1 \cdots 1 & f_{i,t} & 0 \cdots 0 \end{pmatrix} \delta + (x_{i,t} - x_{i,s})'\beta + \varepsilon_{i,t} - \varepsilon_{i,s}. \quad (2)$$

The left-hand-side is the difference in log prices at the time of sale t and purchase s for house i. We specify the annual log index returns by the vector $\delta = (\delta_1 \cdots \delta_T)'$, where T is the number of years. We use a time-weighted version of the repeat sales model; the year dummy variables are replaced by a fractional value ($f_{i,s}$ and $f_{i,t}$) between 0 and 1, corresponding to the proportion of the year during which the property was "held" (Geltner, 1997). The error terms $\varepsilon_{i,t}$ are independently and normally distributed with zero mean and variance σ_ε^2. In order to reduce the impact of noise, we assume that the log index returns are normally distributed with mean zero and variance σ_δ^2 (see for more details: Goetzmann, 1992; Francke, 2010). The price log index at time t is denoted by μ_t and is given by $\delta_1 + \cdots + \delta_t$. The vector $x_{i,t}$ contains month dummy variables to deal with seasonal effects. Most importantly, this vector contains the variables of interest related to the plague. The dummy variable Plague is equal to 1 when in the six months prior to the transaction date, a plague epidemic has started. The 6 and 12 months lagged variables are denoted by Plague.L6M and Plague.L12M.[9]

As a robustness check, we use a hedonic price model (Rosen, 1974), given by

$$\ln P_{i,t} = \alpha + \mu_t + x_{i,t}'\beta + \varepsilon_{i,t}, \quad (3)$$

[9]Conditional on the variances $(\sigma_\varepsilon^2, \sigma_\delta^2)$ the time-weighted repeat sales model (2) can be estimated by generalized least squares. The variance parameters are estimated by maximum likelihood (see for more details Francke, 2010).

where μ_t is the log price index, $x_{i,t}$ is a vector of control variables, and $\varepsilon_{i,t}$ is the error term with zero mean and variance σ_ϵ^2. As we do not have detailed property information, we include street fixed effects (1521 streets). We have information on transaction type (four different types) and some crude descriptions of the property, like the presence of a building, a garden, a shop, etcetera. In total, we have 25 property related dummy variables. We use identical variables for the plague as in the repeat sales model.

Table 2 presents estimation results from the repeat sales and hedonic price model. Our sample covers seven plague outbreaks in 1601, 1617, 1624, 1635, 1652, 1655, and 1663. In the repeat sales (hedonic price) sample, 191 (1003) sales have a plague outbreak in the six months preceding the sale date. In the repeat sales model, we find a negative short-term effect of the plague on house prices of minus 13%, see Column 1. If we do add lags of the plague variable (see Columns 2 and 3), this result is similar. Moreover, the coefficients for the lagged variables are not significant at the 5% level.[10] The results for the plague variables in the hedonic price model (Columns 4 to 6) are comparable to the ones in the repeat sales model, about minus 9%, although they are only statistically significant at the 10% level. We can conclude that there is an immediate effect of around minus 13% in the first six months after the start of the plague. In later months the effect is negligible or even positive.

3.3 Neighbourhood Price Responses in Paris

For Paris, we estimate a modified version of Eq. (2), focusing both on developments in house rents and prices. The idea of this model is to compare house prices and rents in neighborhoods more or less affected by cholera, controlling for aggregate annual price trends. Next to the vector of annual time dummy variables (d_1 with elements -1, 0, and 1), we therefore also compute per repeat pair a vector of bi-annual time dummy variables (d_2 with elements -1, 0, and 1) and multiply these by the log cholera mortality

[10] Our results on the effect of the plague variables are robust to various specifications: The inclusion of a constant in the repeat sales model (Goetzmann and Spiegel, 1995), the inclusion of property-specific random walks, replacing the variance of the error term by $\sigma_\varepsilon^2 + (t_i - s_i)\sigma_\eta^2$ (Case and Shiller, 1987, 1989), and the exclusion of the prior for the log index returns, leading to the standard repeat sales model with time fixed effects.

Table 2: Estimation results from the repeat sales and hedonic price model for Amsterdam.

	Repeat Sales Model			Hedonic Price Model		
	(1)	(2)	(3)	(4)	(5)	(6)
Plague	-0.134***	-0.134**	-0.121**	-0.085*	-0.088*	-0.088*
	(0.0439)	(0.0454)	(0.0459)	(0.0436)	-0.0463	-0.0506
Plague.L6M		0.0019	0.0197		-0.0086	-0.0095
		(0.0368)	(0.0379)		-0.0458	-0.0559
Plague.L12M			0.0858*			-0.0012
			(0.0439)			-0.0467
Adj. R^2	0.6957	0.6957	0.6958	0.5161	0.5161	0.5161
σ_ε	0.3804	0.3804	0.3804	0.8270	0.8270	0.8270
σ_δ	0.0693	0.0694	0.0693			
Plague		191			1003	
Plague.L6M		333			1105	
Plague.L12M		208			802	
Constant		No			Yes	
Year FE					Yes	
Month FE		Yes			Yes	
Street FE		No			Yes	
Controls		No			Yes	
Observations		39,281			133,123	
Sample Period		1602 - 1811			1601 - 1811	

Note: *p<0.1; **p<0.05; ***p<0.01.

in the neighborhood j in which property i is located ($\ln MortalityQ$).[11] We estimate the following regression equation:

$$\ln P_{i,j,t} - \ln P_{i,j,s} = d'_{1,i}\ \mu + d'_{2,i} \times \ln MortalityQ_j\ \beta + \varepsilon_{i,t} - \varepsilon_{i,s}. \tag{4}$$

For additional precision, the two-year time dummy variables each cover the period from the 1st of April to the 31st of March in two years from now, because both cholera outbreaks started around the end of March. We estimate these models separately using 1832 neighborhood mortality and 1849 neighborhood mortality, and for rent prices and house prices. To maximize the number of repeat-sales and rents, we estimate the model on the entire period before World War I.[12] Figure 4 presents the results of this analysis. For brevity, we omit the period after 1860 in the output. Summary statistics on these regressions can be found in the Appendix, Table 3.

Panel 4a plots the evolution of house prices in high relative to low mortality neighborhoods over time, both using log 1832 mortality and log 1849 mortality. Because mortality correlated across the two periods, the coefficients evolve similarly over time. If we focus on neighborhoods with high mortality in 1832, we observe these on average had an insignificantly higher price appreciation in the years leading to the epidemic. Relative to low-mortality areas in 1820, areas with a mortality rate twice as high had 4.4% higher market prices in 1832, just before the outbreak.[13]

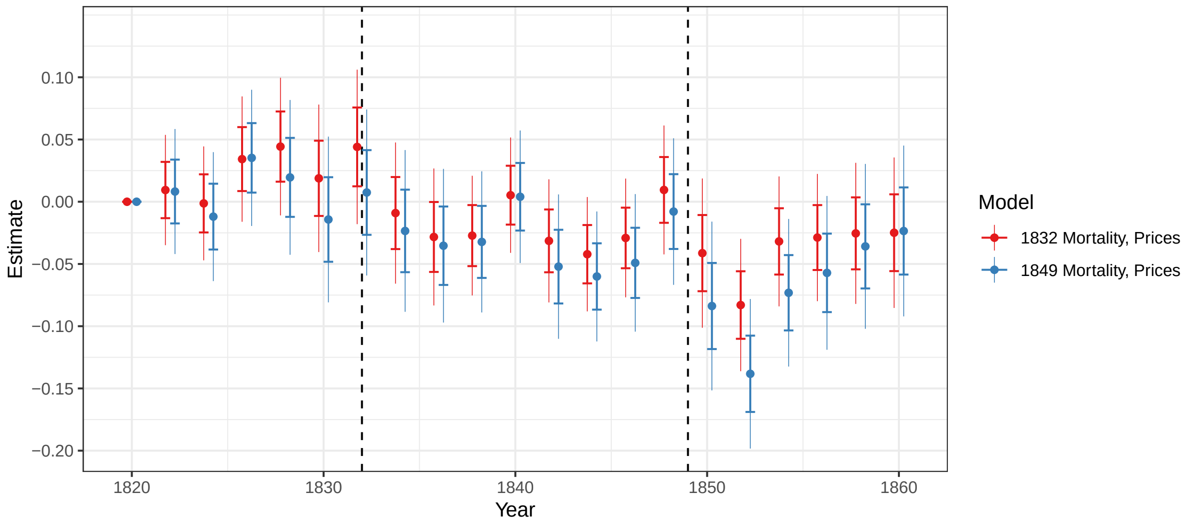
However, 1832 marks a first sharp trend break in the data: between 1832 and 1836, high-mortality areas fall significantly in prices relative to low-mortality areas, with a relative price drop of 7.3%. Reassuringly, this drop is more significant in areas profoundly affected by cholera in 1832 compared to 1849. Until the mid-1840s, house prices between high and low mortality areas remain at relatively stable levels, except for a slight but

[11] Instead of using fractional time dummies, as in Equation 2, we now use the standard model with time fixed effects. We use bi-annual dummies because we have an insufficient number of observations to compute these coefficients precisely at annual level.

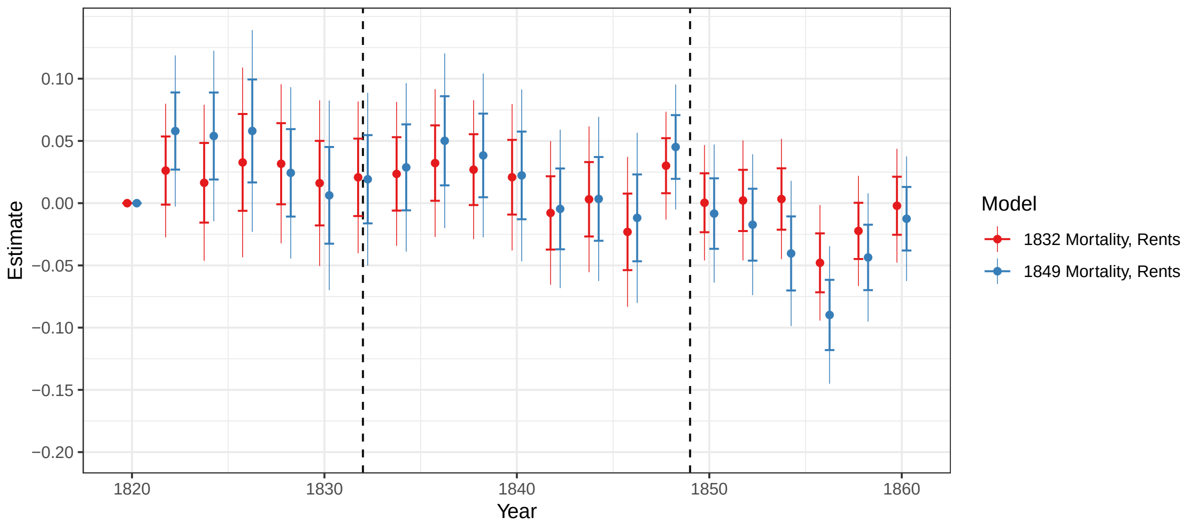
[12] We exclude the period after 1913 because of data complications and strict government controls, see Eichholtz et al. (2020).

[13] This is consistent with the enormous increases in the residential crowding for the working-class population in central Paris, and the fact that most construction in the 1820s housing boom focused on housing in more expensive areas (Green, 1990).

Figure 4: Price-Variation in Neighbourhoods by Cholera Mortality.



(a) House Prices



(b) Rent Prices

Notes: These figures plot the bi-annual estimates of the coefficient on log neighbourhood mortality for every two years, both for rent prices and sales prices, and for the 1832 cholera mortality and the 1849 cholera mortality. A coefficient of 0.1 implies that in the year of observation a neighbourhood had 10% higher prices compared to a neighbourhood with half its cholera mortality, relative to the base year of 1820. Thick bars are White standard errors, thin bars are 95% confidence intervals based on these errors.

insignificant jump in 1840.

Moving to 1849 mortality, we find that relative prices in high-mortality areas in the late 1840s are on a weakly significant upward trend, ruling out that prices were already significantly falling before the cholera outbreak. After 1848, we find sharp drops in property prices, with prices in high-mortality areas are falling by significantly more than prices in low-mortality areas, with an additional drop of 13% between 1848 and 1852.

Again, it is reassuring that the price-effect is more substantial for neighborhoods heavily hit by the 1849 outbreak, relative to the 1832 outbreak. However, prices also bounce back quickly, with no significant differences anymore after 1860.[14]

Moving on to rents, we find no significant patterns at all around the 1832 epidemics. Rent prices do fall more in high-mortality areas following the 1849 epidemic, but this effect is again weaker than for house prices. It also appears that the most significant fall in rent prices happens only five years after the outbreak. There are two potential reasons for this finding. First, most of our rent data is not based on new leases but based on current rent payments. Because rent prices are sticky, and Parisian contracts were often multiyear contracts,[15] rent prices had less room to adjust quickly. Second, population growth remained very high around the 1832 epidemic, with population growing by 14.4% between 1831 and 1846, while it temporarily stagnated around the 1849 epidemic. So around the 1832 epidemic, reductions in rental housing demand were quickly offset by a flow of new migrants.

The limited response of rent prices relative to house prices, as well as the significant but short-lived declines in house prices in heavier-affected neighborhoods, are in line with the increases in risk aversion during outbreaks that we have highlighted in the introduction. Property-owners in heavily affected areas are more exposed to the outbreak, either because they live nearby or because they experience a significant turnover of renters and might thus have larger responses in their property valuations.

4 Conclusion

This paper documents that major epidemics cause significant but short-lived declines in house prices, and have only small effects on rent prices. These effects are most substantial just after the outbreak of an epidemic and in the most-affected areas. For house prices, we interpret our findings in the context of a standard asset pricing model, where epidemics temporarily increase risk aversion, resulting in increasing risk premia and lowering house

[14] We find that this pattern also persists after 1860.

[15] Contracts of three, six or nine years were standard.

prices. We attribute the limited responses of rent prices, and the short nature of property prices, to the resilience of cities to major shocks. In both Paris and Amsterdam, the outbreaks did not stop a massive flow of migrants from coming to the city. In Paris, the epidemic even proved to be a catalyst for significant urban change. So in today's era, where housing shortages increasingly put urban housing affordability under strain, epidemics are unlikely to bring any structural relief.

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A Supplementary Tables

Table 3: Summary Statistics Neighbourhood Regressions

	Dependent variable:			
	Δp_t		Δr_t	
	(1)	(2)	(3)	(4)
Model:				
log 1832 Mortality $\times$ d_2	Yes	No	Yes	No
log 1849 Mortality $\times$ d_2	No	Yes	No	Yes
Annual Time Dummies (d_1)	Yes	Yes	Yes	Yes
Estimation Period	1809–1913			
Observations	9,246	9,246	10,927	10,927
R^2	0.240	0.240	0.336	0.339
Adjusted R^2	0.227	0.227	0.327	0.329
Residual Std. Error	0.521	0.520	0.372	0.371
F Statistic	18.726	18.763	35.693	36.069

Notes: This table provides summary statistics for the regressions plotted in Figure 2, both for house prices (Columns 1 and 2) and rent prices (Columns 3 and 4).