Housing Markets in a Pandemic: Evidence from Historical Outbreaks

Marc Francke* Matthijs Korevaar†

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Abstract

How do pandemics affect urban housing markets? This paper studies historical outbreaks of the plague in 17th-century Amsterdam and cholera in 19th-century Paris to answer this question. Based on micro-level transaction data, we show outbreaks resulted in large declines in house prices, and smaller declines in rent prices. We find particularly large reductions in house prices during the first six months of an epidemic, and in heavily-affected areas. However, these price shocks were only transitory, and both cities quickly reverted to their initial price paths. Our findings suggest these two cities were very resilient to major shocks originating from epidemics.

*Amsterdam Business School, University of Amsterdam; Ortec Finance (email: m.k.francke@uva.nl)

†Corresponding author: Department of Finance, Maastricht University (email: m.korevaar@maastrichtuniversity.nl). *Acknowledgements:* We thank Bram van Besouw, Dorinth van Dijk, Martijn Dröes, Piet Eichholtz, Robert McClelland, Alex van de Minne, Paul Smeets, Niko Szumilo, Ronan Tallec, Patrick Tuijp, Aart de Vos and seminar participants at Maastricht University and the Virtual Real Estate Research Seminar for helpful comments and / or data. Korevaar has been financed by the Netherlands Organisation for Scientific Research under the Research Talent scheme (no. 406.16.552).

The recent outbreak of COVID-19 has brought the globalized world to a standstill, costing the lives of hundred-thousands of people and keeping millions in 'lockdown' in their homes. Although its economic effects are still unfolding, one of the many sectors that could be affected is the housing market.

Assessing the impact of epidemics on housing markets is challenging. While epidemics typically arrive exogenously, 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 is also difficult to separate causal effects from underlying time trends within a single epidemic.

In this paper, we exploit outbreaks of cholera in Paris (1832 and 1849) and the plague in Amsterdam (ten outbreaks, 16th-17th centuries) to study the impact of major epidemics on urban housing markets. Each of these outbreaks resulted in high mortality and significant economic disruption. Importantly, Amsterdam and Paris already had highly-developed housing markets, and unique micro-level data survived in the archives of both cities, allowing us to track mortality and the developments in the housing market following an epidemic. We focus on cholera and the plague, because the other two major pandemics for which we have data, the smallpox epidemic in the 1870s and the Spanish Flu in 1918, were directly linked to wars that also affected the housing market.

First, we find that after an outbreak aggregate house prices fell each year by about six percent until one year after an epidemic ended. We find the same pattern for rent prices, but these declined only by three percent per year. Next, 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 sold within six months after the outbreak of an epidemic realized about 13% lower prices. Third, we study whether heavily affected neighborhoods experienced worse price declines than other neighborhoods, using cholera outbreaks in 1832 and 1849 in Paris. We find that a doubling of cholera mortality reduced neighborhood-level house price growth following the epidemic by about ten percent, but that this decline reversed quickly. Again, the effects on rent prices were smaller.

Are these historical estimates still relevant today? On the one hand, these epidemics might be the closest comparison to the current situation in major cities. The pandemics we study resulted in a large number of deaths and caused major disruptions to economic activity. They happened in growing cities with a substantial flow of migrants and large buy-to-let property markets. On the other hand, today's urban economies are different from historical Amsterdam and Paris, and the current pandemic will almost certainly result in lower mortality rates than the pandemics we study. Because each epidemic and its context are different, it is difficult to extrapolate point estimates from previous outbreaks to the present. For example, for the less severe SARS outbreak in Hong Kong in 2003, Wong (2008) estimated a small house price decline of only 1.5 percent. Relative to Wong, we study multiple epidemics, which had more severe economic and demographic effects, and also consider rent prices.

Our paper highlights three important potential mechanisms in the response of urban housing markets to a major pandemic, which likely hold more generally. First, the large short-term impact of epidemics on house prices relative to rent prices suggests the demand for housing investment falls more than the demand for housing services (measured by rent prices). One channel through which this can happen is that epidemics temporarily increase risk aversion and corresponding risk premia, in line with literature on other disasters.[1] The fact that this increase is temporary could help to explain why prices fall more than rents in the short-term. Rent stickiness or uncertainty regarding future rent prices could play a role as well.

Second, we find that house and rent price growth quickly returned to their initial trends, implying Paris and Amsterdam were highly resilient to shocks caused by epidemics, despite being more affected than their national populations. One important reason is that population losses due to epidemics were quickly compensated

[1] 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. Epidemics might have similar consequences.

by increasing migration. As a result, the demand for housing consumption was not strongly affected by epidemics. This finding contributes to a literature documenting the resilience of large cities to major shocks. Existing work has focused on the physical destruction of cities due to bombing (Davis and Weinstein, 2002; Brakman et al., 2004; Miguel and Roland, 2011), general warfare (Sanso-Navarro et al., 2015), or city fires (Hornbeck and Keniston, 2017). Rather than destroying physical capital, pandemics result in significant losses to human capital: the death of a substantial part of the population.

Finally, the recovery of Parisian rent and house prices, even in heavily-affected neighborhoods that experienced large price drops, highlights the role of urban policy when cities are exposed to major shocks. In Paris, the outbreak of cholera proved to be a catalyst for significant urban redevelopment, as the outbreak made the government realize that the clogged and dense areas of Paris were detrimental to health. The government started significant urban renovations that improved local amenities, particularly in heavily affected areas. We find these coincided with recovering property prices. Hornbeck and Keniston (2017) suggest a similar mechanism. They find that the Great Boston Fire of 1872, which burnt down many old low-quality buildings, paved the way for a higher-quality housing stock, and accordingly increased land values. In related work, Ambrus et al. (2020) exploit the London Broad Street cholera outbreak in 1854 to show the epidemic created a pocket of poverty in the city, persistently lowering rents in the areas affected by the outbreak. This outbreak was confined to a single neighborhood, allowing for precise identification, but it did not result in large changes in infrastructure or housing construction. The different policy response to the London epidemic, or rather the lack of one, might explain why the findings of Ambrus et al. (2020) differ from those in our study and in Hornbeck and Keniston (2017).

1 Historical Background

1.1 Plague in Amsterdam

In the 16th and 17th centuries, outbreaks of plague frequently ravaged large parts of Europe (Alfani, 2013), and also hit Amsterdam. To obtain mortality data for Amsterdam in this period, we use burial registers from parishes and cemeteries provided to us by the Amsterdam city archives (from 1554). Because parish registers are missing in some periods, we construct relative estimates of mortality. We compute these by dividing per parish or cemetery in 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.

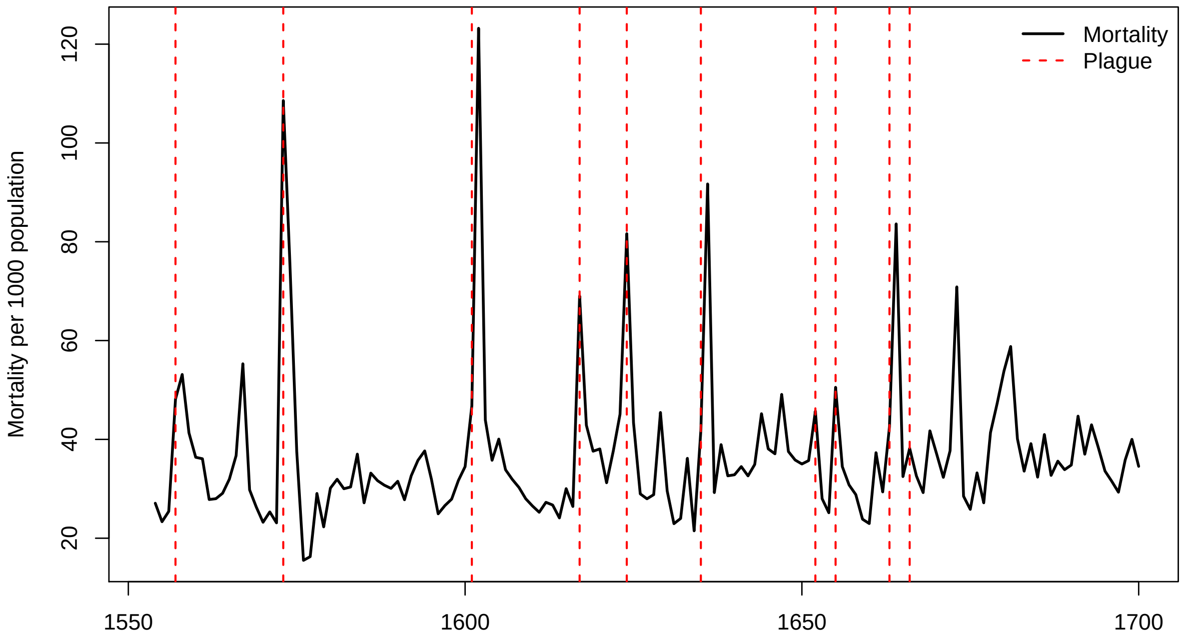
Data on plague outbreaks in Amsterdam comes from Noordegraaf and Valk (1996), which lists each year for which historical sources mention a plague outbreak. They do not provide information on the severity or timing of these. In this paper, we will use two mortality measures. At the annual level, we define a year to be a 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.

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 ten different periods we identified as major plague epidemics.[2] The duration of a plague outbreak varied between two months and two years, with an average of nine months. Major plague epidemics were deadly; the largest epidemics wiped out over ten percent of the total population. Potentially, this number is even higher due to the under-

[2]Based on our definition, epidemics started in 1557, 1573, 1601, 1617, 1624, 1635, 1652, 1655, 1663, and 1666. The 1666 epidemic was the smallest of these.

registration of deaths during severe outbreaks (Noordegraaf and Valk, 1996).

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. To convert these into approximate death rates, we extrapolated based on mortality rates reported in Van Leeuwen and Oeppen (1993) for the late 17th century.

These outbreaks often ravaged other parts of the Dutch Republic and Europe at the same time. 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 Low Countries (see Curtis, 2016). While people died of the plague across all classes, poor people were likely more affected. For example, during plague months relative mortality on the *Karthuizerkerkhof*, the cemetery in the poor Jordaan area, was about 50% higher than on other cemeteries, although this effect varied substantially across epidemics.

The Amsterdam plague outbreaks resulted in widespread death and despair, and also affected the economy. Mooij (2001) writes that during plague outbreaks "the merchant city became a ghost city: trade and business activity came to a halt, market squares were empty, and shops and workshops closed their doors." Sometimes this was the result of direct government interventions. Noordegraaf and Valk (1996) mention that the plague law of 1558 prohibited people from visiting markets, inns, churches, and other places where many people gathered. These had real economic consequences: Noordegraaf and Valk quote owners of inns who complained they lost most of their income because travelers avoided Amsterdam due to the epidemic. How large these impacts were is nonetheless hard to identify. With Amsterdam's economy build on trade, it seems unlikely interventions lasted very long. For example, De Vries (1981) writes that, to his surprise, passenger volumes on barges in Holland were barely affected in the years around epidemics.

1.2 Cholera in Paris

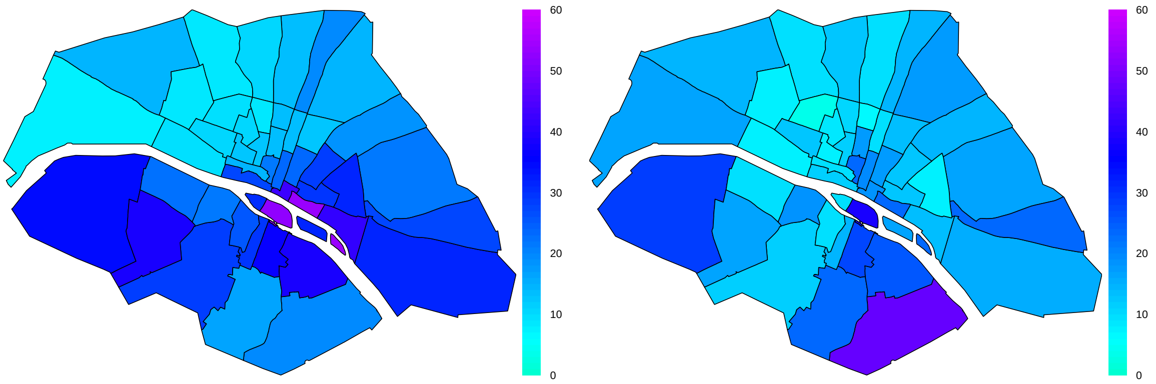
Cholera arrived in Paris for the first time in March 1832, and the outbreak came unexpectedly. As late as 1831, when cholera started breaking out all across Europe, the famous French doctor Baron de Larrey (1831) wrote that "the topographic situation of France is so advantageous, that there is little 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 percent 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 over 15,000 people had died, 1.5 percent of the total population.

Among the most vivid descriptions of the 1832 epidemic is that of German writer Heinrich Heine (1872). He describes the epidemic left the city in a quiet state of despair, with increased security measures and sanitary committees. But the epidemic also raised tensions across social classes, and stories went around quickly that the government had poisoned wells, fueling a rebellion in 1832 prominently described in Victor Hugo's Les Miserables. Tensions in Paris were already high before the outbreaks, following one to two years after the revolutions of July 1830 and February 1848.

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, visible in Panel 2a, primarily affected the most central areas of the city, where up to six percent 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. This is also reflected in housing values: our data show average house prices and rents were substantially lower in heavy affected areas.

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). This link was confirmed during the 1849 outbreak. Mortality levels were high 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).

2 Analysis

Cholera and the plague caused significant mortality and economic disruption in Paris and Amsterdam. In this section, we analyze how these factors influenced house prices and rents. We refer the interested reader to Appendix A for a broader discussion on the effects of the epidemics on other parts of the housing market.

Paris and Amsterdam already had highly-developed and active housing markets. Most properties were buy-to-let properties owned by investors, with only a minority of the population owning its own house.[3] In both cities, properties could be sold in private sales via search-and-matching, and in public auctions. These auctions were a transparent way for investors to gauge the state of the housing market, and they were used for a large fraction of housing sales. Some of these sales were foreclosures, but most were regular sales.[4]

2.1 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 governmental registrations of property purchases, provided by the Amsterdam city archives. This data provides information on 158,757 house transactions, both regular sales and foreclosure sales, between the late 16th century and 1811, with data or prices missing for several years in the 16th and 17th centuries. For our analysis, we use the repeat-sales price pairs and aggregate index Korevaar (2020) identified. For rents, we use the existing index of Eichholtz et al. (2019).

For Paris, we use data from Eichholtz et al. (2020) originating from the *sommier foncier*, a government register containing 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, for most observa-

[3]In Amsterdam, in 1562 31% of properties were owner-occupied, and this reduced to 15% by 1805 (Korevaar, 2020). In Paris, home-ownership was only a few percent (Kesztenbaum and Rosenthal, 2017).

[4]In Paris, 36% of properties were sold in auctions, and in Amsterdam this fraction was likely even higher. For more detail, see Appendix A.

tions, from the current 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. We match the addresses in the data to their respective neighborhoods, in order to link housing transactions and rent prices to neighborhood mortality measures published in the official government reports.

For more background on the transactions data, we refer to Eichholtz et al. (2020) for Paris and Korevaar (2020) for Amsterdam. Plots of property prices and rents for both cities are in the Appendix, Figure 5. As potential control variables, we use information on wages and consumer prices (Eichholtz et al., 2019), and bond interest rates. For Amsterdam, we use Holland annuity bond yields (Gelderblom and Jonker, 2011), and for Paris French 5% annuity bond yields from Hautcoeur and Riva (2018).

2.2 Aggregate Impact on House Prices and Rents

To assess the impact of the epidemics on aggregate house prices and rents, we start by estimating the following model:

$$\mu_{j,t} - \mu_{j,t-1} = \alpha_j + \beta_1 Epidemic_{j,t} + \beta_2 Epidemic_{j,t-1} + x'_{j,t}\gamma + \varepsilon_{j,t}, \tag{1}$$

where $\mu_{j,t}$ denotes the aggregate log house price or rent index in city j in year t. We will also consider a model where we look at the difference between changes in rents and prices: the implied change in gross rental yields.

$Epidemic_{j,t}$ is an annual dummy variable that takes the value of 1 if there is a severe epidemic of cholera or plague, and $Epidemic_{j,t-1}$ is a dummy if there was an epidemic in the previous year (but not in the current year). $x_{j,t}$ is a vector of control variables, including changes in consumer prices and wages and interest rates. We also consider a model where we control for rent or house price growth in the three years around an epidemic, to detect potentially unobserved time trends. For each city, we only include data between ten years before the first epidemic (if available), and ten years after the final epidemic. Table 1 reports the outcome of these regressions.

Table 1: House Prices and Rents in Epidemics.

	Dependent variable:					
	Δp_t	Δr_t	$\Delta r_t - \Delta p_t$	Δp_t	Δr_t	$\Delta r_t - \Delta p_t$
Epidemic_{t+3}				−0.031	0.003	0.044
				(0.028)	(0.011)	(0.033)
Epidemic_{t+2}				0.027	−0.004	−0.029
				(0.020)	(0.012)	(0.022)
Epidemic_{t+1}				−0.008	−0.013	−0.011
				(0.019)	(0.013)	(0.018)
Epidemic_{t}	−0.055	−0.030	0.028	−0.068	−0.029	0.024
	(0.025)	(0.008)	(0.028)	(0.029)	(0.011)	(0.026)
Epidemic_{t-1}	−0.041	−0.025	0.031	−0.062	−0.031	0.031
	(0.012)	(0.011)	(0.015)	(0.015)	(0.011)	(0.016)
Epidemic_{t-2}				−0.046	−0.037	0.011
				(0.025)	(0.021)	(0.020)
Epidemic_{t-3}				0.021	−0.012	−0.037
				(0.026)	(0.020)	(0.031)
Controls	No	No	No	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Observations	94	164	94	94	118	94
R^2	0.076	0.034	0.024	0.238	0.173	0.086
Adjusted R^2	0.056	0.022	0.002	0.146	0.096	−0.024
Residual Std. Error	0.064	0.055	0.070	0.061	0.053	0.071
F Statistic	3.737	2.808	1.098	2.594	2.237	0.783

Estimation results from Eq. (1). Standard Errors are adjusted for heteroskedasticity and autocorrelation.

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). Given that the fall in house prices exceeds those in rent prices, we also find increases in rental yields during and just after epidemics, although not consistently significant. 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.

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 statistical significance and magnitude of our results. Second, other economic trends around epidemics could still explain part of the effect since the number of epidemics is still small in absolute terms. For example, the Parisian outbreaks of cholera followed one to two years after the revolutions of 1830 and 1848, while some outbreaks in Amsterdam happened during periods of war.[5]

We deal with these issues in two ways. First, we exploit differences in the exact timing of the arrival of the plague in Amsterdam. Controlling for all annual time trends, we aim to identify whether the arrival of plagues resulted in significant price distortion in the months following the start of the outbreak. 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 prices after an outbreak. While aggregate economic changes such as the 1830 and 1848 revolutions might have affected property prices the entire city, it seems less plausible they affected property prices or rents more substantially in neighborhoods heavily affected by cholera.

[5]Most notably the 80-Years War between 1568 and 1648, with a 12-year truce between 1609–1621.

2.3 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), given by:

$$\ln P_{i,t} - \ln P_{i,s} = d'_{1,i}\delta + (x_{i,t} - x_{i,s})'\beta + \varepsilon_{i,t} - \varepsilon_{i,s}. \tag{2}$$

The left-hand-side is the difference in log prices at the time of sale t and purchase s for house i. The vector $d'_{1,i}$ contains fractional time dummies between 0 and 1, corresponding to the proportion of the year during which the property was "held" (Geltner, 1997). We use this to control for annual price changes as precisely as possible. The vector $x_{i,t}$ contains month dummy variables to deal with seasonal effects, and, most importantly, the variables of interest related to the plague. The dummy variable Plague is equal to 1 when within 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. The error terms $\varepsilon_{i,t}$ are independently and normally distributed with zero mean and variance σ^2_ε. Conditional on the variances $(\sigma^2_\varepsilon, \sigma^2_\delta)$ the time-weighted repeat sales model (2) is estimated by generalized least squares. The variance parameters are estimated by maximum likelihood (see for more details Francke, 2010). As a robustness check, Appendix B reports output based on a hedonic price model (Rosen, 1974), which is due to the limited number of hedonic variables variables less precisely estimated, but has more price observations around plagues.

Table 2 presents estimation results from the model. Our sample covers seven plague outbreaks in 1601, 1617, 1624, 1635, 1652, 1655, and 1663. In the repeat sales sample, 191 sales have a plague outbreak in the six months preceding the sale date. 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 five percent level. In Column 4, we test whether the effect is different for the bottom third and top third of properties, but do not find this to be the case.[6]

[6]Our results on the effect of the plague variables are robust to various specifications: The inclusion

Table 2: Estimation Results Price Responses Amsterdam.

	Dependent variable:			
	$\ln P_{i,t} - \ln P_{i,s}$			
Plague	-0.135	-0.134	-0.121	-0.146
	(0.044)	(0.045)	(0.046)	(0.046)
Plague.L6M		0.002	0.020	
		(0.037)	(0.038)	
Plague.L12M			0.085	
			(0.046)	
Foreclosure Sale	0.012	0.012	0.012	0.012
	(0.012)	(0.012)	(0.012)	(0.012)
Plague Cheap				0.067
				(0.070)
Plague Expensive				0.084
				(0.072)
Adj. R^2	0.696	0.696	0.696	0.696
σ_ε	0.380	0.380	0.380	0.380
σ_δ	0.069	0.069	0.069	0.069
Year FE	Yes, with fractional time dummies			
Month FE	Yes			
Observations	39,281			
Sample Period	1602 - 1811			

Note: This table reports the output of the time-weighted repeat sales model (2). Standard errors are reported between parentheses.

2.4 Neighbourhood Price Responses in Paris

For Paris, we estimate a modified version of Eq. (2), comparing developments in house prices and rents across neighborhoods more or less affected by cholera, controlling for aggregate price trends using annual time dummy variables. We replace the independent variables with bi-annual time dummy variables interacted with the log cholera mortality in the neighborhood in which the property is located. We use bi-annual dummies because we have an insufficient number of observations to compute these coefficients precisely at the annual level.

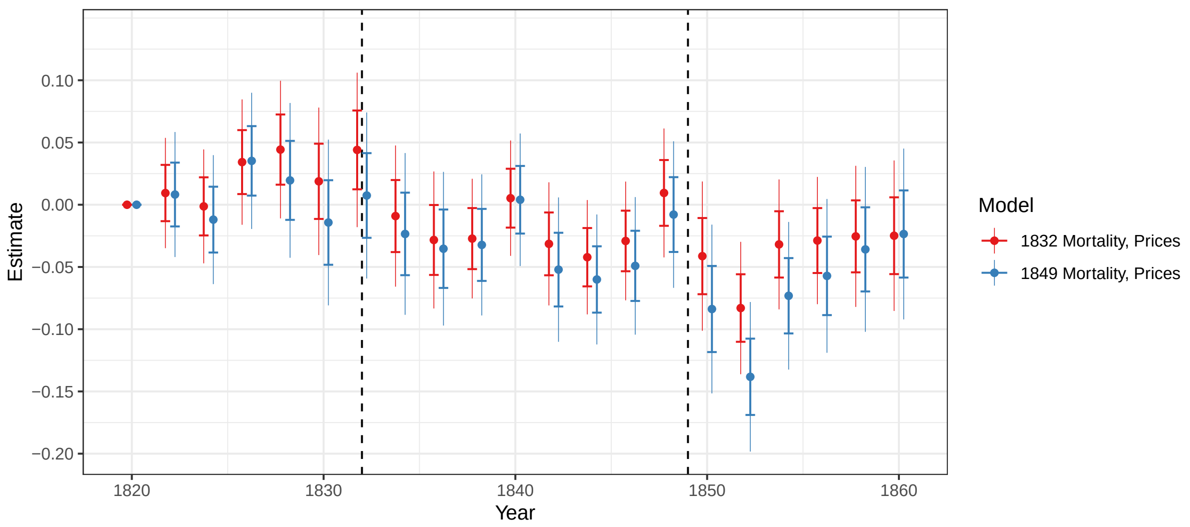
For additional precision, the two-year time dummy variables each cover the period from the 1st of April to the 31st of March in two years from now, because both cholera outbreaks started around the end of March. We estimate these models separately using 1832 neighborhood mortality and 1849 neighborhood 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. Figure 3 presents the results of this analysis. For brevity, we omit the period after 1860 in the output. Other statistics on these regressions are in the Appendix, Table 6.

Panel 3a plots the evolution of house prices in high relative to low mortality neighborhoods over time, both using log 1832 mortality and log 1849 mortality. We use 1820 as base year. Mortality correlated across the two epidemics, so the coefficients on both models evolve similarly over time.

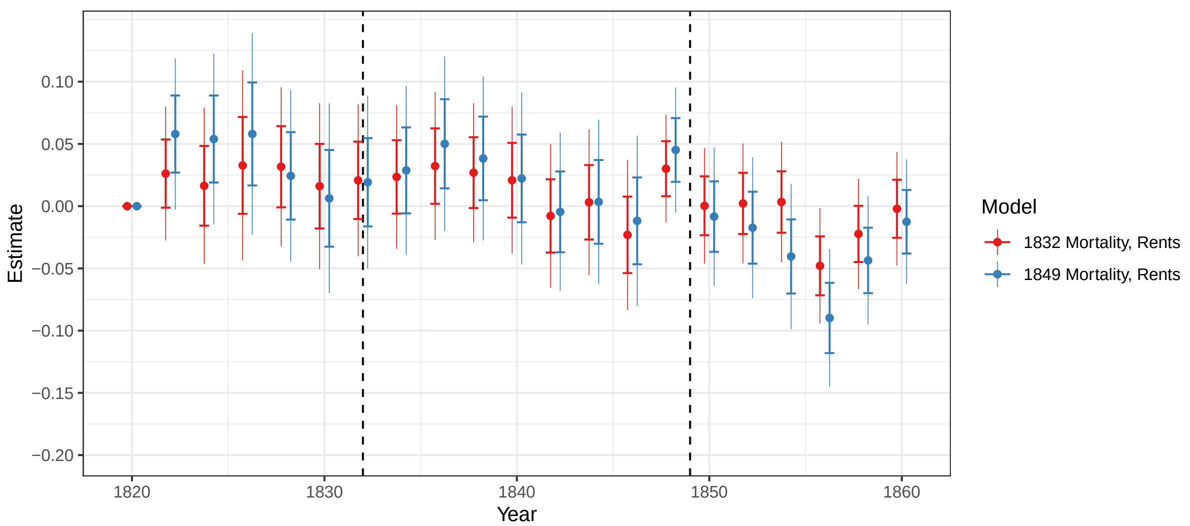
Because the housing stock and inhabitants of high-mortality neighborhoods differed from those in low-mortality neighborhoods, it is crucial to check whether those neighborhoods experienced parallel trends in property price growth before the epidemic. For the 1832 outbreak, we find that areas with a mortality rate twice as high had an insignificant 4.4 percent higher house price growth between 1820 and 1832. However, the outbreak of 1832 marks a sharp trend break in the data. Between 1832 and 1836, high-mortality areas fall significantly in prices relative to low-mortality ar-

of a constant in the repeat sales model (Goetzmann and Spiegel, 1995), the inclusion of property-specific random walks (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.

Figure 3: 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 ten percent higher prices compared to a neighbourhood with half its cholera mortality, relative to the base year of 1820. Around the point estimate we plot +1/-1 White standard error (thick bar), and a 95% confidence intervals based on these errors (thin bar).

eas, with a relative price drop of 7.3 percent. The drop between 1832 and 1834 is 5.5 percent, but only weakly significant. Until the mid-1840s, house price differences between high and low mortality areas remain at relatively stable levels, except for a slight but insignificant jump in 1840.

Moving to 1849 mortality, we find that relative prices in high-mortality areas are on a weakly significant upward trend in the late 1840s, 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 falling by significantly more than prices in low-mortality areas. The an additional drop between 1848 and 1852 is 13 percent. However, prices also bounce back quickly, with no significant differences anymore after 1860.[7]

For rent prices, which are depicted in panel 5a, 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.

3 Mechanisms and Implications

Our combined findings on house prices and rents in Paris and Amsterdam point to three important effects. First, house prices and rents both decline after epidemics, but this effect is more pronounced for house prices. Second, house price declines are particularly significant in the first six months after an outbreak (Amsterdam) and in heavily-affected areas (Paris). Third, these large initial price declines are transitory: heavily affected areas recover in prices, and aggregate house and rent price growth return to their initial growth paths within a few years after an epidemic.

In this section, we discuss potential mechanisms driving these effects and the role of policy responses in shaping the trajectories of house prices and rents after the epidemics. To structure our discussion, we start from a standard asset pricing model for housing, in which house prices equal expected discounted future housing rents, with rents set by the demand and supply for housing.

[7] This pattern also persists after 1860.

3.1 Housing Demand & Urban Growth

Because cholera and plague killed a significant fraction of the population, total housing demand declined significantly during an outbreak. This reduction in housing demand could be strengthened further if the epidemics also resulted in significant drops in income, for which we only have anecdotal evidence. In line with this channel, we find rent prices to decline. However, both at the aggregate level and neighborhood-level this response is small, with aggregate rent prices only declining by about three percent per year until one to two years after the epidemic. Rent price growth returns to its previous level afterward (see Table 1 and Figure 5).

We see two potential mechanisms for this finding. First, and most importantly, the loss of population was quickly made up by increasing migration in both cities. During the period when plagues frequently occurred, Amsterdam experienced its famous Golden Age, with the population increasing from about 30,000 in 1580 to over 200,000 inhabitants in the 1660s (Nusteling, 1985). Economic historians have named this period the 'first round of modern economic growth' (De Vries and Van der Woude, 1997). In Paris, the population grew by almost 15% between 1831 and 1836, despite a deadly cholera epidemic. Population growth halted around the epidemic in 1849, but already recovered in the early 1850s.

One important implication of this finding is that large pandemics, and their corresponding demographic shocks, do not seem to affect the long-term growth trajectories of large cities. Of course, these effects might be different in less successful cities, or in rural areas, for which do not have data (see Alfani and Percoco, 2019).

Second, some of the muted rent price responses could be explained by stickiness in rents. This is not a major concern for our analysis of aggregate prices in Table 1, which primarily builds on rent price indices that only use new contracts. However, for our neighborhood analysis in Paris (Figure 3a) most rents do not originate from new contracts but rather from existing contracts. Because rental contracts often lasted for multiple years, with standard contracts lasting three, six or nine years, rents could not adjust immediately following a shock. This might explain why the fall in rent prices after the 1849 epidemic only comes in the 1850s.

3.2 Housing Supply & Urban Planning

In the short-term, epidemics coincided with falling construction activity, with estimated completed construction going down on average by 40% (see Appendix A.1). However, epidemics had more significant consequences on housing supply over the long run. The City of Paris is probably the most prominent example. After the 1832 outbreak, the government quickly realized that the areas worst affected by cholera were those with high population densities, narrow streets, and with poor inhabitants. 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 (Park, 2018). The 1849 outbreak confirmed the validity of this approach since the central areas that were most affected by Rambuteau's renovations, had much lower mortality than in 1832. This confirmation paved the way for the renowned Haussmann renovations that started in the 1850s. These destroyed nearly all of the unhealthy medieval Paris and gave the city the image it still has today, with its wide boulevards and large apartment blocks. Although the movement to create a more healthy Paris already started before the outbreak of cholera (Park, 2018), following the huge increases in population density of the central parts of the city, cholera turned out to be the catalyst that was needed to push through large scale renovations.

Plague also affected urban planning and housing supply in Amsterdam. Similar to Paris, Amsterdam experienced enormous inflows of migrants, which forced the city to expand significantly. Just prior to the 1617–1618 and 1663–1664 outbreaks, the government had started selling plots of land for these expansions. Strikingly, plots continued to be sold in the plague years, and the city even started selling these plots with mortgages, such that investors did not have to pay the full price upfront (Abrahamse et al., 2015). These mortgages were used widely, in particular around outbreaks.[8] We do not know if the government took these measures because of the pandemic, but they do display a strong commitment to keeping supply expansion going even during epidemics. Beyond housing, the outbreaks of plague caused the city to focus on improving the urban water infrastructure, which was thought to be related to the spread of plague Abrahamse (2010).

Each of these developments might have contributed to the evolution of house prices and rents we observe after epidemics. First, the regeneration of areas heavily affected by cholera likely played an important role in the fact that house prices and rents in these areas did not stay persistently lower relative to less affected areas in Paris, as Ambrus et al. (2020) find for London. The introduction of wider streets, the clearance of slum housing, and access to clean water could improve the valuations of both new and existing properties. Second, the continued expansion of housing supply in both cities after epidemics limited longer-term price growth and could reinforce migration towards the city.

3.3 Expectations and Discount Rates

The fact that epidemics altered the demand and supply for housing could explain the trajectories of rent prices. However, a demand-and-supply based explanation cannot explain why property prices fall more than rents over the very short-term, and in heavier affected areas.

One potential channel is that investors became more pessimistic about future housing demand and corresponding rents and that this decreased their valuation of properties. Note that if investors had perfect foresight on rents, or extrapolated the experience of previous outbreaks, property prices would fall by less than rent prices during an epidemic, because rent prices always recovered. Such changes in expectations can only explain the fall in house prices if investors became very pessimistic and expected housing demand to continue falling after the epidemics. Although we cannot test how

[8] Amsterdam City Archives, Archive 5065: Register van Rentebrieven

likely this channel is, such pessimistic expectations were unjustified ex-post and if investors considered previous outbreaks.

A second channel is that an epidemic temporarily increased discount rates, either by increasing interest rates and housing risk premia. Interest rate fluctuations can only explain a minor part of this effect since the estimates in Table 1 change little when controlling for aggregate interest rates. This also does not explain why prices fall more in heavily-affected areas.[9] It is more likely that the outbreak of an epidemic temporarily increased risk aversion and corresponding risk premia. For example, 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 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). This mechanism could explain why the fall in house prices is particularly large in the short-term and in heavily-affected areas. Uncertainty resolves when the epidemic ends, while homeowners in heavily-affected areas are more exposed to the outbreak, either directly or through their tenants.

One concern is that properties might sell at lower property prices due to changes in the composition of buyers, sellers, and properties for sale, instead of an increase in aggregate risk premia. For example, properties might sell at discounted prices because distressed sellers sell to the first available buyer, rather than waiting to realize the fundamental market price. This mechanism has been well-documented for foreclosure sales (e.g. Campbell et al., 2011), but might also apply to regular fire sales. Table 2 shows that different types of properties did not realize different prices during plague epidemics in Amsterdam, and that foreclosed properties did not realize lower prices

[9] Bond interest data for Amsterdam is less precise than for Paris, but more granular archival data on mortgage interest rates revealed these changed little during outbreaks (Amsterdam City Archives, Archive 5065).

either.[10] In Appendix A.3 and A.4, we show there is no difference in total foreclosure volume and realized holding periods during an outbreak, implying evidence for fire sales is limited.

4 Conclusion

This paper documents that major epidemics cause significant but short-lived declines in house prices, and smaller declines in rent prices. Declines in property prices are most substantial just after the outbreak of an epidemic and in heavily-affected areas. Although various mechanisms could explain this finding, the most plausible explanation for the large and temporary decline in property prices is that epidemics temporarily increase housing risk premia, due to increased uncertainty and economic disruption. We attribute the absence of any long-term effect on house prices and rents 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, and rent and house prices recovered even in the worst-affected areas.

[10] The likely cause for the absence of a foreclosure discount is that there was a large and liquid auction market for real estate property in Amsterdam, where both regular and foreclosed properties were sold.

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A Beyond Prices: Housing Markets in Epidemics

In this Appendix, we provide a descriptive overview of other developments in the Amsterdam and Paris housing market during epidemics. We will discuss changes in housing supply, mortgage supply, transaction volume & foreclosures, and time-between-sales. For a more detailed description of the structure of the housing market in this period, see Korevaar (2020) for Amsterdam and Eichholtz et al. (2020) for Paris.

A.1 Housing Supply and Construction

Amsterdam

Abrahamse (2010) notes that the 1617-1618 epidemic temporarily halted the building industry, with masons and carpenters complaining they experienced a very bad year. From 1632, there are government statistics on the rental value of newly completed buildings in the city, which were made for the purpose of property taxation.[11] For all four epidemics that hit the city after 1632, we find that the number of completed properties falls in the year following the start of the outbreak, with an average fall in completed construction of 38%, with the fall ranging from 27% to 48% across all four epidemics. Because most outbreaks started in the fall, it is unlikely they still had a large effect on completed construction in the year of the outbreak itself. However, we should note that the levels of construction both before and after an epidemic varied significantly: there was significant construction taking place around the 1635-1636 epidemic and even more so during the 1663-1664 epidemic, while construction was already at very low rates around the epidemics in the 1650s.

Paris

In Paris, the outbreaks of cholera coincided with a slump in building activity as well. Based on data from Daumard (1965), the total rental value of new construction fell by about 70% in 1849, and the slump in building activity continued until 1852. After 1852,

[11] Source: Amsterdam City Archives, Archive 5044.

construction quickly resumed due to the start of the Hausmann renovations of Paris. It should be noted that construction was already falling significantly in 1848, due to the economic crisis and revolution that Paris was experiencing at that time.

For 1832, we do not possess exact numbers on the rental value of new construction. The closest equivalent to a construction estimate is the number of bricks that entered Paris in each year, because bricks are essential for housing construction. The number of bricks fell by about 10% in 1832 (relative to a fall of about 33% in 1849), but recovered quickly in the following year (Daumard, 1965). This is consistent with the stronger population growth that happened in the early 1830s, at least when comparing to the period around 1850. Again, we should note that the number of bricks that entered the city was already falling sharply in 1831.

In short, our evidence for both Paris and Amsterdam suggests that housing construction slowed down during an epidemic, consistent with the significant economic and demographic turmoil brought by these epidemics. We want to stress that our evidence on housing construction should be treated as suggestive evidence: we do not have consistent data on housing construction available for all epidemics, leaving too little power for any formal statistical test, and it is hard to control for pre-trends given that the epidemics also coincided with other shocks in building activity, most notably in Paris in 1849 and in Amsterdam around 1663.

A.2 Mortgage Originations

Amsterdam

In the 17th century, a significant fraction of properties was funded using a peer-to-peer mortgage, typically supplied by the seller of the property. The closest analogy to a modern mortgage was a *losrente* contract, which was an interest-only mortgage without a maturity date and an LTV of up to 100%. The borrower could repay the capital sum whenever he wanted. Between the 1630s and the 1660s, around 20% of real estate transactions were financed using such a loan. The City of Amsterdam also often provided such mortgages when it was selling plots of land. Beyond these long-term loans, properties could also be financed using a *schepenkennis*, which was either a loan without interest used to specify a payment schedule (typically for just a year), or a short-term interest-bearing loan with a maturity of up to several years (Gelderblom et al., 2018). We do not know exactly how many of these loans were used as mortgages.

We briefly highlight how long-term mortgage volume changed around the epidemics after 1630, using data on the number of *losrenten* from Korevaar (2020). During the outbreaks in 1635–1636 and 1652, we document significant reductions in the number of mortgages, with the number of contracts dropping monotonically from 321 in 1634 to 134 in 1637, and from 100 contracts in 1651 to just 73 in 1653. There is no fall in mortgage activity during the smaller outbreak in 1655, but it should be noted that mortgage activity was already at very low levels before the outbreak, since there were only 37 mortgages issued in 1654 and around 60 in 1655 and 1656. The outbreak of 1663–1664 is an outlier with respect to the number of mortgages, because mortgage volume doubled in 1664, but fell in subsequent years. Most of the increase in contracts was driven by mortgages on the sales of plots of land by the city. It is possible they hoped to increase land revenue by providing credit, but we do not know whether this decision was related to the outbreak. In 1617-1618, when the city issued a large number of plots of land during a plague epidemic, the government also issued loans to buyers of plots of land for a 50% LTV.

Paris

For Paris, we do not have detailed data on mortgage originations around outbreaks of cholera. However, Paris already had a well-developed mortgage market in the 19th century, with a centralized mortgage register (*hypotheques*), and a large and active market for peer-to-peer loans (Hoffman, 2000). Comparatively, this market was also substantially larger than the peer-to-peer loan market in Amsterdam, at least during the Ancien Regime (Hoffman, 2000; Gelderblom et al., 2018).

A.3 Transaction Volume & Foreclosures

Both Paris and Amsterdam had institutions in place that permitted creditors to auction properties in case the owner foreclosed on its loans or any other type of required payment. These auctions were organized centrally and were also a common way to sell non-foreclosed properties. In Amsterdam, the records do not allow us to distinguish between regular private sales and auctions sales since only foreclosures were registered separately. However, the available auction lists suggest the number of transacted properties was large relative to total volume. For example, in the year 1743, 548 properties were put up for sale, relative to 613 realized total transactions in the cities. Although not every property put up for sale in an auction would eventually transact, this suggests a large fraction of real estate transactions in Amsterdam happened through auctions.

Amsterdam

For Amsterdam, we can reconstruct total volume in the housing market for a substantial number of months, building on the turnover data presented in Korevaar (2020). For four epidemics, we have precise monthly data on regular transaction volume, and for five epidemics we have monthly data on foreclosure volume. This implies that, contrary to our more scattered data on construction and mortgage volume, we have enough observations to statistically test the impact of pandemics on volume.

To do so, we regress the monthly level of turnover on a set of annual time dummies that indicate the number of years until or since the closest outbreak of a plague epidemic, with the number of years ranging from -2 years (12-24 months before the outbreak) to 3 years after the outbreak (24-36 months). We also control for seasonality by including month fixed effects. To estimate the regression, we only incorporate data that is between -24 months and 36 months from an epidemic. Because our volume estimates are monthly, but our plague dummies annual, there is significant autocorrelation (and heteroskedasticity) in the residuals of this regression. We adjust standard errors for heteroskedasticity and autocorrelation using Andrews (1991) HAC errors.

Table 3 reports the results of these regressions, both for regular sales and foreclosure sales. We use transaction volume in the year before an epidemic as a baseline. Transaction volume is expressed as a percentage of the total housing stock.

Table 3: Monthly Transaction Volume around Epidemics.

	Volume:	
	Regular	Foreclosures
Epidemic_{Year-2}	0.003	0.001
	(0.023)	(0.006)
Epidemic_{Year}	−0.049	−0.001
	(0.023)	(0.006)
Epidemic_{Year+1}	−0.026	0.004
	(0.025)	(0.006)
Epidemic_{Year+2}	0.019	0.012
	(0.027)	(0.006)
Month FE	Yes	Yes
Constant	Yes	Yes
Observations	258	260
R^2	0.740	0.252
Adjusted R^2	0.724	0.206
Residual Std. Error	0.083	0.028
F Statistic	46.034	5.488

Notes: HAC-consistent standard errors are reported between parentheses.

The estimates suggest that transaction volume declined significantly during an outbreak, with monthly transaction volume going down by 0.05 percentage points. On average, 0.2 percent of the housing stock traded hands in each month, implying that transaction volume fell by about 25 percent during these epidemics.[12]

For foreclosure volume, we find no significant effects in the first two years after an outbreak, but a significant increase in foreclosure volume 24 to 36 months later. This increase (0.01 percentage point of the housing stock per month) is about 25 percent relative to average monthly foreclosure volume. It should not be surprising that there is a delay between foreclosure sales and the outbreak of an epidemic: lenders might

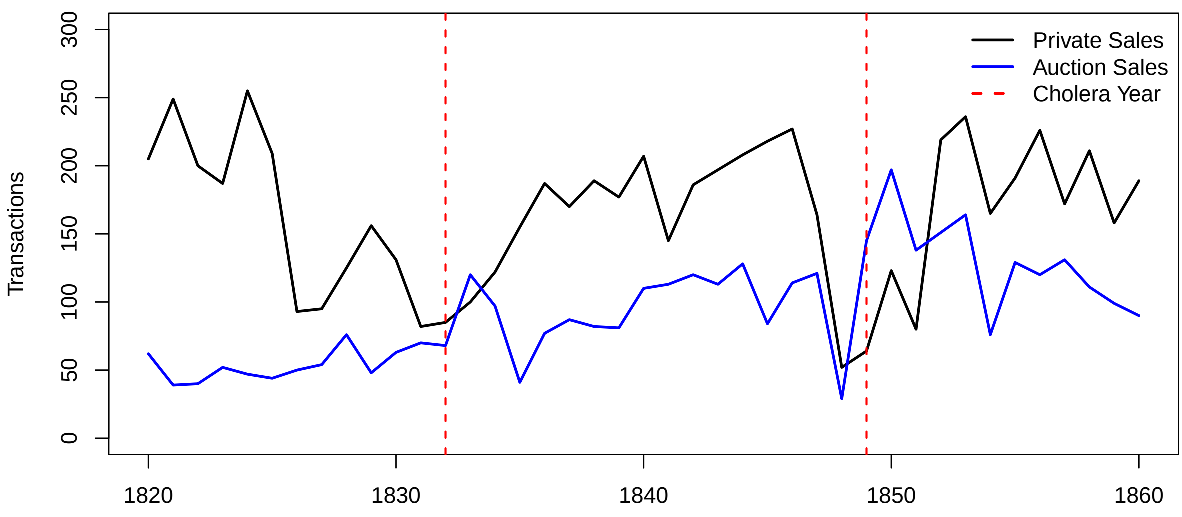
[12] As a robustness check, we also modeled monthly transaction volume in a local linear trend model, that models log sales as a function of a linear trend, a seasonal component and the six-monthly plague variables that we also used in our analysis on Amsterdam prices. This revealed that volume primarily dropped between six and twelve months after an outbreak, and by approximately 29%

have waited for the epidemic to be over before starting a formal foreclosure procedure, both to give debtors extra time to pay or to avoid selling in a distressed market.

Paris

Because our data are only for a sample of streets, we cannot reconstruct transaction volume for Paris. However, the number of transactions in our sample provide, at least over the short-term, an estimate of the changes in transaction activity in the city. Figure 4 plots the volume of annual auction sales and private sales for the streets covered by our data, from 1820 to 1860. In line with our observations on housing construction, transaction volume already dropped substantially in the year before the outbreak, following the economic crisis around the 1830 revolution and the 1848 revolution. In 1849, transaction volume even increases relative to its previous levels, although this is entirely driven by an increase in the number of auctions.

Figure 4: Transactions in Paris.



Notes: These figures plot the annual number of transactions in our sample, separating auction sales and private sales.

A.4 Time-between-Sales

We want to check whether the time-between-sales changes during or just after an epidemic. When owners are forced to sell properties due to the effects of the outbreak of an epidemic, the average time-between-sales might go down. For all repeat sale pairs the time-between-sales is calculated as the difference (in days) between the date of selling and buying a property. We model the average time-between-sales per date of the second sale pair (TBS_t) as

$$\ln \text{TBS}_t = \mu_t + x_t'\beta + \varepsilon_t,\ \mu_{t+1} = \mu_t + \kappa_t + \zeta_t,\ \kappa_t + 1 = \kappa_t + \xi_t,$$

where μ_t is the log time-between-sales trend, specified as a local linear trend model.[13] The vector x_t contains dummy variables for epidemics, specified similarly as in subsection 2.3 for the plague. Table 4 provides the estimation results for the coefficients of the epidemic dummy variables for Amsterdam and Paris. We do not find statistical significant changes in the average time-between-sales during or just after the outbreak of an epidemic. Note that the average number of second sales per month is small, 6.2 and 9.7 for Amsterdam and Paris, respectively. So results may be sensitive to outliers.

Table 4: Estimation Results for Time-between-Sales.

	Dependent variable: $\ln TBS_t$	
	Amsterdam	Paris
Epidemic	0.037	-0.072
	(0.118)	(0.130)
Epidemic.L6M	-0.157	0.038
	(0.119)	(0.131)
Epidemic.L12M	0.108	0.109
	(0.124)	(0.130)
Observations	274	479
Sample Period	1645(1)-1669(12)	1820(1)-1859(12)

[13] See Durbin and Koopman (2012) for more details on the local linear trend model. The model has been estimated by the STAMP software for State Space Models.

B Results using a Hedonic Price Model

In this section of the appendix, we estimate a hedonic price model that aims to control for quality of the sold properties using actually observed quality characteristics. One advantage of this model is that it does not require properties to be sold repeatedly. Because our transaction data for the 17th century is incomplete, the number of repeat-sales around some of the epidemics is small. Using a hedonic price model, we can include over 1000 transaction prices within six months of an epidemic. A disadvantage of this approach is that the data provide very little information on housing quality beyond location, implying estimates contain significant noise.

The hedonic price model is given by:

$$\ln P_{i,t} = \alpha + \mu_t + x'_{i,t}\beta + \varepsilon_{i,t}, \tag{3}$$

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^2_ϵ. Control variables are street fixed effects and very 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.

The results of the hedonic price model are reported in Table 5. In general, the plague variables in the hedonic price model are similar, but slightly smaller and less significant compared to the ones in the repeat sales model. The estimated effect is about minus 9% (significant at the 10 percent level). The weaker significant is unsurprising because the hedonic price model is less precisely estimated than the repeat-sales model (i.e. the high σ_ε relative to Table 2).

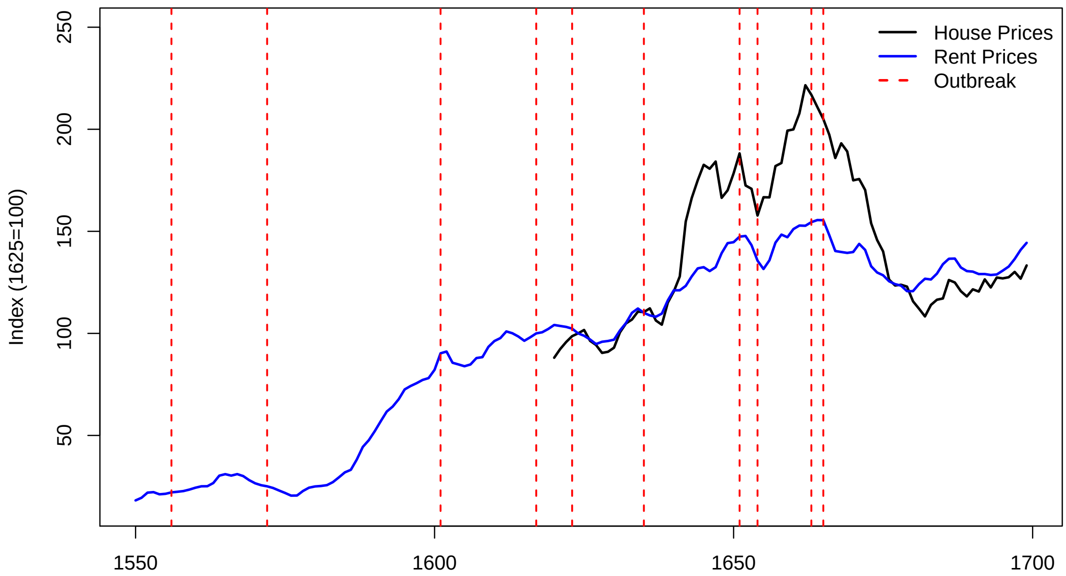
Table 5: Estimation Results Price Responses Amsterdam, Hedonic Price Model

	Dependent variable:		
	$\ln P_{i,t}$		
Plague	-0.085	-0.088	-0.088
	(0.044)	(0.046)	(0.051)
Plague.L6M		-0.009	-0.0095
		(0.046)	(0.056)
Plague.L12M			-0.001
			(0.047)
Foreclosure Sale	0.024	0.024	0.024
	(0.014)	(0.014)	(0.014)
Adj. R^2	0.501	0.501	0.501
σ_ε	0.827	0.827	0.827
Constant		Yes	
Year FE		Yes	
Month FE		Yes	
Hedonic Controls		Yes	
Observations		133,123	
Sample Period		1600 - 1811	

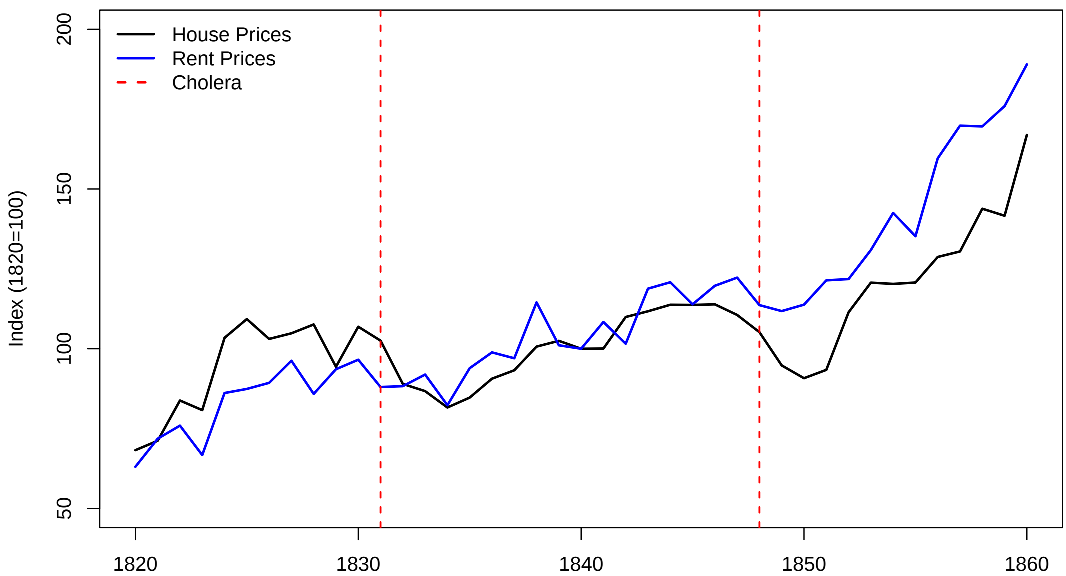
Notes: Standard errors are reported between parentheses.

C Supplementary Figures and Tables

Figure 5: Housing Prices and Rents Around Epidemics.



(a) Amsterdam



(b) Paris

Notes: These figures plot the evolution of house prices and rents in both Paris and Amsterdam, with the dashed line indicating the price level before an outbreak started. These indices 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). They are based on the same repeat-sales methodology that we use. 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, In nearly all cases, epidemics coincided with a subsequent fall in house prices, but this pattern seems less consistent for rent prices. The positive long-term growth trajectory in rent prices in both cities in consistent with the population growth they experienced.

Table 6: 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).