Housing Markets in a Pandemic: Evidence from Historical Outbreaks Online Appendix

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Appendix B. Additional Analysis Amsterdam

Appendix B.1. Additional results from modified repeat sales model

This appendix provides in Table B.3 some additional estimation results from the modified repeat sales model, given by Eq. (A.2). Column one is included as a reference and is identical to column one in Table 1.

Similar to column four of Table 1, we test in column five whether the effect is different for the bottom and top third of properties, based on the average log transaction price per street. In column five we have one variable representing the price level (-1 for cheap properties, 1 for expensive properties, and 0 otherwise) with time-varying effects per two years (represented by the λs). We expect the differences in coefficients to be negative, but we do not find consistent supportive evidence for these claims.[27]

In column six we test whether learning by investors could be an explanation for the short-lived impact on house prices. An outbreak could enable

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[27] Similar results are found using four years periods (not reported).

investors to purchase cheap and to sell it later when prices have recovered. We test for learning effects by interacting the plague variable with the sequence of occurrence of the plague outbreak. Both the coefficient for the plague variable and the interaction term are statistically insignificant. This might be due to the low number of sales during the first six months after the outbreak of the plague, in particular for the first three outbreaks in our sample, see Section 4.2.

Appendix B.2. Results from a Hedonic Price Model

In this appendix, we estimate a hedonic price model (HPM) that controls for quality of the sold properties using actually observed quality characteristics. One advantage of the HPM 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 an HPM, 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 HPM is given by

$$\ln P_{i,t} = \alpha + \mu_t + x'_{i,t}\beta + \varepsilon_{i,t}, \tag{B.1}$$

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, such as the presence of a building, a garden, or a shop. In total, we have 25 property related dummy variables. We use identical variables for the plague as in the RS

Table B.3: Estimation Results Price Responses Amsterdam.

	Dependent variable:		
	$\ln P_{i,t} - \ln P_{i,s}$		
	(1)	(5)	(6)
Plague	-0.136	-0.133	-0.240
	(0.045)	(0.043)	(0.343)
Plague × Sequence			0.012
			(0.039)
Foreclosure Sale	-0.021	-0.009	-0.021
	(0.013)	(0.012)	(0.013)
Widow	-0.046	-0.043	-0.045
	(0.009)	(0.009)	(0.009)
Heirs	-0.036	-0.035	-0.036
	(0.007)	(0.006)	(0.007)
Constant	0.061	0.066	0.061
	(0.005)	(0.005)	(0.005)
$\lambda_{1620} - \lambda_{1618}$		0.092	
		(0.114)	
$\lambda_{1626} - \lambda_{1624}$		0.024	
		(0.051)	
$\lambda_{1638} - \lambda_{1636}$		0.150	
		(0.069)	
$\lambda_{1654} - \lambda_{1652}$		-0.026	
		(0.035)	
$\lambda_{1656} - \lambda_{1654}$		-0.020	
		(0.035)	
$\lambda_{1666} - \lambda_{1664}$		-0.071	
		(0.028)	
σ_ε	0.380	0.371	0.380
	(0.001)	(0.001)	(0.001)
σ_μ	0.071	0.070	0.071
	(0.005)	(0.005)	(0.005)
PSIS-LOO value	-31,381.5	-30,549.6	-31,383.9
Interaction effect	No	Yes	No
Month FE		Yes	
Observations		39,281	
Sample Period		1602 - 1811	

Notes: This table presents estimation results from the modified repeat sales model (A.2). Standard errors are given between parentheses. PSIS-LOO stands for leave-one-out cross-validation using Pareto-smoothed importance sampling (Vehtari et al., 2017).

model.

The results of the HPM are reported in Table B.4. In general, the plague variables in the HPM 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 significance is unsurprising because the HPM is less precisely estimated than the repeat-sales model (i.e. the high σ_ε relative to Table 1).

Table B.4: Estimation Results Price Responses Amsterdam, Hedonic Price Model.

	Dependent variable:		
	$\ln P_{i,t}$		
	(1)	(2)	(3)
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.

Appendix C. 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 discuss the impact of epidemics on rents, changes in housing and 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 Eichholtz et al. (2021) for Paris.

Appendix C.1. 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:

$$\delta_{j,t} = \alpha_j + \text{Epidemic}_{j,t}\beta_1 + \text{Epidemic}_{j,t-1}\beta_2 + x'_{j,t}\gamma + \varepsilon_{j,t}, \tag{C.1}$$

where $\delta_{j,t}$ denotes the aggregate log house price return ($\Delta p_{j,t}$) or log rent index return ($\Delta r_{j,t}$) 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. In all specifications we stack the Amsterdam and Paris data, assuming that the coefficients β and γ do not differ between the cities. Only the constant α_j varies over the cities.

$\text{Epidemic}_{j,t}$ is an annual dummy variable that takes the value of 1 if there is a severe epidemic of cholera or plague in year t, and $\text{Epidemic}_{j,t-1}$ is a dummy if there was an epidemic in the previous year but not in the current year. Epidemics lasted between two months and 24 months, and we count a year as an epidemic year if there was an epidemic going on for at least one month. To estimate the duration of plagues in Amsterdam, for which we have no precise data, we assume that a severe epidemic continues for as long as monthly excess mortality remains above 100% or if excess mortality is positive and exceeds 100% again within six months. $x_{j,t}$ is a vector of control variables, including changes in consumer prices and wages and interest rates. Data on wages and consumer prices originate from Eichholtz et al. (2019), For bond rates in Amsterdam we use Holland annuity bond yields (Gelderblom and Jonker, 2011), and for Paris French 5% annuity bond yields from Hautcoeur and Riva (2018).

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.

We estimate the model on the existing annual repeat-sales indices reported in Eichholtz et al. (2021) for Paris and in Francke and Korevaar (2019) for Amsterdam. For rental prices, we use the indices from Eichholtz et al. (2019). These are repeated-rent indices. To make sure that the rent index accurately tracked market prices, Eichholtz et al. (2019) only included observations for Amsterdam where rental prices of the properties changed, since rental contracts could not be retrieved for most of the properties in their dataset. For Paris, the index uses data from new rental contracts only. Rental contracts in Paris were binding typically signed for 3, 6, or 9 years. In Amsterdam, rental contracts were typically annual contracts or leases that specified annual rental prices that were subject to change. For more detail on rental contracts, we refer to Eichholtz et al. (2019).

Table C.5 reports the estimation results. For house prices, we document a reduction in house prices of about 0.055 (in logs) per year during an epidemic (first column). After an epidemic, prices fall by another 0.041. For rental prices, the effects are substantially smaller, with rent prices falling by

0.030 during an epidemic and another 0.025 when an epidemic ends (second column). Given that the fall in house prices exceeds those in rents, we also find increases in rental yields during and just after epidemics, although not consistently significant (third column). These effects are robust to the inclusion of control variables (columns four to six). We also do not find any significant deviations in house or rent price growth from their average level before an outbreak. About one to two years after the end of an epidemic, price growth is not significantly different anymore from its average trend. Note that we also do not find significant evidence for above-average growth after a pandemic, which would suggest an even quicker rebound of prices. In summary, this suggests that, at least at the annual level, epidemics provide a temporary break in the growth rates of rents and sales prices.

It is not surprising that rents and prices continue to fall also in the year after an outbreak. Most epidemics lasted for less than one year and started in the middle of the year. As a result, many rental prices and transaction prices agreed to in the year of the outbreak would not yet be subject to the price discount that followed the outbreak. In the year after the outbreak, all newly-signed contracts should incorporate the discount (if prices did not recover yet).

If the specific year in which an outbreak arrives in a city is exogenous to its economy, as we have asserted here, the estimates in Table C.5 identify the actual impact of these epidemics on house prices and rents. However, there are several potential limitations to these conclusions.

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 coinciding with outbreaks could 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. Third, these analyses do not allow to distinguish between more and less severe epidemics, even though the epidemics varied significantly in their mortality. Finally, because many epidemics only lasted a few months, using annual changes might already be too coarse to measure their short-term impacts.

Appendix C.2. 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.[28] 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, ranging from 27% to 48%, on average 38%. Because most outbreaks started in the fall, it is unlikely they had a large effect on completed construction in the first calendar year of the outbreak. 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

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

Table C.5: House Prices and Rents in Epidemics.

	Dependent variable:					
	Δp_t	Δr_t	$\Delta r_t - \Delta p_t$	Δp_t	Δr_t	$\Delta r_t - \Delta p_t$
	(1)	(2)	(3)	(4)	(5)	(6)
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

Note: This table presents estimation results from Eq. (C.1). Andrews (1991) standard errors are provided to adjust for heteroskedasticity and autocorrelation (with a quadratic spectral kernel.

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, 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 each year. 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 entering Paris 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 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 a 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.

Appendix C.3. 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. The increase in contracts was mainly 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 during a plague epidemic, the government also issued loans to buyers of plots for a 50% LTV.

Paris

For Paris, we do not have detailed data on mortgage originations around cholera outbreaks. However, Paris had a well-developed mortgage market in the 19th century, with a centralized mortgage register (*hypotheques*), and a large and active peer-to-peer loan market (Hoffman, 2000). 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).

Appendix C.4. 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 auction sales, since only foreclosures were registered separately. However, the available auction lists suggest a large fraction of transacted properties were sold in an auction. 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. Volume is expressed as a percentage of the total housing stock so that it is a measure of turnover.

To do so, we regress the monthly level of turnover on a set of annual time dummy variables 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 before the outbreak, so 12-24 months before the outbreak ($Outbreak_{t+2}$) to 3 years after the outbreak ($Outbreak_{t-2}$, 24-36 months after the outbreak). We also control for seasonality by including month fixed effects. We estimate the model using only data that is between -24 months and 36 months from an epidemic. Because our volume estimates are monthly, but our plague dummy variables annual, there is significant autocorrelation in the residuals. We use transaction volume in the year before an epidemic as the baseline. Transaction volume is expressed as a percentage of total housing stock.

In a second specification, we regress monthly transaction volume on a set of year fixed effects, months fixed effects, and a dummy indicating whether an outbreak started in the past six months. We also include two lags of the outbreak dummy. As a result, this specification only compares the change in volume *within a year*, similar to our analysis of Amsterdam house prices in the main body of the paper.

Table C.6 reports estimation results, both for regular and foreclosure sales. We adjust standard errors for heteroskedasticity and autocorrelation using Andrews (1991) HAC errors.

Table C.6: Monthly Transaction Volume around Epidemics.

	Dependent variable:			
	Regular	Foreclosure	Regular	Foreclosure
	(1)	(2)	(3)	(4)
Outbreak_{t+2}	0.003	0.001		
	(0.023)	(0.006)		
Outbreak_{t}	−0.049	−0.001		
	(0.023)	(0.006)		
Outbreak_{t-1}	−0.026	0.004		
	(0.025)	(0.006)		
Outbreak_{t-2}	0.019	0.012		
	(0.027)	(0.006)		
$\text{Outbreak}_{0-6months}$			0.009	−0.0002
			(0.016)	(0.004)
$\text{Outbreak}_{7-12months}$			−0.038	−0.001
			(0.017)	(0.006)
$\text{Outbreak}_{13-18months}$			0.032	−0.004
			(0.015)	(0.006)
Constant	0.157	0.031	0.220	0.024
	(0.019)	(0.008)	(0.021)	(0.006)
Year FE	No	No	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes
Observations	258	260	258	260
R^2	0.740	0.252	0.845	0.449
Adjusted R^2	0.724	0.206	0.816	0.348
Residual Std. Error	0.083	0.028	0.067	0.026
F Statistic	46.034	5.488	29.485	4.461

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 during the first 12 months of an outbreak. 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. When we control for time using year fixed effects, we find smaller effects concentrating in the 6 to 12 months following an outbreak, with a drop in transaction volume of about 20 percent.[29]

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 the 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 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. Note that when using year fixed effects, similar to the specification in the main body of the paper for house prices, we also find no response in foreclosure volume during the first 18 months.

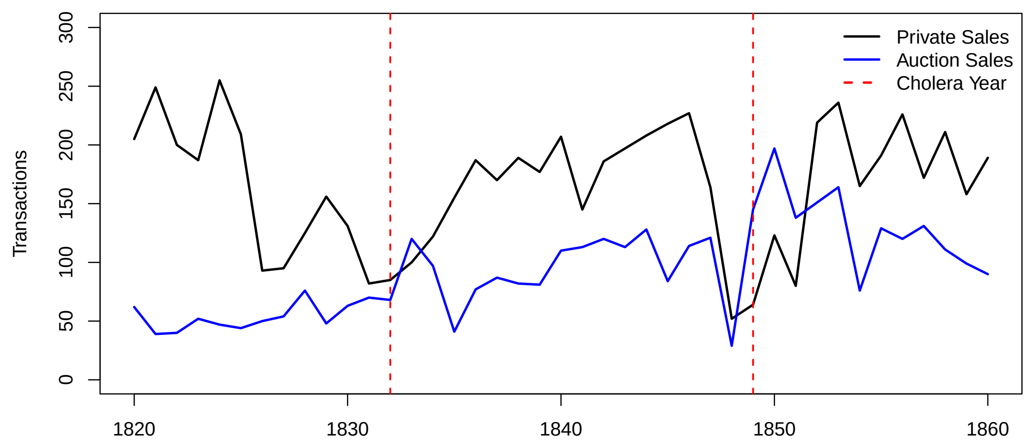
Paris

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 C.6 plots the volume of annual auction sales and private sales for the streets covered by our data, from 1820 to 1860.

[29] 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 indeed revealed that volume primarily dropped between six and twelve months after an outbreak, and by approximately 29%. Here we report OLS estimates, given that our transaction series are not significant.

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 C.6: Transactions in Paris.



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

Appendix C.5. Time-between-Sales

We want to check whether the time-between-sales (TBS) 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 TBS might go down. For all repeat sale pairs, the TBS is calculated as the difference (in days) between the date of selling and buying a property. We model the average TBS 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 TBS trend, specified as a local linear trend model.[30] The vector x_t contains dummy variables for epidemics, similar to subsection 4.2. Table C.7 provides the estimated coefficients of the epidemic dummy variables for Amsterdam and Paris. We do not find statistically significant changes in the average TBS 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 C.7: 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)

Notes: Standard errors are reported between parentheses.

[30]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.

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