Stockholm Papers in Economic History
No. 17

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Second version

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First version presented at Higher Seminar, Department of Economic History, Lund, 22 January 2014 (http://www.lusem.lu.se/media/ekh/seminarie-paper/paper111.pdf).

Department of Economic History
Stockholm University 2015

Stockholm Papers in Economic History, No. 17
2015
Web address of the WP-series: http://swopec.hhs.se/suekhi

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Pre-industrial population and economic growth: Was there a Malthusian mechanism in Sweden?

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Stockholm Papers in Economic History, No. 17

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Abstract

This study examines whether there was a Malthusian equilibrium mechanism in Sweden 1630–1870. A unique data set on harvests, deaths, marriages and births is used to calculate cumulative elasticities of vital rates with respect to harvest. While earlier studies have mostly focused on the impact of real wage, this study contents that the calorie content of harvests is more related to Malthus' concept of the 'produce of land'. It finds that there indeed was a response of vital rates to harvest fluctuations, but there were important structural breaks. While positive checks attenuated after 1720, preventive checks were strengthened. After 1870 preventive checks disappeared, even if positive checks existed up to 1920. The results are robust to different models – DLM, ARMAX and SVAR – and trend specifications.

JEL-classification: N13; N33; N53

Key words: demography; Maltus; mortality; fertility; economic history

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1. Introduction

The relation between population and economic development has been a central theme in economic and social theory since the eighteenth century. The question of the causal connection between economic and population growth in agrarian society is still unresolved. There are two opposing interpretations. While Malthusians emphasise diminishing returns on natural resources, producing mortality crises, their critics point out that population growth by itself generated advances in technology.

The unified growth theory, which aims to model both technological progress and demographic transition in the eighteenth and nineteenth centuries endogenously, predicts that while preventive checks were initially strengthened, positive checks were weakened once technological progress took off.[2] What exactly a Malthusian model entails is a topic for an ongoing discussion, and there is no reason to interpret the Malthusian mechanism in just one way. In fact, Mokyr and Voth suggest that the Malthusian model rests on two assumptions:[3] 1) that population growth reacted positively to living standards through preventive and positive checks and 2) that living standard was negatively related to the size of the population. They contrast two Malthusian versions against each other. In its strongest form, it predicts stagnant per capita income without shifting mortality and fertility schedules and stagnant population in the absence of technological advance. In its weaker version, it accentuates equilibrium mechanisms, i.e. the positive and preventive checks on population rather than the specific outcomes.

[2] Galor and Weil (2000); Pfister and Fertig (2010).

[3] Mokyr and Voth (2008), pp. 14–15.

The analysis of the development of preventive and positive checks is highly dependent on which variables are chosen and not only on the statistical model. Earlier international research on the effect of economic stress on the population in the pre-industrial period has largely relied on real wages or grain prices as indicators of living or nutritional standards,[4] but the approach is problematic. Malthusians often point to the development of real wages, which fell from the late Middle Ages to the early nineteenth century, to advance their main proposition that population growth outpaced production.[5] Anti-Malthusians tend to disagree.[6] Maddison contends that wages cannot be used as indicators of living standards since they do not represent a macroeconomic variable.[7] The volatility in grain prices was also affected by market integration, not only by harvests.[8] While there was a strong correlation between movements in grain prices and harvests in the early modern period, this relation attenuated during the nineteenth and twentieth centuries due to improved international market integration. Recently, Dribe, Olsson and Svensson demonstrate that at the local level in southern Sweden, grain output had a different impact on mortality than grain prices, since the latter reflected conditions in surrounding areas.[9]

This paper utilises recently constructed annual series of vital rates and harvests to estimate the elasticities of vital rates back to 1630. The whole period 1630–1870 is put into

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[4] Wrigley and Schofield (1989), pp. 368–384; Galloway (1988); Galloway (1994); Lee and Anderson (2002); Nicolini (2007); Bengtsson and Broström (2011); Bengtsson and Ohlsson (1985); Dribe (2003); Crafts and Mills (2009); Pfister and Fertig (2010); Chiarini (2010)'; Møller and Sharp (2014); Klemp and Møller (2015). Eckstein et al (1984), and Larsen (1987), use a harvest series to investigate the impact on vital rates in Sweden, but this harvest series is deficient for the period before 1865 (Edvinsson 2009). Dribe, Olsson and Svensson (2011), analyse the mortality response to grain output (derived from tithes), but at the local level in southern Sweden.

[5] Allen (2001), Clark (2007).

[6] Persson (2008).

[7] Maddison (2007), p. 308.

[8] Edvinsson (2012).

[9] Dribe, Olsson and Svensson (2011).

investigation, although a comparison is also made with 1871–1920. Harvests data are transformed into the per capita production of calories. The appendix explains the data sources in detail.

In this paper, the elasticities of vital rates are calculated as cumulative elasticities, since the impact of harvest could be delayed. In the first step a simple distributed lag model (DLM) and an ARMAX (auto-regressive moving average with exogenous input) model are presented. Subsequently a structural vector autoregression model (SVAR) is applied to estimate structural impulse response functions that can be given a causal interprestation.[10] The empirical evidence supports the view that there was a short-term Malthusian equilibrium mechanism in the Swedish pre-industrial economy, even if the mechanism changed over time. The question of whether there was a medium- or long-term Malthusian equilibrium mechanism is, however, outside the scope of this study. A short-term mechanism does not necessitates a long-term one, even if there is usually a connection between the two under ceteris paribus.

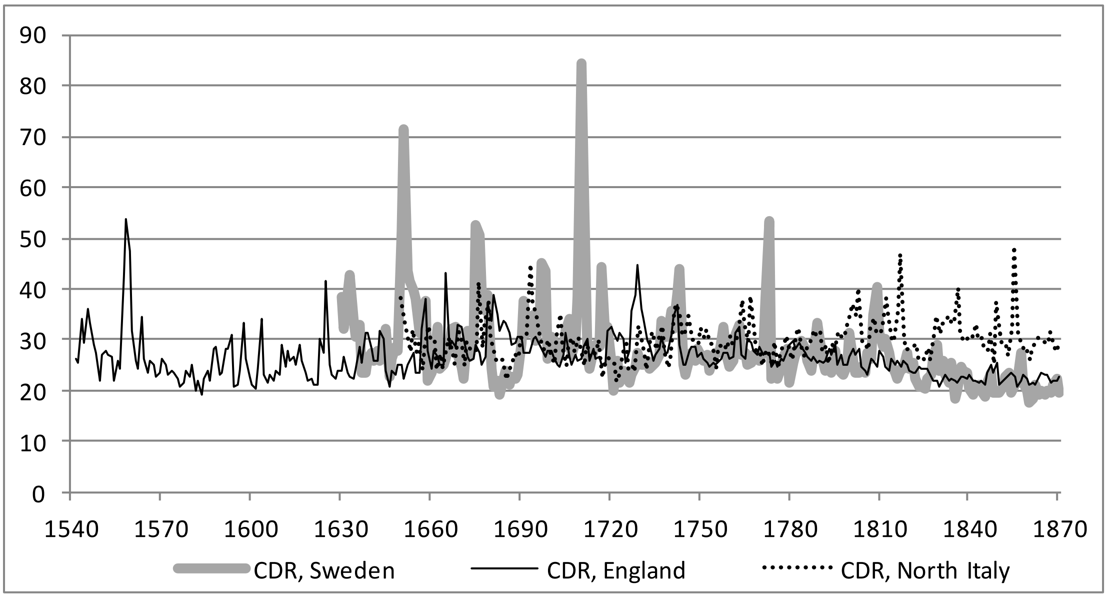
2. An overview of the data

When comparing seventeenth century Sweden with other countries for which data on vital rates exists, Sweden stands out for the occurrence of sever mortality crises. Figure 1 compares the crude death rate in Sweden, England and north Italy. The English data, which are reconstructed by Wrigley and Schofield, go back to 1541, and the data for north Italy to 1650. In Sweden, the crude death rate was highest in 1710, at 84 per 1,000, the last outbreak of the bubonic plague in Sweden. The second highest level was reached in 1651, at 72 per 1000. In comparison, the highest level in England after 1541 was in 1558, at 54 per 1,000, and in north

[10] Eickstein et al. (1984); Nicolini (2007).

Italy after 1650, in 1693, at 45 per 1,000. Still in 1773 the crude death rate rose above 50 per 1,000 in Sweden, while in England after 1558 the rate never rose above that level.

Figure 1: Crude death rate in Sweden, England and north Italy 1540–1870.



Sources: Galloway (1994), Edvinsson (2015), and Wrigley and Schofield (1989).

In Sweden there were two important breaks in mortality: around 1720, after the end of the Great Nordic Wars, and around 1820, when Sweden entered its long period of peace and the low point of death rates started to decline. Up to around 1720 the average crude death rate was higher in Sweden than in England and north Italy. After 1720 it fell to the level in England. According to the data of Wrigley and Schofield, English death rates did not decline in the first half of the eighteenth century. After 1812, the Swedish crude death rate never rose above 30 per 1,000, while that was the average level in north Italy up to the 1860s. By the 1840s the average crude death rate in Sweden fell below the average in England, despite that

Sweden was poorer. Mortality affected various groups differently,[11] but that issue is not considered here.

Figure 2 compares the volatility of the crude death rate in the three areas, measured as the 40-year moving standard deviation of the annual logarithmic change (choosing another moving average period does not change the overall picture). The paths are clearly different in the three areas. In 1650–90, volatility was equal in England and northern Italy, whereas in Sweden it was substantially higher. While volatility decreased in England after 1690, and in Sweden after 1720, the volatility in north Italy did not change. By the first half of the nineteenth century, the volatility in Sweden decreased below the level in north Italy. Sweden and England are therefore comparable in terms of a long-term decline in the occurrence of mortality crises during the early modern period, but Sweden lagged 100 to 150 years behind the development in England.

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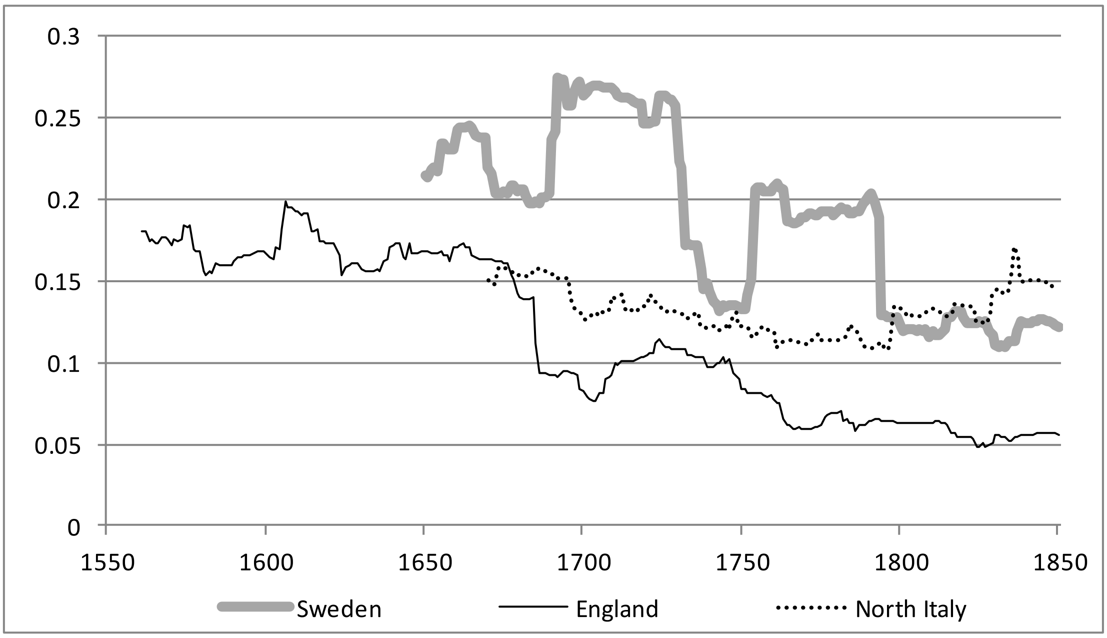
[11] Bengtsson (2004).

Figure 2: The 40-year moving standard deviation of the logarithmic annual changes in crude death rates in Sweden, England and north Italy.



Sources: See Figure 1 and appendix.

The above comparison rests on the assumption that the underlying data are not biased, but there are competing interpretations of the demographic development. The demographic data for Sweden back to 1630 are based on an earlier study by the Swedish historian Lennart Anderssom Palm. As explained in the appendix, the present study uses a revision to the series, which upgrades the size of population and the vital rates especially for the earlier years.[12] Razzel argues that the assumption of Wrigley and Schofield of a burial accuracy of 100 per cent is unrealistic, and that the actual mortality levels could be much higher.[13] He suggests that in reality there was a decline in English death rates in the first half of the eighteenth century, which would make the development in England comparable to Sweden.

[12] Edvinsson (2015).

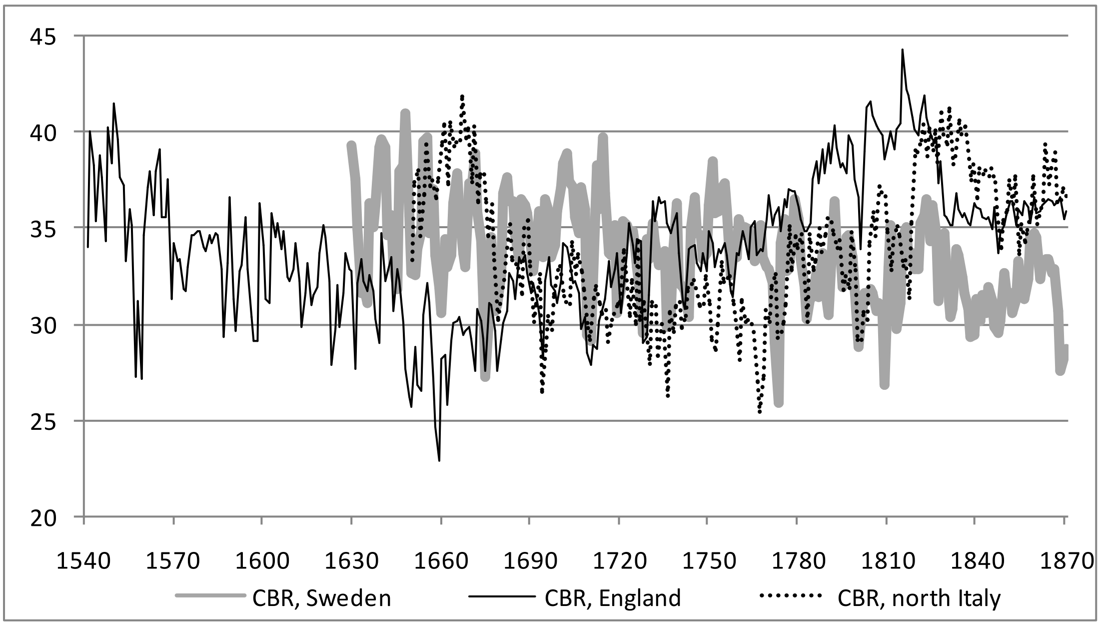
[13] Razzel (1993), p. 752.

Figure 3 presents the development of the crude birth rate in the three areas during the same period as in Figure 1. This is the period before the second phase of the demographic transition, i.e. before fertility declined. Several Swedish historians argue that there was another, hidden, demographic transition between the seventeenth and eighteenth centuries, which increased the age for marriages. Larsson shows that the average age of first marriage among women increased from around 24 years to around 26 years during the first two decades of the eighteenth century and stabilised at this level after a temporary drop in the 1730s.[14] Higher age of marriage indicates strengthened preventive checks. When compared to the quite sharp medium-term fluctuations in England and north Italy the fall in the crude birth rate in the early eighteenth century Sweden was not so large. However, Razzel argues that the rise in birth rates in the eighteenth century according to the data of Wrigley and Schofield (see Figure 3) could be spurious as well.[15]

[14] Larsson (2006), pp. 145–146 and 205.

[15] Razzel (1993), p. 745.

Figure 3: Crude birth rate in Sweden, England and north Italy 1540–1870.



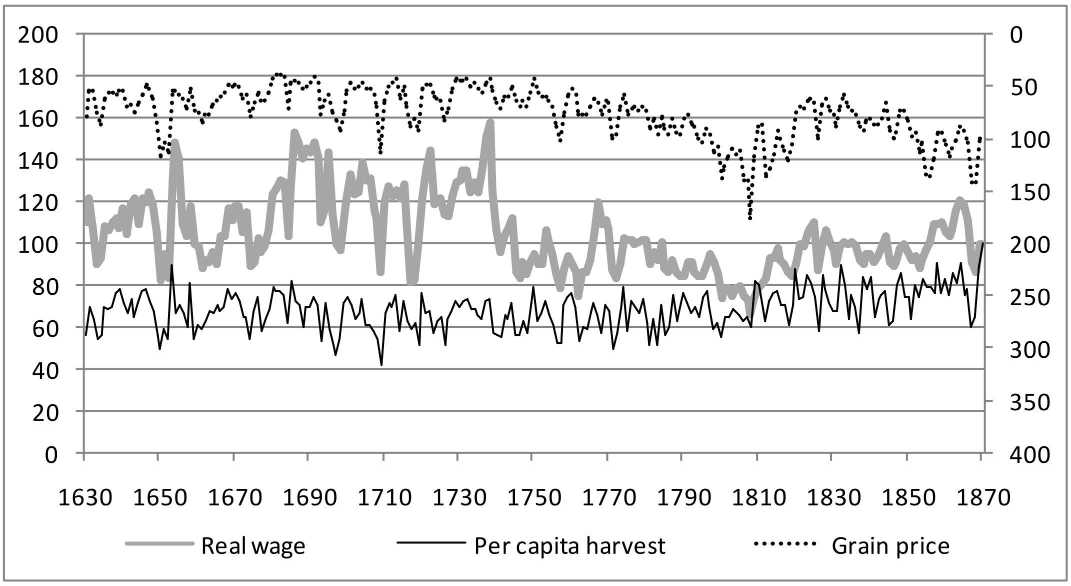
Sources: See Figure 1 and appendix.

Living standards in the pre-industrial can be measured using different indicators. Figure 4 presents the development of the real wage, per capita harvest and the grain price in Sweden 1630–1870 (see the appendix). 1870 is chosen as a benchmark and set equal to 100. The figure shows that several of the mortality crises were preceded by negative shocks to the living standards, whichever indicator is chosen. Most notably both the mortality crisis in the early 1650s and the early 1710s were preceded by sever harvest failures, low real wages and high grain prices.

The mortality crisis in 1772–73 was also preceded by falling livings standards. Official statistics on the causes of deaths shows that in 1772–73 were the only years since 1749 when the number of deaths due to starvation reached above 1,000. However, various infectious diseases, such as dysentery, were a more common cause of deaths. Reduced resistance due to malnutrition and increased travels when people searched the country for food and work contributed to the spread of these diseases.[16]

By the nineteenth century it is not as clear whether chocks to the living standards were followed by mortality crises. Most notably the sever harvest failure in 1867 only slightly raised mortality (mostly affecting northern Sweden[17]), from 19 per 1,000 in 1865 to 22 per 1,000 at its peak in 1869. In comparison, in neighbouring Finland the outcome was different. At the peak of the Finnish famine, in 1868, the crude death rate reached 78 per 1,000,[18] a level which in post-1630 Sweden was only surpassed once, in 1710.

Figure 4: Real wage (left scale), per capita harvest (left scale) and grain price (right scale) 1630–1870 (1870 =100).



Source: See appendix.

[16] Willner (2005), p. 41.

[17] Nelson (1988), p. 82.

[18] Ó Gráda (2001), p. 576.

The indicators of livings standards tended to move together, but there are divergences especially for the medium-term fluctuations. For example, the grain prices were at their highest level, and real wages at their lowest level in the early nineteenth century. Nevertheless, the development of per capita harvests or the crude death rates was different. This study argues that per capita harvest is the superior indicator of nutrition standards. In their study on the post-Malthusian economy in Scandinavia Klemp and Møller (2015, p. 2) use real wage as an indicator of economic conditions, claiming it is "high-quality economic… historical data". However, for Sweden earlier research shows that there is a lack of strong congruence between real wage and macroeconomic conditions. As Lennart Jörberg notes, 'the fall in the real wages of day-workers provides no information on the general economic situation of agriculture during the later part of the eighteenth century'.[19] It is likely that the fall was counteracted by increased labour input per inhabitant. While real wage was very high in 1690–1730, Morell demonstrates low levels of calorie intake in Swedish 'hospitals' in this period.[20] Using real wage as an indicator for living standards may therefore lead to wrong conclusions concerning the relation between demographic indicators and economic conditions.

In his original demographic theory Malthus related population growth to food production rather than to per capita income or wages.[21] He focused on the 'produce of land', while he viewed increases in 'manufactured produce' as immaterial to the wellbeing of the population at large. Even though the Industrial Revolution has later disproved Malthus' view of the role of manufacturing, his argument has some relevance for an agrarian society. In industrialised

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[19] Jörberg (1972), vol. 2, p. 343.

[20] Morell (1986), pp. 260–261.

[21] Malthus (1985), pp. 183–195.

countries, there is a positive correlation between changes in living standards and fertility,[22] but this should not be interpreted as a Malthusian mechanism, since it is not the lack of food per se that poses limits on fertility today. The key indicator of food production is annual harvest. Even though food production also includes animal husbandry, harvest fluctuations largely affected the latter as well. Alternative productivity measures that have been employed by economic historians include yield per hectare, labour productivity and total factor productivity,[23] but per capita harvests are more closely related to the nutrition standard. Furthermore, the most adequate measure of harvest, when related to vital rates, is its calorie content.

From the perspective of analysing the Malthusian mechanism, the response to harvest should be more relevant than to grain prices and real wages, since the faded vulnerability to land output volatility was a fundamental feature of the transformation to a post-Malthusian economy. The response to real wage is evidently an inferior indicator than the response to grain price. In the agrarian society, the monetary wage only reflected the living conditions of a small proportion of the population. The Malthusian theory rests on a relation between harvests and population. Grain prices are relevant only as long as they reflected harvests, and such relation is not automatic, due to trade, storage and shifts in the price elasticity of grains.

3. Models treating harvest as exogenous

One way to study the Malthusian equilibrium mechanism is to calculate cumulative elasticities of vital rates.[24] There are several methods to perform such an analysis. The (short-term) Malthusian preventive check on population implies that the per capita harvest

[22] Galloway (1994), p. 4.

[23] Hoffman (1991), pp. 777–780.

[24] Bengtsson and Ohlsson (1985), p. 316; Voigtländer and Voth (2009), p. 249.

elasticities of birth and marriage rates are positive. The presence of positive checks entails that the elasticity of the death rate is negative. The analysis in this study is based on the logarithms of the calorie content of per capita harvests (*h*), crude death rates (*d*), marriage rates (*m*), and crude birth rates (*b*).

There were substantial shifts in the vital rates and per capita production of calories over time. However, that could entail a deterministic trend rather than a stochastic one. We first investigate whether any of the series contain a unit root, i.e. if any series contains a stochastic trend. For the period 1630–1870, the DF-GLS test strongly (at a 1 percent level) rejects the null hypothesis of a unit root for the logarithms of per capita calorie production, death rates, birth rates and marriage rates, if a time trend is allowed, and irrespective of the information criterion used. However, without a time trend, the null hypothesis of a unit root cannot be rejected for the logarithm of birth rates. The lack of stochastic trends entails that analyses based on first differences or cointegration models are not suitable (stationary series are always cointegrated).

Since we may suspect that the various variables contain a deterministic trend, the correct method is to analyze deviations from trend rather than first differences. Modelling the appropriate trend is problematic, and various specifications can generate different results. In this paper, two specifications are applied: a polynomial of time is included and the series are filtered using a HP-filter, setting λ equal to 10,000. A high value of λ is necessary, to avoid spurious cycles. Usually the values of 100 or 6.25 are used to investigate business cycles, but we here want to investigate movements around a more long-term trend (there is no mathematical reasons to apply just one value for λ in all studies). A polynomial is chosen up to the fifth degree, since in some specifications time to the power of five is significant (see regression (6) in Table 1 and specification (12) in Table 4).

In addition, possible structural breaks are investigated. For this purpose, the timing of possible breaks is assumed to be known. Such possible breaks are suggested in the literature (see discussion above): 1720, 1820, 1870 and 1920. Around 1720 the Great Northern War ended and the Age of Freedom began. After 1820, Sweden was transformed from a net importer of grains to a net exporter.[25] 1870 is often considered as the beginning of Swedish industrialization. After 1920 agriculture stopped having any substantial impact on the aggregate economy.[26]

The simplest way to investigate the elasticities of vital rates is to apply a distributed lag model, DLM(*s*), where *s* is the number of lags in the exogenous variables:

$$y_t = \mu + f(t) + \sum_{i=0}^{s} b_i h_{t-i} + \eta_t \qquad (1)$$

η_t is the error term, which is not necessarily white noise, since there could be auto-correlation. y_t is the logarithm of the vital rate. $f(t)$ is a time polynomial. For the filtered series there is no time polynomial.

The cumulative elasticity can be interpreted as the increase in the expected value of the dependent variable following a one-unit change in the expected value of the independent variable, or as the partial derivative $\partial\mathrm{E}[y_t]/\partial\mathrm{E}[h_t]$. This is also the long-run multiplier:

$$Cum = \frac{\partial \mathrm{E}[y_t]}{\partial \mathrm{E}[h_t]} = \sum_{j=0}^{s} b_i \qquad (2)$$

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[25] Åmark (1915), pp. 354–355.

[26] Edvinsson (2012, 2013a, 2013b and 2015).

In the DLM harvest is assumed to be an exogenous variable, affecting the various vital rates at different lags. An option is to also include various dummy variables, for example, wars, extreme values or plagues. However, it is doubtful whether the inclusion of dummy years is the correct method to measure elasticity. Severe harvest failures in Sweden were often followed by plagues.[27] The extreme changes in mortality levels constituted an important feature of the Malthusian equilibrium mechanism, and should therefore not be abstracted from the model. A problem with including war dummies is that, in the period 1630–1720 Sweden was at war most of the years.

Table 1 presents six different regressions based on a DLM(3), with data for the period 1630–1870. Three lags of harvest are included, since for some, but not all, specifications the third lag is significant. A problem with the DLM is that autocorrelations in the error terms can be detected for all the specifications. Therefore, the significance levels of OLS are not appropriate. The table instead displays results using Newey-West standard errors with one lag. The table presents cumulative elasticities, Cum_{period}, by summing up the coefficients for the harvest and its lags.

[27] Larsson (2006), pp. 93–120.

Table 1: Distributed lag model with the logarithm of per capita harvests as the independent variable, according to different specifications, 1630–1870.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	d_{HP}	d	m_{HP}	m	b_{HP}	b
t		-0.001***		0.008*		-0.006*
t^2				-1.13E-4*		1.54E-4*
t^3				7.32E-7*		-1.52E-6*
t^4				-1.51E-9**		6.31E-9*
t^5						-9.5E-12†
h	-0.199*	-0.155†	0.146**	0.136**	0.037	0.026
Lh	-0.557***	-0.53***	0.343***	0.335***	0.244***	0.239***
L^2h	-0.283*	-0.255*	0.03	0.02	0.176***	0.172***
L^3h	-0.165*	-0.119	-0.13*	-0.141**	-0.027	-0.034
Constant	-0.002	4.898***	0	1.638***	0.001	3.056***
$Cum_{1630\text{-}1870}$	-1.204***	-1.058***	0.389***	0.351**	0.429***	0.403***
$Cum\beta_{1630\text{-}1870}$	-0.793	-0.65	0.452	0.339	0.798	0.731
Autocorrelation, Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Adj. R^2 (OLS)	0.2718	0.4647	0.2334	0.5576	0.3900	0.4703
df	236	235	236	232	236	231

† $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. All standard errors are Newey-West standard errors with one lag.

In regressions (1) and (2) the dependent variables is the (logarithm of) crude death rate. The two different specifications of the trend yield very similar results. The cumulative elasticity is -1.1 to -1.2, entailing that just a one percent permanent decline in harvests caused death rates to (ceteris paribus) permanently increase by 1.1 to 1.2 percent. Harvest lagged by one year had a very substantial effect on current death rates. However, there was also an effect of current year's harvest on the current year's death rates, despite that harvests occurred in September.

For crude birth and marriage rates the result is likewise similar for the two trend specifications. The elasticities of marriage and crude birth rates are estimated to around 0.4 in both specifications. Even if the elasticities were weaker than for death rates, the main explanation for this is that the volatility of death rates was higher than for birth and marriage rates.

An alternative measure of the elasticity is based on the beta coefficients, entailing how much a standard unit change in the expected value of the logarithm of per capita harvest impacted on the expected value of the logarithm of vital rates measured in standard units. The table presents such measure, labelled *Cumβ*. The cumulative beta coefficients were at about the same strength for death and birth rates, while it was weaker for the marriage rates.

This result demonstrates that there was a distinct short-term Malthusian mechanism before the industrial breakthrough in the 1870s.

In Table 2, the investigated period is divided into two, 1630–1720 and 1721–1870. In addition, the period 1871–1920 is also included. Tests were performed whether there occurred any structural breaks in the cumulative elasticities. The result is not completely comparable to Table 1. Although the time polynomials are modelled with the same powers, the time polynomial is assumed to be different in the two sub-periods. For deaths rates both specifications entail that there was a significant decline in the cumulative elasticity. This mirrors the decline in the volatility of death rates. For birth rates there is no indication there was any shift. However, for marriage rates both specifications entails that cumulative elasticity was strengthened after 1720. 1720 therefore seems to be an important structural break in the Malthusian mechanism; while the positive checks attenuated, the preventive checks strengthened.

Somewhat surprising is that the elasticity of death rates in the period 1871–1920 was as strong as in 1721–1870. For marriage rates there was clearly a structural break occurring in 1871 for both specification, while for birth rates such break only occurred in the filtered series.

Table 2: The estimated cumulative elasticity according to a DLM in various sub-periods 1630–1920.

Dependent variable	d_{HP}	d	m_{HP}	m	b_{HP}	b
$Cum_{1630–1720}$	-1.535***	-1.492***	0.224	0.193	0.378***	0.448***
$Cum_{1721–1870}$	-0.676***	-0.85***	0.660***	0.672***	0.511***	0.539***
$Cum_{1871–1920}$	-0.732***	-0.701**	-0.103	-0.307*	-0.158	0.308†
$P(Cum_{1630–1720} = Cum_{1721–1870})$	0.0069	0.0406	0.0358	0.0100	0.2731	0.4746
$P(Cum_{1721–1870} = Cum_{1871–1920})$	0.8401	0.5896	0.0015	0.0000	0.0000	0.1694
Power of time polynomial	0	1	0	4	0	5

† $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. All standard errors are Newey-West standard errors with one lag.

There could be further breaks in the time series. Table 3 investigates whether a break occurred in 1821. There is no indication of any weakening of the Malthusian mechanism occurring in that year. In fact, if there was a shift, it rather indicates a small strengthening. The only significant result, at the 5 percent level, is the strengthening of the cumulative elasticity of marriage rates for the filtered series. Table 3 suggests that the period 1721–1870 can be treated as relatively structurally homogenous concerning the relation between harvests and vital rates.

Table 3: The estimated cumulative elasticity according to a DLM in 1721–1820 and 1821–1870, respectively.

Dependent variable	d_{HP}	d	m_{HP}	m	b_{HP}	b
$Cum_{1721–1820}$	-0.590^{**}	-0.6^{*}	0.545^{***}	0.518^{***}	0.433^{***}	0.467^{***}
$Cum_{1821–1870}$	-0.919^{***}	-0.723^{**}	1.031^{***}	0.717^{***}	0.757^{***}	0.466^{***}
P($Cum_{1721–1820}$ = $Cum_{1821–1870}$)	0.3031	0.6935	0.0186	0.2963	0.098	0.9979
Power of time polynomial	0	1	0	4	0	5

† $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. All standard errors are Newey-West standard errors with one lag.

Time series models are often very sensitive to the underlying assumptions. It is therefore important to investigate whether more complicated models could render other results.

The problem with equation (1) is that there is autocorrelation in the error term. In the ARMAX model the error term is modelled as an ARMA process. Equation (1) is then termed the measurement equation, while the so-called transition equation is (where ε_t is white noise, and ϕ(L) and θ(L) are lag polynomials):

$$\phi(\mathrm{L})\eta_t = \theta(\mathrm{L})\varepsilon_t \qquad (3)$$

The cumulative elasticity can be estimated in the same way as for the DLM. Table 4 presents the relevant regressions, which are the equivalent to the regressions in Table 1. The ARMA specifications are determined based on the minimization of the Akaike information criterion. The Q test shows that there is no remaining autocorrelation in the error term. Interestingly the estimated coefficients were almost the same as in Table 1, although the cumulative elasticities for death and birth rates were somewhat stronger.

Table 4: ARMAX model, with the logarithm of per capita harvests as the independent variable, according to different specifications, 1630–1870.

	(7)	(8)	(9)	(10)	(11)	(12)
Measurement equation:						
Dependent variable	d_{HP}	d	m_{HP}	m	b_{HP}	b
t		-1.11E-3***		6.33E-3*		-8.5E-3**
t^2				-1.07E-4*		2.18E-4**
t^3				6.25E-7*		-2.17E-6**
t^4				-1.33E-9*		9.13E-9*
t^5						-1.4E-11*
h	-0.253**	-0.218**	0.103*	0.091*	0.063**	0.065*
Lh	-0.543***	-0.516***	0.334***	0.32***	0.247***	0.249***
L^2h	-0.282***	-0.243**	0.024	0.016	0.177***	0.177***
L^3h	-0.173*	-0.147*	-0.077†	-0.076†	-0.013	-0.012
Constant	-0.001	4.986***	0.001	1.669***	0.001	2.977***
Transfer equation (ARMA):						
LAR	0.498***	0.226*		0.679***	0.448***	0.532***
L^2AR				-0.223**		
LMA		0.343**	0.635***			
L^2MA			0.178**			
$Cum_{1630\text{-}1870}$	-1.251***	-1.124***	0.384***	0.351**	0.474***	0.479***
Q test	0.1584	0.8511	0.2313	0.1854	0.2290	0.1028
AIC	-236.9705	-224.956	-517.3757	-505.3514	-773.3884	-756.2667
Observations	241	241	241	241	241	241

† $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

4. Estimating a SVAR model

A VAR model takes into account the endogenous relations between variables. For example, good harvests caused higher birth rates, which decreased per capita harvest, which in turn reduced the number of birth rates at later periods. Treating harvests as unaffected of the other variables would entail that such indirect effects are not taken into account. The problem is how to determine the contemporaneous relations. In the reduced VAR model the contemporaneous effects remain unknown. The reduced VAR model can only be used for prediction, and cannot be given any causal interpretation.

In the reduced VAR model, each variable is linear combination of the lagged values of itself and the lagged values of the other variables included in the model:

$$\mathbf{y}_t = \boldsymbol{\mu} + \mathbf{C}\mathbf{t}_t + \sum_{k=1}^{l} \boldsymbol{\Phi}_k \mathbf{y}_{t-k} + \boldsymbol{\varepsilon}_t \qquad (6)$$

$\mathbf{y}_t$ is here a four-element column vector, where the elements consist of the natural logarithms of the calorie content of per capita harvest, the crude death rate, the marriage rate and the crude birth rate. $\boldsymbol{\mu}$ is a four-element column vector of constants, $\mathbf{C}$ is a $4 \times r$ matrix of the coefficients for the time polynomial, $\mathbf{t}_t$ is the r-element vector of time up to the r:th power, $\boldsymbol{\Phi}_k$ represents 4×4 matrices of coefficients, $\boldsymbol{\varepsilon}_t$ is a four-element column vector of the white noise process, and l is the number of lags included in the VAR model. In the structural VAR a causal interpretation can be made. This entails that we multiply expression (6) by a 4×4 matrix, $\mathbf{A}$, whose diagonal consists of ones:

$$\mathbf{A}\mathbf{y}_t = \mathbf{A}\boldsymbol{\mu} + \mathbf{A}\mathbf{C}\mathbf{t}_t + \sum_{k=1}^{l} \mathbf{A}\Phi_k \mathbf{y}_{t-k} + \mathbf{A}\boldsymbol{\varepsilon}_t \qquad (7)$$

While the elements of $\boldsymbol{\varepsilon}_t$ are not necessarily independent from each other, the shocks contained in the vector of $\mathbf{A}\boldsymbol{\varepsilon}_t$ are by construction orthogonal. The problem is that structural VAR cannot be derived from the reduced VAR, due to the endogenous relations between the variables. However, a solution can be imposed. For example, in a recursive VAR, there is an order between the variables. $\mathbf{A}$ then consists of zeros above its diagonal. The zeros above the diagonal entails that there is no current effect of variable X_m on variable X_n if m is larger than n, where m and n are the orders of the variables.

$\mathbf{A}\boldsymbol{\varepsilon}_t$ in equation (7) can also be written as $\mathbf{B}\mathbf{v}_t$, where $\mathbf{v}_t$ is the vector of orthogonalised shocks, while $E[\mathbf{v}_t\mathbf{v}_t']$ is the identity matrix, **I**. **B** is a diagonal matrix. Therefore, the vector $\mathbf{B}\mathbf{v}_t$ is also orthogonalised.

Impulse response functions and cumulative impulse response functions are a way to graphically illustrate the impact of one variable on another over several periods. The structural impulse response function also lends support for causal analysis.

In this study, the following causal order is assumed: harvests, crude death rates, marriage rates and crude birth rates. Harvests should have been causally prior to any of the other three variables. High death rates were often followed by higher marriage rates within a shorter time span than one year. Marriage rates in the beginning of the year most likely affected birth rates at the end of the same year.

The first step is to assess the number of lags in the VAR, which can be derived from various information criteria. The appropriate lag order is always difficult to set. Two trend specifications are investigated. In the specification with a quintic time polynomial, HQIC and SBIC indicate than only one lag should be included. However, FPE and AIC indicates three lags. For the filtered series the information criteria yield the same result.

The next step is to perform various diagnostic tests on the underlying VAR model. Testing for the stability, shows that all eigenvalues of the companion matrix lie within the unit circle, irrespectively of whether the underlying VAR model contains one or three lags. The stability condition is met also when no trend is assumed. Unfortunately, the Lagrange-multiplier test shows that the null hypothesis of no first-order residual autocorrelation is rejected at a one percent level, whichever specification is used (see Table 5). Therefore, there could be a misspecification in the model. The problem lies in the assumption of no structural change during the whole period 1630–1870.

If we instead construct separate VAR models for different sub-periods there are instances where the null hypothesis of no first- or second-order autocorrelation is not rejected. Table 5 summarizes the Lagrange-multiplier test of different specifications of the VAR model. For the period 1630–1720 only in the specifications with no trend is the null hypothesis of no residual first- and second-order autocorrelation not rejected. For the periods 1721–1870 and 1871–1920, the Lagrange-multiplier test indicates that there is no residual autocorrelation for the specification with a quintic time polynomial with three lags. In this study, the choice therefore falls on a VAR with three lags, for the period 1630–1720 with no trend, and for the periods 1721–1870 and 1871–1920 with a quantic time polynomial. The filtered series are not considered since for the period 1630–1720 both specifications of the number of lags included indicates residual first-order autocorrelation.

Table 5: Lagrange-multiplier test of residual first- and second-order autocorrelation (p-values) according to different specifications.

	Filtered series		Quintic time polynomial		No trend	
	1 lag	3 lags	1 lag	3 lags	1 lag	3 lags
1630-1870	1: 0.00171 2: 0.00337	1: 0.00004 2: 0.06977	1: 0.00153 2: 0.00570	1: 0.00027 2: 0.09056	1: 0.00000 2: 0.00017	1: 0.00823 2: 0.00491
1630-1720	1: 0.02975 2: 0.21196	1: 0.00586 2: 0.24518	1: 0.00586 2: 0.26502	1: 0.00070 2: 0.00865	1: 0.08883 2: 0.15288	1: 0.08771 2: 0.43443
1721-1870	1: 0.15621 2: 0.00519	1: 0.14471 2: 0.71550	1: 0.12678 2: 0.01734	1: 0.13863 2: 0.77847	1: 0.00373 2: 0.03409	1: 0.01977 2: 0.30179
1871-1920	1: 0.00005 2: 0.00123	1: 0.18405 2: 0.90436	1: 0.00002 2: 0.01639	1: 0.17053 2: 0.23498	1: 0.00064 2: 0.04286	1: 0.25289 2: 0.22521[a]

[a] This specificiation is unstable, since one of the eigenvalues of the companion matrix lies outside of the unit circle.

Comment: Greyed area indicates specifications with no significant residual autocorrelation.

Figure 5 and 6 present the structural impulse response functions for 1630–1720 and 1721–1870, respectively. The figures also contain the 95 percent confidence intervals. They show that the strongest impact of harvest was after one year which is significant for all vital rates in both periods.

For death rates in 1721–1870, there was also a significant impact in the current year. Since the impact could not have been felt until the end of the year, it shows that death rates reacted to harvests quite immediately. For 1630–1720, the impact of harvest on the death rates was substantially stronger than in any of the subsequent periods. Harvest failures in one year caused increases in death rates in the subsequent three years. In 1721–1870, the impact of harvest on death rates receded substantially although there was still a significant impact of harvests on death rates in the years 1 to 3.

For all vitals rates, the impact of harvests was reversed after 3-7 years. Such oscillation was strongest for marriage rates. For example, high marriages rates following good harvests were followed by lower marriage rates. This explains why the cumulative impact of harvests on marriage rates was quite weak. One explanation could be that high marriage rates caused the proportion of unmarried in the adult population to be reduced, which, in turn, decreased the number of marriages after some time. The impact on birth rates during the first years was not so different in 1630–1720 and 1721–1870, but since the oscillation weakened after 1720, the cumulative impact substantially strengthened.

Figure 5: The estimated structural impulse response function, with harvests as the impulse, for the period 1630–1720 (vertical scale – logarithms, horizontal scale – years).

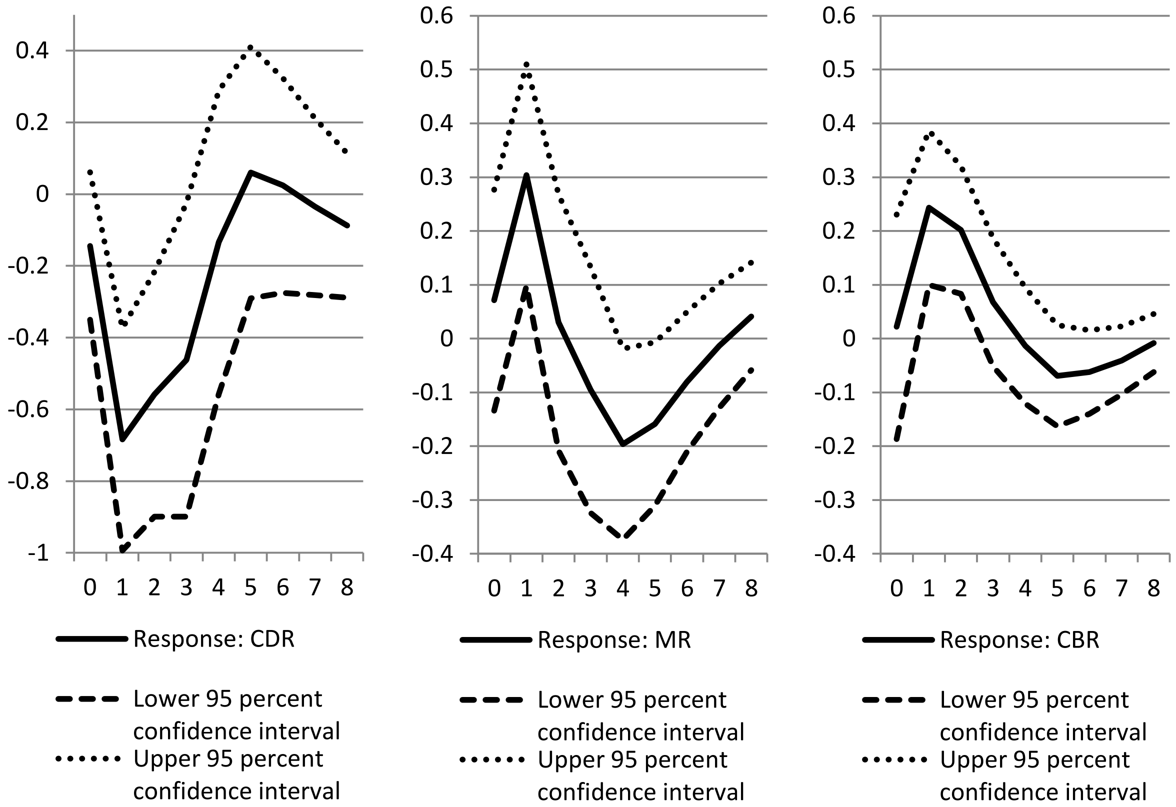
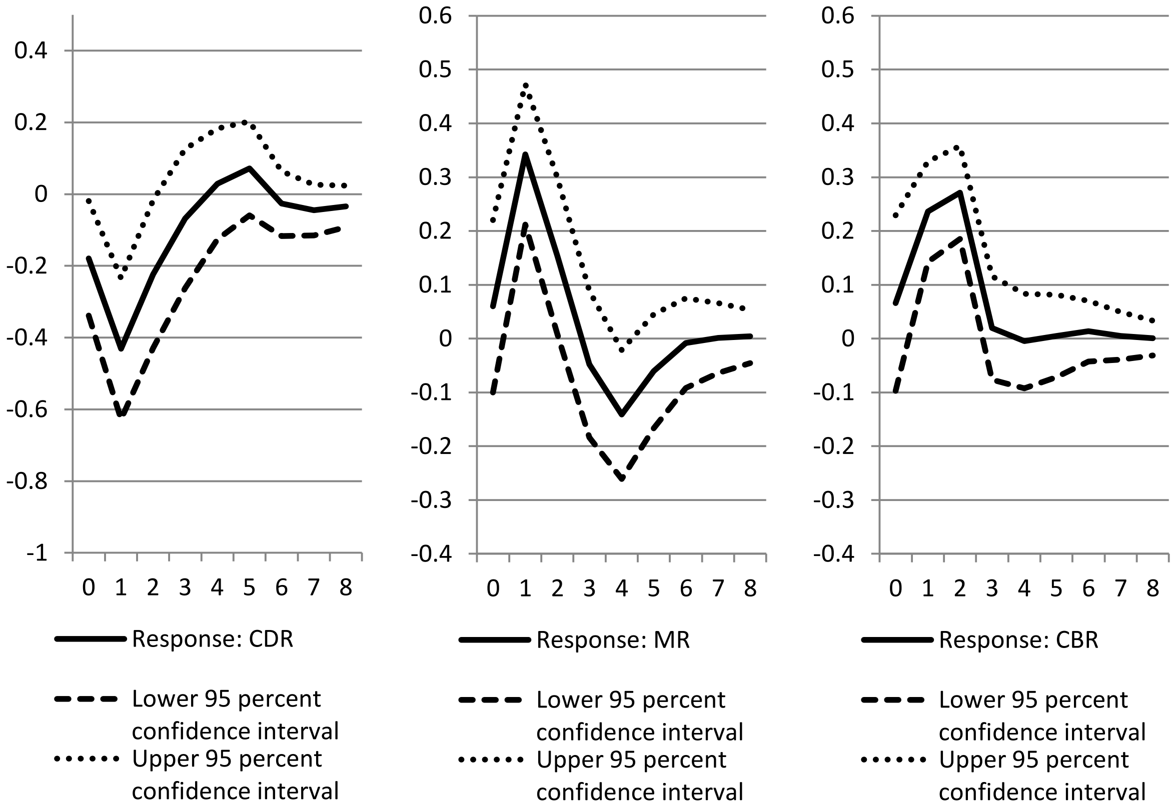


Figure 6: The estimated structural impulse response function, with harvests as the impulse, for the period 1721–1870 (vertical scale – logarithms, horizontal scale – years).



The cumulative structural impulse response function (csirf) is not the same as the cumulative elasticity with harvest as the impulse. The former is the cumulative response of a one-unit shock of harvest on vital rates. However, part of the effect is through changing harvest in the next periods. For example, if a one-unit increase in harvest causes harvest also to increase by half a unit the next year, this also adds to the impact on the vital rates. Therefore a one-unit increase in the harvest the current year is, in this example, a de facto one-and-a-half unit increase in the harvests accumulated during the whole period. To estimate the cumulative elasticity of vital rates with respect to harvest, we have to divide the csirf with harvest as impulse and a vital rate as the response with the csirf with harvest as both impulse and response. Table 5 displays the estimates.

The cumulative structural impulse response function with harvest as impulse and response declined quite dramatically, from 1.85 in 1630–1720 to unity in 1721–1870. Before 1630 chocks to harvests in one year had strong repercussions on later harvests, while after 1720 this was no longer the case. For the period 1630–1720 the decline substantially reduces the estimated cumulative elasticity of vital rates when compared to the cumulative structural impulse response function.

For death rates in 1630–1720, the estimated cumulative elasticity in Table 5, at -1.3, is somewhat weaker than according to the distributed lag model. However, the change in 1720 was not as dramatic as according to the DLM, and there was a slight weakening after 1870, contrary to the result in Table 2.

Table 6 shows that for both marriage and birth rates, the cumulative elasticities significantly strengthened after 1720, while they disappeared after 1870. However, despite the significant impact after one year, the cumulative elasticity of marriage rates was not significant in any of the investigated periods. The cumulative elasticity of birth rates was at 0.6 in 1721–1870, which was stronger than according to the DLM, while it was not significant in any of the other sub-periods.

Overall Table 6 yields a similar picture as for the DLM: while after 1720 positive checks weakened, preventive checks strengthened, and while after 1870 preventive checks disappeared, positive checks continued to exist until 1920.

[Insert Table 6 here]

5. Putting the empirical findings in context

There are several possible explanations for the decline in the elasticity of the crude death rate in Sweden after the 1710s. In particular, the years around 1650–1720 experienced severe economic difficulties. It took time for the economy to recover.[28] Climatic factors might also be important. A reconstruction of winter temperatures for Stockholm shows that a previous cold period beginning in the mid-sixteenth century ended around 1700 and that the 1730s was an unusually warm decade.[29] Other explanations for the decreased occurrence of severe mortality crises in Europe during the eighteenth century include a mutual adaptation between pathogen and host that decreased mortality levels during plagues, improved private and public hygiene and an enhanced system of transportation and market integration.[30]

The result of the present study that preventive checks disappeared after 1870 accords quite well with the description by Dribe of the fertility pattern in Sweden before 1880 as natural.[31] Bengtsson and Dribe find that in Scania there was a strong fertility response to changes in food prices during the whole period 1766–1864.[32]

The strong support for the existence of positive and preventive checks up to the nineteenth century can be contrasted to earlier research on England. Using VAR methods, Nicolini finds that the negative effect of real wages on mortality rates in England was significant only up to 1640, while the positive effect on fertility was significant only up to 1740.[33] Crafts and Mills cannot find any evidence of positive checks even for the period 1542–1645 and conclude that

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[28] Morell (1986), pp. 260–261.

[29] Leijonhufvud et al. (2001).

[30] Livi-Bacci (2007), p. 67.

[31] Dribe (2008).

[32] Bengtsson and Dribe (2006).

[33] Nicolini (2007).

preventive checks disappeared by the early seventeenth century.[34] Recently, Rathnke and Sarferaz question this result, contending that by using a time-varying VAR model preventive and positive checks are made visible in the English data up to the nineteenth century.[35] A problem with all of these studies, and a clear disadvantage to the present study, is that they use real wage as an indicator for living standards.

England was most likely earlier in its transition to a post- or late Malthusian economy. Compared with England,[36] the spikes in Swedish mortality rates up to the early eighteenth century were at a much higher level (see Figure 1). France displayed a similar development as that in Sweden, with a marked decline in severe mortality crises during the course of the eighteenth century, while in other European countries the decline was more protracted and came later.[37] Nevertheless, as for Sweden, it is likely that other results could be found for England if elasticities were computed with respect to harvest or food production or if the series of crude death rate for England is upgraded during mortality peaks in light of the criticism directed against the demographic reconstruction of Wrigley and Schofield.

The decline in the sensitivity of mortality after 1720 may be surprising given that earlier Swedish studies show that there was a very strong dependency on cereal products in the eighteenth century, while animal products stood for only a small part of the diet.[38] However, per capita food consumption did not decline during the course of the seventeenth and eighteenth centuries, while GDP per capita increased somewhat despite the relatively fast population growth.[39] The significant growth in the size of the population during the eighteenth

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[34] Crafts and Mills (2009), p. 80.

[35] Rathnke and Sarferaz (2010).

[36] Wrigley and Schofield (1989), pp. 531–535.

[37] Livi-Bacci (2007), p. 67.

[38] Morell (1986).

[39] Edvinsson (2013a).

century was in itself a manifestation of a dynamic economy. Gadd describes Sweden as going through an agrarian revolution in the eighteenth and nineteenth centuries.[40] Import of grains also dampened the impact of harvest fluctuations on death rates.

For Germany, Pfister and Fertig find that positive checks substantially weakened after the 1810s,[41] which is not as visible in the Swedish material. The present study reproduces the result by Galloway that there were strong positive checks in Sweden after the industrial breakthrough and that positive checks were not attenuated over time (which he also argues was the case for France).[42] It was only after 1920, that the positive checks disappeared, while the structural VAR analysis indicates that some attenuation may have occurred after 1870.

To some extent, the response of the marriage rate is a more direct indicator of preventive checks, since some of the responses of birth rates, at least in the short-term, reflected changed nutritional standards rather than active preventive behaviour. The present study indicates that the elasticity of the marriage rate displayed a similar trend as the elasticity of the birth rate. The very weak, and insignificant, elasticity of the marriage rate in 1630–1720 supports the view that there was a hidden demographic transition between the seventeenth and eighteenth centuries as argued by some Swedish historians. Higher death rates tended to increase the number of marriages. Lower life span induced a lower age at marriage. When the mortality crises attenuated after the 1710s, preventive checks became more predominant.

6. Conclusions

Malthus' original formulation of his model of preventive and positive checks related vital rates to the production of land, not without good reason. The present study argues that one of

[40] Gadd (2000).

[41] Pfister and Fertig (2010), p. 48.

[42] Galloway (1994), p. 24.

the most important indicators used by present-day Malthusians – real wage – could be problematic when analysing the Malthusian world. Instead, this study investigates the short-term Malthusian mechanism by using a series of harvests transformed into the production of per capita calories.

The present study uses different models to estimate the cumulative elasticities of vital rates: DLM, ARMAX and SVAR. In addition, various specifications are used concerning the underlying trends and the number of lags included. The main result is, however, robust to the specifications made. All models support the weaker version of the Malthusian model. In the pre-industrial Sweden, there was a short-term Malthusian mechanism in terms of strong positive and preventive checks, without that implying that per capita income declined due to population growth. Through the effect on death and birth rates, natural population growth was strongly affected by harvest fluctuations. The impact of harvests on various demographic indicators was stretched over several years. The strongest impact was from the harvests lagged by one and two years. All major spikes in death rates were preceded by one or two years of harvest failures. An important finding is that structural breaks occurred around 1720 and 1870.

In line with the finding of Galloway for France and Sweden, the present study finds that positive checks existed up to 1920.[43] In 1630–1720, the cumulative elasticity of the crude death rate was stronger than in any subsequent period according to all the specifications used in this study, reflecting the mortality crises occurring in this period. Up to the early eighteenth century, the cumulative elasticity of death rates was much stronger than of birth and marriage rates. A fundamental change occurred after 1720. Preventive checks were initially strengthened, while they disappeared after the rise of the industrial society in the final decades

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[43] Galloway (1994).

of the nineteenth century, in accordance with earlier findings by Swedish researchers on changing fertility patterns. This development also accords quite well with the prediction of the unified growth theory that in the initial phase of technological acceleration (which Swedish agriculture experienced in the eighteenth century) preventive checks strengthened, while positive checks attenuated. However, to what extent there was a long-term adjustment of vital rates and population growth to harvest output need further investigation.

The demographic transition implied that first death rates went down, but not birth rates, which accelerated population growth. Second, birth rates also declined, which completed the transition.[44] Even if the lower floor of the crude death rate did not start to decline until the 1820s and 1830s (see Figure 1), the transformation in the elasticity of death rates a century earlier was critical.

This paper shows that the Swedish economy in the seventeenth century deviated from that of the English economy. According to the data of Wrigley and Schofield England had already embarked on a similar transformation much earlier than Sweden. Based on English data, Nicoloni concludes that 'perhaps the world before Malthus was not so Malthusian'.[45] Early modern Swedish data can probably better illuminate the dynamics of the agrarian economy, given the special features of England as the first country experiencing an industrial revolution. Furthermore, the reliability of the English data has been questioned. Even if England has a continuous series of vital rates that goes further back in time than for any other country, the reliability of the Swedish data is superior for the second half of the eighteenth century to any other country due to the early official statistics.

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[44] Lee and Anderson (2002).

[45] Nicoloni (2007).

Data appendix

Data on population, mortality, fertility and nuptility is from a previous study.[46] These series are based on data from Palm and Heckscher.[47] For the eighteenth century Palm most likely underestimates the size of population and the vital rates. For 1630 the population within the borders of Sweden is raised from 0.912 to 1.12 million, while for 1700 it is raised from 1.373 to 1.44 million compared to Palm. The trends in vital rates and total population are substantially revised, while annual fluctuations closely follow the data of Palm. From the mid-eighteenth century the population data is from Statistics Sweden.[48]

The series of per capita harvest is from previous published studies of the author.[49] Krantz and Schön present an alternative agricultural series for the early modern period based on the so-called demand approach, but it does not distinguish between harvests and animal products.[50] From 1802, the harvests are derived from reports on the yield ratios (gross harvests divided by seed) of different grains for all Swedish 24 counties. The absolute levels of harvests are uncertain for the nineteenth century, but annual fluctuations are of high reliability due to the detailed make-up of the primary material. For the period before 1802, the harvest series is constructed from three indicators: tithes, subjective harvest estimates and grain prices. Grain prices are not a direct indicator of harvest fluctuations. Nevertheless, in a previous study by the author it is shown that for the early nineteenth century a regression model where grain prices for two consecutive years are included as independent variables, together with another indicator of harvests, can explain over 85 per cent of the variance in

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[46] Edvinsson (2015).

[47] Palm (2000 and 2001); Heckscher (1936).

[48] Statistics Sweden (1999).

[49] Edvinsson (2009, 2013a, and 2013b).

[50] Krantz and Schön (2012).

annual harvest fluctuations. It is only for later periods that grain prices were weakly related to harvests.[51]

For the period from 1802 gross harvests are transformed into calories. One kilogram of wheat is assumed to contain 3365 kcal, one kilogram of rye 3433 kcal, one kilogram of barley 3404 kcal, one kilogram of oats 3369 kcal, one kilogram of dredge 3387 kcal, one kilogram of peas, beans, or vetch 3285 kcal, one kilogram of potatoes 670 kcal, one kilogram of sugar beets 430 kcal, one kilogram of oil plants 2700 kcal, and one kilogram of triticale 3399 kcal. Before 1802 the calorie content of harvests are assumed to follow their volume growth.

The wage series (in Figure 4) is spliced from three series, where the nominal wage is deflated by the Consumer Price Index:[52] for 1630–1732, the day rate of male manual labour in Stockholm;[53] for 1732–1914, the day rate of male agrarian labour in the whole country;[54] and from 1914, the hourly wage of male workers in industry.[55] The standard deviations of the first and third series are adjusted to conform to the standard deviation of the series of 1732–1914, by using the ratios of standard deviations in annual logarithmic changes for overlapping periods.

For 1732–1913, grain prices (in Figure 4) are based on the average national price of various grains[56] using quantity weights from the early twentieth century. For the period 1913–1949, the quantity weights are from 1913. For the period before 1732, the series is mostly based on

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[51] Edvinsson (2009).

[52] Author and co-author, published study from 2011.

[53] Söderberg (2010).

[54] Jörberg (1972), vol. 2.

[55] Prado (2010).

[56] Jörberg (1972), vol. 2.

the prices of rye and barley.[57] The nominal price is transformed to being expressed in grams of gold.

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[57] Edvinsson (2012).

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