Was Malthus right? The relationship between population and real wages in Italian history, 1320 to 1870

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Abstract

In this article we investigate the relation between population and real wages in the Italian economy during the period 1320-1870. The main result is that the positive check is strong and statistically significant but the other equilibrating mechanism in the Malthusian model - the preventive check - based on the positive relationship between fertility and real wages does not operate in pre-industrial Italy. In contrast to the Malthusian hypothesis, we find a negative feedback from wage to population. The empirical result is clearly consistent with the theoretical framework of the "old age security motive". We show, with a simple overlapping generation model, that by allowing for substitution in a pre-industrial economy between child quantity and other assets (such as new seeds, better soybean quality, and new cultivation and irrigation methods) fertility may be negatively affected whenever income rises.

Key words: Malthusian hypotheses; pre-industrial labor productivity and wages; population trend, demographic changes.

JEL: N33; N53; N93; J11; C32

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1. Introduction

In his *Essay on the Principle of Population* of 1798 Thomas Malthus argued that the low and stationary level of per capita incomes prior to the end of the 18th century was causally related to the very slight rates of population growth. This causation works both ways.[2] Higher incomes increase population by stimulating earlier marriages and higher birth rates, and by cutting mortality from malnutrition and other factors (preventive and positive checks). Diminishing marginal productivity also leads to a drop in per capita income for higher populations. This dynamic model implies a stationary population in the long-run equilibrium.

In this article we investigate the relation between population and real wages in the Italian economy during the period 1320-1870. This relationship deserves to be tested for several considerations that still divide the literature. The disagreement concerns the uniqueness of the pattern of the variables before the middle of the 19th century, the selection of which element of the Malthusian scheme is crucial in the models, and the interpretation of the Malthusian model as the unique scheme for describing the economic and demographic patterns in the pre-industrial economies (see, for instance Nicolini 2006 and Allen 2008 for a review of this literature). [3]

Here we are dealing with the latter issue. Although there is a large and growing body of literature which studies economic-demographic relations in pre-industrial Europe using econometric analysis, we do not know of studies for the Italian economy. The object of this article is to test, with aggregate time series, whether Malthusian positive and preventive checks operate in the pre-industrial Italian economy.[4]

In modern data, the relationship between income per capita and population growth is negative, which is the opposite of what the Malthus model assumes. Several authors have developed theories to explain growth takeoff where a decline in fertility is interpreted as substitution of child quantity by child quality (parents invest in education or human capital). In this case, an increase in income per capita (via investment in child quality) lowers fertility.[5] In this paper we address the following two questions: is the observation of a negative relationship between wages and population a necessary and sufficient condition for a growth takeoff? We seek to answer this empirical question by using Italian data for the pre-industrial epoch to show a negative relationship between wages and population. The second question, concerning a theoretical model which supports our findings, is the following: would substitution in the pre-industrial economies between child quantity (number of children) and other assets be possible and able to affect fertility negatively?

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[2] Malthus (1970). The explanation suggested by Malthus has been widely discussed and tested using data of several European countries.

[3] See also Nicolini (2004) and Allen (2001) amongst others. Brezis (2001) and Brezis and Young (2003) develop an alternative approach of modeling demographic transition based upon the interaction between different social classes.

[4] Aggregate time series have been used by many authors for investigating on demographic and economic relationships. See, for instance, Weir (1991), Lee (1997), Lee and Anderson (2002), Malanima (2005), Clark (2006), Craft and Mills (2007), Eckstein et al (1986), Bergtsson and Brostrom (1997) and Nicolini (2006), amongst others.

[5] See Galor and Weil (2000), Boldrin and Jones (2002), Galor and Moav (2002), Doepke and Zilibotti (2005) and Doepke (2004) amongst others, propose different causes which impinge on investment in child quality. See also Galor (2005).

To support this interpretation we use a very simple overlapping-generation economy to emend the Mathusian model of Ashraf and Galor (2008) with the *old wage security motive* assumption. We show that the rise in income per capita may not generate an increase in population.

With regard to the empirical analysis, starting from preliminary statistical analysis based upon the decennial frequencies data set provided by Malanima (2002; 2003; 2005) and Federico and Malanima (2004), we perform a time series analysis to test whether this hypothesis fits the observed patterns in wages and population in pre-industrial Italy. In particular, we estimate and simulate a vector autoregressive (VAR) model. This approach was introduced into historical-demographic research by Eckstein at al. (1986) and is particularly useful in testing the Malthusian hypotheses, since both historical reconstructions and empirical estimates often explicitly impose exogeneity of population in their description of the model. In the Malthusian context, imposing this causal ordering entails ambiguity in the relationships between wages and demographic variables, and simple regressions between the two variables would provide misleading results. In VAR models all variables are treated as being a priori endogenous, and allowance is made for rich dynamics.

Among the main results of the article we find that a better standard of living (measured as an increase in rural real wages) does negatively affect population: one of the key elements to restore the equilibrium in the Malthusian scheme did not operate in Italy in the epoch considered. At least in the pre-industrial age in Italy, and in contrast to the Malthusian hypotheses, a negative relationship between wages and population does not seem to be a necessary and sufficient condition for growth takeoff.

The article is organized as follows. Section 2 reviews a selected literature on Malthus's assumptions, pointing out the causal ordering that many works impose in reading facts and estimating models. Section 3 reports the theoretical model. Section 4 discusses the data set and analyses the dynamics of population and real wages in agriculture. In this section we study the statistical characteristics of the available time series. Section 5 reports estimates and simulations of the real wage-population relationship using a VAR cointegrated model. A summary of the main results and implications ends the article.

2 The Malthusian hypotheses and causal ordering: A brief critique

There is an extensive literature concerning the economic-demographic relations in pre-industrial Europe. A very wide range of these studies sheds light on the Malthusian mechanisms. Abel (1966), Postan (1973), Wrigley and Schofield (1981), Slicher van Bath (1963), Grigg (1980), Weir (1991), and Clark (2007), amongst others,[6] provide detailed descriptions of different European economies in accordance with the Malthusian model.[7] These works report empirical and theoretical discussions on long chronological periods and concern the relationships between fertility, infant and child mortality, standard of living, grain and wheat prices, and population size in several periods between the 13th and 19th century. Similar interpretations are available for areas in several European countries.[8] In Italy, detailed analysis of the pre-industrial Malthusian model is much less frequent, although there are some interesting exceptions such as Bellettini (1973), Romani (1975) and Malanima (2002).

A growing population and labor force encounters diminishing returns in agriculture and therefore a fall in real wage is the first essential element of the Malthusian population theory. Higher wages cause, on the one hand, lower mortality due to better nutrition, clothing and housing, on the other, higher fertility. These aspects are reported by the literature in contexts characterized by (exogenous) harvest variations, adverse weather conditions, epidemics etc. What is interesting is the emphasis laid, in this literature, upon the consequences of population changes (on labor productivity) rather

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[6] Abel (1966) is in German. This seminal work has been translated into French and English, and recently Italian (1976).

[7] See also Weir (1991) and Livi Bacci (2007) for a review.

[8] See, for instance, Livi Bacci (2007) and the literature quoted therein.

than the consequences of changes in wages. Common to all these studies is the historical confirmation of preventive-positive checks, although the latter seem to have been historically more prevalent than preventive checks, which act more slowly.[9]

The fact that wages may drive fertility with long lags (say from 30 to 50 years or more) may have led many economic historians to emphasize the causal ordering from population to wages or to deny that there was any feedback from the wage rate to population.[10] Let us report some examples within the existing literature concerning historical analyses on Malthus's relationships.

Wrigley and Schofield's (1981) reconstruction of England population history from 1551 onward provides figures that have been widely commented upon, showing opposite movements in the real wage and population. Using these data, many authors[11] have pointed out the existence of an inverse relationship between the two variables, and, of course, the existence of the opposite secular path for real wages and productivity and population, stressing the exogenous population impact on the standard of living.

The same interpretation is given by some economists such as Hansen and Prescott (1998), who report English population and wage series from Clark (1998) and Wrigley et al. (1997) for the period 1265-1800: "Once population begins to recover, the real wage falls. This observation is in conformity with the Malthusian theory that a drop in the population due to factors such as plague will result in a high labor marginal product, and therefore real wages, until the population recovers".

Further evidence is represented by the data plotted by Lee (1997) on the relationship between population and real wage in Europe (1200-1830), who emphasizes that the data clearly suggests an inverse association: "a high level of population in the early 13th century coincides with low real wages; sharp population decline following the Black Death in 1348 and subsequent outbreaks of plague is accompanied by an equally sharp increase in wages; population growth from the middle of the 15th century coincides with a long decline in real wages; population stagnation in the 17th century is followed eventually by an upturn in wages.."

With regard to Italian wages, as Malanima (2003) states, "[s]ome clear phases are discernible in the declining trend. A strong rise took place after the Black Death and the late medieval epidemics and lasted until population growth resumed from around 1450. Real wage rates rapidly diminished in Italy thereafter; much earlier than in other European regions. They remained low until the Seventeenth century demographic decline, and rose thereafter. A sharp and rapid decline occurred in the Eighteenth century."

There is nothing wrong with these data as well as the data we report below for the Italian economy. The idea is that there exists (if any) very slow feedback from the wage to population although the empirical relationship may be read by imposing the opposite causal ordering: increases in real wages are accompanied by an equally decline in population. It is the same data as those depicted in the mentioned plots (and indeed, in the plots reported below for the Italian case) but now the Malthusian model is not fully confirmed.

Even when technological process is considered in a pre-industrial economy, as in Aiyar, Dalgaard and Moav (2008)[12], it is supposed that an exogenous technological change (however it is measured) spurs population growth which affects the standard of living.

This reading of the Malthusian scheme leads the time series analyses to formulate population as an exogenous variable to investigate the effect on real wage. In econometric works, exogeneity of population is explicitly included into the models. Lee (1973; 1997) and Lee and Anderson (2002) examine the impact of population growth on real wages with the "usual approach": regressing the

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[9] Wrigley and Schofield (1981). See also Lee and Anderson (2002) and Allen (2008).

[10] See for instance, Clark (2008).

[11] See for instance Livi Bacci (2007).

[12] To cite a new article on the argument considered. See the articles quoted within this work. The prediction that differences in technologies should be reflected in population density but not in standards of living is widely shared in the Malthusian literature. See Livi Bacci (2007) for a review. See also Kremer (1993), Galor and Weil (2000), and Galor (2005), amongst others.

real wages on population.[13] Leaving aside the econometric problems that this regression involves, other than the simultaneity bias recognized by the author, it is important to note that, again, the causality is not tested. A similar analysis is performed by Clark (2006) who plots the estimated real income per person in England against the estimated population from the 1200s to 1790s.

It is known a priori which variables in the model are endogenous (values determined within the model) and which are exogenous (values determined outside the model). The theory could be accepted if the data seemed consistent with it, as evidenced, for example, by the dynamic of the relevant variables described in the studies cited above. However, more than one theory could be supported by the data, and any conclusions are conditional upon the relationship being correct. In other words, the model should be verified directly against rival models. Whether feedback from wages had anything (positively or negatively) to do with fertility or if fertility moves exogenously is an empirical matter. In this case the best testing procedure puts the observed data at the centre of the scene.

Simple regression between the two variables would provide misleading results and this feature is crucial in the context of the Malthusian hypotheses. For example, on the one hand, when mortality increases, real wages should increase; on the other, when real wages increase, mortality should decline: one effect predicts a negative relationship between population and wages, whereas the other predicts a positive relationship. The same ambiguity holds for fertility and wages (the preventive check). This is why testing the Malthusian hypotheses should be addressed through vector autoregression (VAR) analysis. This approach has been introduced into historical-demographic research by Eckstein at al. (1986), Hagnell (1991), Bengtsson and Brostrom (1997) and many others. Nicolini (2006) shows how the English demographic system started to move away from Malthusian dynamics well before the Industrial Revolution. Between 1750 and 1810 population levels increased while real wages were no higher than the average pre-industrial level. Nicolini estimates a VAR for data on fertility, nuptiality, mortality and real wages over the period 1541-1840. More recently, Craft and Mills (2007) claimed that wages ceased to be Malthusian at the end of the 18th century.

3 A theoretical model

In the previous section, we pointed out that changing causal ordering in interpreting wage and population data may lead to a Malthusian model that is not fully confirmed. This section presents an alternative theory to that of Malthus to explain why a better income condition may not push population upward.[14]

A suitable interpretation relies upon the so-called “*old age security motive*” for bringing children. Children are viewed as a capital good or, to be precise, as the only form of capital for parents to transfer income from their productive years to their old age. When there is an alternative to children for transferring present to future consumption, parents will not invest in children if the return that they yield is lower than the return of investment in capital. Whenever improvements in real wages occur, households are prone to invest in new productive technology or in new methods of exploiting and/or storing seeds and wheat for future crops, or, further, they are ready to take this opportunity to introduce and disseminate new cereals (corn etc.).[15]

To support this interpretation we use a very simple overlapping-generation economy to emend the Mathusian model of Ashraf and Galor (2008) (A-G) with the old wage security motive assumption.

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[13] The author extends the basic regression with a time trend and prices. Lee and Anderson (2002) use state space methods.

[14] This stylized fact may be justified by several theoretical frameworks. For instance, note that in the classical market-sector economy an exogenous increase in rural wages pushes down the rural labor force and *vice versa*.

[15] See the surveys of Razin and Sadka (1995) and Nerlove and Raut (1997) amongst others.

3.1 Production

There is a single homogeneous good and the production function is a constant-returns-to-scale technology, $\alpha \in (0,1)$ with the output produced at time *t*:

(1) $$Y_t = (kX)^{\alpha} L_t^{1-\alpha}$$

where *L* and *X* are, respectively, labor and land, and *k* captures the introduction and use of new seeds, better quality of soybean, the use of new cultivation and irrigation methods, new knowledge for engagement in agriculture and so on. Here there is a first difference with the A-G mode: *k* is governed, along with the number of children, by the parent's decision. In other words, *k* may be an alternative to support children as capital. However, to simplify the analysis we may imagine the parent's choice problem as a number of children and a fix the amount *k*. It may be equal to the cost of child rearing. Output per worker at time *t* is

(2) $$y_t = Y_t / L_t = (kX / L_t)^{\alpha}$$

3.2 Preferences

Parent's and children's utilities are not linked. The utility function is a Cobb-Douglas function for the parent's problem:

(3) $$u_t = c_t^{\gamma} c_{t+1}^{1-\gamma}$$

where c_t is the consumption of an individual of generation *t*, and $\gamma \in (0,1)$, the fraction that the household devotes to consumption. Note that γ may be interpreted as the importance that consumption in the second part of life has in the utility function for the parent. Higher values for γ indicate that the parent is less willing to hedge in the second part of life (is less willing to save and invest in children and/or capital).

The production of goods to survive and save in the first period is y_t. The cost of raising a child is v. Thus each child consumes v units of good in each period. The number of the children is n_t and they are viewed as capital goods with a return (for each child) equal to $(y_{t+1} - v) = w$, where y_{t+1} is the production which each can provide in the second period, and v is the relative cost. For the sake of simplicity we may assume that from the single parent's point of view, this income is given and the net income is *w*.

In this setup we allow an alternative to children as capital: for transferring consumption to the future, the parent may invest in capital and innovation available at that time, to cultivate, store and buy better and new quality of seeds: k increases the effective resources used in production. This investment provides a constant real return *r*. The budget constraints in the two periods are, respectively:

(4) $$y_t = c_t + nv + k$$

(5) $$y_{t+1} = \left[c_{t+1} + nv + (1+r)k\right]n^{-1}$$

From the first order condition, the optimal number of children is:

(6) $$n* = \frac{(1-\gamma)}{v}(y_t - k) - \gamma\frac{(1+r)k}{w}$$

We do not include in the utility function the welfare of each child. Hence parents' investments for future consumption will depend on the relative returns. With high costs v and a low return w, population should be reduced. Whenever the capital return *(1+r)* is higher than the net cost of children, the population tends to drop.

3.3 Population evolution

The old age security hypothesis determines the population dynamics. The following first order difference equation drives the time path of the working population:

(7) $$L_{t+1} = nL_t \quad = \quad \left\{\frac{(1-\gamma)}{v}\left[\left(\frac{kX}{L_t}\right)^{\alpha} - k\right] - \frac{\gamma(1+r)k}{w}\right\}L_t$$

Here, at time *t*, parents may invest in new productive technology or in new methods of exploiting and/or storing seeds. Thus output per worker produced at time *t* is defined by (2). At time *t+1* we maintain the assumption on the exogenous positive net return *w*. Since $\partial y_{t+1} / \partial L_{t+1} < 0$, this is a strong assumption for the dynamic evolution of the economy. However, this hypothesis, which makes the analysis more explicit, does not affect the result.[16]

For a given *k*, the unique steady-state level of population is

(8) $$\overline{L} = \xi^{\frac{1}{\alpha}}(kX)(1+\xi k + \Omega k)^{-\frac{1}{\alpha}}; \qquad \Omega = \left[\frac{\gamma(1+r)}{w}\right] \quad \xi = \left[\frac{(1-\gamma)}{v}\right]$$

In this setup a technological advancement provides a decrease in the steady-state level of population:

(9) $$\frac{\partial\overline{L}}{\partial k} = X\left(1 - \frac{k(\xi+\Omega)}{\alpha(1+k(\xi+\Omega))}\right) < 0$$

Given the rate of growth $g_{t+1} = L_{t+1} - L_t / L_t$, a technological advancement provides a decrease in the rate of population growth between t and t+1:

(10) $$\frac{\partial g_{t+1}}{\partial k} = \left[\alpha\frac{(1-\gamma)}{v}k^{\alpha-1}\left(\frac{X}{L}\right)^{\alpha} - \frac{(1-\gamma)}{v} - \Omega\right] < 0,$$

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[16] We may achieve these results by relaxing the assumptions on the dynamic evolution of the economy, using some monotonic transformations of the utility function (3).

Note that the drop in the growth rate will depend on the relative return Ω. The parents will not invest in children if the return that they think to achieve is lower than the return obtained in the alternative investment, and this will affect the growth rate of the population.

Also, note that for a given *k*, the lower the population level, the lower the rate of population growth:

$$\frac{\partial g_{t+1}}{\partial L_t} = -\left[\alpha \frac{(1-\gamma)}{v}(kX)^{\alpha} L^{-\alpha-1}\right] < 0 \tag{11}$$

These results compared with those provided by, say, the A-G model, depict the opposite evolution of population to technological advancement. The rise in income per capita (through a rise in *k* or an exogenous drop in population):

$$\frac{\partial \overline{y}}{\partial k} = \left(1 + \frac{\gamma}{\xi}\frac{(1+r)}{w}\right) > 0 \tag{12}$$

may not generate an increase in population, which is the opposite of the Malthusian assumption. A similar result (an increase in income lowers fertility and hence population) may be obtained, under certain conditions, substituting child quantity by child quality (parents invest in education).[17]

A shock in rural wages may lead the family with primitive technology to increase its livestock and its storage of harvest and products. Saving reduces population and increases labor-force quality. Following the Malthusian scheme, people married earlier when wages were above the equilibrium level and married later when they were below (for instance, Becker 1988). But if the amount of usable land does not increase, and given the presence of infectious diseases that cull many of the children, a wage rise may not stimulate higher birth rates, but may postpone marriage and having children to better times. In this case it does not seem counter-intuitive that households change to a fertility strategy which soon drives income down and increases child mortality. Internalizing the costs of a poor fertility strategy, in the environment of these centuries, would not have been difficult for households.

When incomes increase for poor people, there really does exist the alternative of fewer but higher quality children who may have better prospects. The risks that a child will suffer poor health or die are lower, and the rewards may be positive even in an uncertain future.

4. The Malthusian dynamics of the Italian economy, 1300-1850.

4.1 The data set

Empirical evidence for a long-run economic-demographic equilibrium, as discussed by Classical theory, is investigated using data provided by Malanima (2002; 2003; 2005), where data are reconstructed for population, nominal and real wage rates in both urban (for master masons) and rural contexts (for agricultural workers), GDP and per capita GDP (total and agriculture), prices of agriculture goods, and urban population density. Output variables, population and urbanization rates are measured for central-northern Italy.[18] Direct and official estimates are available for Italy as well

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[17] See, for instance, the review of Razin and Sadka (1995), Nerlove and Raut (1997) and Doepke (2006).

[18] See Malanima (2002; 2005) for detailed analysis and a reconstruction of urbanization rates in Italy.

as many other countries from the mid-19th century onward.[19] However, data construction seems accurate, well-documented, and rich in detail. An extensive and detailed discussion of the criteria used to construct these series and the previous works on which they are based can be found in Malanima (2002).

As regards the notation used for wage variables, *W* represents wages in the agriculture sector. To obtain the real aggregate we used the price index for agricultural goods *P*. In the article, whenever we refer to wages we mean real wages in the agriculture sector. Demographic variables are *Pop* for population and *Urban* for urbanization rates in central-northern Italy from 1320 to 1870. The measure of urbanization used in the models is the proportion of the population in towns of 5,000 or more. Population in central-northern Italy is in thousands; prices and agricultural wages are indices (base 1860-70).

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4.2 Population and wages

From the population data, some clear phases are discernible with respect to the long-run path of the main economic variables. Figures 1-4 report the evolution of population, real wages and productivity during the period 1320-1870. Weather, harvest, war and epidemics, as well as changes in labor demand, shifted the mortality and fertility, impacting upon wages which in turn have led to changes in population. A sharp population drop took place after the Black Death and the later epidemics. This was accompanied by a rapid increase in real wages which, however, diminished thereafter, when population growth resumed after outbreaks of the plague around 1450. Wages remained low until the 17th century demographic decline and rose thereafter. A sharp decline occurred in the 18th century with a trough being reached at the beginning of the 19th century.

Figure 3 shows that a similar picture (described for wages) may be drawn by the per capita output (both using agriculture and total output), although the dynamic of the aggregate production shows a positive trend (Figure 2). Productivity slowdown is constant for the whole period, although the reduction in per capita GDP is curbed whenever a decline in the population trend takes place. Figure 4, as expected, shows the perfect evolution between the agricultural labor force and population.

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[19] See McEvedy and Jones (1978) and De Vries (1984).

Figure 1. Population and Agricult. Real Wage (log)

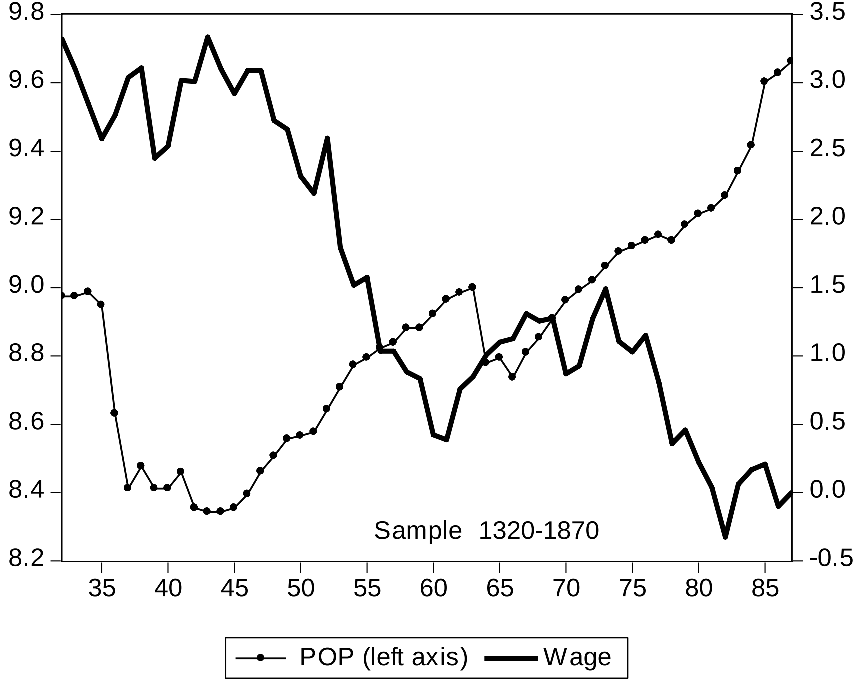


Figure 2. Output and Agricultural Output (log)

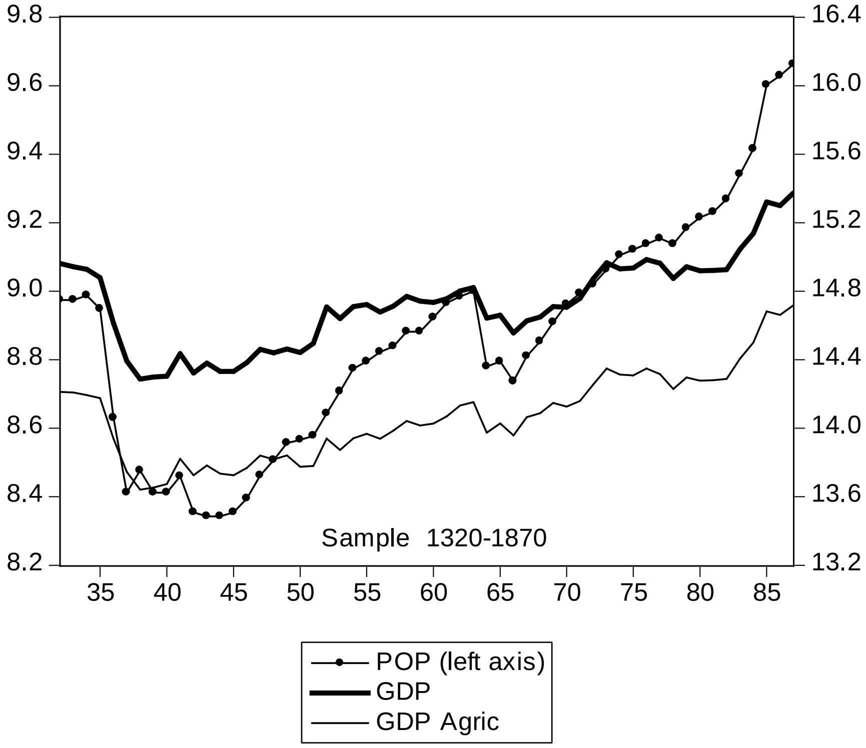


Figure 3. Population and Per Capita Output (log)

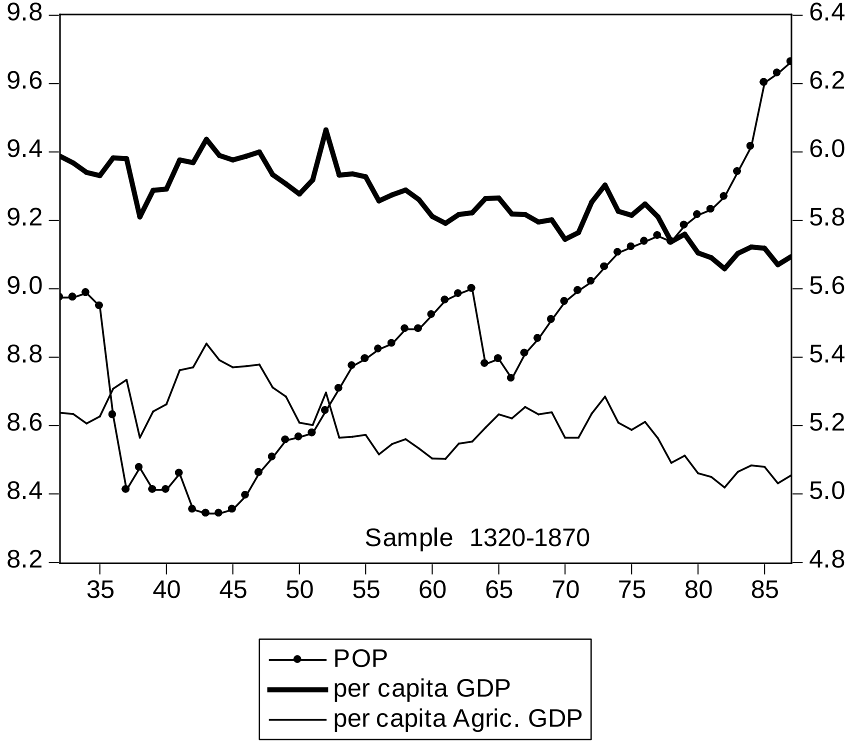
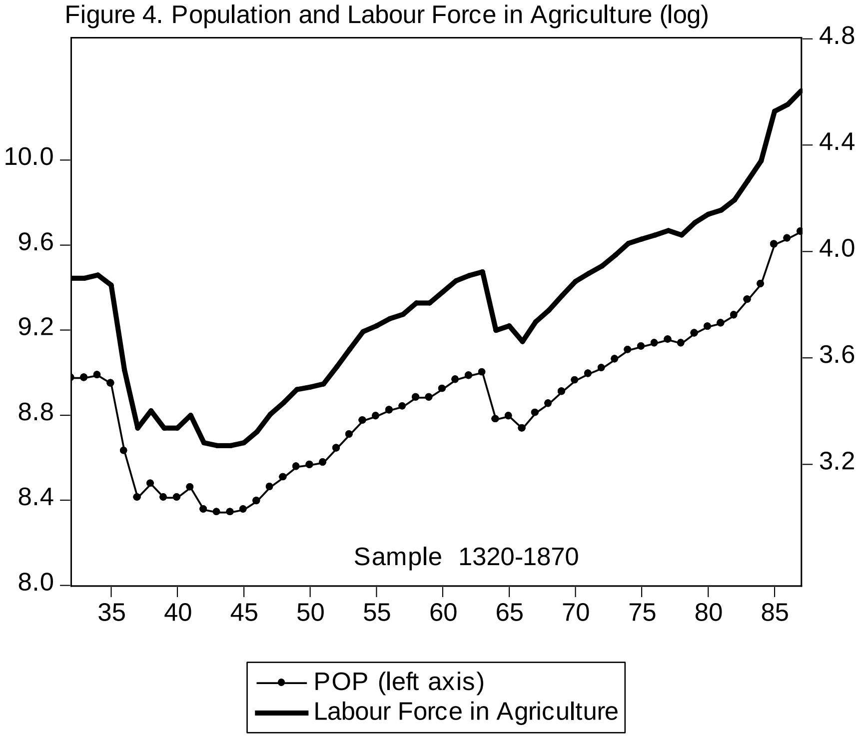


Figure 4. Population and Labour Force in Agriculture (log)



The plots of wages and population series clearly suggest the existence of an inverse relationship between the two variables and, of course, the existence of the opposite secular path for real wages and productivity (which decline through the centuries) and population (which grows after the mid-15th century). The standard of living in Italy did not remain constant, but exhibited a sharp downward trend.

Moreover, Figure 3 testifies to the Malthusian “specter” of diminishing marginal returns to labor and, hence, diminishing output per worker as population (and labor force, Figure 4) increased due to the fixity of other inputs.[20]

In Italy, between 1300 and the late 19th century, real wages and per capita income fell whereas the population grew. Finally, the population was far more variable before 1650 than afterward. In the whole sample reported in the plots above, the standard deviation of population around its trend is 3.9 per cent. In the period between 1300 and 1450 it rose to 6.4 per cent; and with two more centuries included in the sample it drops to 4.7 per cent. The plagues substantially affected the trend before 1430 and after 1630.

5. The wage-population model

-The econometric model

The nonstationary nature of the series is known to have crucial econometric implications.[21] Variables whose means and variance change over time are known as non-stationary or unit root variables and using standard estimation methods to estimate relationships with unit root variables gives misleading inferences (spurious regression problems). In this context it is convenient to use cointegration as a technique to estimate the equilibrium or long-run parameters in a relationship with unit root variables. If several variables are cointegrated, they have a common stochastic trend and one or more linear combinations of them will have a finite variance. Thus cointegration of these variables is stationary even though individually they are not.

Vector autoregressive (VAR) processes are a suitable model class for describing the *data generation process* (the mechanism underlying the observable phenomena of interest)[22] of a small set of time series variables. In these models all variables are treated as being a priori endogenous, and allowance is made for rich dynamics. Restrictions are usually imposed with statistical techniques instead of a prior beliefs based on uncertain theoretical considerations. In fact, the estimable model should be interpreted as an approximation to the actual data generation process. This brings the nature of the observed data to the forefront. A situation of special interest arises if several variables are driven by a common stochastic trend, in which case they have a particularly strong link that may be of interest in economic terms. If cointegrating relations are present in a system of variables, the resulting most convenient model to set up is known as a vector error correction model (VECM). Impulse responses and forecast error variance decomposition are used as tools for analyzing the relations between the variables in a dynamic econometric model.[23]

In the Appendix, we identify the nonstationary nature of our series. The statistics reported in tables A.1 and A.2 seem to suggest that the real wages and population are nonstationary variables. We use Johansen’s (1995) technique to estimate and test the time series model. This procedure allows us to

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[20] This hypothesis, as is well known, may be contested on the grounds that capital accumulation and productivity growth more than offset the law of diminishing returns. Moreover, parents’ altruism and endogenous fertility theories show that the Malthusian hypothesis may be refuted. See amongst others Becker (1960), the articles in Razin and Sadka (1995), and those in the Handbook of Population and Family Economics series (1997).

[21] Nonstationary variables are denoted I(1) (integrated of order one). The nonstationary nature of the time series and their implications have been discussed within historical-demographic research by Bailey and Chambers (1993) and Craft and Mills (2007).

[22] See Spanos (1986).

[23] An updated text on these models is Juselius (2006).

check the validity of the weak exogeneity hypothesis and investigate the strength of feedback coefficients to disequilibrium.[24]

Estimated equations are derived by a two-variable system with one cointegrating equation. Consider the following error correction model (VECM), written in the usual notation:[25]

$$\Delta y_t = \Pi y_{t-1} + \Gamma_1 \Delta y_{t-1} + \Gamma_2 \Delta y_{t-2} + Bz_t + \varepsilon_t \qquad (13)$$

Model (13) is specified for three lags (two lags in first differences). In our case, y is a *k*-vector and contains two nonstationary variables (real wages and population), *z* is a vector of deterministic variables (dummies) and ε_t is a vector of innovations. $\Pi = A_1 + A_2 - I$ are the long-run parameters, and $\Gamma_1 = -A_2, \Gamma_2 = -(A_2 + A_3)$ the short-term parameters, where A_i and B are matrices of coefficients to be estimated. The term Πy_{t-1} contains the cointegrating relations and can be written as the product of matrices (2x1 in our case) α and β such that $\Pi y_{t-1} = \alpha\beta' y_{t-1}$, where β is a cointegrating vector and α are the adjustment parameters. Hence $\beta' y_{t-1}$ contains cointegrating relations.[26]

When two variables share the same stochastic trend, as in our case, it is possible to find a linear combination that cancels the trend, i.e. a cointegration relation. We have seen that our series are characterized, other than by stochastic trends, by nonzero means and deterministic trends. For proper representation of the data generator process it may be necessary to include in the system deterministic terms, such as an intercept or a linear trend.[27]

-The stationary equilibrium relationship

Estimating the stationary model using decennial data for 1320-1870 produces the following result (estimated standard errors in parentheses, all the variables are in log):

$$\beta' y: \quad pop + \underset{(0.051)}{0.335} \cdot w - \underset{(1.78)}{12.78} \cdot . \qquad (14)$$

The adjustment coefficients for the two variables are $\alpha_{pop} = -\underset{(0.041)}{0.111}; \quad \alpha_w = -\underset{(0.058)}{0.17}$

The model has an intercept in the cointegration vector and in the VAR.[28] In the equation, *g=12.78* is the constant term.[29] The α_w term measures the speed of adjustment of the real wage toward the

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[24] Our estimation procedure is the following: after setting the appropriate lag-length of the VAR model, we determine whether the system is conditioned on some dummy variable for controlling for breaks and large shocks which affected the variables over the sample period. Then we test for the existence of a cointegration vector, and finally for weak exogeneity of the wage variable.

[25] See, for instance, Lutkepohl (1991), Johansen (1995), and Juselius (2006).

[26] It is well known that if the coefficient of the matrix Π has a reduced rank *(r<k=1* the number of cointegrating relations in our case), there exists 2x1 matrices α and β such that $\Pi = \alpha\beta'$.

[27] For the population-real wage model the testing procedure reveals that the level data have linear trends and the cointegrating equation has one constant.

[28] The cointegrating vector and the equation residuals seem statistically satisfactory: Trace, and Maximum Eigenvalue tests indicate one stationary relation at the 0.05 level. It is well known that the critical values provided by Johansen and Osterwald-Lenum are only indicative in such situations (small sample, dummy variables and trends). The VEC residual serial correlation LM test shows that the Null of no serial correlation up to lag 3 is not rejected (LM-stat does not reject the Null of serial correlation at lag 1, 4.29 prob. 0.38; lag 2, 2.41 prob. 0.66, lag 3, 0.74 prob 0.95).

equilibrium once the model is re-normalized on the wage variable. We reject the hypothesis of a real wage weakly exogenous with respect to the long-run parameters, and the restriction ($\alpha_w = 0$) is not binding under the assumption that there is one cointegrating relation. This first result indicates that the causal ordering from population to wage is misleading. Standard of living affects population and population affects real wages.

Before going on to analyze in depth the components (wage and population elasticity and adjustment coefficients) of estimated equation (14), a caveat should be made. The data series are in decennial frequencies. Although the sample size (55 observations) is large enough to carry out the analysis in a meaningful manner, the data in ten-year intervals present two problems. First we cannot study short-term interaction but the results will reflect longer-term trends. Second, the sample size is not large enough to render analysis of subsamples possible. This does not allow us to investigate the wage-population relationship in different historical demographic eras such as the plague, post plague and pre-demographic transition.[30] This may represent a limit to our analysis although there is no high-frequency data set (yearly data) over such a long time period either for population and wage series or for other variables such as fertility, mortality and prices.

-Long-run "elasticity"

The long-run relation (14) is normalized with respect to *pop*. The model shows a long-run population-real wage elasticity of 0.335 but a "high" speed of the wage with respect to a disturbance in the equilibrium relation, whereas the estimated stationary relation implies that an increase in population reduces, in the long run, real wages by almost 3%.[31] The result shows a wage which is much more sensitive to changes in population than what emerges from other estimates. For instance, Lee (1987), using a simple regression with decadal data from 1360 to 1790, reports a wage-population elasticity of -1.0 (significant at 0.05 per cent). Lee's result is conditional upon a quadratic time trend, to allow for a growing demand for labor, and the rate of inflation.[32] Once we adopt the first hypothesis (quadratic trend), we are unable to achieve a cointegrating (stationary) relation between the variables: the trend in the VAR is not statistically significant, and the residuals are not white noise (we easily reject the null of first order autocorrelation, and multivariate normal residuals of the bivariate model). Including the inflation rate (decennial changes in prices of agricultural goods or total goods) improves the statistical model and the stationarity of the relationship, and provides a long-run wage-population elasticity of -4.49 (standard deviation of 0.580). However, these "elasticities" are only indicative. Stationary relationships must be interpreted cautiously. The coefficients of the cointegrating relation cannot be interpreted as elasticities, as in the usual sense, even if the variables (as in our case) are in logs, because all the other dynamic relations between the variables which are specified in the VAR model are ignored. The analysis requires that short-term dynamics and intertemporal adjustment processes generated by equilibrium errors are taken into account.[33] Impulse response analysis, taking into account the full system, may provide a more reliable conclusion. To this end, below we report on the model's adjustment coefficients and in the subsequent subsection 5.1, we perform impulse response analysis.

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[29] This is the only deterministic component in the long-run relationship, implying that the equilibrium mean is different from zero. An intercept is generally needed to account for the initial level of measurements.

[30] On these data problems see Galloway (1988) amongst others.

[31] The real wage long-run elasticity to population changes, yielded by the model, is 2.98.

[32] Lee and Anderson (2002) using state-space models found the elasticity of the real wage with respect to the size of population in line with earlier estimates.

[33] Lutkepohl (1991; 1994), amongst others, emphasizes this issue.

-Adjustment coefficients and dynamics

There are several important features that deserve mention. First, in this model population is not Granger-caused by the real wages in agriculture (that is the coefficients of $\Delta w_{t-i}, i = 1,2$ are zero, whereas the lagged $\Delta pop_{t-i}, i=1,2$ have nonzero coefficients). However, in the error correction model, both $\Delta pop_t, \Delta w_t$ are Granger-caused by the stationary relation β (equation 14) which is itself a function of pop_{t-1}, w_{t-1}. Thus, the ECM shows that there is causality in both directions.[34]

A second dynamic aspect to note concerns the size of the adjustment. The lower limit on the adjustment coefficients of -1 implies that there is no distinction between the short run and the long run. Coming to our estimates, for wages the coefficient α_w indicates that 17 per cent of the disequilibrium is removed in a decade. The speed of the adjustment of population is even slower: only 11 per cent of the disequilibrium is now removed after a decade.

If a transitory shock impinges upon the determinant of the birth and mortality curves, changing the population equilibrium, *ceteris paribus*, it would take the population roughly nine decades to restore the equilibrium, whereas it would require less than six decades of changing real wages. Thus, using the Malthusian model, we can claim that the negative feedback loop, whereby in the absence of changes in technology (or availability of land) the size of the population will be self-equilibrating, is quite slow.

To show how the adjustment process operates in (14), consider, in its simplest form, the lagged equilibrium as specified in the cointegrating vector. Suppose that the perspective of time is *t*. Thus if $\beta > 0$ in (14), this means that the economy was not in equilibrium in the last period (decade): population and/or wages have to change:

$$pop_{t-1} > g - \varphi w_{t-1} \tag{15}$$

If population exceeds the target defined by the wage, to keep on target *pop* must be reduced or wage must be increased. Since the population adjustment coefficient is negative, whenever the population exceeds the target and the economy is not in equilibrium, population declines.

-Conditioning (Black Death and Urbanization)

A major feature of the data set is the break occurring in population during the Black Death before 1430 and around 1630. In Italy, as well as the rest of Europe, population reached a peak between 1300 and 1350, but declined sharply following the plague after 1348. A slow recovery initiated only around 1430. A further sharp population decline, following plague outbreaks, started in northern regions around 1630 and in 1656-57 in southern regions.[35]

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[34] In econometrics the most widely used operational definition of causality is that of Granger. See Granger (1969).

[35] Malanima (2002) reports a fascinating and dramatic reconstruction of the evolution of the plague and the fatal diseases of the age. When the first Black Death appeared (1348-49), in Italy the population was 12-13 million; the plague killed 3.5 million (about 27-30% of the population). Major diseases were the Black Death and especially bubonic plague (the main cause of death for about 300 years), but also typhus, dysentery and smallpox. Among the vast literature we cite the data reconstructed by Del Panta (1980) and Bellettini (1973). See Helleiner (1967) and Ziegler (1969) for an analysis of the plague in Europe.

Conditioning the model on a dummy variable for this exogenous drop in population provides a negative coefficient for the population equation and a positive coefficient for the wage equation (estimated standard errors in parentheses):[36]

$$\begin{aligned} &Pop\ eq.: \quad Dummy_{black-D} = \underset{(0.035)}{-0.172}; \\ &Wage\ eq.: \quad Dummy_{black-D} = \underset{(0.11)}{0.149} \end{aligned} \tag{17}$$

Further conditioning of the model involves the urbanization process.[37] By including urbanization as an exogenous variable (urbanization rates, percentage of people living in towns), we are able to improve the statistical model and obtain more Gaussian residuals. The coefficients of the "urbanization" variable in the VAR are strongly significant and negative for both equations:

$$\begin{aligned} &Pop\ equat: \quad Urban = \underset{(0.049)}{-0.126}; \\ &Wage\ equat: \quad Urban = \underset{(0.209)}{-0.629} \end{aligned} \tag{18}$$

The negative sign does not lend support to the hypothesis that the level of urbanization may be a proxy for the level of technology.[38] Urban concentrations probably reduced the resistance of the population to disease, especially to those illnesses which must be restricted to an endemic area, raising the death rate. In the centuries from 1400 and 1700, the multiplications of more or less vast agglomerations of people exercised a profound influence on mortality. Urban centers created a host of problems (food and fuel shortages, water, housing, sewage and garbage disposal etc.) and were often the starting-point of epidemic waves. The negative sign found in our model is thus consistent with the fact that in cities average mortality was significantly higher than the birth rate.

5.1 Simulation results

In this section we perform the impulse response analysis of the model discussed above (charts in Figure 5). A shock to a variable of the system not only directly affects the shocked variable, but is also transmitted to all the other endogenous variables through the dynamic structure of the model. In our case, the impulse response function traces the effect of a one-time shock to one of the innovations on current and future values of the wage and population variables. We set the impulses to one standard deviation of the residuals.

Impulse response analysis[39] shows that an exogenous increase in rural wages negatively affects population dynamics (Figure 5.A). The population response is significantly negative almost two decades after the shock and converges to a lower equilibrium.

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[36] $Dummy_{black}$ =(1350-1360=1; 1640=1).

[37] See Malanima (2005). Other than the urbanization process, promising results can be achieved by conditioning the model on the temperature series as measured in Crowley (2000). A detailed analysis may be found in Fagan (2000). See also Malanima (2002).

[38] See, amongst others, Lee (1980) and Stavins (1988).

[39] The residual correlation matrix is $\Omega = \begin{bmatrix} & pop & w \\ pop & 1.00000 & -0.0971 \\ w & -0.0971 & 1.00000 \end{bmatrix}$. Confidence Intervals (dotted lines in the Figures) are obtained with Hall's percentile interval bootstrap method. To obtain reliable 95% confidence intervals the number of bootstrap replications was set at 4000.

It is important to assess the relative importance of the specified shocked variables on their own dynamic paths. Interestingly, the direct effect of a positive shock in real wages on its own path shows, after one decade of growth, that real wages reduce toward a new equilibrium, whereas a positive shock in population, pushes up population for the first two decades and, after about 30 years, tapers off toward a new equilibrium. An exogenous increase (fall) in population yields an ever higher (lower) population growth rate for the implicit fall (rise) in real wages. After about 40 years, the growth stops and population decreases (increases) to a new equilibrium.

Figure 5 A. Response of POP to POP and WAGES (right). VECM Orthogonal Imp-Respo.

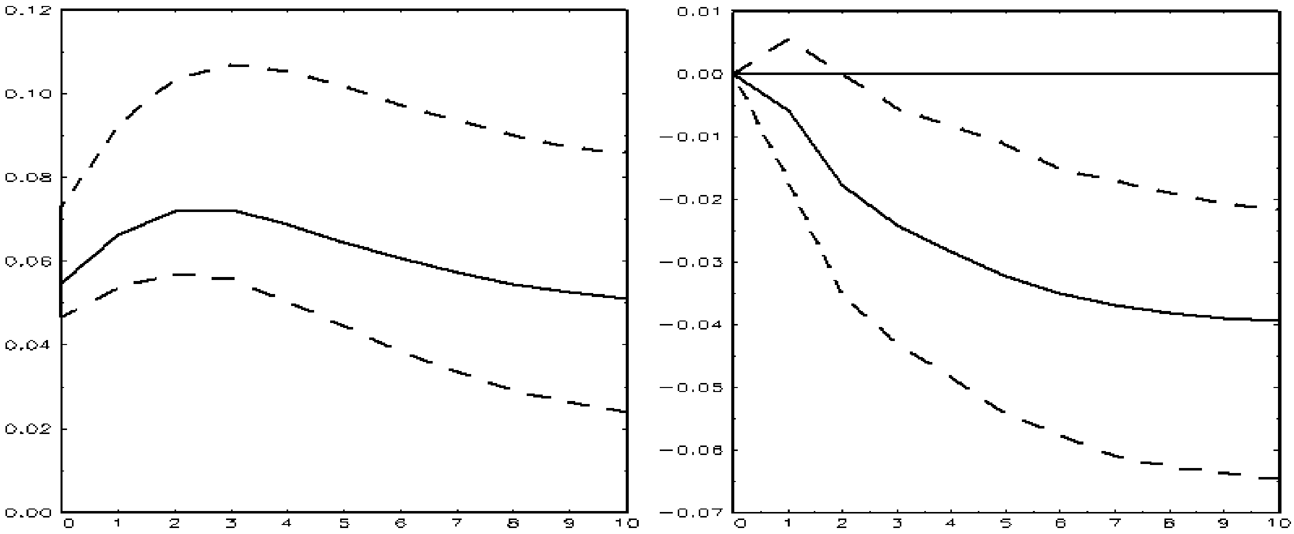
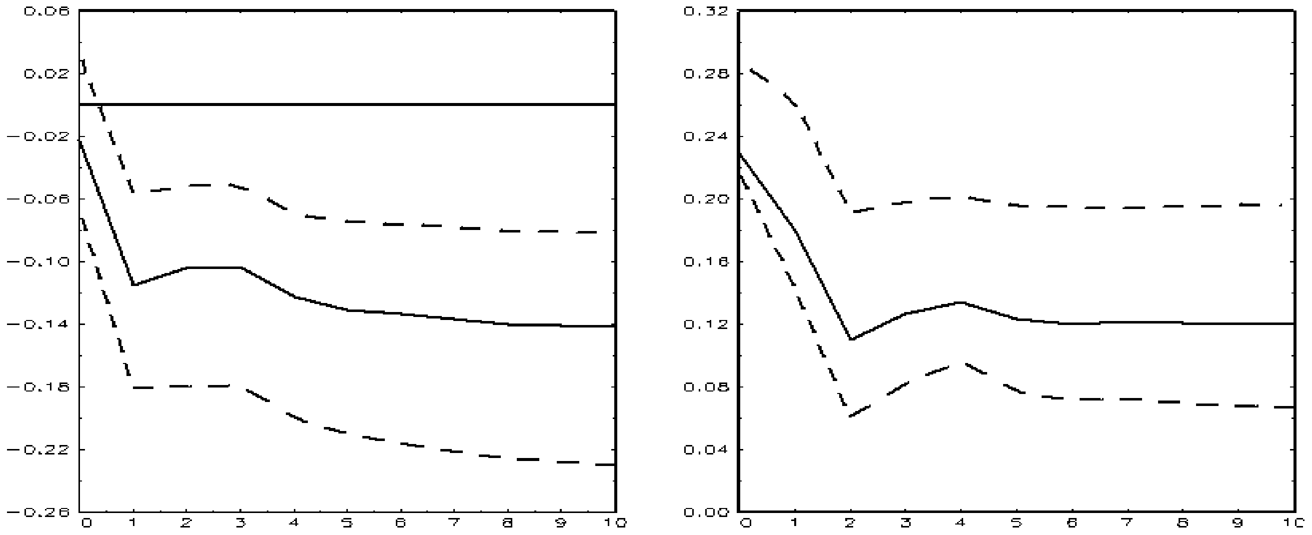


Figure 5 B. Response of WAGES to POP and WAGES (right). VECM Orthogonal Imp-Resp.



Variance decomposition analysis (Table 1), which separates the variation in an endogenous variable into the component shocks to the VAR, shows that in the first ten years the importance of a wage innovation in affecting population in the VAR is zero. The second period decomposition for the population variable (i.e. twenty years) is due to its own innovation for 99.51 and to real wage innovation for 0.48. Thus, there is strong evidence for positive checks and slow feedback from wage to population: wages account for a smaller percentage of the variance in population growth rates.[40]

Summarizing, the positive check is strong and statistically significant and it explains an important part of the dynamic of mortality but the other equilibrating mechanism in the Malthusian model - the preventive check - based on the positive relationship between fertility and real wages does not operate: population reports a negative and statistically significant response to an increase in real wage.

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[40] Each time a negative shock (for instance, the occurrence of a pandemic disease, a war or a reduction in temperature) impinges on population dynamics, wages and production increase. The former tends to remain at a higher level, whereas since productivity of land increases, production tends to increase. Thus, as stressed for instance by Clark (2006), war, banditry, disorder, disease and even “bad” government (kings) policies, all increase death rates and make societies better off.

Table 1: Variance Decomposition in ***Population***

Period	S.E.	POP	W
1	0.058781	100.00	0.000
2	0.092510	99.51	0.481
3	0.122025	97.25	2.745
4	0.146985	94.95	5.045
5	0.167270	92.79	7.204

: Variance Decomposition in ***Real Wages***

Period	S.E.	POP	W
1	0.246622	0.957	99.04
2	0.336619	13.98	86.01
3	0.373933	20.32	79.67
4	0.412974	23.90	76.09
5	0.456630	27.84	72.15

5.2 The Italian wage-population relationship and epidemics

A criticism of this novelty (Granger causality runs both ways from population to wages and *vice versa*, with a negative relationship) is that we find no increase in population after the rise in wages since several minor epidemics, especially from 1350 to 1450, struck the Centre and North of Italy. Population stagnates after large epidemics, although wages are high, simply because there are many smaller, but frequent, epidemics (not only plague, but also typhus).[41] Wage-population causality is hidden by the occurrence of these diseases. Only the decreasing number of minor epidemics allowed population to grow after about 1450-70; and then long after the Black Death. This should be the reason why high wages do not “Granger-cause” population recovery.

In Section 2, we recalled several authors who denied that there was feedback from the wage rate to population, contending that it evolved exogenously: swings in population were driven by exogenous shocks. Two issues may be raised to argue against this viewpoint.

From the theoretical point of view, using the model presented in Section 3 it is easy to show that the occurrence of epidemic waves (but also social disorder, wars and invasions) support our results for the pre-industrial era in Italy. Consider, for instance, the simple *old age security* model reported above, and introduce a probability of survival ρ (or a discount factor) into the utility, $u_t = \gamma \ln(c_t) + \rho(1-\gamma)\ln(c_{t+1})$. It is straightforward to predict the effect of mortality on investment: a lower ρ brings lower investments in absolute and relative (children) terms. For instance, the population drop in the aftermath of the Black Death increases income per capita. In this context the probability of survival is very low and it is therefore much more likely that people engage in short-sighted behavior, using the rise in income per capita to improving their own condition rather than invest in children. Thus, frequent epidemics should lead to lower fertility even with high real wages.

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[41] See the striking reconstruction of epidemics in Italy by Del Panta (1980).

From the empirical point of view, we have no complete series of deaths by epidemic and hence cannot test this effect. Attempts to use deterministic variables in the model to capture the countless epidemics, using information from Del Panta (1980), fail to produce different results, but strengthen the negative feedback from wages to population. The data show (with a good statistical description) that this feedback, albeit very slow, seems appropriate for the pre-industrial era in Italy. Moreover, it is still puzzling as to why the high real wages of the 15th century (both in England and Italy) did not cause the population to rebound as in the Malthusian scheme.

6. Concluding remarks

In the Introduction we addressed two questions concerning the observation of a negative relationship between wages and population in pre-industrial Italy and the theoretical framework used to explain this result. We presented a simple model whereby substitution between child quantity (number of children) and other assets was allowed, and found that it is able to affect fertility negatively when income rises. We answered the empirical question by estimating and simulating a vector error correction model (VECM), showing a negative relationship between real wages and population for pre-industrial epoch in Italy. This does not confirm earlier findings for several European countries although our econometric analysis is a novelty for Italy. Clearly, this result may have implications for the Malthusian income-population feedback (the standard explanation for economic stagnation in the pre-industrial era): living standard and population growth were not positively related.

For the empirical analysis we used a VECM model, which is particularly suitable for describing the *data generation process* (the mechanism underlying the observable phenomena of interest) of a small set of time series variables when these are driven by a common stochastic trend. This method brings the nature of the observed data to center stage, and restrictions are usually imposed with statistical techniques instead of prior beliefs based on theoretical considerations.

Our VECM estimates show two important features of the long-run relationship between income and population. First, the long-run elasticity of population size with respect to the real wage is -0.335 whereas the estimated stationary relation implies that an increase in population reduces, in the long run, real wages by almost 3 per cent. Although these "elasticities" are only indicative and impulse response analysis, taking into account the full system, may provide a more reliable conclusion, the results show a wage which is much more sensitive to changes in population than what emerges from other estimates, and a population which reacts negatively to change in wages.

Second, the VECM allows us to have information on the speed of adjustment of the variables to the stationary (equilibrium) relation. Our estimates indicate that the speed of the adjustment of wages is slow: 17 per cent of the disequilibrium is removed in a decade. The speed of the adjustment of population is even slower: only 11 per cent of the disequilibrium is removed after a decade. If a transitory shock impinges upon the determinant of the birth and mortality curves, changing the population equilibrium, *ceteris paribus*, it would take the population roughly nine decades to restore the equilibrium, whereas it would require less than six decades of changing real wages. The negative feedback loop, whereby in the absence of changes in technology the size of the population will be self-equilibrating, is quite slow.

At least in pre-industrial Italy, and in contrast to the Malthusian hypothesis, a negative relationship between wages and population does not appear to be a necessary and sufficient condition for growth takeoff. This is a stylized fact also shown by modern data in many less developed regions.[42]

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[42] The number of children per woman largely depends upon slow changes in cultural factors (for instance, marital patterns and the level of birth control) and a combination of other factors such as biological, environmental and policy settings which often predict that population moves with sufficient independence: a result confirmed with modern data

A number of extensions of this analysis are called for. Instead of dealing with aggregate variables, fertility and mortality rates should be modeled. Moreover, other relevant variables would improve the relationship between demography and rural wages, such as the degree of urbanization and urban wages. We leave these further steps to future research.

Appendix

Trend characteristics

The order of integration of macroeconomic variables has crucial consequences for appropriate modeling of time series data and for proper understanding of the aggregate phenomenon. It is widely acknowledged that the form of nonstationarity in a time series may well not be evident from examination of the series. Moreover, deterministic rather than stochastic trends have important economic implications. A trend-stationary time series evolves around a deterministic trend, i.e. around some specified and predictable function of time. Conversely, a series with a stochastic trend has no clear long-run pattern, since its longer term movement is affected by stochastic disturbances, which have an enduring effect on the future path of the series. In our context, this means that a shock occurring to the estimated series of population and real wages due, for instance, to weather, harvest, epidemics etc., may have permanent or, conversely, temporary impacts on the long-run movement of the series.

Thus it is essential to identify the nonstationary nature of our series. Statistical inference about a stochastic trend is often combined with a deterministic trend, and it is not straightforward to distinguish between them when several breaks are present in the variables. Furthermore, analysis is complicated by the weakness of the unit root tests when small samples are used.

Trends, whether stochastic or deterministic, may give rise to spurious regressions; they provide, if erroneously identified, uninterpretable or misleading results. To this end, our variables, which seem subject to breaks and to have a peculiar evolution, deserve more attention.

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by the World Fertility Surveys analyses on the poorer African, Asian and Pacific countries. See, amongst others, Livi Bacci (2007).

Table A1: Stationarity tests: The Null H0 of Unit Root (H0: stationarity for KPSS)

Variable: ***Population***	*Deterministic term**	*t-statistic (probab.)*	*Critical val: 1% (5%)*
ADF	*G*	-2.14 (0.94)	-3.56 (-2.91)
ADF	*g+t*	-3.16 (0.10)	-3.49 (-3.17)
ADF 1st diff.	*G*	-3.08 (0.03)	-3.56 (-2.91)
ADF 1st diff.	*g+t*	-3.78 (0.02)	-4.14 (-3.49)
ADF 2nd diff		-6.78 (0.00)	-4.14 (-3.50)
PP	*G*	0.34 (0.97)	-3.55 (-2.91)
PP	*g+t*	-2.50 (0.32)	-4.13 (-3.49)
PP 1st diff	*G*	-5.05 (0.00)	-3.55 (-2.91)
PP 1st diff	*g+t*	-5.67 (0.00)	-4.13 (-3.49)
ADF-GLS	*G*	-0.47	-2.61 (-1.95)
ADF-GLS	*g+t*	-1.76	-3.75 (-3.18)
ADF-GLS 1st diff.	*G*	-3.09	-2.61 (-1.95)
KPSS	*G*	1.42	0.73 (0.46)
KPSS	*g+t*	0.29	0.21 (0.14)
KPSS 1st diff.	*G*	0.50	0.73 (0.46)
KPSS 1st diff.	*g+t*	0.09	0.21 (0.14)

ADF*=Augmented Dickey-Fuller;* ***PP****= Phillips-Perron;* ***DF-GLS****=Elliot-Rothenberg-Stock DF-GLS;* ***KPSS****=Kwiatkowski-Phillips-Schmidt-Shin test;*

*Note that the KPSS test output provides the asymptotic critical values tabulated by the KPSS. The series is assumed stationary under the null hypothesis. The PP test uses an alternative method of controlling for serial correlation when testing for a unit root. The DF-GLS test modifies the ADF. Data are detrended in the presence of a constant and/or linear trend. * In the tests, g is a constant and t is a deterministic linear trend.*

Table A2: Stationarity tests: The Null H0 of Unit Root (H0: stationarity for KPSS)

Variable: ***Real Wage (Agriculture)***	*Deterministic term*	*t-statistic (probab.)*	*Critical val: 1% (5%)*
ADF	G	-0.64 (0.85)	-3.56 (-2.91)
ADF	g+t	-1.81 (0.68)	-4.14 (-3.49)
ADF 1st diff.	G	-4.42 (0.00)	-3.56 (-2.91)
ADF 1st diff.	g+t	-4.38 (0.00)	-4.14 (-3.49)
ADF 2nd diff		-7.88 (0.00)	-2.61 (-1.94)
PP	g	-1.01 (0.74)	-3.55 (-2.91)
PP	g+t	-2.22 (0.46)	-4.13 (-3.49)
PP 1st diff	g	-7.59 (0.00)	-3.55 (-2.91)
PP 1st diff	g+t	-7.51 (0.00)	-4.13 (-3.49)
ADF-GLS	g	0.39	-2.61 (-1.95)
ADF-GLS	g+t	-1.86	-3.75 (-3.18)
ADF-GLS 1st diff.	g	-3.82	-2.61 (-1.95)
KPSS	g	1.69	0.73 (0.46)
KPSS	g+t	0.14	0.21 (0.14)
KPSS 1st diff.	g	0.06	0.73 (0.46)
KPSS 1st diff.	g+t	0.06	0.21 (0.14)
ADF*=Augmented Dickey-Fuller;* ***PP****= Phillips-Perron;* ***DF-GLS****=Elliot-Rothenberg-Stock DF-GLS;* ***KPSS****=Kwiatkowski-Phillips-Schmidt-Shin test; For a comment see Table A.1.*			

Following the Choi and Yu (1997) approach, we test sequentially I(0) versus I(1) and I(1) versus I(2) if the first hypothesis is rejected, taking into account drifts and deterministic trends in the data.

a) Results from ADF, DF-GLS, PP and KPSS test are reported in Table A.1 whereas Table A.2 reports the relative tests for real wages. As is evident, all tests fail to reject the null hypothesis of a unit root in the time series at 5 percent significance level, implying that the levels of population and real wages are nonstationary. Notice that the ADF test for both real wages and population may appear less clear, but we can reject the nonstationarity of the series at first differences. This is an important issue, since the log of a variable which is I(2) will have an I(1) growth rate; thus a shock to the series will result in persistence in the growth rate and level of the series. Alternatively, some evidence of a deterministic trend in the data may emerge from the tests.

b) However, it should be borne in mind that it is not easy to operate for such discrimination between an I(2) model, a model with a deterministic trend in the data and a model with a structural break. As Figure A.1 shows, the first difference in population seems affected by nonstationarity elements. However, it is also clear from the figure that these elements are linked to the two outliers that characterize the variable.

c) Based on these results we may claim for the evidence in support of the unit root hypothesis for the differenced series of both variables rested on the failure to account for structural change in the data. Moreover, all the other statistics seem to suggest that the real wages and population are I(1).

Figure A.1. Population: First differences and Relative Trend

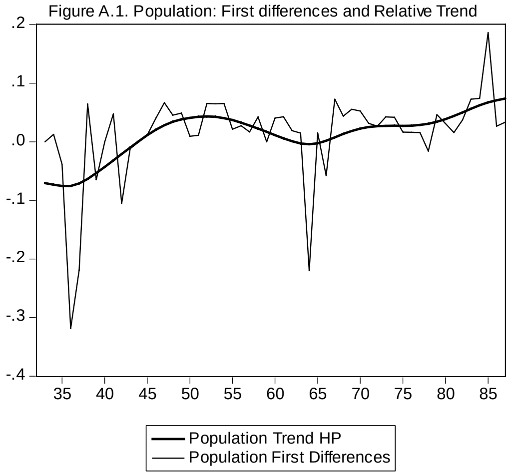

Figure A.2. Real Wages and Population (first differences)

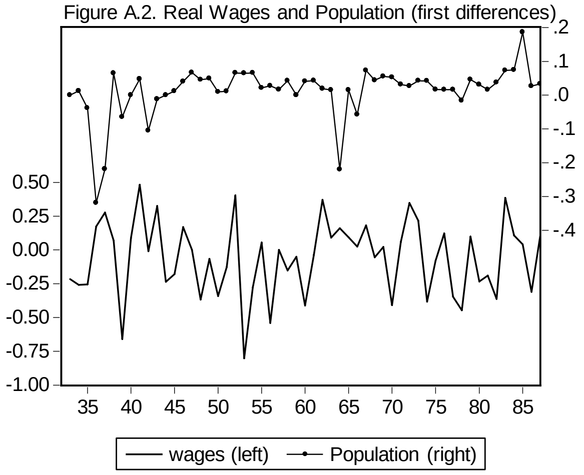

Figure A.2 above also shows that no progress may be made, allowing for a nonstationary stochastic process driving the data along with a quadratic trend, although the ADF and PP tests may suggest some evidence for this hypothesis. However, as the figure shows, the true data generating process of the first difference of the variables does not seem to include a deterministic component. On the contrary, the first difference of the population series is clearly affected by the Black Death outliers.

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