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Modelling Population and Resource Scarcity in Fourteenth-century England

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Abstract

This paper examines the empirical data relevant in the analysis of the agrarian transformation of England in the Middle Ages. It presents an empirical analysis of available data that investigates the role and extent of resource scarcity in 14th-century England. The analysis offers a way forward for economists and historians to reach a plausible consensus about the reality of what may be one of the most important transition periods in European economic history. The insights gained throw useful light on the processes whereby agricultural relations evolved from ancient feudal structures.

Keywords: *agrarian history; England; fourteenth century; resource scarcity.*

JEL classifications: *N53, Q1, O4, J1.*

1. Introduction

Many studies have examined the evolution of the agrarian economy in England during the Middle Ages. There are two general theories about the 13th and 14th centuries.[1] The account starting with M. M. Postan developed the dominant theory firmly grounded in Ricardian economics. The 'Postan Thesis' regarded these two centuries in quite pronounced Malthusian terms (Postan, 1973a,b). This account is one of continued population growth, increased pressure on agricultural resources, soil exhaustion, declining yields, increased immiserization and the encroachment of arable on pastures in the relentless quest for more grain (Campbell, 1983). This set of circumstances is claimed to be unprecedented in English history.[2] Barbara Harvey concluded her paper on the first half of the 14th century with these words:

We would like to thank two anonymous reviewers for useful comments on an earlier draft of the paper.

[1] The story of Marxist exploitation will not be discussed here (see Kosminsky, 1956). The 'Brenner Debate' revived an interest in the role of class in the study of medieval economics (see Brenner, 1976). Reactions to Brenner are: Bois (1978), Cooper (1978), Ladurie (1978), Wunder (1978), Croot and Parker (1978), and Postan and Hatcher (1978). Brenner replied to these in 1982 (see Brenner, 1982).

[2] In addition to those cited below, see Chambers (1972), Grigg (1980) and Bailey (1998).

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The interpretation of demographic history between 1300 and 1348 which has been considered in this paper is a dramatic one; much of English society was living at the Malthusian level of subsistence by 1300; the entire trend of two centuries or more was reversed within the next twenty or twenty-five years; men were punished for the temerity of the earlier expansion by inundations, desiccations, and dust-storms. It is just this sense of a consummation in man's ancient conflict with nature that the sources of this period fail to impart (Harvey 1966, p. 42).

However, other interpretations have also been presented.[3] For example, H. E. Hallam concluded a study of this period with the question:

Could it be that advanced technology, free institutions, a large population in a small space and a progressive economy somehow go together? Can we perhaps stand Rev. Dr Malthus on his head and say that technological advance needs population pressure? (Hallam, 1972, p. 222.)

Hallam argues that the steady population rise of the 12th and 13th centuries may not have been the main cause of the crisis of the 14th century. First, unprecedented harvest failures and animal diseases between 1315 and 1322 had significant adverse effects on peasant welfare. Secondly, there is some contradicting evidence that demographic growth may have continued during the first half of the 14th century (Campbell, 1984, 1991, 2000). Thirdly, the onset of plague in 1348–1349 was clearly a major cause of short-term population decline, irrespective of the level of resource scarcity. Fourthly, the Malthusian scenario fails to explain why population did not rebound in England after 1350 (e.g. towards the end of the 14th century or during the 15th century), when population pressure was much reduced. To quote Poos:

Perhaps most importantly for historians of early-modern demography, the Essex data imply that at the beginning of the sixteenth century local population stood at well under one-half the level it had achieved two centuries earlier, and that England experienced renewed demographic growth only from the second quarter of the sixteenth century (Poos, 1985, pp. 529–530).[4]

Finally, as pointed out by Boserup (1965) and others, there is historical evidence that population increase can stimulate technological and institutional innovations that can effectively mitigate the scarcity of resources.[5] In this context, population rise may not lead to a subsistence crisis. These alternative interpretations indicate that there is much to learn about the historical transformations that took place in 14th-century England. How much of the 14th-century crisis was associated with a Malthusian scenario? And how effective were Boserupian institutional and technological innovations in stimulating productivity growth and dealing with resource scarcity during this period?

These studies remind us just how little agreement there is about this important period. Two questions dominate the conflicting accounts: (1) the plausibility of

[3] See Hatcher and Bailey (2001) for an overview.

[4] England seems not to be alone in this: '…the population of Europe, so far from continuing its growth, suffered a sudden decline about 1350, and for one hundred and fifty years thereafter remained more or less stationary' (Helleiner, 1950, p. 372).

[5] For example, North and Thomas (1971) interpreted the evolution of the manorial system in terms of induced institutional change to changing economic conditions during the Middle Ages.

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Malthusian pressure during the 14th-century, pressure that might have accumulated through the 13th-century; and (2) the reasons for the failure of England's population to recover for nearly 200 years following the Great Plague.

The objective of this paper is to renew economic interest in this historical debate, and analyse this profound period in English agrarian history. As we see in the brief synopsis above, there are profoundly conflicting accounts of these historical events. This suggests a need to re-examine the empirical data relevant in the analysis of the agrarian transformation of England in the Middle Ages. The insights gained can help throw light on the processes whereby modern agricultural relations evolved from ancient feudal structures.

Our paper develops and presents an empirical analysis of available data that investigates the role and extent of resource scarcity in 14th-century England. The analysis offers a way forward for economists and historians to reach a plausible consensus on the reality of what may be one of the most important transition periods in European economic history.

2. Model of Population Growth and Resource Scarcity

To investigate the historical situation in 14th-century England, we first developed a generic model of population growth and resource scarcity. The model is used specifically to provide insights into the role of resource scarcity, with a special focus on the Malthusian and Boserupian propositions. The model is relatively simple, and hence remains empirically tractable. The model is then estimated with historical data to provide empirical evidence on the nature of the transformations that took place in 14th-century England.

2.1. *The model*

Consider the evolution of human population in a given location. Let pop_t denote population size at time t. We expect population dynamics to depend on the resources available to the human population. Let s_t denote an index of resource scarcity at time t, where s increases when resources become scarcer. We consider the general case where population growth is determined as follows:

$$\frac{(\text{pop}_t - \text{pop}_{t-1})}{\text{pop}_{t-1}} = f(\text{pop}_{t-1}, s_{t-1}). \tag{1a}$$

Equation (1a) expresses the rate of population growth $(\text{pop}_t - \text{pop}_{t-1})/\text{pop}_{t-1}$ as a function of a lagged population pop_{t-1} and lagged scarcity s_{t-1}. The lags indicate that population adjustments are not instantaneous. We have some *a priori* hypotheses about the properties of the function $f(\cdot)$ in equation (1a). First, we expect positive population growth [with $f(\text{pop}, s) > 0$ in equation (1a)] when population (pop) is small and resources abundant (s being small). Secondly, for a given scarcity index s_{t-1}, the law of diminishing returns implies that $f(\cdot)$ is a decreasing function of population pop_{t-1}: $\partial f/\partial \text{pop}_{t-1} < 0$. This is intuitive: conditional on resource scarcity s_{t-1}; although a small population may be able to grow fast, it becomes more difficult to generate population growth as population size increases. To the extent that $f(\text{pop}, s_{t-1})$ becomes negative when population (pop) becomes large, this implies the existence of a maximum human population that can be supported under a given stock of resources. Thirdly, for a given population pop_{t-1}, increasing resource

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scarcity is expected to have a negative effect on population growth: $\partial f/\partial s_{t-1} < 0$. This means that, although population can grow fast under conditions of resource abundance (where s_{t-1} is small), increasing resource scarcity (with s_{t-1} becoming large) makes it more difficult to support population growth. Again, to the extent that f(pop, s) becomes negative when resources become scarce (i.e. when s becomes large), resource scarcity restricts the size of the human population.

Two key questions are: (1) what are the determinants of resource scarcity (as represented by s); and (2) how does resource scarcity interact with population? At time t, we hypothesize that the resource scarcity index s_t in equation (1a) depends on population pop_t as well as food prices as represented by a food price index pr_t:

$$s_t = s(\text{pop}_t, \text{pr}_t). \tag{1b}$$

First, we expect higher food prices to correspond to higher scarcity: $\partial s/\partial \text{pr}_t > 0$ in equation (1b). Secondly, equation (1b) allows population (pop_t) to affect resource scarcity s_t. Boserup (1965) and others have stressed how a higher population can stimulate technological change that contributes to a reduction in resource scarcity. This implies that $\partial s/\partial \text{pop}_t \leq 0$ in equation (1b). A growing population can be a stimulus for scarcity-reducing technological change for three reasons. First, higher population means more potential inventors. If the probability of each person to invent a new technology is independent of population, then the growth rate of technology is expected to be proportional to population. Secondly, technology is typically characterized by nonrivalry: once discovered, useful new technologies can diffuse quickly among their potential users. Thirdly, there are often economic incentives to adopt technologies that reduce resource scarcity. Taken together, these three characteristics suggest that a rise in population can stimulate technological progress. In this case, population growth can mean more rapid technological change, contributing to increased productivity and improved ability to feed the growing population. For example, high population pressure against land can induce land-saving technical changes contributing to increased land productivity and food production. In this context, Boserup (1965) has argued convincingly that agriculture would not have developed historically without increased population density. Indeed, compared with agriculture, hunting and food gathering tend to require little labour input. As a result, there is little incentive for individuals to switch to labour-intensive agriculture without increased population pressure. More generally, technological changes can develop in response to changes in relative resource scarcity. This is the theory of 'induced innovation' elaborated by Binswanger and Ruttan (1978), and Hayami and Ruttan (1985). This idea suggests positive effects of population size on the development of new technology. Boserup (1965), Kremer (1993), and Goodfriend and McDermott (1995) have presented historical evidence that technological progress tends to be faster in regions with high population densities.

As measuring the scarcity index s_t can be empirically difficult, it will be convenient to substitute equation (1b) into (1a). This yields the following determination of population growth:

$$\begin{aligned}\frac{(\text{pop}_t - \text{pop}_{t-1})}{\text{pop}_{t-1}} &= f(\text{pop}_{t-1}, s(\text{pop}_{t-1}, \text{pr}_{t-1})),\\ &= g(\text{pop}_{t-1}, \text{pr}_{t-1}).\end{aligned} \tag{2}$$

Equation (2) shows the effects of lagged population pop_{t-1} and lagged food price pr_{t-1} on population growth. With $\partial g/\partial \text{pr}_{t-1} = (\partial f/\partial s)(\partial s/\partial \text{pr}_{t-1})$ and given $\partial f/\partial s < 0$

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and $\partial s/\partial \mathrm{pr}_{t-1} > 0$, we expect price pr_{t-1} to have a negative effect on population growth: $\partial g/\partial \mathrm{pr}_{t-1} < 0$. This is intuitive because feeding a growing population is easier (more difficult) when food prices are relatively low (high). However, the effects of pop_{t-1} on population growth in equation (2) are more complex and have been the subject of much debate. From equation (2), we have

$$\frac{\partial g}{\partial \mathrm{pop}_{t-1}} = \frac{\partial f}{\partial \mathrm{pop}_{t-1}} + \left(\frac{\partial f}{\partial s}\right)\left(\frac{\partial s}{\partial \mathrm{pop}_{t-1}}\right).$$

This decomposes the effects of population on population growth into two additive terms. The first term measures $\partial f/\partial \mathrm{pop}_{t-1}$ and thus reflects the direct effect. As just discussed, it is expected to be negative, $\partial f/\partial \mathrm{pop}_{t-1} < 0$, reflecting diminishing returns. The second term reflects indirect effects because of induced innovations. Given $\partial f/\partial s < 0$, and $\partial s/\partial \mathrm{pop}_{t-1} \leq 0$, it is expected to be non-negative, $(\partial f/\partial s) \times (\partial s/\partial \mathrm{pop}_{t-1}) \geq 0$. As a result, the net effect of population on population growth, $\partial g/\partial \mathrm{pop}_{t-1}$, is indeterminate in sign. Determining the sign of $\partial g/\partial \mathrm{pop}_{t-1}$ depends on the relative magnitude of these two terms. This can identify two scenarios. Under the Malthusian scenario, the first term dominates the second term, and $\partial g/\partial \mathrm{pop}_{t-1} < 0$. In this case, increasing population has a negative effect on population growth. This means that the effect of diminishing return dominates, and resource scarcity limits population growth. Moreover, to the extent that $g(\mathrm{pop}, \mathrm{pr})$ becomes negative when population (pop) becomes large, resource scarcity also restricts the size of human population.

Alternatively, under the Boserupian scenario, the second term dominates the first term, and $\partial g/\partial \mathrm{pop}_{t-1} > 0$. In this case, increasing population contributes to a sufficient reduction in resource scarcity (under induced innovations) such that a higher population can actually lead to additional population growth. Under such a scenario, induced innovations are strong enough to generate new technologies that can overcome the adverse effects of diminishing returns on both population growth and population size.

How do technological innovations actually respond to population pressure? This is a difficult question to answer. Technological progress is complex and not fully understood. There are many factors playing a role in the creation of knowledge and in its use. To the extent that some of these factors are not controllable (e.g. luck, climatic variations), one cannot be sure that every resource-scarcity problem can be solved by some timely technological breakthrough. For example, there is historical evidence that climate changes have had important long-run effects on food supply and human population (Galloway, 1986). These considerations imply the limitations of man's ability to find technological solutions to some resource-scarcity issues. Historical examples of economic and social collapse serve as a reminder of these limitations (Tainter, 1988), indicating that there are times and situations where technological progress may not provide a way to sustain a large population. Yet, as noted above, there is historical evidence supporting the Boserupian scenario, where increasing population size has positive and significant effects on the development and implementation of new technologies (Boserup, 1965; Kremer, 1993; Goodfriend and McDermott, 1995). These arguments suggest that the net effects of resource scarcity on population dynamics [as given in equation (2)] are largely an empirical issue. We now investigate such an issue in the context of 14th-century England.

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2.2. *Population growth*

For the purpose of analysing the historical transformations in 14th-century England, we developed a simple model of population growth based on equation (2). We consider the following econometric specification for equation (2):

$$\frac{(\text{pop}_t - \text{pop}_{t-1})}{\text{pop}_{t-1}} = a_0 + a_1\text{pop}_{t-1} + a_2\text{pr}_{t-1} + a_3\text{pop}_{t-1}\text{pr}_{t-1} + a_4\text{BD} + e_{pt}, \quad (3)$$

where BD is a dummy variable for the Black Death, and e_{pt} is an error term assumed to be distributed with mean zero. Equation (3) expresses the growth rate of population $[(\text{pop}_t - \text{pop}_{t-1})/\text{pop}_{t-1}]$ as a function-lagged population (pop_{t-1}), lagged price (pr_{t-1}) and population–price interaction ($\text{pop}_{t-1}\text{pr}_{t-1}$). The interaction variable in equation (3) allows the effect of price (pr_{t-1}) to vary with population level, with $\partial[(\text{pop}_t - \text{pop}_{t-1})/\text{pop}_{t-1}]/\partial\text{pr}_{t-1} = a_2 + a_3\text{pop}_{t-1}$. Alternatively, the specification (3) allows the effect of population (pop_{t-1}) to vary with the extent of resource scarcity (as represented by the price pr_{t-1}), with $\partial[(\text{pop}_t - \text{pop}_{t-1})/\text{pop}_{t-1}]/\partial\text{pop}_{t-1} = a_1 + a_3\text{pr}_{t-1}$. As discussed above, we associate $[a_1 + a_3\text{pr}_{t-1}] < 0$ with the Malthusian scenario (where a higher population necessarily decreases population growth), whereas $[a_1 + a_3\text{pr}_{t-1}] > 0$ would correspond to the Boserupian scenario. As such, an empirical evaluation of $[a_1 + a_3\text{pr}_{t-1}]$ and its sign will provide useful information on the linkages between population and resource scarcity.

2.3. *Price determination*

Although equation (3) provides linkages between population dynamics and food price pr, it will also be useful to examine the determinants of the price index pr. For this purpose, we consider the price specification:

$$\text{pr}_t = c_0 + c_1\text{pop}_t + c_2 y_t + c_3\text{pr}_{t-1} + e_{qt}. \quad (4)$$

This expresses food price at time t (pr_t) as a function of population (pop_t), crop yield (y_t), lagged price (pr_{t-1}), and an error term e_{qt}. In equation (4), population can affect price (possibly both as a supply shifter and a demand shifter), while yield acts as a supply shifter. To the extent that short-term yield variations reflect weather effects, this captures how resource scarcity can vary with weather. Finally, to the extent that food prices evolve slowly over time, the lagged price in equation (4) captures such dynamic adjustments.

2.4. *Crop yield*

Finally, we analyse the determinants of crop yield given by the reduced-form specification:

$$y_t = b_0 + b_1 t + b_2 y_{t-1} + e_{yt}. \quad (5)$$

This expresses crop yield (y_t) as a function of a time trend (t), lagged yield (y_{t-1}), and an error term e_{yt}. The time trend in equation (5) represents the long-term effects of technological change on production. This relation will provide useful information about the nature of technological progress in agriculture. The lagged price captures the dynamics of yield adjustments over time. We now turn to the empirical evidence.

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3. The Empirical Evidence

Equations (3)–(5) provide a specification that is now used to gain insights concerning how to model the economic history of England during the 14th century. The challenge here is to obtain good historical data that will permit estimation of the model. In this context, our analysis is based on the most reliable data we could find for 14th-century England.

Population data are the most problematic. For modelling purposes, population data need to cover the period 1300–1399, with frequent (i.e. annual) observations. Many data sources are available (e.g. Russell, 1948; Razi, 1980; Campbell, 1984; Poos, 1985; Dyer, 2002). However, each data set has its own limitations. For example, Razi (1980) reconstructed the population trend in the manor of Halesowen from 1270 to 1395. Unfortunately, this data set contains only 13 data points. These are too few observations to support econometric analyses. The same shortcoming pertains to many data sets. For example, Dyer (2002) recently constructed an estimate for England's population from 1200 to 1550, using all available historical sources. However, Dyer's reconstruction also lacks enough data points to support careful econometric analysis. Population data reported at 10-year intervals (e.g. as in Razi, 1980 or Dyer, 2002) are not sufficient for modelling and estimation purposes. More importantly, interpolating between 10-year estimates creates artificial population dynamics that are not supported by data. These arguments leave researchers with few options. The evaluation of these options led us to use the data developed by Poos (1985) for the population of High Easter and Great Waltham in Essex during the 14th century. We are aware that these data are not necessarily representative of England's population during the period. However, the data have three attractive characteristics. First, they are available on an annual scale. Secondly, they are broadly consistent with that reported by Dyer (2002) for England's population during the 14th century. For example, both data sets show a population peak around 1315,[6] a sharp decline in 1349 (at the time of the Black Death), and population stagnation in the latter part of the 14th century. Thirdly, the Poos data cover the period 1265–1399. On that basis, the Poos population data set provides a good foundation for modelling efforts.

For prices and yields, we rely on the data collected by the late David Farmer (1988, 1991) and appearing in: *The Agrarian History of England and Wales: 1042–1350*; and *The Agrarian History of England and Wales: 1348–1500*. The yield data were taken from the seigniorial demesnes of the bishops of Winchester across southern England. These are, for the most part, dominated by the Hampshire estates. Note that the yield data are not representative of agricultural yields in England. Indeed, the recorded yields come from good-quality land under reasonably good management, thus are likely to be above average. Yet, their short-term variations can be attributed to weather effects; their long-term trend reflects changes in long-term productivity in agriculture. As such, even if not representative, the yield data provide useful information on both short- and long-term conditions present in 14th-century English agriculture. On that basis, using Farmer data, we constructed a

[6] However, note that Campbell (1984) found some evidence of continuing demographic growth through the first half of the 14th century. This indicates that the prospects for demographic growth varied across space.

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yield index from reported yields for wheat, barley and oats. The yield index was used in the estimation of equations (4) and (5).

The price data obtained from Farmer include the prices for wheat, barley, oats and agricultural labour. They measure prices across the greater part of central and southern England. These prices reflect changes in market conditions as well as in the value of money. For example, the period 1350–1370 was a period of price inflation (following the massive plague-induced reduction in population). Taking into consideration the changing value of money suggests using real prices in the analysis. On that basis, we construct a real price index for agricultural commodities. It is obtained in two steps. First, we calculate a nominal agricultural price index from Farmer price data for wheat, barley and oats. Secondly, we calculate a real agricultural price, defined as nominal agricultural price index deflated by agricultural wage. By using price ratio, real agricultural price is not sensitive to the changing value of money. Both the yield index and the nominal agricultural price index are calculated as a weighted average of the corresponding measures for wheat, barley and oats, with weights of 0.5, 0.35 and 0.15, respectively. These weights reflect the relative importance of these three commodities in 14th-century rural England.[7] Our analysis relies on annual data for the period 1265–1399.

3.1. *The data*

The data are presented for population (Figure 1), yield (Figure 2),[8] and prices (Figure 3). Figure 1 shows that population reached its highest level in the late 13th century. Population started declining in 1315, triggered by the 1315–1317 famine. Moreover, it took a precipitous drop in 1349, reflecting the large effect of the bubonic plague (the Black Death) on human population that swept through England at that time. In the sample villages, population declined about 50% in 1348–1349 and then recovered some after a few years, still generating a net population loss of about 25% (compared with pre-Black Death levels). These patterns reflect two factors: (1) the death rate was not uniform across locations; and (2) migrations contributed to a spatial redistribution of population. The villages in the sample were hit particularly hard by the Black Death, which contributed to a large initial decline in population. However, migrations from surrounding regions that were less affected contributed to the population rebound observed in the early 1350s (see Figure 1). For the remainder of the 14th century, population remained approximately constant. In addition, the population not only failed to increase, but it also continued to stagnate throughout the 15th century (Poos, 1985). This identifies the 14th century as a period of significant crisis.

Figure 2 shows the evolution of grain yield during the sample period. As discussed above, although the yield data are likely not representative of agricultural yields in England, they do provide useful information on both weather shocks and long-term productivity growth. Most noticeable in Figure 2 is the large yield drop in 1315, corresponding to crop failures that affected Europe as a whole. This

[7] The analysis was also carried out with different measurements for food price pr and yield y. In general, the main results presented below were found to be robust to these alternative measurements.

[8] As seen in Figure 2, there are some missing data points for agricultural yield.

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Figure 1. The population data – the population data measure the number of males aged twelve and older in High Easter and Great Waltham in Essex [from Poos (1985)].

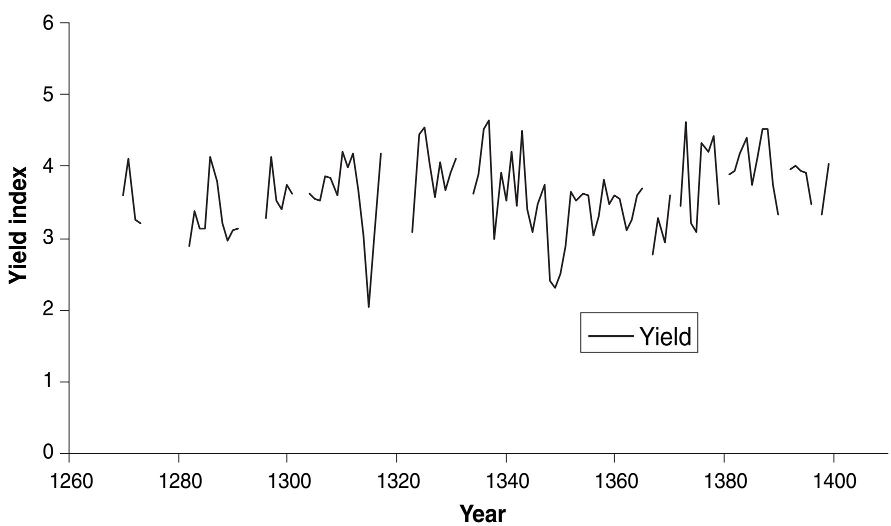

Figure 2. Agricultural yield – agricultural yield is calculated as a weighted average of gross yield ratio for wheat, barley and oats, with weights of 0.5, 0.35 and 0.15, respectively. Gross yield ratio is measured by the quantity harvested per acre divided by the quantity of seed used (from Farmer).

corresponds to a wave of cold and very wet weather throughout Europe. This induced widespread crop failures, food shortages, and the worst famine in European history. Many people starved to death, especially among the poor. This accounts for the start of the population decline observed in Figure 1.

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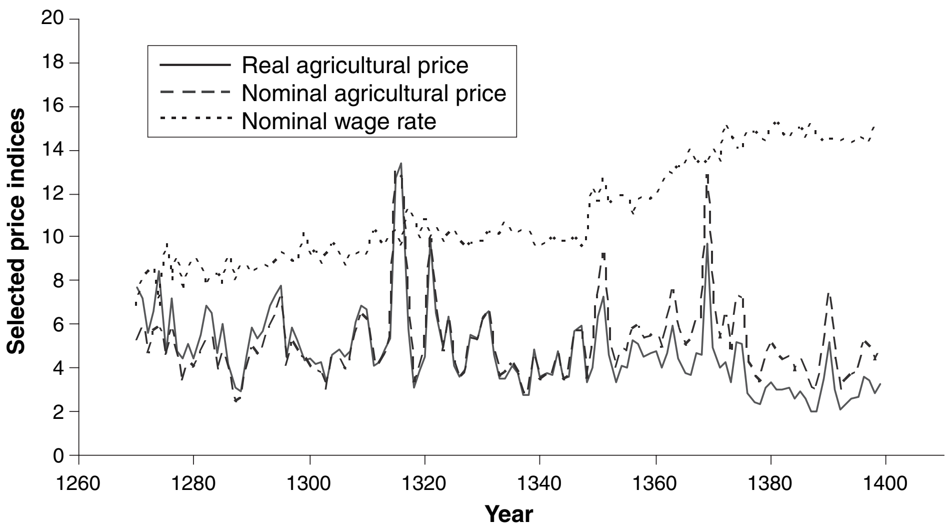

Figure 3. Agricultural price – nominal agricultural price is calculated as a weighted average of prices for wheat, barley and oats (shillings per quarter, with weights of 0.5, 0.35 and 0.15, respectively). The nominal wage rate is Winchester wage index (= 10 during the period 1330–1347). Real agricultural price is nominal agricultural price deflated by agricultural wage. All price data are from Farmer.

Figure 3 shows the evolution of prices. This includes nominal agricultural price (measured as weighted average of wheat, barley and oat prices), agricultural wage and real agricultural price (measured as nominal agricultural price deflated by agricultural wage rate). To control for inflation, real agricultural price is used in our econometric analysis. As shown in Figure 3, prices fluctuated over time. In general, nominal agricultural prices are more volatile than the wage rate. Parts of the fluctuations in nominal food price reflect the adverse impact of weather on food production. This is seen in 1315–1316, when nominal food prices almost tripled following massive crop failures. The patterns for the wage rate are also of interest: wages increased by 20% in 1349. This can be attributed to the Black Death, leading to a large population decline and labour shortages. Further increases in the wage rate are also observed in the second part of the 14th century. As shown in Figure 3, the real agricultural price fluctuated throughout the century, with a tendency to decrease in the period 1360–1400, reflecting, in part, a rise in the wage rate towards the end of the century.

In a preliminary analysis, linear time-series properties of population (pop_t), yield (y_t), and real agricultural price (pr_t) were investigated. The Dickey–Fuller test was used to examine whether each variable may have a unit root. The Dickey–Fuller test statistic was −1.96, −7.14, and −6.60 for population, yield, and real agricultural price, respectively. This indicates that we fail to reject a unit-root process for population (using either a 5% or 10% significant level), suggesting that analysing population using first difference would be appropriate. This helps justify the specification (3) for population dynamics. However, the Dickey–Fuller test indicates a strong rejection of unit root for yield as well as real agricultural price. It suggests that it is

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appropriate to analyse such variables 'in levels'. Again, this helps justify the specifications (4) and (5) for pr_t and y_t, respectively.[9]

3.2. *Model estimation*

Based on these data, we estimated the models (3)–(5). This is a simultaneous equation model estimated by the instrumental variable method. When instruments are uncorrelated with the error terms in equation, (3)–(4), the corresponding estimates are consistent and asymptotically unbiased. The instruments used are: lagged population pop_{t-2}, lagged price pr_{t-2}, lagged yield y_{t-2}, the dummy variable for the Black Death (BD), and a time trend. The estimation allows the error terms in equation (3)–(5) to be correlated across equations. The model is estimated using Hansen's generalized method of moments (GMM). The parameter estimates are presented in Table 1. The standard errors are White heteroscedasticity-adjusted standard errors. The general validity of the model and of the instruments used is tested using Hansen's *J*-test. Based on overidentifying restrictions, this tests the orthogonality conditions between the instruments and the error terms. The *J*-statistic is 10.040. Under the null hypothesis of orthogonality, the *J*-test has a chi-square distribution with six degrees of freedom. Thus, our *J*-statistic of 10.040 is not significant at either the 5% or 10% significant level. This provides evidence that the instruments satisfy the orthogonality conditions and that GMM provides consistent estimates of the parameters.

Table 1 reveals that most coefficients are significantly different from zero. In the population equation, all coefficients are significant at the 10% level. The coefficients are $a_1 = 0.0886$, $a_2 = 0.0936$, and $a_3 = -0.0206$. The marginal effect of price pr_{t-1} on population growth $(\text{pop}_t - \text{pop}_{t-1})/\text{pop}_{t-1}$ is $(0.0936 - 0.0206\text{pop}_{t-1})$, where the last term reflects the interaction between price and population. At sample mean (with population mean = 4.20), this marginal effect is slightly positive and equal to 0.0071. The marginal effect of price on population growth vanishes when pop = 4.54. This marginal effect means that the effect of price on population varies with population pressure. In situations where population is above average with pop > 4.54, a higher price induces population decline. These conditions characterise the pre-1330 period (see Figure 1). Alternatively, when pop < 4.54, a higher price tends to stimulate population growth. From Figure 1, this would apply to the post-1335 period. To the extent that the price pr reflects resource scarcity in rural England, it means that the linkages between resource scarcity and population growth changed over time.

Similarly, the marginal effect of lagged population (pop_{t-1}) on population growth $(\text{pop}_t - \text{pop}_{t-1})/\text{pop}_{t-1}$ is $(0.0886 - 0.0206\text{pr}_{t-1})$, the last term reflecting the interaction between price and population. At sample mean (with mean price =

[9] Note that the Dickey–Fuller unit-root test applies to linear dynamics. Our model specifications (3)–(5) involves non-linear dynamics (e.g. it allows the dynamic effects of population to depend on price). In general, a unit-root process can fail to provide an appropriate representation of dynamics in the presence of non-linearity. As such, our Dickey–Fuller test results should be interpreted with caution. We interpret them simply as providing a useful summary of the time-series properties of the data. Unfortunately, the econometrics of non-linear dynamics remains poorly understood. This appears to be a good topic for further research.

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4.70), this marginal effect is −0.008. The marginal effect of lagged population on population growth vanishes when price is pr = 4.30. It means that the effect of lagged population on population growth varies with resource scarcity (as measured by the price pr). In situations where price is high (with pr > 4.30), any population increase induces future population decline. This situation corresponds to the Malthusian scenario. From Figure 3, this would apply during the 1315–1330 period, and in the 1350s and 1360s. Alternatively, when < 4.30, an initial population increase tends to stimulate population growth. This situation corresponds to the Boserupian scenario and as we see in Figure 3, these circumstances would apply in the period 1300–1310, in the 1330s, and in the 1380s and 1390s. Again, this provides evidence that the linkages between resource scarcity and population growth have changed over time. Moreover, note that the marginal effects just discussed neglect the effects of other factors (besides price and the level of population) on the rate of population growth. A more global analysis of population dynamics is presented below.

3.3. *Interpretation*

From Table 1, the estimates of the b coefficients indicate that crop yields are increasing over time. The coefficient b_1 on the time trend t is positive although not statistically significant. Evaluated at the sample mean (with mean yield = 3.62), this implies a modest yield increase of 0.02% per year. This suggests a modest rate of technological progress. Although yields fluctuated a lot from year to year (because of weather effects), the analysis shows no strong evidence of a long-term decline in

Table 1
Parameter estimate[1]

Parameters	Estimate	Standard error
Population growth: $(\text{pop}_t - \text{pop}_{t-1})/\text{pop}_{t-1}$		
a_0: intercept	−0.3875*	0.2097
a_1: pop_{t-1}	0.0886*	0.0508
a_2: pr_{t-1}	0.0936*	0.0493
a_3: $\text{pop}_{t-1}\text{pr}_{t-1}$	−0.0206*	0.0112
a_4: BD	−0.5336***	0.0088
Yield: y_t		
b_0: intercept	0.3542	1.7272
b_1: t	0.0008	0.0014
b_2: y_{t-1}	0.5920***	0.1845
Price: pr_t		
c_0: intercept	7.3723***	2.5162
c_1: pop_t	0.2940**	0.1184
c_2: y_t	−1.4535**	0.6405
c_3: pr_{t-1}	0.2964***	0.1126

[1]The analysis is based on 85 observations. Standard errors are White-heteroscedasticity-adjusted standard errors.
Asterisks indicate significance levels: *at the 10% level, **at the 5% level, and ***at the 1% level. The generalised method of moments minimum distance is 10.040.

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crop yields over the sample period. The coefficient of lagged yield b_2 is 0.592, which is statistically significant at the 1% level. This indicates the presence of significant dynamics, with yields adjusting slowly over time.

Finally, Table 1 reports the estimated coefficients for the food price equation, pr_t. The coefficient c_1 associated with population (pop_t) is positive and significant at the 5% level. It shows that increasing population behaves as a demand shifter which puts upward pressure on food prices. The coefficient c_2 associated with yield (y_t) shows the effect of yield on price: it is negative and significant at the 5% level. If yield is interpreted as a multiplicative supply shifter, this estimate can be used to calculate the demand elasticity for cereals. Evaluated at sample means, the price elasticity of demand for cereals is −0.893, which appears reasonable. Finally, the coefficient of lagged price c_3 is 0.296, which is significant at the 1% level. It shows that agricultural price adjusts slowly over time.

The estimated model can be used in at least two ways. First, it can be used to assess its explanatory power. Figure 4 shows the actual population in the sample plotted next to the population predicted from the model. Here, the predictions are obtained as short-term forecasts from a static simulation of equation (3). Figure 4 indicates that the model has a high explanatory power: the differences between actual and predicted populations are small.

Secondly, the model can be used to generate long-term predictions via simulation. This can provide useful information on the fundamental factors affecting long-term dynamics. A dynamic analysis of the estimated model is conducted as follows. Using 1314 as initial conditions, we simulated the model forward for the endogenous variables in equations (3)–(5): population (pop), yield (y), and price (pr). The dynamic simulation results for population are presented in Figure 5 for the period 1315–1400 (which also shows the actual sample population during that period).

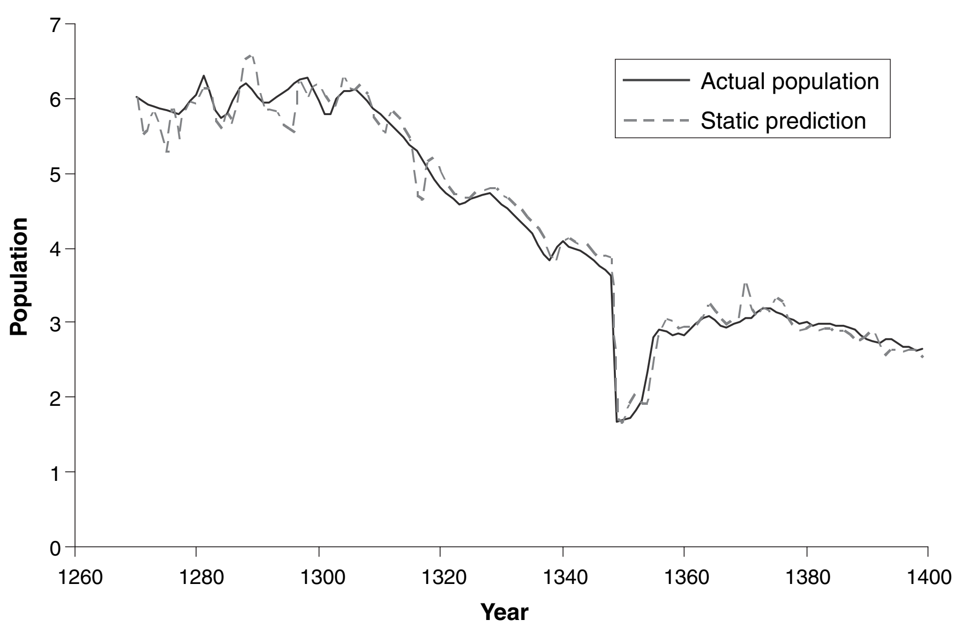

Figure 4. Population: fit vs. actual.

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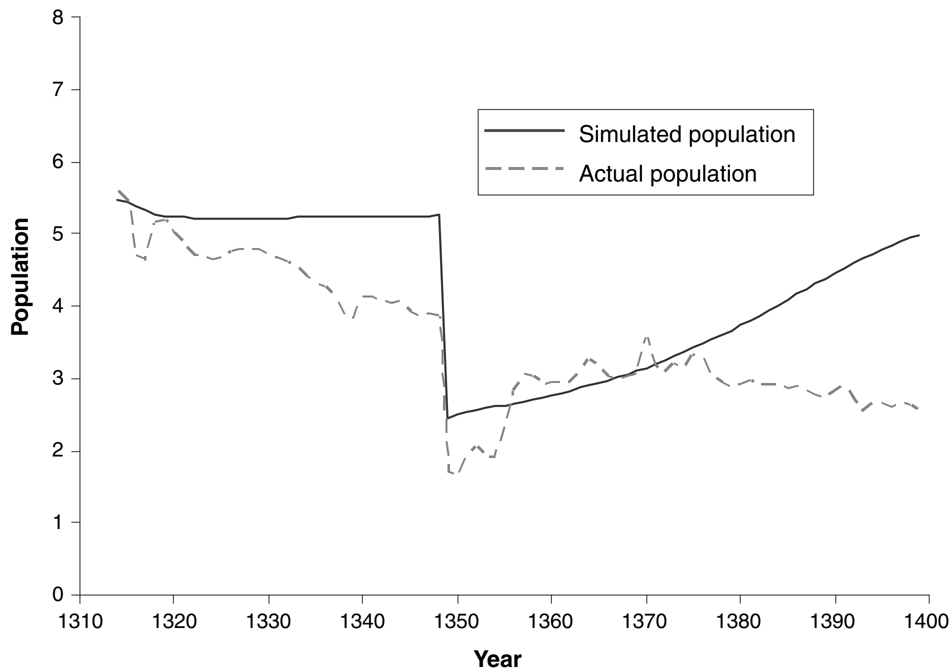

Figure 5. Dynamic simulation.

Except for the effects of the Black Death, the simulation is based on the information available in 1314. As can be anticipated for any long-term forecast, the simulation does not provide very accurate predictions beyond the first few years. However, the discrepancies between actual and simulated populations are instructive: they reflect the influence of factors that were not present in 1314. As such, the simulation generates useful information on the long-term determination of population during most of the 14th century.

Using 1314 as initial conditions, the simulation predicts a long-run equilibrium for population around 5.20. Figure 5 identifies several important sub-periods of the 14th century. First, the period 1315–1320 is one where both actual and predicted population declined. We might think of this period as being associated with a Malthusian scenario: high population pressure and high levels of resource scarcity (as reflected by prices) contribute to a population decline. It appears that the poor weather conditions in 1315–1316 may have been the trigger mechanism for the observed population decline: low yields contributed to both higher cereal prices and famine conditions in England.

The period 1330–1349 shows a continued decline in population (see Figure 1). However, population was below the model long-term prediction during that period (actual population decline being stronger than that predicted by the model). This suggests that the population decline during the 1330s and 1340s was due to economic disruptions that were not present at the beginning of the century.

Next, the Black Death (1348–1349) generated a large population decline (see Figure 5). The following period (1350–1399) is of particular interest. Following the Black Death, the model predicts a long recovery period. In the 1360s, the model

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long-term predictions are fairly accurate: the forecasted values are similar to observed population patterns. It indicates the start of a slow population increase. However, the discrepancy between predicted and actual population becomes large in the 1380s and 1390s: actual population failed to increase in the last two decades of the 14th century. On average, the model overpredicts population by about 30% for the 1380s and close to 50% in the 1390s. This raises the fundamental question: given the large population decline caused by the Black Death, why did the population fail to recover in the following decades? In the late 14th century, population pressure was much less than during the early part of the century. Moreover, there is no strong evidence that yields were declining and/or that resource scarcity was increasing (as measured by price levels). On the contrary, real agricultural price was declining during that period (see Figure 3). This means that there is no evidence of a Malthusian scenario during the last part of the 14th century. Yet, why did the population fail to recover? The only possible explanation is that demographic and economic disruptions were at play, introducing conditions that are not captured by either yield or price information. To the extent that prices and yield reflect both resource scarcity and technology, it appears that neither resource scarcity nor technology were the limiting factors preventing population growth during this period.

4. Implications

Our empirical analysis suggests that the standard hypotheses about the 14th century might well be reconsidered. We find some evidence supporting the Malthusian scenario for the period from 1315 to 1330, and in the 1350s and 1360s. However, for other periods, we failed to find evidence that population levels contributed to negative population growth. In particular, we find empirical support for the Boserupian scenario in 1300–1310, in the 1330s, and the 1380s and 1390s. For these periods, our evidence suggests that induced innovations played a role. This raises two important questions: (1) what is the historical record of technological and institutional innovations in 13th- and 14th-century England? and (2) what factors contributed to population stagnation following the Black Death?

The 12th and 13th centuries saw a significant switch from a hook-plough to a wheeled-plough under animal power, and from a two-field rotation (crop–fallow) to a three-field rotation system (winter crop–summer crop–fallow) (Langdon, 1986; Astill and Langdon, 1997).[10] The wheeled-plough enhanced weed control, improved agricultural labour productivity, and allowed the cultivation of heavy rich soils. This latter innovation contributed to significant increases in yield as well as area cultivated throughout Central and Northern Europe. The switch from a two- to three-field rotation had at least three advantages. First, it contributed to significant yield increases (up to a 50% increase). Secondly, it increased labour productivity by spreading labour allocation more evenly over the entire year. Thirdly, it improved the nutrient balance of the soil and prevented premature soil exhaustion (especially

[10] Note that neither the wheeled-plough nor the three-field system was an invention of the Middle Ages (Fox, 1986): both were found much earlier in some Roman provinces. However, their diffusion and utilization was a notable characteristic of the Middle Ages, at least on high-quality land.

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if combined with manuring). As a result, the Middle Ages exhibited significant productivity growth. It appears that the large population increases of the 12th and 13th centuries in England (as well as most of Western Europe) would not have been possible without large productivity increases in agriculture.

By 1280, at least half of the peasants in the agricultural heartland of south central England had gained their legal freedom. This contributed to the development of both a land market and a labour market in rural England. The development of markets and trade contributed to the transformation of the English society (Britnell, 1993; Britnell and Campbell, 1995; Masschaele, 1997). It stimulated agricultural productivity growth in at least two ways: (1) higher labour productivity from a more efficient structure of farm production; and (2) lower cost of production as the development of agricultural markets allowed specialization of each region according to its own comparative advantage. Trade with the continent was also a factor.

All these arguments speak in favour of the Boserupian scenario at least during the 12th and 13th centuries in England, where productivity growth and institutional innovations were associated with population growth (mostly caused by a rise in fertility). But what happened in the 14th century? First, in the late 13th century, population increases seem to have flattened out. This has been interpreted as indirect evidence in favour of a Malthusian scenario. Yet, our empirical analysis suggests that the first decade of the 14th century was still associated with a Boserupian scenario. That is, while population was stationary, low food prices indicated little evidence of strong Malthusian pressure at that time. Things changed in 1315–1317 with the beginning of a period of massive and generalized crop failures because of extremely poor weather conditions (Kershaw, 1973). The result was famine and starvation for many of the poor in England (and in the rest of Europe). Although this pattern appears consistent with a Malthusian scenario, this change occurred under very extreme and rare weather conditions. This crop failure and famine were then followed by a severe cattle plague in 1319 which destroyed draught animals and contributed to a significant decrease in agricultural productivity. In addition, changing climatic conditions (the beginning of the 'little ice age') may have further reduced agricultural productivity for the remaining of the 14th century. Perhaps more importantly, the events of 1315–1317 made it clear that a large proportion of the poor, whether serfs or free subjects were exposed to a significant risk of food insecurity (Bailey, 1998). A short-term response to this food crisis was social unrest and a marked increase in crime: many of the poor left their home in search of food and tried to find some by any available means. A long-term response was a further decline in population through the 1330s up to the onset of the Great Plague.[11] Moreover, as indicated in our empirical analysis, such patterns cannot easily be attributed to a Malthusian scenario (as the earlier famines had already reduced population pressure).

Paradoxically, the period following the Great Plague may be more puzzling than that leading up to 1348. For this post-plague period, our model's long-term

[11] The general decrease in population in the 1320s, 1330s and 1340s is supported by the data of Poos (1985), Razi (1980) and Dyer (2002). However, as noted in footnote 6, Campbell (1984) found some contradicting evidence of continuing demographic growth through the first half of the 14th century. This indicates that the prospects for demographic growth varied across space, with some regions exhibiting better prospects than those analysed in this paper.

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prediction is fairly accurate in the decade following the Black Death effect. However, the long-term prediction also indicates that population levels should have been increasing much more than observed in the later part of the 14th century. How can this discrepancy be explained? Again, new factors that were absent at the beginning of the 14th century must have been at work preventing a population recovery of even modest proportions. Hatcher notes the general consensus on these matters and calls attention to the '… difficulty of producing satisfactory explanations of why this should be so' (Hatcher, 1994, p. 8).[12]

Was there a new immiserization of the masses? Farmer (1991) suggests that the purchasing power of labour fell in the 25 years immediately following the Black Death. We know that the 14th century was turbulent – the Hundred-Year War, constant intrigue against the monarchy, and of course the Peasants' Revolt of 1381. We also know that the wool trade crashed in the second half of the 14th century and that although the growth in the cloth trade was significant, it did not make up for the losses associated with wool exports to the Low Countries. Postan writes of this period:

> *On most of the estates for which the evidence is available, more land was withdrawn from the demesne than was let out to tenants. In other words there was a net contraction of the area under cultivation. The impression of contraction is further supported by what we learn of the area actually occupied by peasant tenants. From the fifties and sixties of the fourteenth century right until the last quarter of the fifteenth, ominous entries of vacant lands, "terre in manu domini,"* appear in manorial accounts; and the number of vacant holdings and lapsed rents grow continually throughout the period (Postan, 1938/39, p. 161).

Helleiner (1950) observes that the spread of pasture at the expense of arable land in the 15th century was not the logical response of an expansion in the demand for wool, but rather a redefinition of the Ricardian extensive margin pushed by lower population levels. Moreover, the English population did not achieve demographic growth until approximately 1525 – almost two centuries after the Great Plague (Poos, 1985).

As noted above, following the famines of 1315–1317, perceived insecurity had adverse effects on long-term fertility, thus contributing to population stagnation. The Great Plague further contributed to this stagnation. Indeed, the Black Death of 1348–1349 was an indiscriminant killer: it affected the poor as well as the rich, clergy and royal family. As a result, it killed both workers and managers, and contributed to a massive destruction of human capital. Following the Black Death, many businesses and manors lost their manager. This created considerable difficulties in managing available resources, thus contributing to a significant decline in productive efficiency. This decline apparently contributed to our empirical finding supporting a Malthusian scenario for the 1350s and 1360s. Indeed, the Black Death destruction of human capital was in a way similar to an increase in resource scarcity. Yet, the main cause of high real food prices in the 1350s and 1360s was apparently not the scarcity of natural resources, but plausibly a shortage of human capital and deterioration in managerial abilities.

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[12] Bean admits that it is '… impossible to discover satisfactory proof of the theory that outbreaks of endemic plague led to a continuous decline in the population of England in the late fourteenth and fifteenth centuries' (Bean, 1963, pp. 434–435).

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The 1380s and 1390s saw a decline in food prices and a rise in wages in England. The model here suggests that this period might be associated with a Boserupian scenario. The apparent increase in wages would seem to reflect labour shortages, which harmed landowners. Such wage increases suggest a rise in the purchasing power and welfare of labourers towards the end of the 14th century. Such changes were also associated with a slow demise of the manorial system and the development of private property in England (North and Thomas, 1971). Yet, population remained stagnant for more than a century. Again, the puzzle is: why was there no population recovery?

The history of the 14th century seems to provide evidence on the structural transformations involved in the evolution towards an integrated economy. This transformation was associated with a shift away from feudalism towards a market economy. This was part of long process of economic and institutional evolution that took pace over several centuries. The origins of English individualism – and the emergence of capitalist relations – have been the subject of controversy (Faith, 1966; Macfarlane, 1978, 1987). The difficulties associated with the full development of a market economy are now understood to be greater than has heretofore been acknowledged. If Macfarlane is to be believed, individualism was much more prevalent in 14th-century England than has traditionally been supposed. Moreover, given what Polanyi (1957) wrote about the problems of the 'great transformation', there is much to be learned from the history of 14th-century England: it sheds light on the difficulties of a rural economy moving towards more integrated markets. This may be particularly relevant today in assessing the current difficulties facing former centrally-planned economies in their attempts to enter a market economy.

5. Concluding Remarks

Our analysis has focused on the role and extent of resource scarcity in 14th-century England. The analytical model used population, price and yield data to test for the presence of Malthusian or Boserupian pressures during that period. The analysis includes the effects of two significant shocks: the widespread crop failures of 1315–1316, and the Black Death of 1348–1349. Although both the events are rare, they had significant short- as well as long-run effects on England's rural economy. In the short run, both events contributed to a decline in population. The crop failures of 1315–1316 created food insecurity and famine. They may have been exacerbated by the cattle plague of 1319, contributing to reduced agricultural productivity; and while drastically reducing population pressure and increasing labour scarcity, the Black Death destroyed much human capital, with adverse effects on land and labour productivity. Both events contributed to lowering human fertility, even in periods when land and natural resources were less scarce. This reminds us of the importance of food security and human capital in long-term economic growth. Our analysis provides evidence of situations where large shocks or structural changes negatively affected productive efficiency. The adjustments of the economy to such changes were slow and costly. This documents some of the long-term dynamics involved in structural transformations. In particular, it points to the crucial role of human capital (and of the institutions supporting its efficient use) in long-term economic development.

Our analysis relied on available historical data covering England in the 14th century. Collecting historical data is a difficult research undertaking. Our empir-

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ical results are subject to the limitations of our data on prices, yields and population. Although the price and yield data are subject to a variety of challenges, the greatest weakness in our modelling effort is probably associated with population data. Indeed less is known about population changes during this period than perhaps any other pertinent variable. In this difficult context, we made use of available data collected by historians from various sources. This allowed us to cast some useful light on a complex and important era in England's agrarian history. In particular, although we have found a fair amount of empirical support for the Boserupian scenario, we have also uncovered evidence that human abilities to deal with resource scarcity may deteriorate in the presence of large economic shocks. We hope that our analysis will stimulate additional research on this topic.

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