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Chapter Author: Ronald Lee

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9 A Historical Perspective on Economic Aspects of the Population Explosion: The Case of Preindustrial England

Ronald Demos Lee

9.1 Introduction

The preindustrial context offers particular advantages for the study of population change and its consequences. Over the course of centuries the effects of population pressure on resources have a chance to emerge and to dominate the more transitory influences. And other sources of long-run economic change, such as technology, capital accumulation, education, and institutional reorganization, were formerly weaker or absent. Thus history may provide us with an actual ceteris paribus situation where statistical attempts to control for extraneous influences on contemporary development have failed. Of course there is always the risk that changing circumstances may have rendered the lessons of history obsolete, but one has to start someplace; the drunk looks for his dime under the lamppost, though he lost it down the street.

There have been many studies of the effects of population growth on economic development, but only a few of these studies are empirical.

Ronald Demos Lee is associated with the Department of Economics and the Population Studies Center, the University of Michigan.

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Theoretical studies, and the many simulation studies in the tradition of the classic work by Coale and Hoover (1958), can be queried on their premises (see Simon 1976). Cost-benefit studies of marginal lives, pioneered by Enke (1960), are empirical only in appearance; their results can actually be derived a priori for virtually any country, regardless of its economic situation, as Ohlin (1969) has shown in an ingenious article.[1] Cross-national studies, seeking correlations of population growth rates and growth rates of per capita income (see, e.g., Kuznets 1967; Chesnai and Sauvy 1973; Easterlin 1972) have invariably found no significant association.[2] Leff's (1969) well-known article on savings rates and dependency rates has been so heavily criticized as to leave the results in serious doubt. So although most economists and almost all demographers believe high population growth rates are a problem, there is a surprising shortage of empirical evidence. A study of the consequences of population change in a historical context may help demonstrate the importance of the variable in at least the simplest case.

Historical studies may also aid our understanding of the causes of population change. It is sometimes suggested that until a couple of centuries ago the size of human populations in relation to resources was effectively regulated by socioeconomic institutions, but that in recent times these mechanisms have broken down under the influences of mortality decline, urbanization, technical change, and modernization in general. However, there is little understanding of how such mechanisms functioned in the past, how effective they were, and how they reacted to various kinds of external shocks. An examination of these historical mechanisms should help us understand to what extent modern and historical experience differ qualitatively, and should provide some perspective on current high rates of population growth.

This paper has three major parts. The first discusses the consequences of population change in preindustrial England, concentrating on wages, rents, and the ratio of industrial to agricultural prices. A simple two-sector model is developed to organize the analysis. The second part discusses the cause of population change, focusing on the nature of the social mechanisms that controlled it and their reaction to variations in mortality and productivity. In the third part, a simple model of economic-demographic equilibrium is developed, in which steady shifts in labor demand are the main determinant of sustained population growth, while the equilibrium living standards maintained during expansion result from the interplay of largely exogenous mortality and institutionally regulated fertility. These three parts are followed by a brief summary and conclusion. Appendixes describe the data sources and the formal development of the dual-sector model.

9.2 Effects of Population Change

9.2.1 Overview

> For those who care for the overmastering pattern, the elements are evidently there for a heroically simplified version of English history before the nineteenth century in which the long-term movements in prices, in income distribution, in investment, in real wages, and in migration are dominated by changes in the growth of population. [Habakkuk 1965, p. 148]

This "heroically simplified version" of English history, which gives the central role to population change, appears to be accepted by a majority of economic historians. And since there was a rough synchronism of changes in population, wages, rents, and industrial and agricultural prices across Western Europe, many economic historians extend the same argument to the Continent as well.[3] The assertion is that when population grew, the additional labor that was applied to a relatively fixed amount of land brought diminishing returns, leading to falling real wages and rising real rents. Since industry's main input was labor, industrial prices closely followed the real wage. Thus a large population caused low prices for industrial goods relative to agricultural ones. Since, however, total agricultural incomes rose with population, so did the demand for industrial goods; thus industrial output—and with it urbanization—increased when population grew. This extension of the market encouraged specialization and trade.

Figure 9.1 shows the basic data series for England over the period 1250 to 1800. This analysis will focus on the latter part, from 1540 to 1800, for which better data are available; however, the earlier data help put this later period into perspective and strengthen the findings by suggesting their wider applicability. The data plotted in figure 9.1 are described in Appendix 9.1; however, the population series merits special mention. It is based on data from 404 parishes, collected and aggregated by the Cambridge Group for the History of Population and Social Structure. Although the population estimates used here are still preliminary, they are far superior to the demographic data previously available.

The series in figure 9.1 shows that the population-induced changes in the preindustrial economy were not trivial; rather, they were of fundamental importance to the people of the time. For example, the segment of society dependent primarily on wage income was comfortably off at the end of the fifteenth century; after a century of population growth their wages had fallen by 60% and their situation was desperate. Landlords were enriched over this period; industry grew rapidly; and industrial prices plummeted in relation to agricultural prices.

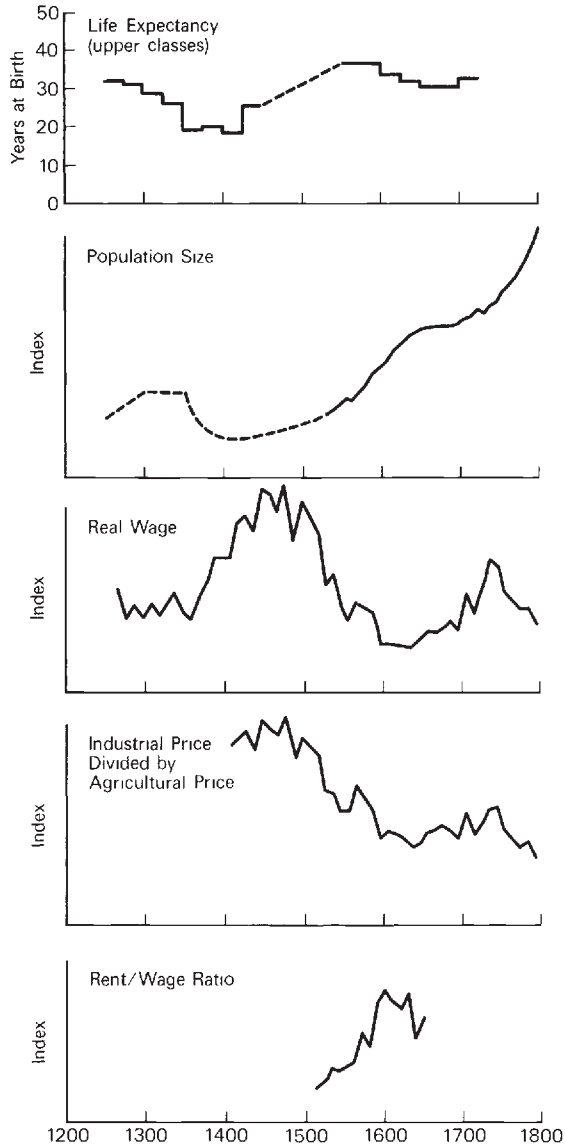

Fig. 9.1 Basic data for England, 1250–1800. For a description of the data and sources, see Appendix 9.1.

9.2.2 Population and Wages

Before developing and estimating the dual-sector model, I will examine the relation between population and wages in a simpler context. This will allow me to use annual data and to develop results comparable to my earlier work.

The wage is of interest because it reflects the marginal product of labor throughout the economy. It is also of interest because it represents the chief source of income for a large and growing segment of the population, rising from about 30% in rural areas in the sixteenth century to about 50% in 1700, and perhaps 75% in 1800 (Everitt 1967, pp. 397–99). While the wages of labor varied by skill and location, the various wage rates seem to have maintained rather fixed ratios one to the other (see Finberg 1967, p. 599, and Phelps-Brown and Hopkins 1955), so that a single wage can be used to represent changes over time in the experience of most workers.

Under competitive conditions, the real wage is determined by the intersection of the schedules relating labor supply and demand to the real wage. The labor demand schedule corresponds to the relation between the amount of labor utilized in the economy and its marginal productivity. This will depend on available land, capital, and technology, among other things, and in England during this period it is reasonable to expect changes in these to have increased the demand for labor in a cumulative manner. If the demand schedule shifts outward at a constant rate ρ, while maintaining its shape, then its position over time will be indexed by $e^{\rho t}$.

Now consider labor supply. In the short run, the labor services provided by the population might depend positively or negatively on the real wage, but there is no possibility of identifying such an effect empirically with these data. Over the longer run, the supply of labor varies roughly in proportion to population size, although the age-sex distribution of the population should also be taken into account.

The combined effects of the shifting supply and demand schedules on the short-run equilibrium wage may be expressed as:

$$(1) \qquad w_t = e^{\mu + \rho t + \epsilon_t} N_t^{-\eta},$$

or, in log form, as:

$$(2) \qquad ln\, w_t = \mu + \rho t - \eta ln N_t + \epsilon_t.$$

If the the short-run labor supply schedule is inelastic to the wage, then η measures the elasticity of the labor-demand schedule. The rate of shift of labor demand is ρ; μ is a scale parameter; and ϵ_t reflects the influence of climate and other omitted variables. The rate at which population can grow without altering the wage, or the rate of population "absorption," is ρ/η.

Note that from equation 2 the rate of change of wages ($\dot{w}/w$) should be related to the rate of population change ($\dot{N}/N$) by: $\dot{w}/w = \rho + \eta\dot{N}/N$. The data on w and N that were plotted in figure 9.1 can be used to get a rough idea of η and ρ/η. Inspection of the population series suggests the following periodization:

Date	*Population Growth Rate (% per year)*	*Rate of Change of Wages (% per year)*
1535–1605	.65	—.72
1605–45	.49	.15
1645–95	.08	.54
1695–1745	.23	.60
1745–95	.58	—.86

Figure 9.2 plots $\dot{w}/w$ against $\dot{N}/N$, treating each subperiod as an observation. There is indeed a clear negative relationship between the growth rates of population and wages, and the slope suggests that η is about -2 or -2.5. The rate of absorption is apparently about 0.4% per year, since at that rate of population growth, $\dot{w}/w = 0$. More rapid population growth sharply depresses wages; slower growth allows wages to rise.

The relation of wages to population over this period can be explored more exactly with regression analysis. For this purpose I have used not the real wage series shown in figure 9.1, which is deflated by agricultural prices alone, but the Phelps-Brown and Hopkins (1956) series, which is deflated by the cost of a mixed basket of goods including both agricultural and industrial commodities. This deflator is more appropriate for measuring welfare changes. The estimated equation is similar to equation 2, but somewhat more flexible. In addition to N, population size, I included variables $N1$ and $N2$, which give population size in subperiods, allowing the wage-population elasticities to be different in 1539–1638, 1639–1745, and 1746–1839. In addition to t, I also included t^3. This allows for the *rate* of shift to be quadratic in time, accelerating in the eighteenth century. Omitting the t^2 term constrains the rate of shift to change monotonically over the period. A special time variable, Dt, allows the period after 1809 to have a different rate of shift; this was included after inspection of residuals from earlier specifications. Finally, the error term was corrected for first-order autocorrelation, using the noniterative Cochrane-Orcutt procedure. The equation was fitted to annual data for 1539–1839, with the following result:

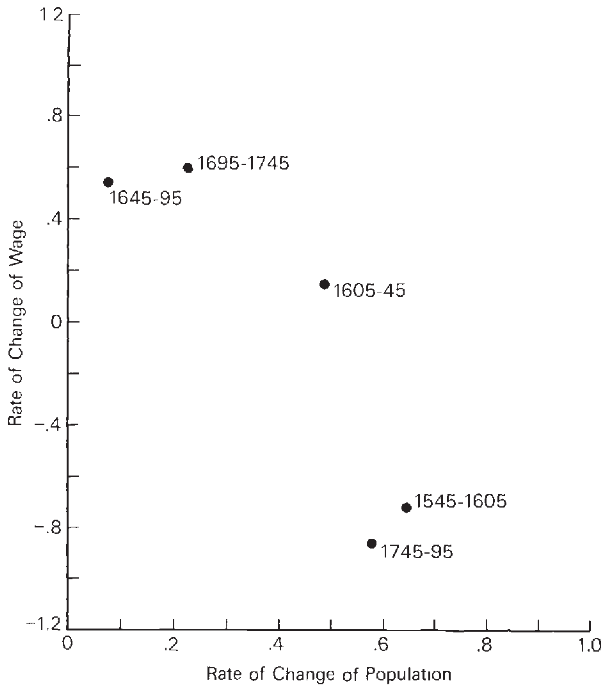

Fig. 9.2 Rates of change for population and wages in England, 1540–1800. Rates are given in percentage per year. Rates of change of wages are calculated from centered thirty-year averages of wages, except for 1795.

(3)

$$\underset{}{\ln w_t} = \underset{(7.27)}{6.81} + \underset{(3.16)}{.0057t} - \underset{(.13)}{.18 \times 10^{-8}\, t^3} + \underset{(3.77)}{.008Dt}$$

$$- \underset{(5.61)}{1.51\, \ln N_t} + \underset{(.87)}{.0071\, \ln N1_t} + \underset{(.58)}{.0075\, \ln N2_t}$$

$$R^2 = .161 \text{ (for changes in } \ln w\text{);}$$

t-statistics are given in parentheses below each estimate.

The results may be interpreted as follows:

i. Real wage levels were very sensitive to population size, with an elasticity of -1.5; thus a 10% increase in population caused a 15% decrease in real wages. This estimate is significant at the .001 level. The elasticity is lower than that suggested by figure 9.2 because of the difference in deflators.

ii. Surprisingly, there is virtually no change in this elasticity from subperiod to subperiod, as is shown by the small and insignificant coefficients for $1nN1$ and $1nN2$.
iii. The coefficients of t and t^3 show that the rate of shift in the relation between population and wages, reflecting technical change and capital accumulation, did not accelerate in the eighteenth century with early stages of the industrial revolution. This also is a surprising result.
iv. From 1539 to 1810, a population growth rate of 0.38% per year would have been consistent with a constant real wage. After the Napoleonic wars, the rate of shift more than doubled, and a growth rate of 0.88% per year would have left wages unchanged. This shows a dramatic alteration in the growth rate of the demand for labor.
v. The low R^2 is due to the Cochrane-Orcutt transformation, which causes quasi-differences in the data, emphasizing their short-run variability.

Perhaps the most striking aspect of all these estimates is the size of the wage-population elasticity. If production obeyed a Cobb-Douglas production function, these elasticities would equal minus the share of nonlabor inputs, or 0.4 to 0.6. The estimate above is about three times this great, suggesting that the Cobb-Douglas interpretation is incorrect. I will discuss this point in detail in the next section.

Since t^3, $N1$, and $N2$ all had insignificant effects, and the period after 1809 seemed quite different, I reestimated a simpler version of equation 3 for 1539–1809, correcting for second-order autocorrelation using an iterative Cochrane-Orcutt procedure.

$$(4) \qquad \underset{}{lnw_t} = \underset{(11.73)}{25.59} + \underset{(10.03)}{.00645t} - \underset{(9.23)}{1.62\, lnN_t}$$

$$R^2 = .75 \qquad DW = 1.97$$

$$R^2 \text{ for changes} = .19;$$

t-statistics are given in parentheses. These estimates are consistent with equation 3. The implied rate of absorption is 0.4% per year, and the wage-population elasticity is —1.62.

It is interesting to compare the results of this part with previous work I have done using less satisfactory demographic data[4] (see table on next page).

The elasticities estimated in equations 3 and 4 are larger in absolute value than the earlier estimates, but given the differences in data, time periods, and time units, I do not find the differences troubling. The principal inconsistency arises from the estimates of rate of population absorption. The previous studies, taken together, suggest a fivefold in-

Source	*Period Covered*	*Time Units*	*Wage-Population Elasticity* (η)	*Annual Rate of Absorption*
Lee 1973	1250–1700	50 years	−1.10 (7.05)	.00089
Lee 1977	1705–89	5 years	−1.29 (3.69)	.0046
Equation 4	1539–1809	1 year	−1.62 (9.23)	.0040

crease in this rate between 1250–1700 and 1705–89. This increase seems a plausible reflection of the agricultural and industrial revolutions. However the estimate in equation 3 shows no sign of an accelerating rate of shift. I have no explanation for this inconsistency, although the estimated dual-sector model will show that this constant rate of absorption masks important differences in rates of shift between sectors.

9.2.3 A Dual-Sector Model

The effects of population growth on the economy can be understood in richer detail if we distinguish between the agricultural and nonagricultural sectors. In this section I will develop a simple model of a dual-sector economy; in a subsequent section I will test it empirically. In the model, agricultural production exhibits sharply diminishing returns to labor, owing to the relatively fixed supply of land. Industrial production, which uses labor and agricultural output in fixed proportions, encounters no such bottleneck. The demand for industrial and agricultural output is such as to leave their shares in national income constant, when valued at current prices.

Throughout I will assume that the English economy was closed. In fact, exports made up about 5% or 6% of national income in 1688, rising to 14% by 1800 (see Deane and Cole 1969, p. 309). Some justification for the closure assumption is given by Kelley and Williamson in the context of Meiji Japan (1974, chap. 12).[5]

Capital and capitalists are ignored completely by the model, except that land-augmenting investment and technical progress at a constant rate are allowed in agriculture.[6] This is a model of a preindustrial economy; the industrial sector is largely passive and is not intended to provide insights into the beginnings of the industrial revolution. Details of the development of the model are given in Appendix 9.2; here I will discuss only the assumptions and the main results.

Industrial Production

The nonagricultural sector, which I will for convenience call "industrial," provides such diverse items as domestic service, buildings, textiles, lace, household goods, iron products, and so on.[7] Production in this sector directly requires only trivial amounts of land. The main inputs are labor and agricultural output, such as skins, wool, and grain. I assume that these inputs are combined in fixed proportions.

By appropriate choice of units of measure for agricultural output, A, and labor, N, the fixed input coefficients can be made to equal unity. Thus,

$$I = min(N_I, A_I), \tag{5}$$

where I is "industrial" output, N_I is labor employed in the industrial sector, and A_I is agricultural output used in the industrial sector. If no inputs are wasted, then:

$$I = N_I = A_I. \tag{6}$$

I will further assume that there are no profits in this sector, so that the price of industrial output, P_I, just equals the cost of inputs, $W_I + P_A$, where W_I is the industrial-sector wage and P_A is the price of agricultural output. A comparison of the wages of builders' helpers (Phelps-Brown and Hopkins 1955) and agricultural laborers employed in nonseasonal work without remuneration in kind (Finberg 1967) shows that these were equal in southern England from 1450 to 1650. I will therefore assume that $W_I = W_A$ and drop the subscript. Thus:

$$P_I = W + P_A, \tag{7}$$

or, taking A as the numeraire, as I will throughout,

$$p = w + 1, \tag{8}$$

where $p = PA/PI$ and $w = W/P_A$.

From equation 8 it is easy to determine the effect of population change on the terms of trade between industry and agriculture. Let $\gamma_I = w/p$ be labor costs as a proportion of total costs in industry. Then, if $N = N_A + N_I$ is the total labor force (by assumption, fully employed), and E denotes "elasticity,"

$$E_{p,N} = \gamma_I E_{w,N}. \tag{9}$$

Changes in technology and formation of industrial capital can best be described as labor-saving rather than material-saving. This was particularly true for textile manufacture but probably was false for the iron industry, which became important only at the very end of the period. Labor-augmenting change at the constant rate ρ has the effect of reducing labor requirements by a factor of $e^{-\rho t}$. Thus, for example, equation 8 can be rewritten:

$$p = e^{-\rho t} w + 1. \tag{10}$$

The Demand for Industrial Output

The amount of industrial output demanded by a household typically depends on its income, with an elasticity greater than 1, and on the relative price of industrial goods, with an elasticity less than 0. These effects can be incorporated at the household level by a linear expenditure system, which has the advantage of being aggregable. Although it would be desirable to incorporate such a demand specification, in the present model I assume that the shares of agriculture and industry in national income, valued at current prices, are fixed. This is equivalent to assuming income elasticities of unity for both kinds of goods, and price elasticities of minus one. The assumption is not so implausible as it may first appear, since the incomes of landlords and laborers typically moved in opposite directions. Historical data suggest a major decline in agriculture's share at the end of the eighteenth century but have been interpreted in conflicting ways concerning earlier changes.[8]

Final product in agriculture is total product less the portion used in the industrial sector: $A - I$. The value of total output is: $A - I + pI = A + I(p - 1)$. The assumption of constant shares can conveniently be written:

$$pI = \lambda(A - I), \tag{11}$$

since this yields a share of final product in agriculture of $1/(1 + \lambda)$, a constant.

This does not mean, of course, that in real terms the ratio of nonagricultural to agricultural consumption was constant; quite the contrary. Growing population would confront diminishing returns in agriculture, depressing wages and industrial prices, as indicated by equation 9. The assumption of a constant share of industry in national income would therefore require an increasing share of industry in *real* output, when population grew. And indeed this is historically accurate (see Deane and Cole 1969, p. 162).

The ratio of industrial to agricultural output, both intermediate and final, I/A, turns out to be:

$$I/A = \lambda/(w + 1 + \lambda). \tag{12}$$

This clearly increases as w falls; therefore, when population grows, industrial output increases more, proportionately, than does agricultural output. For a detailed discussion, see Appendix 2F.

Agricultural Production

Unlike industry, agricultural production is constrained by a relatively invariant supply of potentially arable land. However, conditions of agricultural production certainly did not remain static over the period under consideration. On the one hand, new rotations were adopted and new crops sown, land tenure arrangements were altered, and greater use was made of farm animals and fertilizer. Some of these changes may be regarded as reactions to changing factor prices, themselves due to population change; others represent genuine technological progress. On the other hand, the supply of land was increased through investment in such projects as draining the fens; and investments also facilitated the more efficient use of existing arable land, particularly in association with enclosure. These changes can be described as "land-augmenting." Lacking detailed information on the timing and extent of these changes, I will attempt to capture them by an exponential trend.

As noted above, the large (in absolute value) estimated wage-population elasticity is inconsistent with a Cobb-Douglas production function; so a CES (constant elasticity of substitution) production function will be assumed in agriculture. Denoting by F the initial quantity of land, and by ρ the rate at which land is augmented by reclamation, investment, and technological progress, the CES production function can be written:

$$(13) \qquad A = \mu_0[\mu_1 (Fe^{\rho t})^{-\beta} + (1 - \mu_1) N_A{}^{-\beta}]^{-1/\beta}.$$

If agricultural labor is paid its marginal product, then $w = [(1 - \mu_1)/\mu_0{}^{\beta}](A/N_A)^{1+\beta}$ or, alternatively, for appropriate a and b:

$$(14) \qquad w = a[N_A{}^{\beta}e^{-\beta\rho t} + b]^{-(1+\beta)/\beta}.$$

This relation can be estimated from data on real wages and employment in agriculture.

Total rents—whether explicitly treated as such or merely imputed to land—are the remainder after labor has been paid: $R = A - wN_A$, where R is total money rents divided by P_A. In a CES production function, the ratio of returns to inputs is simply related to the ratio of input quantities; here:

$$(15) \qquad R/w = [(1 - \mu_1)/\mu_1]N_A{}^{1+\beta}e^{-\beta\rho t}\, F^{-(1+\beta)}.$$

Alternatively, the rent per efficiency-unit of land, $r = R/(Fe^{\rho t})$, is related to wages by:

$$(16) \qquad r/w = [(1 - \mu_1)/\mu_1]N_A{}^{1+\beta}e^{-(\beta+1)\rho t}\, F^{-(1+\beta)}.$$

These equations are easily estimable after a log transformation. However, it is impossible to know for any particular rent series whether it indexes R or r, since it may or may not include the return to new investments in the land.

An important shortcoming of this analysis is that investment in agriculture is left exogenous and is indeed assumed to take place at a constant rate. But it is clear that agricultural investment and also perhaps technical change was more rapid when rents and agricultural prices were relatively high, and these themselves depended on population. It might be possible to get at these issues empirically through analysis of bills of enclosure. By ignoring these effects, I have surely overstated the long-run negative effects of population growth in England. However, regressions that do not include a shift term do not suffer from this bias, and they confirm the negative effects of population, although with a lower elasticity (see Lee 1973, p. 588).

Labor Force Allocation

In this model, wages vary because of variation in the labor employed in agriculture, N_A. However, data on N_A are not available; there are only data on N, the total labor force. Estimated relations between w and N reflect in part the effect of N on the allocation of labor between the two sectors. For this reason it is important to analyze the determinants of sectoral labor force allocation.

In Appendix 9.2.B it is shown that:

$$(17) \qquad N_A/N = \gamma_A/[\gamma_A + \lambda w/(p + \lambda)],$$

where γ_A is labor's proportional share of agricultural output, which makes it possible to calculate the implied labor force share of agriculture.

In Appendix 9.2.C, following Marc Nerlove's analysis of this model, it is shown that:

$$(18) \qquad E_{N_A,N} = \left\{1 + E_{w,N}\frac{N_I}{N}\frac{w}{(p + \lambda)}\right\} / \left\{1 - (1 - \gamma_A)\frac{N_I}{N}\right\}.$$

This result is particularly useful, because it makes possible the calculation of E_{w,N_A} and $\sigma = 1/(1 + \beta)$. In Appendix 9.2.D it is shown that:

$$(19) \qquad \sigma = -(1 - \gamma_A)E_{N_A,N}/E_{w,N}.$$

9.2.4 Empirical Results for the Two-Sector Model

Population and Wages

Under the CES specification, the elasticity of wages with respect to labor is a variable, not a constant. It is therefore inappropriate to estimate log-linear equations such as equations 1 through 4 above. The appropriate procedure is to estimate the highly nonlinear equation 14, using maximum likelihood methods. My attempts to do so failed; the program encountered nearly singular matrixes it could not invert. An alternative approach is to estimate a log-quadratic approximation (see

Kmenta 1971, pp. 462–65); my attempts to estimate β and σ in this way were also unsuccessful. Therefore I reverted to estimates of the log-linear equation, a decidedly inferior procedure.

In the dual-sector context, the log-linear wage-population regressions discussed above in section 9.2.2 are *not* appropriate, since the real wage employed there was based on a fixed basket of goods that included both industrial and agricultural products. This is an appropriate standard to use for welfare comparisons, but for the purpose at hand the money wage should be deflated by agricultural prices alone. The regression reported below uses decadal averages of money wages from Phelps-Brown and Hopkins (1955) for 1540 through 1700, and for the eighteenth century uses a series reported in Deane and Cole (1969, p. 19), which takes into account regional differences in wages and population growth. The wage is deflated using the agricultural price index described in Appendix 1.

Rather than using total population as a proxy for labor supply, it was possible to take account of age structure, as estimated by the inverse projection method (see Lee 1974). Ages 0–14 were weighted by zero, 15–64 by 1, and 65+ by 0.5.

Several versions of the log-linear regression were run. The one reported below allows for different $E_{w,N}$ in three time periods: 1540–1629, 1630–1719, and 1720–1800. It also includes linear and cubic shift terms.

$$\ln(w) = \underset{(9.16)}{14.6} + \underset{(5.21)}{.0103t} - \underset{(3.43)}{.533 \times 10^{-7}t^3} \tag{20}$$

$$- \underset{(7.08)}{2.22\, lnN} + \underset{(1.20)}{.0197\, lnN1} + \underset{(2.31)}{.0596\, lnN2}$$

$$R^2 = .832 \qquad D.W. = 2.14.$$

There are several points worth noting. First, the estimates of $E_{w.N}$, which range from -2.22 to -2.16 depending on the period, are even greater in absolute value than those in section 9.2.2. In other specifications of this equation, not reported here, they reach -2.7. There is a simple explanation for the discrepancy between these and the earlier results: when the cost of a mixed bundle of commodities is used to deflate the money wage, population change induces partially offsetting variations in the costs of the industrial and agricultural components. Therefore the estimated elasticity is closer to zero.

Second, although there is a statistically significant change in $E_{w.N}$ for the last subperiod, the effect is numerically inconsequential.

Third, and quite striking, the initial annual rate of land-augmenting change, measured as ρ/η, is 0.45%, but by 1800 it has declined to zero (that is, for fixed N, $\partial lnw/\partial t$ evaluated at $t = 260$ is roughly zero).

In other specifications the rate of shift also declines, but only by about two-thirds. This eighteenth-century retardation in agricultural progress is consistent with the view of Deane and Cole (1969, p. 75), which was based on quite different evidence.

Population and Terms of Trade

Data for constructing the terms-of-trade index were available for ten-year periods from 1541–50 to 1791–1800, giving 26 observations. Some splicing was necessary, and the last 100 years of the series are not completely comparable with the first 160. This is a serious difficulty with the results presented below, since different industrial commodities have different labor intensities. Nonetheless, I have taken the data at face value for present purposes.

In developing the model, I made simplifying assumptions about units of measure. In practice the simplifying transformations can be made only after estimation has taken place. The equation estimated, therefore, was not equation 10; two scaling parameters were added, as well as a more flexible rate of labor-saving progress. The following are maximum likelihood estimates:

$$(21) \qquad \underset{}{p_t} = \underset{(4.24)}{12.8} + \underset{(14.1)}{1.63} e^{-\underset{(2.49)}{.0017t} - \underset{(2.79)}{.243 \times 10^{-7} t^3}} w_t$$

$$R^2 = .91 \qquad D.W. = 1.58.$$

This estimated equation can be transformed to the form of (10) by defining: $\tilde{p} = p/12.8$ and $\tilde{w} = (1.63/12.8)w = .127w$. Then:

$$(22) \qquad \tilde{p}_t = 1 + e^{-.00117t - .243 \times 10^{-7} t^3} \tilde{w}_t.$$

The estimated coefficients of t and t^3 imply an annual rate of labor-saving change of only 0.117% in 1540, rising to 0.304% in 1700 and 0.061% in 1800. Thus, while the rate of progress in agriculture was declining, that in industry was accelerating. The cumulative effect of this change was to reduce the labor inputs per unit of output by 25% between 1540 and 1700, and between 1700 and 1800 by a further 36%. Over the entire 260-year period, labor requirements were reduced to 48% of their initial level.

The rates of shift in the two sectors, and their changes over time, are plotted in figure 9.3. The time paths appear to be mirror images, and the sum of the two rates is nearly constant. This reveals clearly the sectoral differences that were concealed by the constant rate of absorption.

The parameter estimates in equation 21 can also be used to estimate γ_I, labor's share of costs in industry. The average wage was 29.5, which transforms to $.127 \times 29.5 = 3.75$. Initially, therefore, $\gamma_I = 3.75/4.75 = .79$; labor costs were about 80% of total costs of industrial produc-

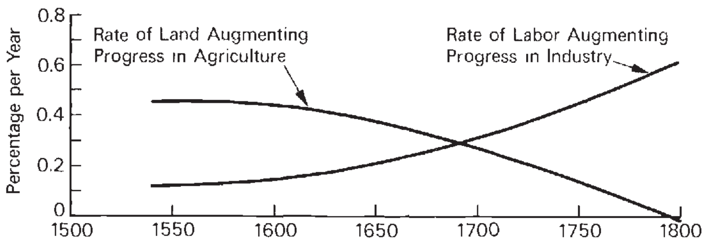

Fig. 9.3 Estimated rates of progress in agriculture and industry. Calculated from equations 20 and 21.

tion. By 1800, however, γ_I had fallen to $.48 \times 3.75/(.48 \times 3.75 + 1) = .64$. These estimates suggest that the effect of population change on terms of trade also declined (see eq. 9). In 1540, $E_{p,N} = .79(-2.22) = -1.75$; in 1800, $E_{p,N} = .64(-2.16) = -1.38$. These estimates seem on the high side (in absolute value) when compared directly with historical evidence (see Lee 1973, p. 591).

I should caution that domestic service, which made up a large proportion of the nonagricultural sector, is not included in the industrial price index. The effect of its inclusion would doubtless be to raise γ, labor's share of the cost inputs.

Population and Rent

Of all the data series, that for rent is undoubtedly the worst (see Appendix 1E). It is the shortest, covering only the period 1540 to 1660, in time units of ten years; thus there are only twelve observations. It is also unclear just what theoretical concept is represented: Does the series include rents on marginal lands brought into cultivation only under pressure of rising agricultural prices? If so, the increase in rents as population grows will be understated. Does it include rent changes reflecting investment in the land?

I used the rent series to form the ratio R/w, which under the CES specification is log-linearly related to N_A, as in equations 14 and 15. The actual regression uses N, not N_A; results can be interpreted with the help of $E_{N_A,N}$ (see Appendix 2E).

(23)
$$ln(R_t/w_t) = \underset{(2.99)}{-36.6} - \underset{(2.63)}{.0420t} + \underset{(3.08)}{7.50\, lnN_t}$$
$$R^2 = .77 \qquad D.W. = 2.60.$$

Because the time period is relatively short, and population was growing fairly rapidly over most of it, time is quite colinear with lnN. When a quadratic or cubic time-shift term is included, population's coefficient becomes small and insignificant.

The implied annual rate of land augmenting change is roughly .042/7.50 = 0.56%, compared with an estimate of 0.44% for this period from equation 20.

From equation 20 or equation 23, we can derive an estimate of the elasticity of substitution in agriculture. First, however, $E_{N_A,N}$ must be evaluated using equation A20 in Appendix 2. This requires estimates of N_I/N, γ_A, $E_{w,N}$, and $w/(p+\lambda)$. Reasonable mean values of these variables are $N_I/N = .35$, $\gamma_A = .45$, $E_{w,N} = -2.22$, and $w/(p+\lambda) = .6$.[9] These imply $E_{N_A,N} = .66$, so that as population rises, the proportion of the labor force agriculture declines quite markedly. Using equations A22 and A27, the implied estimates of σ can be derived. These are 0.16 from equation 20 or 0.09 from equation 23. The first figure is surely more accurate, since it is based on the full 260 years, while the second is based on only 120 years.

Is an estimated elasticity of substitution as low as 0.16 at all plausible? I am not sufficiently familiar with the agricultural techniques used to be able to form a judgment. Most modern studies of agricultural production report values in the neighborhood of unity, although low values, near 0.2, have been estimated for Meiji Japan (Sawada 1970) and India (Srivastava and Heady 1973).

The reader may have noted that all the estimates of population's effects were made using single-equation methods. However, if population growth rates are themselves dependent on economic welfare, then the system is simultaneously determined, and single equation methods will yield biased parameter estimates. In previous work (1973, 1978*a*, *b*) I have dealt with this problem at length. It turns out that simultaneity bias is not very important when estimating *effects* of population change; it is, however, a serious problem when examining the causes of population change. So the results reported in this part should not have been seriously biased by the use of single-equation methods.

Miscellaneous Effects of Population Growth

I have already discussed the effects of population growth, relative to augmented land, on wages, rents, and the terms of trade. Population also affected the composition of output. In Appendix 2, expressions for the effect of population on I and on I/A are derived (see eq. A29, A30). Evaluating these expressions gives $E_{I/A,N} = 1.33$ and $E_{I,N} = 1.65$. Thus a 10% increase in population would increase I/A by 13% and increase I by 16.5%.

Labor-saving progress in industry has a similar effect on the composition of output. Evaluating expression A42 yields $E_{I,\alpha} = -.85$; thus almost all the labor released by progress in industry is used to boost output in industry.

The effects of technical change and population growth taken together go a long way toward explaining the rapid industrial growth of the late eighteenth century. Using expression A28 for I/A and evaluating it in 1731–40 and in 1791–1800, I find that over this sixty-year period, industrial output in *real* terms should have increased by 60% more than did agricultural output. This compares with a figure of 90% derived from Deane and Cole (1969, p. 78). Thus the combination of rapid population growth, rapid improvement in industrial technology, and slowing change in agricultural technology accounts for much of the increased importance of industry.

Population growth also had an important effect on the factor distribution of income. For farmers working their own land, these effects would have been relatively unimportant; but for landlords and laborers the effects were very large. Evaluating expression A37, I find $E_{S,N} = -1.4$, where S is labor's share of total output. Thus a 10% increase in population would reduce S from perhaps 55% to 47%.

Finally, I should stress that the estimated value of $E_{w,N} = -2.22$ greatly *overstates* the effect of population change on material welfare, because the wage is expressed in terms of the agricultural commodity. Consider instead a wage deflator based on a 50-50 mix (in terms of mean value) of agricultural and industrial commodities. This is essentially the real wage concept measured by Phelps-Brown and Hopkins (1956), and used in section 9.2.2 above. Call this real wage w^*. Then, given actual mean values for w and p, it can be shown that $E_{w^*,N} \doteq (5/8)E_{w,N} \doteq -1.4$.[10] This agrees very well with the estimates of section 9.2.2 above (-1.5 and -1.6).

9.3 Causes of Population Change

9.3.1 A Test of Two Simple Theories

The broad issues were already sketched in the Introduction: Is population an endogenous element in the socioeconomic system, regulated by norms and institutions so as to establish and protect a culturally defined standard of living? Or is population an independent force that determines levels of living, and to which the society and economy must adjust as best they can? The former view has been held by many classical and neoclassical economists from Malthus to Harberger (1958, pp. 109–10), and by many biologists and ecologists as well (e.g., Dubos 1965, pp. 286–87). The latter view is generally held by historians, demographers, and some economists.

In its simplest form the classical theory—which makes population endogenous—posits a functional relation between the population growth rate and the level of wages. There will be some wage corresponding to zero population growth; this equilibrium wage is the conventional living standard or natural price of labor. In figure 9.4 I have plotted population growth rates against the wage level for twenty-five-year periods, 1550 to 1799, using the data introduced above. It is clear that there is no strong relation between the two; the scatter provides no support for the classical theory as applied to this period. In fact, similar results hold for the entire period 1250 to 1789 (see Lee 1973, 1978*a*).

The alternate theory holds that population varied independently. The simplest version argues that fertility is maintained at relatively fixed levels by institutions and customs that have evolved over the long run to ensure population replacement. Over the shorter run, population growth rates are determined by variations in mortality, since fertility does not change. In figure 9.5 I have plotted English population growth rates against the life expectancy of the British aristocracy (see Appendix 1A) for twenty-five-year periods, 1550 to 1724. After 1724, this life-expectancy series is no longer representative of the general population; before then, it compares well with other series in so far as changes are concerned, if not levels.[11] Figure 9.5 shows a very close relation between mortality and population change over this 175-year period. And since the data come from totally different sources, there is no possibility that the relation is an artifact due to errors in measurement.

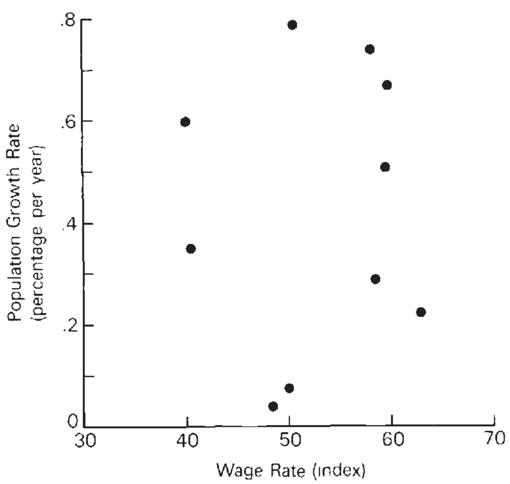

Fig. 9.4 Population growth rates and the real wage for twenty-five year periods, 1550–74 to 1775–1799.

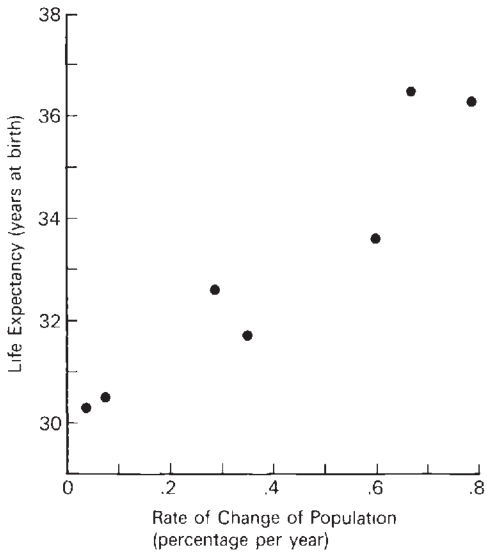

Fig. 9.5 Population growth rates and life expectancy of the British aristocracy, by twenty-five-year periods 1550–74 to 1700–1724.

This is strong support for the view that population growth rates varied independently, not primarily in response to changes in wages or the demand for labor (for formal tests of these hypotheses see Lee 1973, 1978*a*, *b*). But how then are we to explain the broad historical agreement of economic and demographic trends? In subsequent sections I will discuss in more detail the mechanisms thought to have regulated population in relation to resources in preindustrial Western Europe and attempt to reconcile the dependent and independent aspects of population change.

9.3.2 Fertility and Mortality

The Preventive Check

To the extent that European societies controlled population, it was almost entirely through regulation of fertility, not mortality. The conventional view of the mechanism linking fertility to resources in preindustrial Western Europe has not changed in broad outline since Malthus: Marriage required a sufficient livelihood, in the form of property or an adequate wage income. "Sufficiency" was defined by longstanding norms and institutions, which varied from country to country. Thus Malthus thought that the English were more prosperous than other Europeans *because* they regarded wheat and meat as necessities and would not marry without income enough to provide them for their families. Europeans in general were regarded as more prosperous than other peoples *because* they required more comfortable circumstances before they were willing to marry. Once married, couples were believed to bear children at a "natural" rate, while making no efforts to control family size. Such a system would relate aggregate fertility rates to per capita income or wealth, and to wage rates.

Whereas historical demographers have confirmed the general outline of the natural fertility theory, a number of studies have shown that in the eighteenth and nineteenth centuries, at least, marital fertility as well as nuptiality responded positively to the harvest cycle. There is also some mixed evidence that on balance suggests that wealthier couples may not only have married earlier, but also have had higher fertility within marriage (see Smith 1977).

The Cambridge Group's aggregate parish register data set makes it possible to analyze the effect on vital rates of short-run variations in the real wage. It provides series of the annual numbers of baptisms, burials, and marriages in 404 parishes from 1539 to 1839. In theoretical work described elsewhere (Lee 1975, 1978*a*) I have shown that short-run fluctuations in such series can be interpreted as fluctuations in marital fertility, mortality, and nuptiality. This enables us to draw demographic inferences from changes in the numbers of events without bothering about the size and structure of the population at risk. I have also shown (Lee 1978*a*) that short-run fluctuations can be used to study the causes of population change without contamination by the simultaneity in the system.

I have used cross-spectral analysis to estimate these relations, in part because for compelling reasons the theoretical analysis mentioned above had to be carried out in spectral terms.[12] However, given the theoretical results, the empirical work could have been carried out by regression analysis after suitable "filtering" of the series.

Spectral analysis examines the variances and covariances of sets of series by frequency or periodicity. Any detrended series may be examined in this way; there is no presumption that there are cycles in the data. It is convenient, although not entirely accurate, to think of frequency here as distinguishing, say, between long-run (low-frequency) and short-run (high-frequency) components of variation in the series. My previous work has established that for wavelengths of less than fifteen years or so, the population size and age structure, and the duration structure of marriages, have only negligible effects on births, deaths, and marriages. For my purposes, therefore, I will refer to these as "short run."

I will use three basic cross-spectral concepts in this paper. The first is "coherence squared," denoted $C^2(\lambda)$, which is analogous to R^2 in regression analysis but is specific to wavelength λ. The second is phase shift, $\phi(\lambda)$, which measures the lag of one series behind the other in radians at each wavelength. The third is "gain squared," $G^2(\lambda)$, which is analogous to the square of a regression coefficient, again specific to wavelength.

Estimated cross spectra for births and marriages in relation to wages are presented in figure 9.6. First consider births. For periods of thirteen years or less, $C^2(\lambda)$ is typically significantly greater than zero, indicating that wage fluctuations did indeed affect marital fertility, explaining perhaps 25% of the variance. The phase shift diagram indicates that marital fertility lagged slightly behind the wage rate, by something less than a year. I have not drawn in confidence bands for the phase estimates, but

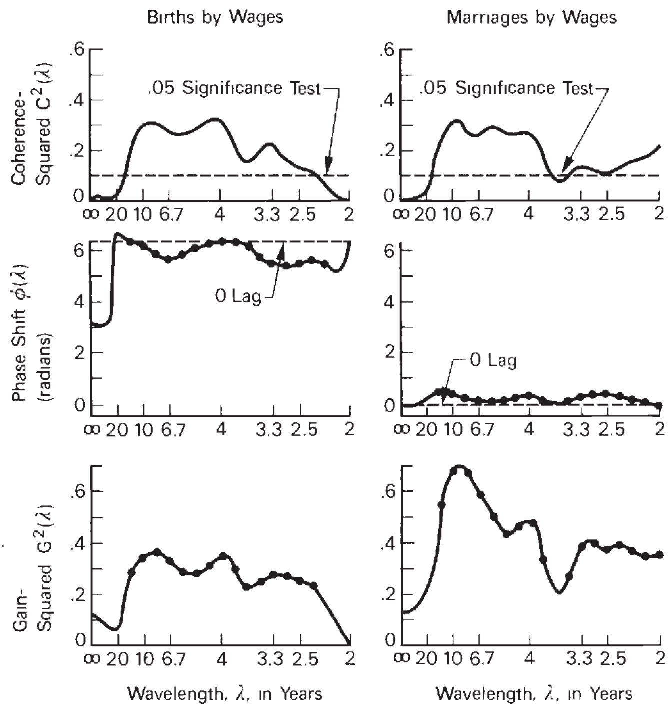

Fig. 9.6 Cross-spectral estimates of births and marriages by wages for England, 1539–1839. Phase estimates indicated by solid circles correspond to significant estimates of coherence squared and are more accurate than others. Estimates were made using a Parzen window with T = 301, M = 20. Births, marriages, and wages were measured as the residuals from a regression of the lag of the basic series on time.

they are very narrow, typically about ± 0.3 radians. The estimates of $G^2(\lambda)$ can here be interpreted as elasticities,[13] suggesting a value of 0.3. I also estimated separate cross spectra for each of the periods 1539–1638, 1639–1745, and 1746–1839 and found virtually identical results within each subperiod. This establishes the existence of a procyclical response of marital fertility to wages as far back as the sixteenth century, with no noticeable change in the timing or sensitivity of the relationship.

The estimated cross spectrum for marriages and wages shows a coherence-squared very similar to that for fertility. The phase diagram shows that nuptiality responded to wages with no lag at all, in contrast to fertility. The gain-squared estimates show that the elasticity for nuptiality was on the order of 0.5, or nearly twice as high as that of fertility. Generally, the association was closer and more sensitive for fluctuations of about ten years' periodicity than it was for very short-run fluctuations. To summarize, these results show that as far back as the sixteenth century, both marital fertility and nuptiality were strongly influenced by short-run variations in the real wage, which explained 20% to 30% of their short-run variance. Without making any judgment on whether the association of marital fertility with wage variations was due to voluntary limitation of fertility, these results provide some support for the existence of an aggregate relation between general fertility and wages.[14]

The Positive Check

While the role of exogenous mortality decline in the current LDCs' rapid population growth is widely acknowledged, it is less well known that large exogenous changes in mortality occurred in the past, leading to major population swings in Europe from the thirteenth through the eighteenth centuries. And I refer not to catastrophic mortality associated with periodic harvest failure or epidemic, but rather to long-run changes persisting for decades or centuries. The causes of these shifts are obscure; they may have been climatic, or the by-product of independent epidemiological and ecological changes, or the result of voyages of exploration. But that these changes occurred is clear; their magnitude is suggested by the life expectancy series for upper-class Englishmen shown in figure 9.1. Other confirming evidence is found both for England and for the Continent in reconstitution studies based on parish registers, in data from religious orders and the professions, and in the analysis of wills and death taxes. The exogeneity of the changes is clear from their temporal relation to changes in wages and population size, and from their disregard for class distinctions (see Chambers 1972; Lee 1973, 1978*a* and 1978*b*).

I do not mean to suggest that mortality was completely independent of income; but the importance of this endogenous component has been greatly exaggerated. The extent to which mortality was associated with wages in the short-run can be studied with the Cambridge Group's parish data; figure 9.7 shows the relevant cross-spectral estimates. The coherence-squared indicates that only about 10% of the variance is explained, less than half the amount explained for nuptiality and marital fertility. The phase diagram is somewhat erratic but suggests that mortality and wages were negatively related, with mortality lagging by from zero to one year. The squared gain, not shown here, suggests an elasticity of about —0.5. (For an analysis of wages and mortality by cause of death in sixteenth- and seventeenth-century London, see Mirowski 1976.)

I have also analyzed the relation of wages to the rate of natural increase; these results are also shown in figure 9.7. The coherence-squared averages about 0.15, with a very small lag of growth behind wages. The elasticity is not a useful measure of sensitivity in this case. It is more helpful to note that a doubling of the real wage would increase the population growth rate by about 1.25% per year, ceteris paribus.

Direct Links of Fertility to Mortality

I have so far discussed the relations of fertility and mortality to wages. Now I will briefly consider the possibility that there were direct links of fertility to mortality, such that fertility would adjust to changes in mortality. Several such links have been suggested in the literature. One is that, through inheritance, high mortality resulted in the transfer of assets to the nubile, thus increasing nuptiality, then fertility (Ohlin 1961). The cross spectrum of marriages and deaths lends some support to this hypothesis. However, it is only the redistributive effect that should be counted here; changes in the population/wealth ratio are an indirect influence of mortality on fertility, already reflected in the wage rate. Another suggested link is that couples may have attempted to replace unexpected infant and child deaths and that, when mortality changed, they would eventually revise their mortality expectations and adjust their fertility accordingly. This argument requires the assumption that couples controlled their fertility and strove for some number of surviving children, in contrast to the natural-fertility hypothesis. Knodel (1975) has shown that this "replacement hypothesis" is false for a sample of preindustrial European parish populations. My own studies of the short-run relation of fertility to mortality show a very strong *negative* relation. Perhaps the most convincing evidence that fertility did not strongly compensate for mortality changes even over the long run is given by figure 9.5, which shows a very close correlation of mortality and population growth rates over a period of 175 years.

To sum up section 9.3, I have shown that, at least in the short-run, there was an endogenous component to population change, operating through nuptiality, marital fertility, and mortality. Presumably these

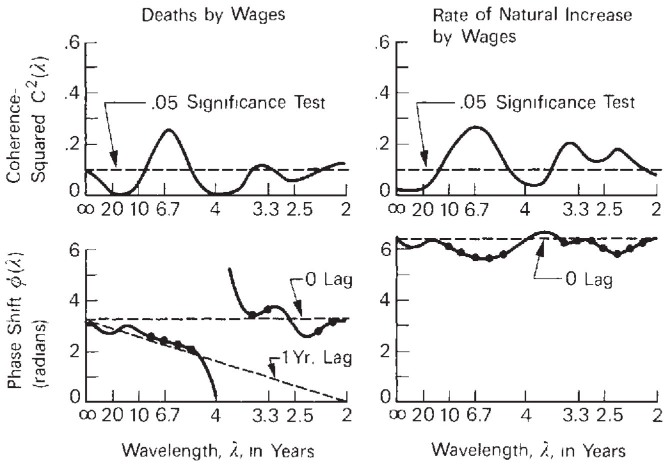

Fig. 9.7 Cross-spectral estimates of deaths and rate of natural increase in relation to real wages for England, 1539–1839. Phase estimates indicated by solid circles correspond to significant estimates of coherence-squared and are more accurate than the others. Estimates were made using a Parzen window with T = 301, M = 20. Deaths and wages were measured as residuals from the regression of the log of the basic series on time. Natural increase was used untransformed.

short-run relations also held over the long run, although these data provide no evidence on this point. Even in the short run, however, wages account for only about 15% of the variance in growth rates, so that most of the variation is exogenous. Furthermore, inspection of long-run life-expectancy series, as in figures 9.1 and 9.4, suggests that long-run variation in population growth rates was also dominated by exogenous variation.

Under these circumstances, over the very long run, the average wage level will be an important determinant of average population growth rates. But even over the course of centuries, fluctuations of growth rates about that average level may be largely exogenous.

9.4 A Model of Economic-Demographic Equilibrium

At this point it will be helpful to introduce a simple equilibrating model relating fertility, mortality, wages, and population. Rent and terms of trade could also be added, but they play an essentially passive role and would only clutter the diagram.

The relation of fertility and mortality to wages, measured by their crude rates b and d, may be plotted as in the top half of figure 9.8. The

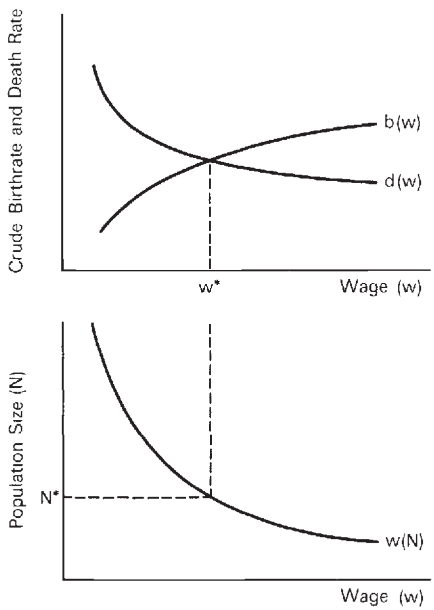

Fig. 9.8 Economic-demographic equilibrium.

level and curvature of the birthrate curve are determined primarily by norms and institutions, although at very low wages biological considerations may become important. Some societies might have horizontal fertility curves, if neither nuptiality nor marital fertility depended on material well-being. Societies with institutional arrangements conducive to high fertility, such as the extended family system, would have higher birthrate curves than those with less pronatalist institutions, such as the nuclear family. The death-rate curve is primarily biologically determined, although such additional factors as income distribution, centralized famine precautions, and in some cases infanticide and geronticide are also important.

The population growth rate, equal to $b - d$, is given by the difference between the two schedules; where they intersect, the growth rate is zero and the population is stationary. The corresponding wage, w^*, is variously known as the "long-run equilibrium wage," the "natural wage," the "conventional standard of living," or "subsistence."

The lower half of the diagram shows the relation between the wage rate and the size of the population; it corresponds to the demand for labor, which I assume is fixed. Corresponding to the equilibrium wage is an equilibrium size of population, N^*. There will also be equilibrium levels of rent and terms of trade, which are not shown. Evidently the equilibrium is stable; when population size is below N^* its growth rate will be positive, and conversely.

Now consider the effect of a once-for-all shift in the demand for labor; this situation is shown in figure 9.9. When $w(N)$ shifts out to $w_1(N)$, the wage will initially rise, inducing population growth until population attains its new equilibrium at the old wage level. Thus, over the long run, population responds passively to economic advance, while a roughly constant level of material well-being is maintained; this is the "iron law of wages."

Now consider the effect of a permanent exogenous decline in mortality, shifting the schedule from $d(w)$ to $d_1(w)$. This is shown in figure 9.10.[15] The decline in mortality lowers the equilibrium wage and population size; growth rates are initially positive until a new equilibrium is established with lower fertility and wages and larger population size. The point to note is that the equilibrium wage is not a culturally determined parameter, as the classical economists thought; it depends also on a level of mortality that was subject to autonomous long-run change. It is this that gives population an independent role in history: within broad limits, the equilibrium population and living standard changed when mortality changed, even if institutions and the economic base of society remained completely unaltered.

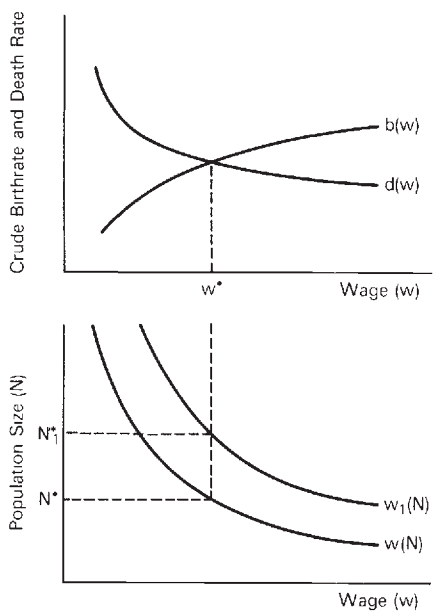

Fig. 9.9 Increased demand for labor.

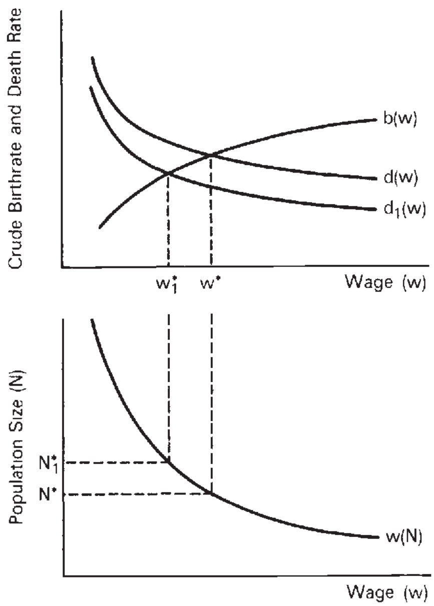

Fig. 9.10 Exogenous mortality decline.

I have simplified here by ignoring the direct links of fertility to mortality; these would cause the fertility curve to shift in response to shifts in the mortality curve. However, such direct links were very weak (see Lee 1973, p. 598; 1978*a*, p. 167). Therefore it was only through long-run change in the norms and institutions themselves that society could maintain constant population and wages in the face of exogenous change in mortality. The automatic homeostatic mechanisms were not adequate in these circumstances.

In earlier papers (Lee, 1973, 1978*a*, *b*) I used estimated forms of this model to simulate the course of wages, population, and fertility, assuming that only mortality varied exogenously. These simulations fit the historical data remarkably well for 1250 to 1700 and 1705 to 1784.

The diagram can also be used to illustrate the effect of a steady rate of shift of the demand for labor, of the sort included in the equations estimated earlier. Suppose that this rate of shift is such that population growth at rate r leaves wages unchanged; the estimates suggested $r = 0.4\%$ per year. Then in steady state growth, population will grow at rate r, and the wage will be constant at a level such that $b(w) - d(w) = r$. This situation is shown in figure 9.11. Evidently the wage will have to be a bit above its "natural" level in order to induce growth. Exogenous change in mortality will alter the steady-state wage but will only temporarily affect the population's growth rate.

Finally, consider a simultaneous decline in mortality and initiation of growth at rate r in the demand for labor. This situation is shown in figure 9.12. In this case we might observe constant fertility, low mortality, and population growth with no diminution in wages. This is the situation T. H. Marshall had in mind when he wrote of eighteenth-century England (1965, p. 248):

> The obvious temptation is to assert that the death rate was not only the variable, but also the determining, factor in the increase of population, and that, to understand the causes of this increase, we should study the deaths rather than the births. But, clearly, a horizontal line on a graph may be as dynamic as a diagonal; the forces that prevent a birth rate from falling may be as significant as those that make it rise.

Ordinarily, one would expect a fall in the death rate to be followed by a fall in fertility, as equilibrium is attained at a lower rate and larger population; if this does not happen, it suggests that the underlying cause of continuing population growth is economic progress, not the mortality decline.

Might this be similar to the situation in today's LDCs? We often observe exogenously declining mortality, relatively constant fertility and per capita income, and rapid population growth. Without the concurrent

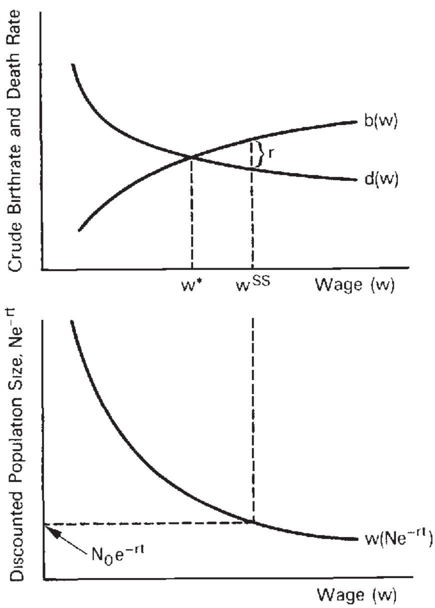

Fig. 9.11 Labor demand increasing at a constant rate.

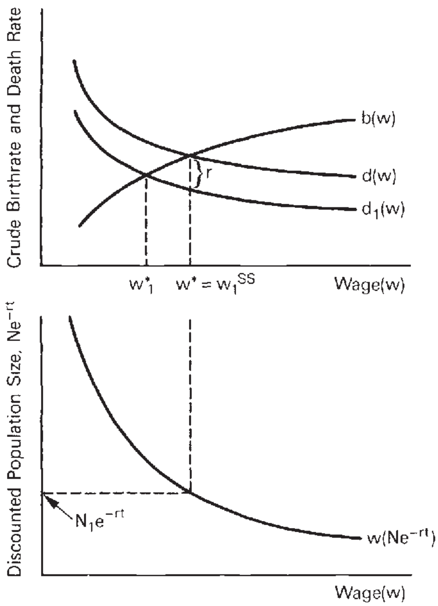

Fig. 9.12 Offsetting changes in growth of labor demand and mortality.

economic development, surely by now incomes and fertility would have fallen and mortality risen. It is not quite right to attribute the population growth to the mortality decline, although this may be the most conspicuous exogenous change; growth in the capacities of these economies to sustain population should perhaps be accorded the major responsibility.

A final comment on this model in relation to the LDCs is in order. Whatever the nature of the social mechanisms that may have regulated population in Asia, it is clear that a balance was reached at a much higher level of fertility and mortality than in Europe. Apparently life expectancy in China and India at the turn of this century was about 23 years (see Barclay et al. 1976; Das Gupta 1971), versus perhaps 30 years in Europe; the total fertility rate must consequently have been about 6.5 versus 4.5 in Europe. The necessary change in fertility-regulating institutions, in response to declining mortality, is staggering.

9.5 Summary and Conclusions

For today's LDCs there is little empirical evidence on the economic effects of population change. For the economy of preindustrial England and perhaps Europe, on the other hand, population emerges clearly as the dominant cause of long-run change in wages, rents, industrial prices, and income distribution. The economy could absorb population growth at about 0.4% per year with little effect; deviations of population size above or below this trend line, however, had dramatic consequences. And perhaps more striking than the existence of these effects is the extreme sensitivity of the economy's reaction: reckoning in terms of agricultural goods, a 10% increase in population depressed wages by 22%; raised rents by 19%; lowered industrial prices relative to agricultural prices by 17%; raised the ratio of industrial to agricultural production by 13%; and lowered labor's share of national income by 14%. This sensitivity of response poses the principal puzzle to emerge from this research. My attempt to account for these large (in absolute value) elasticities by means of a very low elasticity of substitution of labor for land is not altogether convincing without corroborating evidence.

In this study I looked for negative consequences of population growth, and I found them. However, I made no effort to analyze such positive effects as the stimulation of agricultural investment or of technical change, the role of rising domestic demand for basic industrial commodities, or industrial wage rates held down by population growth and sharply diminishing returns in agriculture.[16] Nor can these possible positive effects be brushed aside as merely partially offsetting reactions to dominant adverse effects; if they in any way brought on the industrial revolution, then their net effect was overwhelmingly positive. But surely the links of today's LDCs with the world economy greatly reduce the advantages of scale, home demand, and home-produced technology. Perhaps after all it is the centuries before the industrial revolution that are most relevant for the LDCs, when population growth did have strong and predictable effects, beneficial for some social classes and damaging for others. In any event, a more balanced treatment of these issues would require a second paper.

Now let me turn to the causes of population change. There is a notion that social mechanisms cause population to grow and decline in response to changes in productive capacity, in such a way as to keep incomes close to a culturally defined standard of well-being. And some who reject this model as descriptive of the present still believe it is appropriate for the past. In fact it is a poor description of both. In preindustrial Europe, as far back as records will take us, population swings were largely autonomous, not a response to economic variation. Their active determinant was mortality, which then as now experienced large exogenous variation. Our current experience is not unique in this respect, and, indeed, though the present decline in mortality has been much greater and more sudden than those of the past, its effects on welfare have so far been much less.

On the other hand, it would be a mistake to ignore the institutional mechanisms of population control that existed in preindustrial times. The point is not that they were absent, but that the equilibriums to which they steered society were largely accidental, resulting as they did from the interaction of cultural control with independent mortality. And while mortality largely determined the equilibrium and actual standard of living, it was the social mechanisms that produced sustained population growth in response to economic progress.

In short, the social protection of living standards through population regulation has always been vulnerable to mortality change, and it would be folly to expect longstanding demographic adjustment mechanisms to prevent population growth from forcing material welfare below some conventional standard in today's LDCs.

It is only in the *very* long run, over which the institutional mechanisms are themselves variable, that such automaticity can be expected, and the European experience suggests that even centuries may not suffice.

Appendix 1. Data Used in Figure 9.1 and Section 9.2

A. Life Expectancy

For 1250–1450, estimates are based on J. C. Russell's (1958) life tables that refer to the mortality experience of a predominantly upper-class, geographically dispersed group of English males holding property granted by the king. Some errors in the original tables were corrected; the infant mortality rates in the tables were revised; and estimates were converted from a cohort to a period basis. These estimates appear consistent with scattered evidence for other social classes. For details on all this, see Lee (1978*b*, appendix 4).

For 1550 to 1725, the estimates are based on Hollingsworth's study of the British peerage (1964). These estimates refer to the mortality of male peers. I have converted them from a cohort to a period basis. Extensive comparisons suggest that these estimates accurately reflect relative changes in the mortality of other social groups through 1725. For details, see Lee (1978*b*, appendix 2). Between 1450 and 1550, life expectancy estimates are not available.

B. Population Size

From 1250 to 1540, the dotted line indicates rough estimates of population size, based principally on Russell's work (1948); for details see Lee (1978*b*, appendix 1).

The remaining population estimates for 1540 to 1800 are based on a preliminary version of the Cambridge Group's aggregate parish register series. These series, generously made available to me by E. A. Wrigley and Roger Schofield, give the annual number of baptisms and burials for a nonrandom sample of 404 English parishes, covering about 6 or 7% of the total population. Various adjustments were made to correct for gaps, underregistration, and the entry and departure of parishes to and from the sample. Using a variety of methods, population size for the sample was estimated to be roughly 230,000 at the beginning of the period. Annual population estimates were formed by cumulating the difference between adjusted baptisms and burials, resulting in a population size of 1,055,000 for 1840. This implies a 4.6-fold increase over the three centuries, agreeing well with estimates from other sources. Estimates for the sample were inflated to the national scale using a ratio calculated for the end of the period when national population data are available. These estimates are preliminary. Figure 9.1 shows population size at five-year intervals, for 1540, 1545, . . . , 1800.

C. Real Wage (w)

The numerator (W) of the real wage series is taken from Phelps-Brown and Hopkins (1955), with some interpolation, for 1261 through 1700. It is the wage for building craftsmen. Thereafter, it is taken from Deane and Cole (1969, p. 19) and represents a population-weighted average of regions. A splicing ratio was derived from the overlap. The figure for 1790–99 was again taken from Phelps-Brown and Hopkins (1955).

For 1261–1400, the deflator of the real wage series is the Phelps-Brown and Hopkins (1956) cost of a composite basket of consumables including both agricultural and industrial commodities.

For 1401 to 1800, the deflator is an agricultural price index (P_A). It is taken from Phelps-Brown and Hopkins (1957), through 1700. From 1701 to 1760 it is based on the Phelps-Brown and Hopkins grain index as reported in A. H. John (1967, p. 191), using the overlap 1671–1700 to derive a splicing ratio. For 1761–1800, a wheat price index from Deane and Cole (1969, p. 91), is used, with splicing ratio based on 1641–70.

D. Terms of Trade (P_I/P_A)

The denominator, P_A, is exactly as described above in section C. The numerator, P_I, is taken from Phelps-Brown and Hopkins (1957) through 1700; thereafter the series is based on the average of the Schumpeter-Gilboy producers' goods index and consumers' goods other-than-cereals index, as reported in Deane and Cole (1969, p. 91). Because this average gives animal products a weight of 1/11, I assumed animal products were similar to wheat and subtracted 1/11 of the wheat price series from it. The splicing ratio was calculated from the Gilboy-Schumpeter index for 1680–1710, as reported in Mitchell and Deane (1962, p. 468). The price ratio, p, was calculated as $p = 100(P_I/P_A)$.

E. Rent/Wage Ratio (R/w)

The nominal rent index (RP_A) is taken from Kerridge (1953) and is an average of the two series for the Herbert estates (with weight 1/4 each) and the Seymour estate (with weight 1/2). The ratio R/w is calculated as RP_A/W times 100.

Appendix 2. Formal Development of the Two-Sector Model

This appendix sets out the assumptions of the model explicitly and develops a number of results that are used in the main body of the paper. The development presented here owes much to Marc Nerlove, particularly the material in section C. In what follows, agricultural output is the numeraire.

A. Assumptions

(A1) $$A = \mu_0(\mu_1 F^{-\beta} + (1 - \mu_1)N_A{}^{-\beta})^{-1/\beta}.$$

Agricultural production follows a constant return to scale, constant elasticity of substitution production function, with inputs of labor and land-plus-other factors.

(A2) $$I = min\{N_I, A_I\}.$$

Nonagricultural production follows a fixed-coefficients production function with inputs of labor and agricultural output; units of measure for labor and agricultural output are chosen so that the production coefficients are unity.

(A3) $$w_I = w_A = w.$$

Wages are equal in the two sectors.

(A4) $$w = \partial A/\partial N_A.$$

The wage in agriculture is competitively determined.

(A5) $$p = w + 1.$$

The price of industrial output equals its cost of production.

(A6) $$N = N_A + N_I.$$

There is full employment (or employment of a constant proportion of the working-age population).

(A7) $pI = \lambda(A - I)$ or, equivalently, $(A - I)/(A - I + pI) = 1/(1 + \lambda)$.

The demand for nonagricultural output is such that net agricultural output is a constant proportion of total net output, valued at current prices.

B. Derivation of the Sectoral Allocation of Labor

Let γ_A be labor's proportional share of agricultural product; by (A4) this equals $E_{A,N_A} \times N_A$ can be expressed as:

(A8) $$N_A = A\gamma_A/w.$$

From equation A2 it follows that $I = N_I$, and combining this with equation A7 and solving for N_I yields:

(A9) $$N_I = \lambda A/(p + \lambda).$$

From equations A8, A9, and A6 it follows that:

(A10) $$N_A/N = \gamma_A/[\gamma_A + \lambda w/(p + \lambda)],$$

which gives agricultural employment as a proportion of the total labor force.

C. The Effect of Population Growth on the Sectoral Allocation of Labor

The goal here is to derive an explicit expression for the elasticity of N_A with respect to N. From equations A6 and A9 it follows that:

(A11) $$N_A = N - \lambda A/(p + \lambda).$$

Differentiating with respect to N gives:

(A12) $$\frac{\partial N_A}{\partial N} = 1 - \lambda\frac{\partial N_A}{\partial N}\left\{\frac{\partial A/\partial N_A}{p + \lambda} - \frac{A\,\partial w/\partial N_A}{(p + \lambda)^2}\right\}.$$

Solving equation A12 for $\partial N_A/\partial N$ yields:

(A13) $$\frac{\partial N_A}{\partial N} = 1/\left\{1 + \frac{\lambda\partial A/\partial N_A}{p + \lambda} - \frac{\lambda A\,\partial w/\partial N_A}{(p + \lambda)^2}\right\}.$$

From equation A9:

(A14) $$\lambda/(p + \lambda) = N_I/A.$$

Substituting in equation A13 yields:

(A15) $$\frac{\partial N_A}{\partial N} = 1/\left\{1 + \frac{N_I \partial A/\partial N_A}{A} - \frac{N_I \partial w/\partial N_A}{p+\lambda}\right\}.$$

Multiplying by N/N_A on both sides yields:

(A16) $$E_{N_A,N} = 1/\left\{\frac{N_A}{N} + \frac{N_A N_I \partial A/\partial N_A}{AN} - \frac{N_A N_I \partial w/\partial N_A}{N(p+\lambda)}\right\}$$

This can be rewritten:

(A17) $$E_{N_A,N} = 1/\left\{1 - (1-\gamma_A)\frac{N_I}{N} - \frac{N_I}{N} E_{w,N_A} \frac{w}{(p+\lambda)}\right\}$$

Equation A17 relates two unknown and unobservable elasticities, $E_{N_A,N}$ and E_{w,N_A}. Fortunately these same two elasticities are also related by the identity:

(A18) $$E_{w,N_A} = E_{w,N}/E_{N_A,N},$$

where $E_{w,N}$ is directly estimable. Substituting from equation A18 into equation A17 yields:

(A19) $$E_{N_A,N} = 1/\left\{1 - (1-\gamma_A)\frac{N_I}{N} - \frac{E_{w,N} N_I}{E_{N_A,N} N}\frac{w}{p+\lambda}\right\}.$$

Solving for $E_{N_A,N}$ yields:

(A20) $$E_{N_A,N} = \left\{1 + E_{w,N}\frac{N_I}{N}\frac{w}{(p+\lambda)}\right\}/ \left\{1 - (1-\gamma_A)\frac{N_I}{N}\right\}.$$

This last equation permits estimation of $E_{N_A,N}$ from estimable quantities. And it is also true, of course, that:

(A21) $$E_{N_A/N,N} = E_{N_A,N} - 1.$$

D. Estimation of E_{w,N_A} and the Elasticity of Substitution in Agriculture

Once we have derived the effect of population change on the sectoral allocation of labor, $E_{N_A,N}$, it is simple to find E_{w,N_A} and $\sigma = 1/(1+\beta)$. In fact, E_{w,N_A} can be calculated directly from equations A20 and A18. Since the elasticity of substitution equals $-(1-\gamma_A)/E_{w,N_A}$, it is also true that:

(A22) $$\sigma = -(1-\gamma_A)E_{N_A,N}/E_{w,N}.$$

Substituting from equation A20, this gives:

(A23)
$$\sigma = -(1-\gamma_A)\left\{1 + E_{w,N}\frac{N_I}{N}\frac{w}{(p+\lambda)}\right\}/$$
$$\left\{E_{w,N}[1-(1-\gamma_A)\frac{N_I}{N}]\right\},$$

or

(A24)
$$\sigma = -(1-\gamma_A)\left\{1/E_{w,N} + \frac{N_I}{N}\frac{w}{(p+\lambda)}\right\}/$$
$$\left\{1-(1-\gamma_A)\frac{N_I}{N}\right\}.$$

E. Rent and Population

From equations A1 and A4 it follows that:

(A25) $$R/w = [(1-\mu_1)/\mu_1](N_A/F)^{1+\beta}.$$

This could be estimated in log-linear form, except that N_A is not directly observed. However if $E_{R/w,N}$ is estimated, then $E_{R/w,N_A} = 1+\beta = 1/\sigma$ can be calculated as:

(A26) $$1+\beta = E_{R/w,N}/E_{N_A,N},$$

or

(A27) $$\sigma = E_{N_A,N}/E_{R/w,N}.$$

F. The Effect of Population on the Ratio of Industrial to Agricultural Output in Real Terms

Solving equation A7 for I, and dividing by A, gives:

(A28) $$I/A = \lambda/(\lambda + p).$$

Calculation of the elasticity of I/A with respect to N yields:

(A29) $$E_{I/A,N} = -wE_{w,N}/(p+\lambda).$$

Inspection shows that this is a positive number; population growth increases industrial output more, proportionately, than agricultural output. In fact, since $I = N_I$, and $N_I = N - N_A$, the elasticity of I with respect to N is easily shown to be:

(A30) $$E_{I,N} = 1 + (N_A/N_I)\,(1 - E_{N_A,N}).$$

Thus, to a first approximation, industrial output increases in proportion to population; more accurately, it increases *more* than proportionately when $E_{N_A,N}$ is less than one.

G. Population and Terms of Trade

Since $p = 1 + w$, it is easily shown that:

(A31) $$E_{p,N} = \gamma_I E_{w,N},$$

where γ_I is $w/(1 + w)$, the share of labor in the cost of industrial production.

H. Population and Income Distribution

In the model, all income accrues either to labor or to "land" (which includes all agricultural nonlabor inputs). Labor's share of output in proportionate terms, denoted S, is therefore:

(A32) $$S = wN/(wN + R) = 1/[1 + R/(wN)].$$

Dividing numerator and denominator of $R/(wN)$ by A gives $(1 - \gamma_A)/(\gamma_A N/N_A)$, so equation A32 can be rewritten:

(A33) $$S = \gamma_A/[\gamma_A + (1 - \gamma_A)\ (N_A/N)],$$

so that labor's share in all output is greater than it share in agricultural output.

Equation A33 can also be used to calculate γ_A, which is unobserved, from S and N_A/N, for which estimates exist. Solving for γ_A yields:

(A34) $$\gamma_A = (SN_A/N)/(1 - SN_I/N).$$

The elasticity of labor's proportionate share with respect to population size can be calculated from equation A32 as follows:

(A35) $$\frac{\partial S}{\partial N}\frac{N}{S} = \frac{-\{[\partial(R/w)/\partial N](1/N) + [\partial(1/N)/\partial N](R/w)\}N}{[1 + R/(wN)]^2\{1/[1 + R/(wN)']\}}.$$

This simplifies to:

(A36) $$E_{S,N} = -\{\partial(R/w)/\partial N - R/(wN)\}$$
$$/[1 + R/(wN)],$$

which further simplifies to:

(A37) $$E_{S,N} = (1 - E_{R/w,N})(1 - S),$$

which is easily evaluated.

I. Nonagricultural Technical Change, Wages, and Labor Force Allocation

Suppose equation A2 is altered to: $I = \min\ (N_I/\alpha, A_I)$, so that $\alpha I = N_I$ and $p = \alpha w + 1$. Then equation A11 becomes:

(A38) $$N_A = N - \alpha\lambda A/(\alpha w + 1 + \lambda).$$

This can be differentiated to find the effect of a change in α on labor force allocation, for constant N.

(A39) $$\frac{\partial N_A}{\partial \alpha} = \frac{-\lambda}{(p+\lambda)^2}\{(A + \frac{\partial A}{\partial N_A}\frac{\partial N_A}{\partial w}\alpha)(p+\lambda) - (w + \alpha\frac{\partial w}{\partial N_A}\frac{\partial N_A}{\partial \alpha})\alpha A\}.$$

After solving for $\partial N_A/\partial \alpha$ and simplifying:

(A40) $$\frac{\partial N_A}{\partial \alpha} = \frac{-\lambda A(1+\lambda)/(p+\lambda)^2}{1 + \frac{\lambda \alpha w}{p+\lambda} - \frac{\lambda \alpha^2 A \partial w/\partial N_A}{(p+\lambda)^2}}.$$

Further simplifying, and expressing as an elasticity, this gives:

(A41) $$E_{N_A,\alpha} = -1/\{pN_A/N_I - [\alpha w/(1+\lambda)]E_{w,N_A}\}.$$

It is also easily shown that $E_{N_I,\alpha} = -(N_A/N_I)E_{N_A,\alpha}$ so that:

(A42) $$E_{I,\alpha} = -[(N_A/N_I)E_{N_A\ \alpha} + 1].$$

And, finally, the effect of changes in α on w are easily assessed, since:

(A43) $$E_{w,\alpha} = E_{w,N_A} \times E_{N_A,\alpha}.$$

Notes

1. He has shown that in a stable population with growth rate r, whose economy has a rate of disembodied technological progress s, and in which savings are less than or equal to profits, the internal rate of return to a marginal birth, viewed as an investment, is less than or equal to $r + s$. If r is 0.02 and s is 0.01, then discounting over a life cycle at a rate above 3% yields a negative present value of a birth.

2. This may in part reflect their methodology. In a single-sector neoclassical growth model, rates of population growth have no effect on steady-state growth rates. Weak negative effects arise in transitional disequilibriums, and strong effects occur in nonneoclassical economies with surplus labor. It might be worth redoing the analysis while distinguishing among these three categories.

3. See, for example, Van Bath (1963); North and Thomas (1973); and Phelps-Brown and Hopkins (1959). Properly put, the argument is that population change accounted for changes in relative prices over the period; some historians, however, go too far and suggest that population growth caused the general price inflation of the sixteenth century. For a perceptive review see McCloskey (1972). In a recent paper, Cohen and Weitzman (1975) have suggested that the process of enclosure might also explain these changes; however, they have drastically underestimated the strength of the demographic data.

4. For the regression covering the years 1250 to 1700, the Phelps-Brown and Hopkins (1956) real wage series was used, which is money wages deflated by the price of a basket of goods including both agricultural and industrial items. The wage series used for 1705–89 was deflated in a similar manner; it is based on data given in Deane and Cole (1969, p. 19) and takes account of regional differences in wages and population growth rates.

5. In any case, if the economy is viewed as open, then relative prices are determined in large measure exogenously. But until midway through the eighteenth century, Europe accounted for most of England's trade (see Deane and Cole 1969, p. 34), and changes in European factor supplies and factor prices paralleled those in England (see e.g. Phelps-Brown and Hopkins 1959).

6. This view of the English economy, which emphasizes land and labor to the total exclusion of capital, receives some support from estimates of the capital stock in the late seventeenth century. From Gregory King's tabulations, Deane and Cole (1969, p. 270) estimate that 64% of capital was in land, 8% in livestock, 17.5% in buildings, and only 10.5% in transportation, inventories, machines, and the military. The saving rate was 3 to 6%, and savings went to a considerable extent into agriculture.

By 1698, the "industrial" category had risen to about 21%, while land had fallen to 55%; but the economy's capital was still largely agricultural (Deane and Cole 1969, p. 271).

7. In 1798, roughly 12% to 16% of the population were "living-in" employees; of these, domestic servants were the largest group. See Mathias (1969, p. 25). In 1801, according to Colquhoun, about 7.5% of the population were personal and household servants.

8. According to Deane and Cole (1969, p. 154–64) the proportional share of agriculture in national income was 40–45% in 1688 and in 1770; by 1801 it had declined to about 32–36%. Pollard and Crossley (1968), put the 1688 figure at 56%, which if correct would change the picture considerably.

9. Mean values are needed for the variables N_I/N, γ_A, $E_{w,N}$ and $w/(p+\lambda)$, all of which are actually endogenous. Based on Gregory King, Deane and Cole (1969, p. 137) estimate that 60 to 80% of the labor force was primarily engaged in agriculture in 1688. Since many of those primarily engaged in agriculture nonetheless did nonagricultural work as by-employment or for their own consumption, I will take 65% as the proportion of labor services engaged in agriculture: so $N_I/N = .35$.

An estimate of γ_A can be derived from an estimate of S, labor's share of total national income, using equation A34. For 1688 Deane and Cole, based on Gregory King, estimate that between 25% and 39% of national income was wages and salaries. However, not included is the labor contribution of farmers and freeholders, whose income accounts for about 40% of national income. I will somewhat arbitrarily take $S = .55$, which implies that $\gamma_A = .45$. $E_{w,N}$ has been estimated to be -2.22 in equation 20; $w/(p+\lambda)$ should be estimated for the mean amount of labor augmentation. Taking $\lambda = 1$ (i.e., 50% of final product is in agriculture), and $w = 3$, gives $w/(p+\lambda) = .6$.

10. In transformed terms, $w = 3$ and $p = w+1 = 4$. Since agricultural prices are by definition 1, the quantity of I consumed must be 1/4 as large as that of A. Thus $w^* = w/[c + (c/4)p] = (4/c)[w/(w+5)]$. From this, $E_{w,N} = [5/(5+w)]$ $E_{w,N} = (5/8)E_{w,N}$ evaluated at $w = 3$.

11. See Lee (1971) for a comparison of this series with others for Colyton, a small rural parish, and for "professional men" in England.

12. The theoretical cross spectrum is ideally suited to analyze the interactions of two series that are related to one another approximately linearly with known sets of lagged coefficients, as is the case with demographic series.

13. The variables are measured as residuals from the regression of the log of the basic series on time.

14. Many dozens of previous studies of populations, in many social contexts and time periods, have demonstrated this sort of procyclical response, including situations in which the cross-sectional and secular relationship of fertility to income appears to be negative. Therefore this cross-spectral evidence is weak support at best for the existence of a long-run positive aggregate relation of fertility and income.

15. For diagrammatic simplicity, I have assumed that fertility is completely independent of mortality, so that $b(w)$ remains unchanged. The results are not qualitatively different so long as compensation is less than perfect.

16. These positive effects of population growth have been stressed by Boserup (1965) and others and have been modeled and simulated in a recent article by Simon (1976).

Comment Nathan Keyfitz

Is population growth the cause or the result of economic change? Ronald Lee tackles nothing smaller than this central problem of demography. The answer he provides is limited in space and time, but his analysis is nonetheless a tour de force combining economic time series, parish records, and simple models.

Everyone wants to endogenize population in his economic model, but there are doubts whether the real world is made in a way that permits this. Adam Smith seemed to do it: for him the production of people responded to the demand, just like the supply of shoes. For Malthus the number of people the landscape could support was limited just like the number of animals that could be sustained on a given food supply. Though they did not use the expression, Smith and Malthus in their different ways both saw a negative feedback by which the family received signals either from the larger society or from the environment, and so family behavior could never be destabilizing.

Neither view is wholly inapplicable—places and times can be found to illustrate both. So can places and times be found in which they do not apply. The Kung Bushmen, with densities of about one person per two square miles, do not seem to produce people up to either the economic or the biological limit. They avoid any sense of population pressure, keeping their numbers below the physiological maximum—by what means and under what motivation no one seems to know.

Nathan Keyfitz is professor of sociology at Harvard University.

Thus population in some places goes up either with capital (Smith) or with land (Malthus); among the Kung and elsewhere it stays well below the limits set by either. To make matters more difficult, the dominant tendency in most industrial societies has been for the birthrate to go *down* with the increase of income, a social mobility effect that overcomes the Smith and Malthus effects. The would-be endogenizer does not even know whether to insert in his model a positive, zero, or negative relation of population to income, let alone how strong to make that relation.

Lee's empirical finding that in preindustrial Europe income does not affect population accords with the theoretical ambiguity. However, in the other direction there does appear to be clear causation both theoretically and empirically. The result that when population rose by 10%, as it could easily do in a period of low mortality, wages went down by 15%, is surprising and important. The two-sector model is simple and convincing. My only wish is that he could reassure us more about the quality of the wage and other data to which it was fitted.

What is implicit in Lee's paper, as in other work, is two systems: the small system of the family and the large system of the population, whether it be parish, county, nation, or world. Each of the two systems has its own laws and variables, and the two sets of variables mesh differently in different circumstances. This paper tells us something important about both the small and the large systems as well as about the relation between them in preindustrial England.

It considers Smith's device for linking the two through the birthrate: with more capital and hence more jobs, young people will be able to marry earlier and so will have children sooner. Lee shows that the number of children within marriage did vary with jobs, a feature Smith did not recognize. But this and marriage seem to have been less important than the exogenously caused fluctuations in the death rates whose action is the main feature of the paper.

Lee mentions at the beginning of his paper the belief that in modern times the old regulatory mechanisms have broken down under the influences of mortality decline, urbanization, technical change, and modernization in general. He speaks of the finite world of preindustrial England with limits not yet rendered flexible by technology, and of how ancient regulatory mechanisms fail to operate in the twentieth century. But then at the end of the paper he transfers his major result from preindustrial England to the present LDCs. I am more convinced by his initial reservation than by his later transfer. For various reasons it seems unlikely that the currently developing countries will duplicate Europe's early experience.

The most conspicuous difference is in the rapid urbanization of the LDCs. In past centuries when remnants of feudal class respect were still controlling, communication was slow, and most of the population worked on the land, fluctuations of income were accepted even when they brought part of the population below the starvation line. In the 1970s, with huge migration to the cities—Cairo, Calcutta, Mexico City each have as many people as the whole of England and ten times as many as London—surplus population has a social and political visibility that daily reminds the elite of the importance of birth control. Each day's newspapers tell us about a turnaround or accentuation of birth-control policy in one or another country, conspicuously in certain countries where urbanization is most rapid.

But this does not say anything about the smaller system—it refers only to the policy of the larger society. Does the turnaround that is occurring in elite views tell us what will happen within the smaller system of the family? How can the elite control the family-building practices of their masses? Certainly they cannot do so directly or immediately. By the 1990s we should have a clear idea of the manner and degree in which currently visible economic and political forces of the larger society will penetrate the family. Sooner or later they will; it is the timing that is important. How much will the current fall in mortality and rapid population growth affect wages in the LDCs? One has trouble seeing how such a question can be answered by analysis of the forces operating in preindustrial England.

But this doubt about generalizing to the late twentieth century in no way lessens my admiration of Lee's historical work. His choice of models is judicious, and the method will be exemplary for others who use time series and parish registers to answer real questions.

Comment Marc Nerlove

In 1973 Lee published a paper entitled "Population in Preindustrial England: An Econometric Analysis," based on his 1971 dissertation.[1] In that paper Lee presented a model relating crude birthrates and death rates, population size, and the real wage rate that is the same in all essentials as that underlying figures 9.7, 9.8, 9.9 and 9.10 in the present paper. In the model of economic demographic equilibrium, real wages and population sizes are inversely related, whereas fertility, as measured by the crude birthrate, is positively related and mortality, as measured by the crude death rate, is negatively related to real wages. Population size is simply connected with the crude birthrate and death rate by the identity

Marc Nerlove is associated with Northwestern University.

$$(1) \qquad \frac{dP}{dt}/P = b - d,$$

where P is population size and b and d are the crude birthrate and death rate, respectively.

Lee estimated the basic relationships of his model using fifty-year averages of population size (aggregate data from Wrigley and Russell), a wage index (from Phelps-Brown and Hopkins) deflated by an index of prices for both agricultural and nonagricultural commodities, and life expectancies at birth for the peerage (from Russell and Hollingsworth). Assuming a stable population, Lee was able to derive estimates of the crude birthrate and death rate from the growth of population over time. The basic equations of the model—real wages as a function of population size, and crude birthrate and death rate as functions of the real wage rate—were estimated for the period 1250–1700 using both ordinary least squares and two-stage least squares, assuming mortality to be exogenous.[2] Indeed, the simple correlation between mortality and the real wage turns out to be positive in this period, a result that can be attributed almost entirely to the simultaneity of the system Lee considers. It is also possible to estimate many of the basic parameters of the system without using the wage data at all, or without using the population or fertility data but only the crude death rates related to the life-expectancy data, by exploiting the overidentification of Lee's system. These estimates provide tests of the overidentification of the system and its consistency with the data, unreliable as these may be.

On the basis of his 1973 analysis, Lee concluded that "long-run changes in the real wage are adequately accounted for by changes in population size" and that "there were no dramatic shifts in the demand for labor over this period. . . . The relationship between population and the real wage was stable until the beginning of the eighteenth century, at which time it began to change markedly. . . . The great swings in population during this period were due to swings in mortality." These latter were largely exogenous according to Lee (1973, pp. 604–5). Lee found a "highly variable equilibrium wage in conjunction with a relatively constant demand for labor" (1973, p. 606).

It is worth stressing two aspects of Lee's earlier paper in conjunction with the one presented at this conference. First, "The end point, 1700 [of the period analyzed], was chosen because the relation between wages and population size began to shift unmistakably after this, and because the mortality of the aristocracy, from which we have derived our estimates, was no longer representative of that of the general population" (Lee 1973, p. 583). Second, the interpretation of the wage-population relationship, in terms of a one-sector model with a Cobb-Douglas production function, is a key element in assessing the adequacy of this central relationship of the economic-demographic model. Lee's difficulties in this connection have led to an extensive investigation, in the present paper, of a two-sector model with a CES production function for agriculture and fixed-coefficients technology for the nonagricultural sector. This two-sector model was discussed in detail at the conference in an appendix to these comments. That material, however, has been largely incorporated in Lee's Appendix 2 and is therefore omitted here.

The paper under discussion contains four important innovations:

1. Lee utilizes greatly superior population data derived from the sample of 404 parish registers collected by the Cambridge Group for the History of Population and Social Structure, spanning the period 1538–1840. For some analyses Lee has used decadal averages, for others the annual data themselves, and the latter are clearly essential to the cross-spectral statistical analyses he carries out in section 9.3.2.

2. This paper focuses on a later period, 1530–1800 (sometimes 1839) for which the clearly superior data are available. Use of better data is certainly desirable, but, especially in view of Lee's earlier cautionary statement concerning the noncomparability of the period after 1700 with the period before, combining data for the period after industrialization had clearly gotten under way with prior data may raise some serious questions about the stability of the relationships estimated. To some degree Lee tries to handle this problem in his regression (eq. 3), but he succeeds only in capturing an acceleration of the trend in real wages after 1809 and does not detect a significant shift in the two subperiods 1639–1745 and 1746–1839. However, this analysis should be reworked using real wage data more appropriate to the two-sector model (deflating money wages by agricultural prices alone rather than an index of both agricultural and industrial prices). The regression result reported in equation 20 uses data from 1540 only to 1800 and omits a variable designed to detect acceleration of the trend in the demand for labor after the Napoleonic wars and is thus not so directly comparable.

Using the older set of data, Lee reports a significant shift of the wage-population relation between 1250–1700 and 1705–89 in the form of a fivefold increase in the rate of exponential trend.

3. A central, and most attractive, feature of the present paper is its attempt to interpret the real wage-population relation within the framework of a two-sector model that assumes CES technology in the agricultural sector and fixed coefficients in the nonagricultural sector. Despite several limitations, this new model allows a much richer set of tests for consistency of the relationship between real wages and population important in Lee's later analysis of economic-demographic interactions. The two-sector model and its implications are described in detail in Appendix 2 to Lee's paper.

Major limitations in the model and its estimation, of which Lee is aware, include: (*a*) The fact that under CES technology, in either a two-sector or a one-sector model, the elasticity of the real wage with respect to the labor force is not constant and should not be treated as such in estimating the relationship between real wages and population. (*b*) The assumption that net agricultural production is a constant proportion of total output valued at market prices is surely a poor one during a period that encompasses the beginning of rapid industrialization. Moreover, two-sector model results tend to be quite sensitive to assumptions on the demand side. (*c*) The inverse projection method used to estimate labor force from population size by taking age structure into account may not be entirely adequate when using data for relatively short periods during which fertility and mortality may be changing rapidly. (*d*) Finally, the use of OLS instead of simultaneous-equations estimation procedures in a model in which population or labor force or both is, potentially at least, endogenous is inappropriate. This treatment contrasts with Lee's 1973 paper, in which both OLS and two-state least-squares procedures were used in some of the estimations. Lee, however, does go to some lengths in section 9.3 to show that population may be treated exogenously and that it varied largely in response to variations in mortality, which was not itself affected by the real wage.

4. The discussion in section 9.3 of the interrelations among fluctuations in mortality, marital fertility, nuptiality, and real wages represents an important modification and amplification of Lee's earlier work, although much of this material has been developed in subsequent papers presented at MSSB conferences or published elsewhere. All of this work relies heavily on cross-spectral analysis, which Lee argues has to be used because "for compelling reasons, the theoretical analysis had to be carried out in spectral terms." I would be the last person to argue against use of frequency domain techniques in appropriate circumstances, but I have yet to see a distributed lag relationship that could not be more easily interpreted in the time than in the frequency domain. Moreover, cross-spectral estimates, especially of phase, are notoriously difficult to interpret when the coherence between the two series analyzed is highly variable and frequently low. In addition, it is not at all clear to me that Lee's general finding that marital fertility and nuptiality were related to real wages and the population size and age structure only at high frequencies (1/15 cycle/year and higher) is evidence that such relations are not important for the wage population and other relations that Lee fits in section 9.2 and interprets further in section 9.3.3. In the first place, Lee has not used ten-year averages throughout, although he might argue that use of such averages constitutes a low frequency band-pass filter that allows him to look only at movements unaffected by the feedback between real wages and population size and structure. In the sec-

ond place, even if he had used such averages, they do not constitute an appropriate filter, and substantial "contamination" of his estimates is likely to occur. And finally, as Lee recognizes, low and high frequencies do not represent appropriately the economist's intuitive distinction between long- and short-run movements and relations, nor is filtering by band-pass filters a good way to get at the dynamic lag structure that must surely lie at the heart of a useful formulation of the nexus of economic-demographic interactions.

Lee concludes his paper with the comment that, "For the economy of preindustrial England . . . population emerges clearly as the dominant source of long-run changes in wages, rents, industrial prices, and income distribution," whereas, "For today's LDCs there is little convincing empirical evidence of the economic effects of population change." From what I have heard at this conference and read elsewhere, I would say, quite to the contrary, there is plenty of empirical evidence that population change and economic growth and development are intimately related—only lots of it is conflicting! Perhaps what Lee means to say, and I would heartily agree, is that we have a long way to go before we really understand these connections for today's LDCs. I add that, despite Lee's pioneering work, we also have some distance to go in understanding the nexus for preindustrial and industrializing England.

Notes

1. Lee (1973). The dissertation, *Econometric Studies of Topics in Demographic History* (Harvard University) has been published as Lee (1978*b*).
2. There is a great deal of discussion in Lee's paper about the possibility that mortality is not exogenous and that that of the peerage may not reflect mortality in the population at large. Obviously it is not possible to do justice to Lee's lengthy and complex discussion in this brief summary.

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