Interdependency between fertility and real wages in England, 1541-1871

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Section I

Wrigley and Schofield, in their *The Population History of England: 1541-1871*, find long swings in population growth rates and in real wages.[1] They argue these cycles are due mainly to fertility-real wage interdependency. Upon completing the monumental task of assembling and testing the basic series, they outline an intuitively plausible and provocative conceptual structure through which one can understand this complex system. They then face the issue of how far to carry specification of structural relationships which will provide a specific interpretation of their conceptual approach. In Schofield's words,[2]

> in the final chapter of *Population History* we sought a middle ground, sketching out a conceptual structure in which the interacting dynamics of demographic and economic change could be discussed with due regard to their historical context. We resisted the temptation to carry abstraction a stage further and express the structure in a series of equations, the coefficients between which would indicate the strengths of the relationships between the demographic and economic variables.

Important work has followed from their book, but further

[1] Wrigley and Schofield, *The Population*.
[2] Schofield, "Through a glass", p. 590.

development of their conceptual approach will be limited until there exists an estimated structural model which reflects their approach and which contributes to our ability to understand the forces driving the interrelated cycles they find.[3] We contribute to these investigations by proposing a structural model which explores dynamic interdependence between vital rates and real income. One distinctive feature of this structure is its incorporation of immediate links between vital rates and real income as well as intergenerational links between these same factors. The structure is then estimated using Wrigley and Schofield's English demographic data and Phelps Brown and Hopkins real wage data. These relations are explicitly based upon prior information which includes Malthus's writings, historical studies, and other obvious biological and cultural constraints.[4]

These structural equations illustrate a conceptual framework within which issues raised in several recent studies can be discussed. These studies include Olney's in which, using statistical search techniques, she examines Wrigley and Schofield's cycles. She finds the dominant fertility lag to be between 15 and 35 years rather than the 40 to 60 years cited by Wrigley and Schofield. Because her study does not utilize specific structural relations, she concludes there remains "the task of determining how this link between economic conditions and fertility manifested itself in pre-industrial English society."[5]

Goldstone and Weir find that until the 1700s birth rates were most closely controlled by the proportion of the population marrying.[6] Goldstone contends that by 1700 social conditions changed such that the age at first marriage came to most affect the birth rate. This suggests that the duration and amplitude of such cycles as occurred were sensitive to England's social and economic milieu.

Lindert challenges aspects of Wrigley and Schofield's basic data

[3] Other conceptual approaches, of course, can be advanced.

[4] The model used here is based upon, among others, Costabile and Rowthorn, "Malthus's theory", Eagly, *The structure*, Eltis, *The Classical*, Lee and Loschky, "Malthusian"; Malthus, *An essay* and Malthus, *Principles*.

[5] Olney, "Fertility", p. 77.

[6] Goldstone, "The demographic" and Weir, "Rather never".

and explores economic-demographic interrelationships through estimating several single-equation models.[7] He finds little support for either the population's impact upon real income or real income's impact upon population growth. He then sets the determinants of population growth rates aside and, focusing upon the determinants of real income, explores various monetary arguments which could support Malthus's contention that population increase leads to changes in relative prices.

Lee's extensive studies use both single and simultaneous equation models and include exploratory investigations of short-run interactions in Wrigley and Schofield.[8] Lee's general conclusions can be summarized by the contention that *over the very long-run* population levels certainly are limited by a society's resources, i.e., *the population's vital rates are interdependent with income levels*. On the other hand, his position is that the long swings found by Wrigley and Schofield were driven by exogenous changes in vital rates. In other words, contrary to the assertions of Wrigley and Schofield, there is no mutual, dynamic interdependency between population growth, real incomes and vital rates which can explain these long swings. He argues that reconciling these findings is a major task facing economic historians.

Stavins' work expands upon Lee's concern with the form which any explanation for England's demographic history must take. He constructs and estimates simultaneous equation models using 25-year averages of the relevant data series to determine whether an explanation tying fertility to real income can explain any part of English history from the late 1500s through the late 1800s.[9] He argues that the models reveal a fertility-real income interaction during the industrial revolution and beyond. His work also is distinguished by its inclusion of a variable designed to measure the rate of technical change.

The structural approach followed here utilizes links between

[7] Lindert, "English living standards" and "English population".

[8] Lee, "Population in pre-industrial", "Models", *Econometric Studies*, "A Historical" and "Population homeostasis". Lee's investigations of short-run interactions appears as chapter nine in Wrigley and Schofield, *The Population*.

[9] Stavins, "A model".

real income and population growth rates as suggested by Olney. It contains terms intended to capture the changing social conditions emphasized by Goldstone and Weir. The model fleshes out dynamic interdependencies between economic and demographic factors not employed by Lindert. The structural relationships include important immediate and intergenerational links between fertility and real incomes not used by Stavins or by Lee which may be useful in reconciling Lee's short-run and long-run findings. Lastly, the equations are estimated using systems methods in contrast to the single equation methods employed hitherto.[10]

Estimated coefficients are statistically significant. The model, therefore, provides *one* indication of "the strengths of the relationships between the demographic and economic variables" discussed by Wrigley and Schofield. When outside events perturb the system, interdependent cycles in both real income and vital rates follow. These characteristics suggest the conceptual approach, of which these equations are one exemplification, provides a framework within which the cyclical consequences of economic and demographic interdependencies can be examined and within which exploratory investigations of England's economic-demographic interactions can be conducted.

We proceed as follows: Section II sketches out theoretical considerations relevant to economic-demographic interactions drawn from prior information which includes Malthus's writings. Structural relationships flowing from this theory are laid out in Section III. Lags within the model are established using historical works on English economic and social history. Data and estimates are described in Section IV. Section V examines interrelatedness between variables, establishes the existence of real income-fertility cycles, discusses factors which affect cycle length, explores the change in fertility regulation noted by Goldstone and Weir and concludes with an illustrative simulation exercise. Section VI concludes our work.

[10] When interdependencies exist in a set of equations, accurate estimates of the set's coefficients can only be obtained using systems methods. Single equations methods may lead one to believe no relationship exists between terms when in fact interdependency does exist. The two - stage least - squares method used by Stavins and sometimes used by Lee is a single equation method.

Section II

Wrigley and Schofield base their conceptual approach upon Malthus's works and we follow their usage here. This Malthusian model connects economic and demographic factors as suggested by Olney and it extends the fertility-real-wage interaction identified by Stavins backward in time. Its intergenerational links connect short -run conditions to long- term consequences. How does Malthus envision such an integrated economic-demographic system?

Malthus's theory of the preventive check assumes most births occur within established marital unions. Since this makes the marriage rate an important determinant of fertility, he must have a theory explaining changes in marriage rates. He argues marriage takes place within social institutions which differ between cultures and over time within the same culture. *Granting these institutions' existence and influence.* Malthus uses differences between subsistence and real incomes to explain changes in marriage rates. He argues individuals have in mind a desired life style which they seek to maintain; in Malthus' usage this is the subsistence income. When deciding whether or not to marry at some particular time, individuals evaluate the impact which their expected family size will have upon their desired life styles given their expected income flows. When marriage means one's real income will be low relative to one's subsistence income, marriage either will be delayed and years of potential reproduction will be lost or celibacy will be chosen over marriage as a way of life. His discussion of the preventive check in England clearly states his views.[11]

> The most cursory view of society in this country must convince us that throughout all ranks the preventive check to population prevails in a considerable degree... A man of liberal education, with an income only just sufficient to enable him to associate in the rank of gentlemen, must feel absolutely certain that if he marry, and have a family, he shall be obliged to give up all his former connections... These considerations certainly

[11] Malthus, *An Essay*, pp. 193-4.

> prevent many in this rank of life from following the bent of their inclinations in an early attachment.... The sons of tradesmen and farmers are exhorted not to marry, and generally find it necessary to comply with this advice, till they are settled in some business or farm which may enable them to support a family. These events may not perhaps occur till they are far advanced in life...The servants who live in the families of the rich...deterred by this uninviting view of their future situation, content themselves with remaining single where they are...If this sketch of the state of society in England be near the truth, it will be allowed that the preventive check to population operates with considerable force throughout all the classes of the community.

Factors other than differences between the subsistence income and expected income also influence marriage rates. For the institutions within which marriage occurs change, and when they do so does the preventive check. Speaking of Europe's future Malthus asserts "much would be done if merely the institutions which directly encourage marriage were gradually changed and we ceased to circulate opinions and inculcate doctrines which positively counteract the lessons of nature. [These lessons relate to the impact of early marriage upon life styles.]"[12] Malthus, therefore, contends the marriage rate is influenced both by real incomes as well as other factors including the social institutions within which marriage occurs.

Marriage rates, as well as other crude rates, also depend upon a society's age-sex structure. Marriages certainly are limited by the number of marriageable people. Consequently, the marriage rate must respond to past birth rates for those rates help determine age structure. And which past birth rate is most significant will depend in turn upon the age at which men and women first marry. This, of course, brings us back to Malthus's institutions and beliefs and the historical matrix within which they are manifested.

[12] Malthus, *An Essay*, pp. 477-78.

Birth rates are determined by marriage rates and real incomes. Death rates also are determined in part by real incomes. Furthermore, Malthus discusses the consequences of advances in medical technology, the introduction of the cowpox vaccine for instance, and the consequences that urbanization with its crowding has upon death rates, particularly for the poor.

Malthus contends incomes are determined by the demand for and supply of labour. In wealthy old states, such as he believed England to be, the demand for labour shifts outward when population grows (of course, when these individuals enter the labour force the labour supply shifts outward and wages are depressed). The demand for labour also is related to the accumulation of capital, the point upon which Costabile and Rowthorn build much of their analysis,[13] and this can be especially important in wealthy old states. Lastly, technical change also increases the demand for labour. Change in the labour supply depends upon change in the labour force.

Labour-force changes occur when individuals enter the adult labour force and when workers die. The rate at which individuals enter the labour force depends in part upon past birth rates. Malthus uses this fact to support his argument that cycles in real wages occur in response to changes in birth rates.[14]

These constitute the Malthusian and the age-structure arguments we incorporate within our structural relations. The model which we form from this information appears in our next section.

Section III

Wrigley and Schofield's study spanned the more than three centuries within which England moved from subsistence farming to industrial maturity. They articulate a conceptual approach capable, in principle, of explaining events during these diverse times. Recognizing that the specific links between population and the economy changed during this dynamic period, they present several models all falling within the purview of their general conceptual approach each of which is designed to fit specific changes in the

[13] Costabile and Rowthorn, "Malthus's theory".

[14] Malthus, *An essay*, pp. 11-2

structural relationships lying behind the data.[15] This amounts to specifying several sets of equations, each set identifying a specific structure. We seek to deal with this issue of structural change by including within a single set of equations variables meant to capture the impact of change in the structural relations (the change from fertility control through celibacy to control through age at first marriage cited by Goldstone and Weir is an instance of a change in the structural relations). The equations constituting this structural approach follow.

Listed below are the variables that appear in our structural model.

TP_t Total population in period t.

TP_{t-1} Total population lagged one period.

MR_t Marriage rate: marriages in period t as a percentage of total population in period t-1.[16]

MR_{t-1} Marriage rate in period t-l

BR_t Birth rate: total births in period t as a percentage of total population in period t-1.

BR_{t-19} Birth rate lagged 19 years.

BR_{t-26} Birth rate lagged 26 years.

DR_t Death rate: total deaths in period t as a percentage of total population in period t-1.

DR_{t-1} Death rate lagged one period.

PGR_t Population growth: $1/100 (BR_t - DRt)$

LF_t Labour force in period t.

[15] In chapter 11, *The Population*, Wrigley and Schofield present one model which applies to the XVIth Century, one which applies to the XVIIth century, one for the early XIXth century and one for England toward the end of the XIXth century. We noted above Goldstone's "The demographic" and Weir's "Rather never" contentions that the marriage determinants changed sometime after the start of the XVIIth century. Such a change in determinants does not mean abandonment of the overall conceptual approach but it does mean that the specific determinants of the marriage rate are deemed to have changed.

[16] In the case of this and other rates, we utilize rates per hundred - percentages - rather than the more familiar rates per thousand. When interpreting the estimated coefficients, ***this must be kept in mind.*** To translate the coefficients into those we would find given the usual demographic definitions of births per thousand, multiply each coefficient for a vital rate by ten.

M_t Net migration in period t.

RW_t Real wage in period t.

RW_{t-1} Real wage lagged one period.

GP_t Grain prices in period t.

UR_t The percentage of the population living in urban areas in period t.

D_{cw} A variable that takes a value of one for the period 1641-1670 and zero otherwise.

D_{nw} A variable that takes the value of one for the period 1789-1825 and zero otherwise.

D_1 A variable that takes the value of one for the period 1671-1788 and zero otherwise.

D_2 A variable that takes the value of one for the period 1826-1871 and zero otherwise.

When discussing theoretical issues, we used the term "real income" because this is the concept which both Wrigley and Schofield and Malthus have in mind. Our data, however, are limited to the real-wage series developed by Phelps Brown and Hopkins.[17] We use these data as did Wrigley and Schofield and Lee.[18] Consequently, we hereafter speak in terms of the real wage.

Five structural equations and one definitional equation constitute our model. Our definitional equation is:

$$TP_t = TP_{t-1} + (PGR_t)TP_{t-1} + M_t \qquad (1)$$

We do not consider M_t, net migration, further.

In accordance with the above discussion, marriage rates are determined by real wages, past birth rates and social institutions. Several studies have used wheat prices in their analysis and we

[17] Phelps Brown and Hopkins, *A Perspective*. Malthus argued in terms of real income. Because real income figures are not available for the entire period we must use real wage data.

[18] Wrigley and Schofield, *The Population*. They make some modifications in the Phelps Brown and Hopkins index (see their appendix 9, *A Perspective*, pp. 638-44) to eliminate the wage plateaus Phelps Brown and Hopkins built into their data. We continue to use the original Phelps Brown and Hopkins series without trying to eliminate the wage plateaus. We do, however, make other modifications mentioned later in footnote 30.

follow this practice. From the perspective of Easterlin's analysis, real-wage increases shift the demand for children outward while increased wheat prices, by increasing the cost of raising children, increase the relative price of children and hence would shift the supply of children backward.[19] This formulation is consistent with Malthus's interpretation. Consequently, real wages should be positively related to the marriage rate while grain prices should be negatively related to the marriage rate.

Today's marriage rate also depends upon past birth rates. Which lag is appropriate for the birth rate in this structure depends upon the age at which English women first married. During the most of the seventeenth and eighteenth centuries women first married between 23 and 28 with the difference largely a matter of social class.[20] Because the proportions in each social class differed between parishes and over time, one cannot identify an exact national age at first marriage without additional information on the distribution of social classes and information on how this distribution changed over time. We can press prior information this far and no further. We chose to search within the limits 23-28 to determine the best fit which we found to be 26 years.[21] This lag is used.

[19] "The demand for children...depends on household tastes (including tastes relating to child 'quality'), income, and child cost considerations, including both the economic and noneconomic returns from children as well as their costs." Easterlin and Crimmins, *The Fertility*, p. 14. See also Easterlin, Pollak, and Wachter, "Toward", and Easterlin, "Economic perceptions".

[20] Loschky and Krier, "Income" shows the importance of social class.

[21] In fact not all women marry for the first time at the same age. This means the pool of women who become married for the first time in any year is drawn from those born over a spread of years. However, the inclusion of additional lagged birth rate variables does not increase significantly the conceptual structures explanatory power. For *exactly* the same reasons additional lagged marriage rates were not used in our birth rate equation and additional lagged birth rates were not used in the real wage equation. All other lags are justified solely on the grounds drawn from historical materials.

Nevertheless, we explored the significance of different lags and found that coefficients for lags both longer and shorter than 26 years dropped in both their value and in their levels of statistical significance. Were we interested in how much of the change in interdependent variables we could explain, we would include these lags within our model. But our purpose is to develop and explore a set of structural equations which express in their essence the conceptual structure adumbrated by Wrigley and Schofield. For this reason we do not employ elaborate distributed lags within this model.

It is clear that nuptuality also is strongly influenced by a country's social institutions. And many authors, for example Easterlin and Caldwell, stress the impact modernization and industrialization have upon these social institutions.[22] Furthermore, Goldstone and Weir argue that before the XVIIIth century the birth rate was controlled by the rate of celibacy and that during that century changes in the age at first marriage became the important social control. These are the kinds of events which Wrigley and Schofield include within their analysis by specifying several different models. Furthermore, the Civil War period with its civil registration had such a serious impact upon church registration that Wrigley and Schofield made major adjustments to the basic data. And in addition to these data problems associated with wartime, there was social disruption both in this period as well as in the Napoleonic era. We include dummy variables intended to capture these changes in the system's underlying structural relationships as well as to isolate the effect of both war periods. We include the variable D_{cw} (1641-70) to account for registration issues and other lingering effects of the Civil War and D_{nw} (1789-25) to allow for the Napoleonic period. We account for changing social institutions such as the relative importance of celibacy versus age at first marriage with the variables D_1 dated 1671-1789 and D_2 dated 1825-71. This dating gives us three different non-wartime structures. The first, 1541-1640, could be linked to Wrigley and Schofield's "England in the late sixteenth century." The second, 1671-1789, collapses Wrigley and Schofield's second and third models into one. Our last non-wartime model, 1826-71, corresponds roughly to Wrigley and Schofield's last model. These considerations give us

$$MR_t = f(BR_{t-26}, RW_t, GP_t, D_{cw}, D_{nw}, D_1 \text{ and } D_2) \qquad (2)$$

Birth rates largely depend upon the marriage rate and real wages. While some marriages took place after conception occurred, most did not. Since gestation normally takes nine months, we lag the marriage rate one year. For the same reason, we

[22] Easterlin, Pollack and Wachter, "Toward", Easterlin and Crimmins, *The Fertility* and Easterlin, "Economic preconceptions". See also Caldwell.

lag real wages one year. We also include a shift variable meant to capture social disturbances caused by and felt during the Napoleonic Wars and their immediate aftermath.

$$BR_t = f(MR_{t-1}, RW_{t-1}, D_{nw}) \qquad (3)$$

Death rates are determined by real wages, urbanization and health related improvements. Urbanization is important because urban death rates were well above rural rates.[23] Furthermore, McKeown's studies indicate substantial XIXth century health improvements.[24] We include a shift variable meant to capture these health improvements. These considerations give us a death rate equation.

$$DR_t = f(RW_t, UR_t, D_2) \qquad (4)$$

Malthus held real wages are determined by the demand for and supply of labour. Within wealthy old states, shifts in the demand for labour are derived from the demand for products which in turn depends upon population growth. According to Malthus, demand also is affected by capital accumulation, which determines the funds for the maintenance of labourers, and by technical change.[25] There are no series which chronicle the accumulation of capital or the rate of technical change but both factors are related to the shift of labour out of agriculture and into the towns. We seek to capture these important demand determinants using the degree to which England was urbanized. No account of English real wages would be complete without allowing for the truly tremendous impact exerted by the industrial revolution, an event associated with profound changes in the structure of the English economy and in the determinants of real wages. While there is considerable doubt concerning whether real wages rose or fell in industrialization's first years, particularly because of the disturbing effects felt from the

[23] An analysis using rural and urban rates reveals urbanization's impact upon English mortality change. See Loschky, "Urbanization".

[24] McKeown, *The Modern*.

[25] See Costabile and Rowthorn, "Malthus's" and Eltis, *The Classical*.

Napoleonic Era, there is no question but that they rose by the 1820s or 1830s. We include a shift variable, D_{nw}, to allow for the effect exerted by the Napoleonic Era and a shift variable, D_2, to allow for the consequence of the mature industrial revolution after the Napoleonic War's impact.[26] The supply of labour is determined by the labour force. These considerations give us

$$RW_t = f[(BR_t - DR_t), LF_t, UR_t, D_{nw}, D_2] \quad (5)$$

Lastly, labour-force size changes largely result from entrants who reach working age and from departures due to death. The lag between birth and entry into the labour force helps account for the cycles that Malthus sees as inherent in any population's history. But which lagged birth rate is appropriate? Kussmaul's study argues that adolescents worked as servants in husbandry but settled into the adult labour force in their late teens or early twenties and at that point began to earn adult wages.[27] A limited specification search within the range of 17 to 25 years led us to a lag of 19 years.

$$LF_t = f(BR_{t-19}, DR_{t-1}) \quad (6)$$

These equations bring out major economic-demographic links emphasized in Malthus, Wrigley and Schofield, and other writings.

Section IV

Wrigley and Schofield provide us with the necessary crude birth, death, and marriage rates.

Wage data come from Phelps Brown and Hopkins.[28] Their index has been criticized and, given these comments, we recompute as nearly a true Laspeyres index as is possible given their original data.[29] We utilize Phelps Brown and Hopkins farinaceous foods price index rather than wheat prices as has been done by some.[30] Urbanization

[26] We include this variable to allow for the issues concerning technical change brought out by Stavins, "A model".

[27] Kussmaul, *Servants*.

[28] Brown and Hopkins, *A Perspective*.

[29] The index can be had upon request.

[30] For instance, Lee's work in Wrigley and Schofield "Short-term" used only wheat prices. On the other hand, Lindert "English" uses both wheat prices and a measure for real per head income.

figures are extrapolated from de Vries's materials.[31]

We utilize the log-linear form. Three - stage least - squares methods are used to correct for contemporaneous correlation in error terms between equations.[32] First-order autocorrelation is removed, prior to obtaining three-stage least squares estimates, using a procedure described by Pindyck and Rubinfeld that "combines two-stage least squares with a first-order serial-correlation correction".[33] Annual data are used. Wrigley and Schofield suggest the elasticity of birth rate response to real wage variation changed over time and we allow for this in our estimates of equation 3E.

Table I

The Estimated Model*

$$MR_t = \underset{}{-0.07989} + \underset{(2.66)}{0.04685}BR_{t-26} + \underset{(5.18)}{0.23279}\ln RW_t - \underset{(8.56)}{0.15597}\ln GP_t$$
$$\underset{(3.65)}{-0.04800}D_{cw} - \underset{(4.15)}{0.04520}D_1 - \underset{(4.52)}{0.06286}D_{nw} - \underset{(6.21)}{0.10752}D_2 \qquad (2E)$$

$$BR_t = \underset{(3.84)}{0.85895} + \underset{(5.88)}{0.72689}MR_{t-1} + \underset{(2.40)}{0.26485}\ln RW_{t-1} + \underset{(1.95)}{0.76530}D_{nw} \qquad (3E)$$
$$+ \underset{(1.34)}{0.20979}\ln RW_{t-1}\,(D_{cw})$$
$$+ \underset{(2.70)}{0.27435}\ln RW_{t-1}\,(D_1)$$
$$+ \underset{(0.40)}{0.08829}\ln RW_{t-1}\,(D_{nw})$$
$$+ \underset{(3.16)}{0.29573}\ln RW_{t-1}\,(D_2)$$

$$DR_t = \underset{(8.78)}{2.55706} - \underset{(4.16)}{0.77036}\ln RW_t + \underset{(5.20)}{0.04026}UR_t - \underset{(4.85)}{0.33490}D_2 \qquad (4E)$$

[31] de Vries *European* provides us with estimates for the urban population of England and Wales from 1500 to 1800. We obtain the percentage of England's population which was urban by dividing de Vries urban populations by Wrigley and Schofield's total population figures for England and Wales. To extend our urbanization figures to 1871 we employ the urbanization data given by Mitchell *Abstract* (pp. 94-5) which we adjust to fit de Vries data in 1800. Mitchell has 17.6% of the population (we use Wrigley and Schofield's total population figures) living in urban areas England and Wales in 1800 whereas de Vries has 21.6% urbanized in 1800. We adjust Mitchell's figures for 1850-1, 1860-1 and 1870-1 upward to accord with de Vries and then we utilize linear interpolation between these decadal figures to obtain yearly estimates.

[32] In three stage least squares, each variable becomes an instrument.

[33] Pindyck and Rubinfeld, *Econometric Methods*, pp. 456-8.

$$\ln RW_t = 3.24921 + 0.37852(BR_t - DR_t) - 0.21172\ln LF_t + 0.03887UR_t$$
$$(4.14) \quad (12.28) \quad (2.27) \quad (6.77)$$
$$- 0.08036D_a - 0.04786D_2 \quad (5E)$$
$$(3.61) \quad (1.28)$$

$$\ln LF = -0.02953 + 0.48811BR_{t-19} - 0.68925DR_{t-1} \quad (6E)$$
$$(0.22) \quad (7.53) \quad (13.41)$$

* t-ratios are in parentheses.

Estimated coefficients in equation (2E) support this Malthusian account of the marriage process. The birth rate lagged 26 years influences marriages, as do real wages and grain prices. The estimates indicate structural change in the marriage equation occurred over this period. All dummy variables differ from our base period, 1541-1640. These shifts appear stable between 1641-1789 and increase thereafter. The coefficient for 1826-71 indicates a greater change than for any prior period. These coefficients are consistent with Goldstone's and Weir's argument that the determinants of the marriage rate changed and particularly so by the late XVIIIth century. Equation (3E) shows that births respond to the lagged marriage rate. The estimates also support Wrigley and Schofield's arguments that structural change in the relationship between the birth rate and real wages occurred.

Death rates (4E) are negatively related to real wages. Urbanization has a positive impact upon death rates. The coefficient of D2, used to identify XIXth century improvements in health studied by McKeown, has a negative sign and is statistically significant.

Estimated coefficients for population growth, the labour force and urbanization in equation (5E) have the expected signs and are statistically significant. A growing English population shifts labour *demand* outward. Increases in the labour force depress wages. Urbanization increases wages. The Napoleonic Era saw relatively depressed real wages, perhaps because money-wage changes lag product-price changes.

Past births shift the labour supply (6E) outward and the death rate is negatively related to labour supply. The statistical significance of both coefficients is high.

Section V

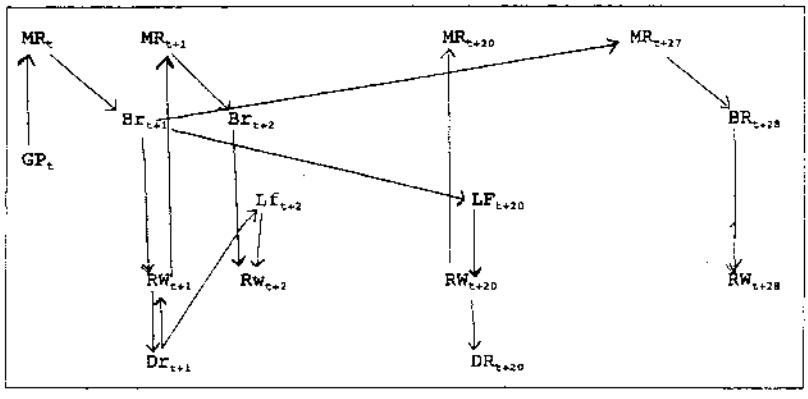
This estimated model captures interdependencies between economic and demographic variables; change in any variable has direct effects upon selected other variables and indirect effects are communicated throughout the entire system. To illustrate this view, we assume an autonomous decrease in grain prices and utilize the flow diagram in Figure I below.

Figure I

Direct and Indirect Effects

Immediate Effects *Intergenerational Effects*

year t year t+1 year t+2 *year t+20 year t+27 year t+28*



Decreased grain prices in year t immediately increase marriages. Increased marriages in year t increase birth rates in year t+1 which, in turn, shift the demand for labour in t+1 and, hence, the real wage in t+1. These births, however, will not affect the labour force for some years. Increased real wages in year t+1 lead to an increase in marriages in t+1 which then further increase births in year t+2 and these increased births affect the demand for labour and, hence, real wages in t+2. Increased real wages in year t+1 also reduce deaths in t+1 and this reduction in deaths influences the labour force in year t+2 which affects real wages in t+2. Real wages, therefore, rise or fall depending upon the impact of the various indirect effects transmitted to them.

Figure 1 and this discussion shows the decreased grain prices

in year t have led to interactions between all endogenous variables by year t+2. In addition to these relatively immediate interactions, the biological and cultural constraints also entail long lags.

In year t+20 labour supply shifts outward because of year t+1's increased birth rate. The resultant real-wage change will affect deaths and marriages in year t+20 and births, the labour force and real wages in year t+21. All endogenous variables again will have been influenced.

Similarly, in year t+27 marriages are affected by birth-rate changes in period t+1 and births in year t+28 feel the impact of birth-rate changes over a quarter century earlier. Year t+28's rise in births immediately affects real wages and through this link, all other vital rates. Because of its intergenerational links, the structure, *with its clearly defined short-run interactions*, produces responses far into the future. This suggests the structure may exhibit recurring cycles similar to those uncovered by Wrigley and Schofield.

To explore this point, we simulate the response of real wages and birth rates to changes in our exogenous variables which are grain prices and urbanization.[34] Actual and simulated birth rates are shown in Figure II and actual and simulated real wages are shown in Figure III below.

Figures II and III show that the system responds to changes in grain prices and urbanization with cycles in both real wages and fertility. The long cycles found by Wrigley and Schofield appear in the birth rate and real wages. Of course, events other than grain-price changes and increasing urbanization strongly affected both birth rates and real wages, but the point we make here is that these cycles are produced within this system of structural relations and the fit between observed and actual series is close enough to suggest that further work with this expression of Wrigley and Schofield's conceptual structure is warranted.

The results discussed thus far raise an important issue. Can these structural relations be used to probe English history to further our understanding of the dynamics of English population growth? We believe this model provides a working framework within which this

[34] Further developments of this model may lead to the incorporation of the urbanization data as an interdependent variable rather than treating it as exogenous which we do here.

goal can be realized. We illustrate these remarks with the following discussion which focuses upon the impact various events will have upon cycles in both fertility and real wages. We break the discussion into two parts; the first focuses upon events which do not change the structural relations, and the second focuses upon events which do change the structural relations. This second corresponds to Wrigley and Schofield's discussion of various models.

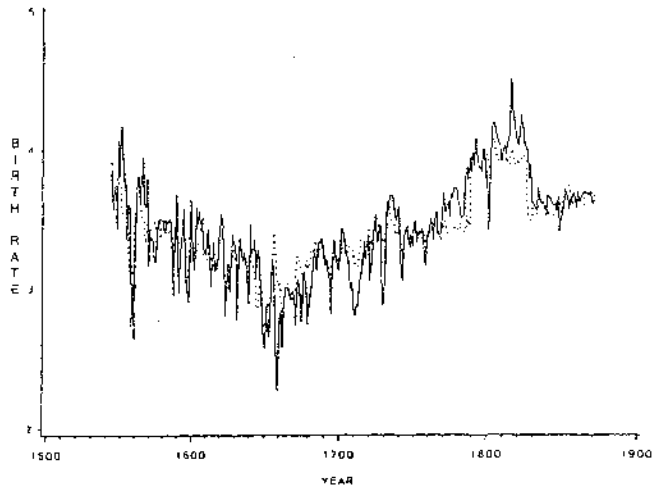
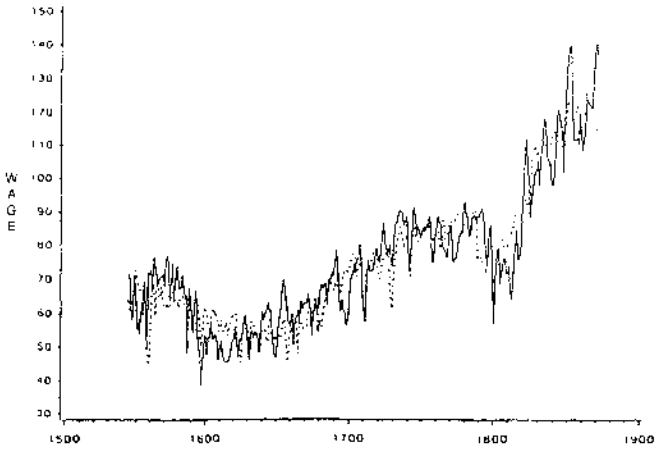


Figure 2 : Actual And Predicted Laspeyres Wage



Within a given structure:

Lee has argued that unless we develop a system within which self-generating cycles occur, we cannot explain Wrigley and Schofield's long swings.[35] The model developed here will embody cycle if there are autonomous changes in grain prices caused, for instance, by variations in the weather. We can, therefore, explore the ability various exogenous events have to produce the cycles which characterize English demographic growth.

Cycle amplitude clearly is affected by the *magnitude* of changes in vital rates or real wages, changes which could be due to such autonomous factors as weather, temperature or exogenous shifts in the demand for labour. The framework, therefore, can be used to explore the consequences of various events for cycle amplitude.

Cycle amplitude *and period* depend upon whether population growth is controlled largely by the preventive or the positive check. This is a point implicit in Malthus and discussed by Wrigley and Schofield. We see, when discussing the flow diagram in Figure 1, birth-rate changes immediately affect the demand for labour while their impact upon supply lags by many years. Death-rate changes, on the other hand, affect both demand and supply at the same time. This suggests that population-real wage explanations must be able to distinguish between population change caused by variation in the death rate as opposed to population change caused by fluctuations in the birth rate. In turn this suggests the testable hypothesis that the real-wage reaction to population change will differ between the late 1600s, during which time England's population growth was restrained by rising death rates, and the late 1700s when population growth was fueled by a rising birth rate.

This discussion shows that *without introducing structural change* we can expect to find cycles and change in both cycle period and amplitude if for no other reason that variations in

[35] Lee's argument, to be found in "Population homeostasis", is that if the system must be driven by outside shocks, then one cannot explain Wrigley and Schofield's long swings as due to economic-demographic interaction. He contends that only a model capable of self-generated cycles can explain these facts in a manner consistent with Wrigley and Schofield's analysis. He asserts that "if the answer is that high wages favorably influenced the vital rates, then the whole explanation lacks a driving force...unless the system moves in self-generating cycles, a possibility which is not discussed in this article." p. 639.

weather. This means that cycles can be examined and their causes explained within structural relations such as these.

When the structure changes:

Cycle length depends in part upon the length of the lag between birth and entry into the labour force. The development of factories lowered the age at which the English began their working lives and this historical occurrence must have shortened cycle length. This means we can explore the impact this aspect of industrialization had upon English population growth. This point bears upon issues raised by Levine.[36]

Cycle length or period depends in part upon the lag between birth and marriage. Marriage ages were different for different social classes, for example, male labourers first married at younger ages and married younger women than did yeomen.[37] Consequently, changes in the nation's class structure brought about, for example, by a shift from rural to urban occupations would change the average age at first marriage and hence cycle period. This point bears upon issues raised by Chambers among others.[38] Furthermore, questions have arisen concerning the impact a parent's occupation or property rights in land as opposed to houses has upon the age at which the children marry.[39] Such issues can be assessed within this framework.

Goldstone and Weir argue the average age at first marriage began to change and to control the birth rate sometime in the XVIIIth century.[40] Hajnal argues that great changes in the age at first marriage occurred well before the 1800s.[41] Similar comments hold for changes in social structure of the sort envisioned by Caldwell.[42] Changes in the institutional background of this sort certainly also change cycle length. This framework can facilitate the investigations of these positions.

Structural change, such as change in the age at first marriage, can

[36] Levine, *Family*.
[37] Loschky and Krier, "Income".
[38] J. D. Chambers, "The vale", "Population change."
[39] Smith, *Land* and Wall, "Real".
[40] Goldstone "The demographic" and Weir "Rather never".
[41] Hajnal, "European".
[42] Caldwell, *Theory*.

arise because population increases, *independent of changes in agricultural productivity*, will lead to increased town size. This certainly will affect crude death rates in towns. We mention issues such as this are raised by studies such as Finley's.[43] Furthermore, rising death rates for infants and children will have an immediate affect upon the demand for labour and in this manner affect real wages. Furthermore, because death rates help determine the labour force, the supply of labour also will be affected. In this second way, real wages will respond to changes in population growth. Needless to say, if agricultural productivity is affected by increasing pressure upon limited land resources, further consequences for these population cycles can be envisioned. We can, therefore, not only explore the impact growth of such urban centres as London had upon national crude death rates, we can extend the discussion to real wage levels and the period and magnitude of cycles in real wages.

Another interesting point which should be noted is that changing lags *can* dampen or augment cycle amplitude. For example, we note that the age at first marriage and the age of entry into the labour force differed for most or all of the period 1541-1871. This fact means cycle amplitude was damped. On the other hand, when and if these lags correspond, as they may well in some historical periods, cycle amplitude will be increased. This means we can explore the impact changes in marriage patterns, such as those explored by Goldstone and Weir[44], had upon real wages and cycles in real wages. Another example of the fact that changes in the institutional environment can affect fertility can be found in our estimates of the elasticity of births with respect to the real wage. We find the impact of real wages was roughly consistent over time, with the exception of the Napoleonic Era. During this time the real wage coefficient fell dramatically and was not significantly different from zero. Furthermore, the coefficient of real wages in this period is significantly different from the others we estimate. These remarks are stronger than those we can make concerning the Civil War period but both periods display similarities. These findings suggest that war affects fertility by

[43] Finley, Roger, *Population and.*

[44] Goldstone, "The demographic" and Weir, "Rather"

making that decision less dependent upon real wages than is true in more settled times.

This discussion shows that changes in the institutional environment affect both cycle length and amplitude. Furthermore, the structure can develop self-generating cycles *so long as* the institutional environment within which the English operated is seen as part of the model and there is interaction between population growth and the institutional environment. This is a point made by Malthus and by Wrigley and Schofield. This approach, therefore, leads to sets of specific structural relations within which concern for historical changes in the cultural environment is incorporated and the impact of these and other factors can be explored.

This discussion bears upon an important point. Within this conceptual approach, a population's history is a mosaic within which *all events* combine to form an integrated whole. Any autonomous event such as a war or such as changes in weather or the international demand for the population's products, has an impact upon the system which becomes internalized leading to cycles in both vital rates and real wages or to changes in cycle length or amplitude. It follows, therefore, that an emphasis upon whether population cycles are due to exogenous or endogenous causes is not central to an understanding of English history since *external events become internalized.*

Section VI

A principal finding by Wrigley and Schofield are long cycles in fertility, population growth rates, and real wages. Their findings have been questioned. To further our understanding of fertility real-wage interdependency, we construct and estimate a structural model. Estimated coefficients show that considerable interdependency between all variables in the system existed in England. Because of this interdependency, disturbances in English society and in the economy led to cycles in vital rates as well as in real wages.

An important methodological point established by this study is the value of Wrigley and Schofield's conceptual structure, of Malthus's works and of other historical studies such as Goldstone's and Weir's, all of which provide prior information upon which to base structured econometric investigations into English population history.

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