The U.S. Demographic Transition

By JEREMY GREENWOOD AND ANANTH SESHADRI*

Picture the United States in 1800. The vast majority (94 percent) of the populace lived in rural areas. The average white woman gave birth to seven children. Now, move forward to 1940. Only 43 percent of the population lived in rural areas, and the average white woman birthed two children. Figure 1 illustrates the demographic transition.

What was the force underlying this decline in fertility? The answer is technological progress. Two factors are relevant here. First, between 1800 and 1940 real wages grew sixfold. This increased the time cost of children in terms of consumption goods. America was sparsely populated as it entered the 19th century, with just 4.5 people per square mile. Parts were "so thinly scattered" that one writer advised immigrants that "no assistance worthy of notice can be obtained from others outside the family" (as quoted by Stanley Lebergott [1964 p. 49]). Thus, children undoubtedly made an important contribution to the early household economy. With industrialization, part of the utility flow accruing from children (via household production) could be replaced less expensively by purchasing goods and services on the market.

Second, the role of agriculture in the economy declined over this period. This contributed to the fall in fertility since, historically, women in the rural economy had a higher fertility rate than those in urban areas. In 1830 it took a farmer 250–330 hours to produce 100 bushels of wheat; by 1890 this was reduced to 40–50 hours with the help of a horse-drawn machine; only 15–20 hours were required with the aid of a tractor in 1930; by 1975 large tractors and combines had reduced the labor input needed to just 3.3 hours. Similarly, it took 344 hours to produce 100 bushels of corn, and 601 hours to produce a bale of cotton in 1800. These times dropped to 7 and 26 hours by 1970. Fewer people were needed to feed the nation, given the relatively low income elasticity of agricultural goods. Thus, while agriculture accounted for 85 percent of the labor force in 1810, only about 30 percent of the population was employed in this sector by 1910, and just a paltry 3 percent in 1995. With economic progress, other sectors of the economy began to outpace agriculture. Agriculture's share of output fell from 41 percent in 1840 to 2 percent in 1997.

I. The Model

The world is described by a two-sector overlapping-generations model. An individual lives for three periods, one as a child and two as an adult. He consumes two goods: agricultural and manufactured. The relative price of agricultural goods is p. Young adults work. They have one unit of time. Unskilled young adults earn the wage w, while skilled ones receive v. Each young adult must save for his old age since no one works when old. The gross interest rate on savings is r. A young adult must decide how many children, q, to have, and whether or not to educate them. There is a fixed time cost, τ, associated with raising each child. Endowing a child with skills costs t units of time.

The lifetime utility function for a young adult is

$$
\begin{aligned}
T(c, a, c', a', q, e; w', v')
&= (\psi/\gamma)(c + \mathcal{c})^{\gamma} + (\alpha/\omega)(a - \mathcal{a})^{\omega} \\
&\quad + (\beta\psi/\gamma)(c' + \mathcal{c})^{\gamma} + (\beta\alpha/\omega)(a' - \mathcal{a})^{\omega} \\
&\quad + [(1 + \beta)\chi/\zeta]q^{\zeta}[(1 - e)w' + ev']^{\xi}
\end{aligned}
$$

with $\text{sgn}(\zeta) = \text{sgn}(\xi)$. Here c and c' denote the

* Department of Economics, University of Rochester, Rochester, NY 14627, and Department of Economics, University of Wisconsin, Madison, WI 53706, respectively. We thank Stanley Engerman for help with this project. Financial support from the NSF is gratefully acknowledged. The computer programs used for this research are available from Ananth Seshadri upon request.

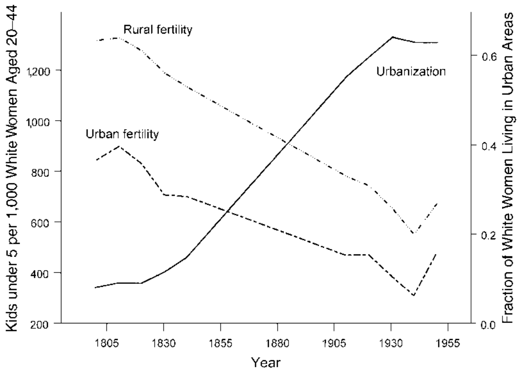

FIGURE 1. THE U.S. DEMOGRAPHIC TRANSITION, 1800–1950

individual's consumption of manufactured goods when young and old, respectively, while a and a' represent consumption of agricultural goods. A person derives utility from the quantity, q, and quality of children. A parent picks a discrete level of education, $e \in \{0, 1\}$, for his child; a choice of $e = 1$ corresponds with endowing the child with skills. Quality is measured by the wage that a child will earn as a young adult. A skilled child will earn v' when he grows up, while an unskilled child will receive w'.

Manufactured goods are produced in line with the Cobb-Douglas production technology

$$o_c = z k_c^{\kappa} s_c^{1-\kappa}$$

where o_c denotes output, z is total factor productivity, and k_c and s_c are the inputs of capital and skilled labor. Agriculture is governed by the constant-elasticity-of-substitution production function

$$o_a = x[\nu k_a^{\rho} + (1 - \nu) u_a^{\rho}]^{\lambda/\rho} s_a^{1-\lambda}$$

where o_a is output, x is total factor productivity, and k_a, u_a, and s_a are the inputs of capital, unskilled labor, and skilled labor. Observe that unskilled labor is used only in agriculture. Manufactured output can be used either for consumption or for capital accumulation. The aggregate stock of capital, k, evolves according to

$$k' = \delta k + i$$

where i is investment and δ is the factor of depreciation.

The choice problem facing an unskilled parent with unskilled children is

$$U(w, w', p, p', r)$$

$$= \max_{c,a,c',a',q} \{(\psi/\gamma)(c + \mathfrak{c})^{\gamma} + (\alpha/\omega)(a - \mathfrak{a})^{\omega}$$

$$+ (\beta\psi/\gamma)(c' + \mathfrak{c})^{\gamma} + (\beta\alpha/\omega)(a' - \mathfrak{a})^{\omega}$$

$$+ [(1 + \beta)\chi/\zeta] q^{\zeta} w'^{\xi}\}$$

subject to

$$c + pa + \frac{c'}{r} + \frac{p'a'}{r} + qw\tau = w.$$

Denote the optimal number of children and the level of first-period savings that arise from this problem by q_{uu} and b_{uu}. Likewise, the problem facing an unskilled parent with skilled children will read

$$V(w, v', p, p', r) = \max_{c,a,c',a',q} \{(\psi/\gamma)(c + \mathfrak{c})^{\gamma}$$

$$+ (\alpha/\omega)(a - \mathfrak{a})^{\omega}$$

$$+ (\beta\psi/\gamma)(c' + \mathfrak{c})^{\gamma}$$

$$+ (\beta\alpha/\omega)(a' - \mathfrak{a})^{\omega}$$

$$+ [(1 + \beta)\chi/\zeta] q^{\zeta} v'^{\xi}\}$$

subject to

$$c + pa + \frac{c'}{r} + \frac{p'a'}{r} + qw(\tau + t) = w.$$

Represent this parent's optimal number of children and first-period savings by q_{us} and b_{us}.

Clearly, all unskilled parents will choose to educate their children if $V(w, v', p, p', r) > U(w, w', p, p', r)$, and will choose not to when $V(w, v', p, p', r) < U(w, w', p, p', r)$. If $V(w, v', p, p', r) = U(w, w', p, p', r)$, then some unskilled parents may choose to educate their children while others will not. Skilled parents face a similar decision. Now, in equilibrium the time path of wages adjusts so that all unskilled parents will be indifferent between endowing their children with skills or not. Skilled parents always (weakly) prefer to educate their offspring. Let q_{ss} and b_{ss} denote the number of children and the level of savings that are chosen by a young skilled parent.

Suppose the number of young adults is n. Out of this population some fraction μ will be unskilled, implying that the fraction $1 - \mu$ will be skilled. Some (endogenous) fraction, σ, of unskilled parents will choose to endow their children with skills. Hence, the number of young adults next period, n', will be given by

$$n' = \{\mu[(1 - \sigma)q_{uu} + \sigma q_{us}] + (1 - \mu)q_{ss}\}n.$$

Analogously, the fraction who will be unskilled is determined by

$$\mu' = \frac{\mu(1 - \sigma)q_{uu}n}{n'}.$$

Firms in agriculture and manufacturing are competitive and seek to maximize profits. They solve the problems

$$\max_{k_a, u_a, s_a} \{px[\nu k_a^{\rho} + (1 - \nu)u_a^{\rho}]^{\lambda/\rho} s_a^{1-\lambda} - (r - \delta)k_a - wu_a - \upsilon s_a\}$$

and

$$\max_{k_c, s_c} \{zk_c^{\kappa} s_c^{1-\kappa} - (r - \delta)k_c - \upsilon s_c\}.$$

These problems imply that all factors will get paid their marginal products.

In equilibrium various market-clearing conditions must hold. For instance, savings by the young must equal next period's capital stock, k', so that

$$n[\mu(1 - \sigma)b_{uu} + \mu\sigma b_{us} + (1 - \mu)b_{ss}] = k' = k'_a + k'_c.$$

TABLE 1—PARAMETER VALUES

Parameter class	Parameter values
A. *Tastes:*	
Agriculture	$\alpha = 0.09$, $\omega = -0.05$, $\mathcal{a} = 0.25$
Manufacturing	$\psi = 0.5$, $\gamma = 0.01$, $\mathcal{c} = 1.35$
Fertility	$\chi = 0.08$, $\zeta = -0.08$, $\xi = -0.08$
Miscellaneous	$\beta = 0.94^{20}$
B. *Technology:*	
Agriculture	$\nu = 0.5$, $\rho = 0.6$, $\lambda = 0.8$, $x_1 = 3.77 = x_T/1.95$
Manufacturing	$\kappa = 0.33$, $z_1 = 3.77 = z_T/4.11$
Fertility	$\tau = 0.06$, $t = 0.04$
Miscellaneous	$\delta = (1.0 - 0.1)^{20}$

Likewise, the demand for unskilled labor must equal its supply, implying

$$u_a = \mu n\{(1 - \sigma)[1 - q_{uu}\tau] + \sigma[1 - q_{us}(\tau + t)]\}.$$

Observe that the supply of unskilled labor is reduced by the time young adults spend on child care and education.

II. Findings

Can the model replicate the decline in fertility that occurred between 1800 and 1940? This question is quantitative in nature. To answer it, the model must be solved numerically. To do this, the model's parameters are assigned the values presented in Table 1. Before proceeding to the quantitative analysis, we ask: exactly how much technological progress was there in agriculture and manufacturing between 1800 and 1940?

Take agriculture first. Total factor productivity (TFP) grew at 0.49 percent per year between 1800 and 1900. Its annual growth rate fell to 0.26 percent in the interval 1900–1929 and then rose to 0.94 percent over the 1929–1940 period. Hence, by chaining these estimates together, it is easy to calculate that TFP increased by a factor of $1.0049^{100} \times 1.0026^{29} \times 1.0094^{11} = 1.95$ between 1800 and 1940. TFP in the nonagricultural sector (labeled "manufacturing") rose at a faster clip. It grew at 0.79 percent per year between 1800 and 1840 and at an annual rate of 0.73 percent over the period 1840–1900. Its growth rate then picked up to 1.63 percent between 1900 and 1929 and to 1.78 percent from 1929 to 1940. Therefore, over the period 1800–1940 nonagricultural TFP grew by a factor of $1.0079^{40} \times 1.0073^{60} \times 1.0163^{29} \times 1.0178^{11} = 4.11$.[1]

A. *Steady-State Analysis*

Now, suppose that at time 1 (or just before 1800) the economy is initially in a steady state with $x_1 = 3.77$ and $z_1 = 3.77$. The model then predicts that on average there will be 3.5 children per parent in the economy, exactly the number observed in 1800.[2] In the model's countryside there are about 3.8 children per parent versus 2.1 in its cities. This compares with 3.6 and 2.4 in the data. (Note that the model equates agriculture with the rural economy and manufacturing with the urban one. The alignment with the U.S. data is therefore somewhat imperfect.) Furthermore, in the data about 50 percent of parents had more than 3.5 children; 55.7 percent of families in the artificial economy do. Last, 82.4 percent of the model's population work in the country, the same as at the beginning of the 19th century.

Likewise, assume that at time T (sometime after 1940) the model ends up in a new steady state with $x_T = 1.95x_1$ and $z_T = 4.11z_1$. Now there is just slightly more than one child per parent, the same as in 1940. Rural families are a little bigger (1.3 children per parent) than urban ones (1.05). Only 14.9 percent of the population work in agriculture, roughly the same as in 1940. Table 2 decomposes the decline in aggregate fertility into its three sources: the decline in rural fertility, the decline in urban fertility, and the decline due to rural-to-urban migration.[3] The model matches the U.S. data quite well.

TABLE 2.—DECOMPOSITION OF THE DECLINE IN FERTILITY

	Fraction of fertility decline (percentage)		
Source	Migration	Rural	Urban
Data[a]	20.2	56.0	23.8
Model	28.3	50.0	21.7

[a] U.S. data, 1810–1940.

Why does fertility drop with economic progress? Consider the marginal costs and benefits from having a child. To do this focus on the first-order condition associated with the number of children that arises out of the optimization problem of, say, an unskilled parent who chooses to have unskilled children. This first-order condition can be written as

$$(1 + \beta)\chi q_{\mathrm{uu}}^{\zeta - 1} w'^{\xi} = \psi(c_{\mathrm{uu}} + c)^{\gamma - 1} w\tau$$

[1] The estimates for the growth rates of agricultural productivity from 1800 to 1900 come from Jeremy Atack et al. (2000 table 6.1). The estimates for both agricultural and nonagricultural total factor productivity (TFP) for the 1900–1929 and 1929–1940 periods are taken from *Historical Statistics of the United States: Colonial Times to 1970* (U.S. Bureau of the Census, 1975 [series W7 and W8]). Last, the early estimates for the growth rate of technological progress in the nonagricultural sector are backed out using economy-wide TFP and sectoral-share data taken from Robert E. Gallman (2000 tables 1.7 and 1.14) in conjunction with the Atack et al. (2000) agricultural estimates.

[2] In the real world each child has two parents, while in the unisexual model each child has one parent. Hence, in the U.S. data the fertility rate for women should be divided by 2 to get the rate per parent. If the model is calibrated to obtain seven children per parent (the female fertility rate in 1800) then the rate of growth for the population is far too high (10 percent per year versus 3 percent in the data).

[3] The decline in fertility is decomposed as follows. Total fertility, f, is a weighted average of rural fertility, r, and urban fertility, u, where the weights π and $1 - \pi$ are the fractions of the total population living in rural and urban areas. Thus, $f = \pi r + (1 - \pi)u$. The change in fertility between any two dates can then be written as

$$f' - f = \left[\frac{\pi' + \pi}{2}(r' - r)\right] + \left[\frac{(1 - \pi') + (1 - \pi)}{2}(u' - u)\right] + \left[\frac{(r' - u') + (r - u)}{2}(\pi' - \pi)\right].$$

The first term in brackets gives the contribution of the decline in rural fertility to the total decline in fertility, the second measures the amount arising from the decline in urban fertility, and the third term shows the amount due to migration. The figures for the United States are taken from Wilson Grabill et al. (1958 table 8).

(where again the subscript uu denotes the actions of an unskilled parent with unskilled children). The marginal cost of a child is made up of two components: the wage rate, w, and marginal utility of manufactured goods, $\psi(c_{uu} + \mathcal{c})^{\gamma-1}$. The former rises with economic development while the latter falls. The less concave utility is in manufactured goods (as measured by the exponent γ), the faster the marginal cost of a child will rise over time. The marginal benefit of a child also rises with wages through the quality term, w'^{ξ}. The more concave utility is in child quality (i.e., the smaller is ξ), the less will be the benefit of an extra child as wages rise. Now, suppose that the marginal cost of children increases relative to the benefit. By making utility concave enough in child quality, at least relative to manufactured goods, a decline in fertility can be generated. The drop-off in fertility will be bigger the less concave utility is in child quantity, since marginal benefit then declines less in quantity.

Additionally, less unskilled labor is needed as agriculture declines. Rural parents increasingly choose to educate their children so that the latter can work in manufacturing. Agriculture's share of income will decline faster the more concave utility is in agricultural consumption relative to manufactured consumption (or the smaller is ω vs. γ). With economic progress wages rise, and this makes labor more expensive relative to capital. Increasingly expensive unskilled labor can be more easily replaced by less expensive capital the greater is the degree of substitutability between capital and brawn in agriculture. Hence, capital–brawn substitutability (or a high ρ) promotes rural-to-urban migration.

Last, the constant terms $\mathcal{a}$ and $\mathcal{c}$ in the utility function play a very important role in getting a high expenditure share for agricultural goods, and a low one for manufactured goods, in the early stage of development. The constant $\mathcal{a}$ operates to increase the marginal utility of agricultural goods at low consumption levels. For example, if $\mathcal{a}$ drops from 0.25 to 0.01, the marginal utility of agricultural goods falls. As a consequence, agriculture's share of GDP in the initial steady state decreases from 0.68 to 0.39. The $\mathcal{c}$ term does the opposite for manufactured goods. To illustrate its effect reduce $\mathcal{c}$ from 1.35 to 0.01. Here agriculture's share of GDP in the initial steady state falls from 0.68 to 0.35. Since the marginal utility of manufacturing goods rises, fewer resources are devoted to having children. Fertility plummets from 3.48 to 0.98.[4]

In the model, the real interest remains roughly constant across the two steady states at about 6.2 percent, a reasonable value. As the model economy develops, agriculture's share of output falls from 68.4 percent to 20 percent. In 1840 agricultural production made up about 40 percent of U.S. output. This had declined to 5 percent by 1950. There is a decline in the model's investment-to-GDP ratio from about 17.8 percent to 12.1 percent. At the same time, labor's share of income drops from 82.4 percent to 60.8 percent, which contradicts the conventional wisdom that it either remained constant or rose. This is due to the assumed degree of substitutability between capital and brawn in the agricultural production function. With economic development, brawn is replaced by capital in agriculture. Capital's share of income thus rises.

B. *Transitional Dynamics*

The analysis of comparative steady states suggests that the model may be capable of explaining the U.S. demographic transition. Will the drop-off in fertility, however, be too fast or too slow? To answer this question, time paths for TFP similar to those found in the U.S. data for the 1800–1940 period are fed into the model. Specifically, let $\{x_1, x_2, x_3, \ldots, x_8, \ldots\} = \{3.77, 4.16, 4.58, 5.06, 5.57, 6.15, 6.47, 1.95 \times 3.77, \ldots\}$ and $\{z_1, z_2, z_3, \ldots, z_8, \ldots\} = \{3.77, 4.41, 5.16, 5.97, 6.91, 7.99, 11.04, 4.11 \times 3.77, \ldots\}$. This time path is counterfactual in the sense that no technological advance is assumed to take place after seven periods (or after 1940). The sudden death in technological progress

[4] To highlight the importance of $\mathcal{a}$ and $\mathcal{c}$, set $\omega = \gamma = \zeta = \xi = 0$ (i.e., assume logarithmic preferences). Adjust the initial levels of TFP to get back the circa 1800 steady state. Fertility across the two steady states falls from 3.5 to 1.35, which is just a little worse than the benchmark equilibrium.

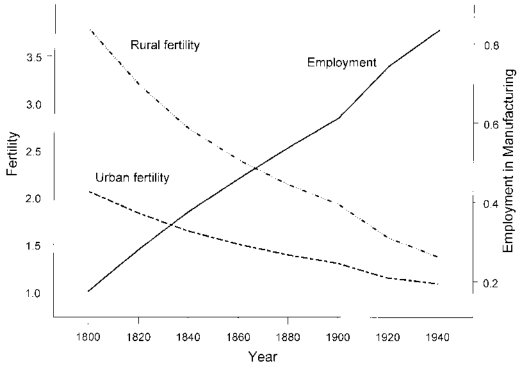

FIGURE 2. THE DEMOGRAPHIC TRANSITION, MODEL

does not appear to do any damage to the analysis.

The upshot of this experiment is presented in Figure 2. Both urban and rural fertility decline smoothly between 1800 and 1940, much like the data. The share of manufacturing in employment rises in a steady fashion, too. Note that the model has not reached its final steady state by 1940 (i.e., it takes longer than seven periods for the model to converge).

III. Literature Review

The macroeconomics of population growth starts with classic papers by Assaf Razin and Uri Ben-Zion (1975) and Gary S. Becker and Robert J. Barro (1988). The ∩-shaped pattern of fertility, observed over epochs in the Western world, is analyzed in interesting work by Oded Galor and David Weil (2000). Matthias Doepke (2000) also examines the relationship between long-run growth and fertility. He studies the impact of education policies and child-labor laws on fertility. Over time, child mortality has declined. The effect that this had on Swedish fertility is studied by Zvi Eckstein et al. (1999). In the United States (unlike Sweden), infant mortality did not begin to fall until the late 19th century (i.e., after the decline in fertility was well underway), at which time it fell dramatically. Jesus Fernandez-Villaverde (2001) discusses the English case. Cristina Echevarria (1997) and John Laitner (2000) develop well-known models of structural change (see also Piyabha Kongsamut et al., 2001). The process of U.S. regional convergence, whereby the agricultural South caught up with the manufacturing North, is modeled by Francesco Caselli and Wilbur John Coleman (2001). The current work blends the fertility and structural change literature together.

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