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The U.S. Demographic Transition Perfect Capital Markets

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Between 1800 and 1940 the United States went through a dramatic demographic transition. In 1800 the average woman had seven children, and 94 percent of the population lived in rural areas. By 1940 the average woman birthed just two kids, and only 43 percent of populace lived in the country. The question is: What accounted for this shift in the demographic landscape? The answer given here is that technological progress in agriculture and manufacturing explains these facts.

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I. Introduction

Picture the U.S. in 1800. The vast majority of the populace lived in rural areas; 94 percent did. The average white woman gave birth to 7 children. Now, move forward in time to 1940. Only 43 percent of the population lived in rural areas, and the average white woman birthed 2 kids. The demographic transition is shown in Figure 1.

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 about 5 fold. This increased the time cost of children in terms of consumption goods. America was sparsely populated as it entered the 19th century, 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 of the family." So, children undoubtedly made an important contribution to the early household economy. With industrialization part of the utility flow accruing from children could be replaced less expensively by purchasing goods and services on the market.

Second, the role of agriculture in economy declined over this period. This contributed to the decline 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 15-30 hours was required with the aid of a tractor in 1930; by 1975 large tractors and combines had reduced the labor input needed to just 3-4 hours. Similarly, it took 236 and 439 hours to produce a bushel of corn and bale of cotton in 1840. This had dropped to 8 and 32 hours by 1970. Less people were needed to feed the nation, given the relatively low income elasticity of agricultural goods. So while agriculture accounted for about 80 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 2 percent in 1997. 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.

II. The Model

Environment.– 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 manufacturing. 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 skill them. There is a fixed cost, τ, associated with raising each child. Endowing a child with skills costs t units of time.

Tastes.– The lifetime utility function for a young adult is

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

with sgn(ζ)=sgn(ξ). Here c and c' denote the 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 the 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 kid will receive w'.

Technology.– 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. Agricultural goods production is governed the CES 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 the agricultural sector. Manufacturing 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 Unskilled Parent.– The choice problem facing an unskilled parent with unskilled kids is

$$\begin{aligned} U(w, w', p, r) &= \max_{c,a,c^{\theta},a^{\theta},q} \{(\psi/\gamma)(c + \mathsf{c})^{\gamma} + (\alpha/\omega)(a - \mathsf{a})^{\omega} + (\beta\psi/\gamma)(c' + \mathsf{c})^{\gamma} \\ &\quad + (\beta\alpha/\omega)(a' - \mathsf{a})^{\omega} + [(1+\beta)\chi/\zeta]q^{\zeta}w'^{\xi}\}, \end{aligned}$$

subject to

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

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 a unskilled parent with skilled children will read

$$\begin{aligned} V(w, w', p, r) &= \max_{c,a,c^{\theta},a^{\theta},q} \{(\psi/\gamma)(c + \mathsf{c})^{\gamma} + (\alpha/\omega)(a - \mathsf{a})^{\omega} + (\beta\psi/\gamma)(c' + \mathsf{c})^{\gamma} \\ &\quad + (\beta\alpha/\omega)(a' - \mathsf{a})^{\omega} + [(1+\beta)\chi/\zeta]q^{\zeta}v'^{\xi}\}, \end{aligned}$$

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 skill their children if $V(w, w', p, r) >$

$U(w, w', p, r)$, and all will choose not to when $V(w, w', p, r) < U(w, w', p, r)$. If $V(w, w', p, r) = U(w, w', p, r)$ then some unskilled parents may pick to skill their children while others don't. Skilled parents face a similar decision. Now, in the equilibrium modelled here 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 skill their offspring. Let q_{ss} and b_{ss} denote the number of children and level of savings that are chosen by a young skilled parent.

Population Dynamics.– 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 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

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

Firms.– Firms in the agricultural and manufacturing sectors of the economy are competitive and seek to maximize profits. They solve the problems

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

and

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

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

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

$$\mu(1 - \sigma)b_{uu} + \mu\sigma b_{us} + (1 - \mu)b_{ss} = k' = k_a' + k_c'.$$

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 childcare and education.

III. 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 onto the quantitative analysis, exactly how much technological progress was there in the agricultural and nonagricultural sectors between 1810 and 1940?

Technological Progress in Agriculture and Manufacturing. Take agriculture first. Total factor productivity (TFP) grew at 0.51 percent per year between 1810 and 1900. Its annual growth rate fell to 0.26 percent in the interval 1900 to 1929 and then rose to 0.94 percent over the 1929-to-1940 period. Hence, by chaining these estimates together, it is easy to calculate that TFP increased by a factor of $1.0049^{100}1.0026^{29}1.0094^{11} = 1.95$ between 1800 and 1940. TFP in the nonagricultural sector – labelled 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 to 1900. Its growth rate then picked up to 1.63 percent across 1900 to 1929 and to 1.78 percent from 1929 to 1940. Therefore, over the period 1810 to 1940 nonagricultural TFP grew by a factor of $1.0079^{40}1.0073^{60}1.0163^{29}1.0178^{11} = 4.11$.[1]

A. Steady-State Analysis

The Decline in Fertility.– Now, suppose that at time 1 (some period 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 3.48 kids *per parent* in the economy, exactly the number observed in 1800.[2] In the model's countryside there are about 3.78 kids per parent versus 2.06 in its cities. This compares with 3.7 and 2.5 in the data. Furthermore, in the data about 50 percent of parents had more than 3.5 kids; 55.7 percent of families in the artificial economy do. Last, about 82.43 percent of the model's population work in country, the same as at the beginning of the 19th century.

Likewise, assume that at time T (sometime after 1940) the model somehow 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 1 kid per parent, the same as in 1940. Rural families are a little bigger (1.33 kids per parent) than urban ones (1.05). Only 14.92 percent of the population work in agriculture, 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 rural-to-urban migration.[3] The model matches the U.S. data quite well.

Intuition.– So 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 has chosen to have unskilled kids. This first-order condition can be written as

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

(where again the subscript uu denotes the actions of an unskilled parent with unskilled kids). The marginal cost of a child is made up of two components: the wage rate, w, and marginal utility of manufactured goods, $\psi(c_{uu}+\mathsf{c})^{\gamma-1}$. 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 kid 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. The drop off in fertility will be bigger the less concave utility is in child quantity, since marginal benefit then declines less in quantity. By making utility concave enough in child quality, at least relative to manufactured goods, a decline in fertility can be generated.

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

Last, the constant terms a and c in utility play a very important role in getting a high expenditure share for agricultural goods, and a low one for manufacturing goods, in the early stage of development. The constant a operates to increase the marginal utility of agricultural goods at low consumptions levels. For example, drop a from 0.25 to 0.20. 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 0.62. The c term does the opposite for manufactured goods. To illustrate its effect reduce 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, less resources are devoted to having children too. Fertility plummets from 3.48 to 0.98.[4]

Other Facts.– In the model the real interest remains constant across the two steady states at about 6.36 percent, a reasonable value. As the model economy develops with technological progress agriculture's share of output falls from to 68.36 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 declines from 82.43 percent to 60.8 percent, which contradicts the conventional wisdom that it either remained constant or rose. This is due to assumed degree of substitutability between capital and brawn in the production agricultural production function. With economic development, brawn is replaced by capital in agricultural production. 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 $\{x_1, x_2, x_3, \cdots, x_8, \cdots\} = \{3.77, 4.16, 4.58, 5.05, 5.57, 6.15, 6.47, 1.95 \times 3.77, \cdots\}$ and $\{z_1, z_2, z_3, \cdots, z_8, \cdots\} = \{3.77, 4.41, 5.15, 5.97, 6.91, 7.99, 11.04, 4.11 \times 3.77, \cdots\}$. This time path is counterfactual in the sense that no technological advance is assumed to take place after 7 periods (or after 1940). The sudden death in technological progress doesn't 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 model has not reached its final steady state by 1940 (i.e., it takes longer than 7 periods for the model to converge).

IV. Postscript – Literature Review

The macroeconomics of population growth started with classic papers by Gary S. Becker and Robert J. Barro (1986) and Assaf Razin and Uri Ben-Zion (1975). The $\cap$-shaped pattern of fertility that has been observed over epochs in the Western world has been analyzed in interesting work by Oded Galor and David Weil (2000). Matthias Doepke (2000) has also examined the relationship between long-run growth and fertility. He studies the impact of education policies and child labor laws on fertility. Cristina Echevarria (1997) and John Laitner (2000) have developed well-known models of secular sectoral shifts. The process of U.S. regional convergence, whereby the agricultural south caught up with the manufacturing north, has been modelled by Francesco Caselli and Wilbur John Coleman (2001). In a sense the current work blends the fertility and sectoral shifts literature together.

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FOOTNOTES

1. The estimates for the growth rates of agricultural productivity from 1800 to 1900 come from Jeremy Atack, Fred Bateman and William N. Parker (2000, Table 6.1). The estimates for both agricultural and nonagricultural TFP for the 1900-to-1929 and 1929-to-1940 periods are taken from *Historical Statistics of the United States: Colonial Times to 1970* (Series W7 and W8). Last, the estimates of 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 kid 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 get 7 kids 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 the 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 $f' - f = [\frac{\pi^0 + \pi}{2}(r' - r)] + [\frac{(1-\pi^0)+(1-\pi)}{2}(u' - u)] + [\frac{(r^0 - u^0)+(r-u)}{2}(\pi' - \pi)]$. 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, while the third term shows the amount due to migration. The figures for the U.S. are taken from Wilson Grabill, Clyde V. Kiser and Pascal K. Whelpton (1958, Table 8).

4. To highlight the importance of a and 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 simulated model.

TABLE 1. Parameter Values

	Tastes	Technology
Agr.	$\alpha = 0.09, \omega = -0.05, a = 0.25$	$\nu = 0.5, \rho = 0.6, \lambda = 0.8, x_1 = 3.77 = x_T/1.95$
Man.	$\psi = 0.5, \gamma = 0.01, c = 1.35$	$\kappa = 0.33, z_1 = 3.77 = z_T/4.11$
Fert.	$\chi = 0.08, \zeta = -0.08, \xi = -0.08$	$\tau = 0.06, t = 0.04$
Misc.	$\beta = 0.94^{20}$	$\delta = (1.0 - 0.1)^{20}$

TABLE 2. Decomposition of the Decline in Fertility

	R.-to-U. Migr.	Dec. in R. Fert.	Dec. in U. Fert.
U.S. Data, 1810-1940	20.2%	56.0%	23.8%
Model	28.3%	50.0%	21.7%

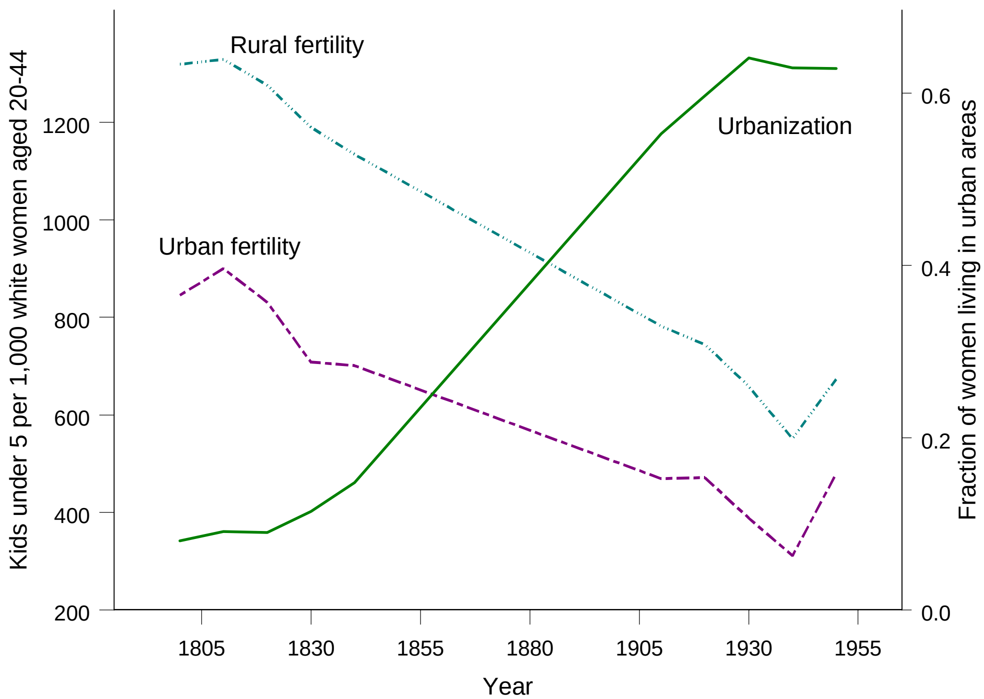

Figure 1: The U.S. Demographic Transition, 1800-1950

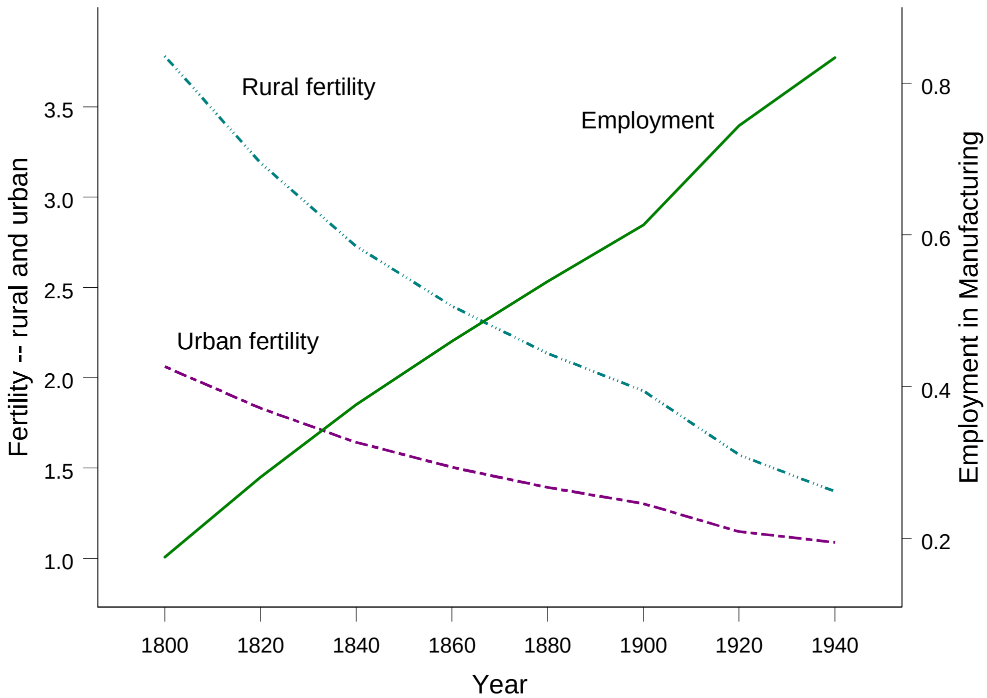

Figure 2: The Demographic Transition, Model